Functions of Nature

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Functions of Nature

Evaluation of nature in environmental planning, management and decision making

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Contents

This book illustrates what I should like to call the "coming of age" of the conservation movement.

I can still clearly remember a time when love of nature was looked upon as the sentimental indulgence of a privileged group and the protection of wild species was considered an unnecessary waste of time and money. Not until the 1960's, when certain large African mammals were becoming scarce or were seriously endangered, did some people become more worried. Gradually, an international conservation movement took form. At first we believed that the establishment and management of a number of protected areas would be sufficient. But Nature takes no account of human boundaries: migrating animals are not aware of them, and they form no barrier to pollution. Although large undisturbed areas will remain essential for the preservation of species, it became clear that the problem we were facing was far more complex than it had originally appeared: The rapid growth of the Earth's human population, expanding industrial activity, accompanied by pollution, poverty and other socio-economic ills, formed an ever increasing threat to the natural world. For the solution of our problem we needed the help of many other groups in our society.

Since the 1970's much has been done to educate public opinion, to monitor and evaluate the various threats to the natural environment and to enact and enforce laws spelling out what should be done. Although this campaign has been successful in increasing public awareness, it could not remedy the inbuilt shortsightedness of our modern technological economies, which is still the main cause for the continuing loss of natural habitats and for environmental pollution.

And so we are now on the eve of such a massive extinction as this planet has never before witnessed, exceeding even the "great dying" of the dinosaurus. This time, however, the extinction is not the result of a natural process but deliberate extermination, with Man himself as the biggest loser.

It became more and more evident that, in order to preserve a reasonable amount of the remaining natural resources, we had to succeed in integrating ecological values into economic planning and decision making. In the 1980's a concerted effort has been made to establish that conservation and economic development are not incompatible. The World Conservation Strategy, published by IUCN, UNEP and WWF, brought the message that exploitation of natural resources

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is often possible on a sustainable basis without affecting their values. Co-operation, and not conflict, between the two interests should be pursued; and this point was again stressed in the "Brundtland Report" of 1987 by the UN World Commission on Environment. Both documents recognized the need for methods of demonstrating the full value of Nature to human society, not only in ecological but also in socio-economic terms. But of course neither of them went so far as to provide specific guidelines for assessing the value of nature and natural resources to human society or for determining the effects on these of human activities.

Now this is clearly a difficult and time-consuming problem, if only because it requires an interdisciplinary approach. In the Netherlands the first discussions on this subject between ecologists and economists took place in 1968 following a report on the UNESCO conference in Paris on the rational use of the biosphere. In subsequent studies a "functional approach" has been recommended, and the book now before you is based upon this principle. It describes the many functions and socio-economic values of nature to human society in a clear and comprehensive way, and is a commendable achievement to make a complicated theoretical matter applicable in practice for conservation and sustainable development.

I therefore hope that all who are concerned with Man's relationship to his natural environment will use this book as a reference.

Bernhard

Prince of the Netherlands

Introduction

by M.G. Wagenaar Hummelinck

Prince Bernard concludes his foreword by expressing the wish that everybody involved with our natural environment will use this book. This sentence raises an interesting problem which is not immediately obvious. The book is a contribution to a new and rapidly-developing discipline, derived from ecology and economics. This means that some parts require rather detailed explanation, so that at first sight it may appear to be a complicated text-book intended for readers having specialised knowledge and experience of environment and conservation issues. In fact, the contrary is the case.
The system of evaluation discussed here is intended to shorten the process of making these new theories on estimating the socio-economic value of nature and wildlife accessible to all those who can apply them in practice. The time-saving which can result from this is very valuable. As things are now, the viability of our planet is decreasing at an alarming rate in consequence of human interference with the natural environment. Clearly, this can be reduced to a number of specific causes: the rapid increase in the birth-rate, the excessive per capita energy consumption, loss of natural resources and arable ground, worldwide climatic changes, and so on. One very important cause is that we continue to destroy such wild nature as still survives; we destroy it from ignorance or even indifference, failing to realise that all those other living organisms are essential to our own survival. We shall have to develop a new rationale so as to be able to make sensible decisions when wildlife conservation competes with other human objectives.
To deal with such urgent problems, we need to be able to express in current economic terms - if possible in actual cash - the value of an 'ecosystem', that is, the total interdependent group of plants and animals living in their natural state in a given geographic location. In this way, we know what it is costing us when some human undertaking changes or destroys parts of the natural environment.

Initially, real nature-lovers displayed little enthusiasm for the idea of quantifying nature in economic terms. This attitude reflects to a large extent their aversion from the fact that in their opinion nature is thereby reduced to the status of a commercial commodity. They regard such calculations as both futile and ethically questionable. Whilst this reaction is understandable it should not be overlooked that the immaterial values of nature become most clearly apparent through this very process of identifying and distinguishing her separate and specific functions. And certainly, the process cannot diminish those intrinsic values which are, in any case, beyond the scope of human computation. Another objection is that describing nature as it now exists leads to resigned acceptance of a possibly unfavourable situation, whereas in some cases nature in the area in question could have recovered if it had enjoyed a long period of undisturbed development. In practice, however, it is the common experience of conservationists trying to resist encroachments on nature that they encounter procedures in which the claims of interested parties are processed within a fixed framework of laws, rules and economic regulations, and they realize that it is self-defeating merely to remain aloof from these procedures.

There are countless situations in which a clearly-defined and systematically applied knowledge of the actual value of wild nature is indispensable if a sound decision is to be arrived at. Such situation arise when a choice must be made among various possible uses for a given area such as mining, agriculture, forestry, urban development, industry, traffic and transport facilities, energy production, waste-disposal or - preservation of the natural state. It is to be expected that in such situations a cost-benefit analysis and environmental impact assessment will become a matter of routine and part of a standard procedure in extending aid to developing countries. The environment will be increasingly subject to regulation and control, and business firms, governmental bodies and even whole nations will have to keep accounting records of the influence of their activities on the natural environment. The world will have to learn a new kind of book-keeping.
Scientists are certainly not the only ones who will have to come to grips with this problem: it will confront decision-makers such as politicians, financiers, planners, even private citizens, in short everybody who is concerned with the potential consequences of Man's influence on the biosphere of this planet.

We should not be deterred by the fact that this book appears rather complex at first sight. 'Functions of Nature' has no pretention to being anything more than a guide, a reference book which will provide help in evaluating a given object. It suggests a framework within which the data can be organised into a comprehensive whole, but familiarity with the locality and some ingenuity on the part of the user are certainly required. The system described here is really based on a old device: a problem so huge that all its facets cannot be kept in view is first dismantled, the components are examined separately and then reassembled. The nucleus of this book is a universally valid list of all imaginable goods and services - called 'functions' for our present purpose - which the natural environment can provide. For convenience, the environment can be divided into two classes: inanimate (air, soil, water, etc.) and animate (plants, animals, micro-organisms, etc.). In the interest of a well-rounded system the author has listed both the animate and inanimate elements. The greatest difficulty in evaluation is presented by living self-regulating systems: the functions of these are consequently treated at some length.

When we come to evaluating an object, we begin by listing the already known functions that can be attributed to it. These may consist of 'goods' that are easily expressed in terms of money: wood, fish, raw materials and the like; or they may consist of 'services': the value of which may have to be indirectly estimated or perhaps can only be described such as recreation, water-purification, climate control, and so on, when assessing features which are intangible such as cultural and spiritual inspiration. We then set down what each of these functions, taken separately, is thought to be worth, and a summary is made of the whole. By this procedure, not only do we obtain a comprehensive impression of the value of the object in its entirety, but also the analysis thus produced is an excellent instrument for investigating the consequences for nature of human activities; for intervention will lead to partial or total loss of existing functions or to their being replaced by other functions. In this connection we should remember that functions are not always compatible with one another, so that our attempts to regulate nature frequently lead to less favourable results than were expected. With the knowledge which functions will be lost and the social and economic value of those functions, we are in a position to judge what a given activity is really costing us and what the most sensible decision is for our particular aims.

Much is being written nowadays about 'sustainable development', often in the sense of continuous economic growth. But the principle of sustainable development does not necessarily imply preservation of nature and the environment. If we wish to achieve a truly sustainable use of nature we should become extremely selective, and remain within the carrying capacity of the given system. This is a point which often gives rise to misunderstandings. Wherever possible, the author has pointed out the extent to which a certain function can be regarded as sustainable. However the term 'sustainable' is used here in the sense it had when applied to conservation and implies that making use of the function in question does not change or deplete the ecosystem and that consequently no loss of functions can occur.

A special feature of the function-evaluation method set out in this book is that it is a universal aid, applicable to any object in any situation. If the method is widely applied and if 'thinking in functions' meets with general acceptance, this will mean that an important first step has been taken on the path towards a more rational relationship between human beings and the biosphere.

'Functions of Nature' contains a fair amount of technical jargon from two different disciplines, each of which has developed a formidable arsenal of terminology. These are ecology and economics. As the prefix 'eco' (Gr. oikos=house) indicates, both are connected with housekeeping in the sense of management or stewardship, the former of plants and animals , the latter of human society.

Ecology, which is a relatively recent development of biology, studies not only individual plants and animals but also the behaviour and characteristics of entire populations, as well as their relationship to the wider environment. The term 'biodiversity' is used to express the idea that it is this whole complex structure which must be preserved. It has been gradually realized that every organism in nature is dependent on countless other organisms for its continued existence, and that this is equally true of the human species. Production and consumption proved to be heavily dependent on the natural surroundings and had, in turn, a significant effect on ecosystems. As early as 1976, the ecologist Eugene Odum referred to the inevitable 'coming merger of ecology and economics'.

In the mean time there also have been some changes in the theory of economics. Here too there was insufficient awareness of these interrelationships, and the economic process of production and consumption had long been accepted as a self-contained element in the pattern of human society. The inadequacy of this view became evident when the process was seen as one part of the phenomenon of life on earth; it was then realized that the world's production process is kept going by a constant stream of valuable raw materials taken from nature but never paid for. This circumstance had never been taken into account; it was tacitly assumed that these resources were available free of charge and in unlimited quantities. Similarly, in the course of this process no attention was paid to the free use that was made of nature's services in the form of climate control and the supply of water and energy; and, when the end-product was at last complete, nature was left with the task of cleaning up and decontaminating the waste residue. No charges for these services were reflected in the price of the product. In this form, the world economy can be compared with a business firm which inflates its profitability by secretly drawing on its capital.

Economics will have to reach a better understanding of its relationship with the natural world and incorporate this into its theory. Aurelio Pecci, founder of the Club of Rome and himself an industrialist, was one of the first to recognize this. In 1979 he wrote, in a foreword to the Spanish edition of the book Nature's Price: Economic and ecological disciplines have become so intertwined that what we need now is an interdiscipline 'econology'.

In recent years both disciplines have worked hard at formulating the conditions for a stable world-wide stewardship, and a coherent theoretical structure has emerged under the name 'environmental' economics or 'ecological' economics. Within the framework of this new discipline various systems have been developed to provide better descriptions of the social and economic aspects of the biosphere. The present book is a contribution to this work.

In the foregoing we have said something about the problems which are the subject matter of this book and the body of ideas which offers new methods for solving them, but the questions still remain whether preservation of the natural environment is really so important after all and whether there is not enough being done about it already.
A glance at the functions listed in this book is sufficient answer to the first question. The outlook for humanity will not be too bright if the favourable effect of natural ecosystems on the quality of air, water and soil declines even further and if art, medical science, agriculture and industry wither away because they are no longer nourished by a continuous stream of inspiration, genetic qualities and raw materials from nature.
And indeed, to judge by the number of international reports and conferences devoted to the environment in recent decades, there is a lot of work being done on it. Nevertheless, in contrast to what many think, nature conservation is in a worse position than it has ever been. If we look at what all this talking and writing has been about, then we notice that with the possible exception of tropical rain-forests it is mainly matters connected with the non-living environment, such as the earth's atmosphere which succeed in bringing government leaders together at well-published conferences. But there is seldom any attempt at a purposeful response to the rapidly approaching wholesale loss of species and ecosystems, to say nothing of any type of world-wide effective legislation.
That is understandable to a certain extent. Political leaders respond only to public demand. The disturbing consequences for our daily existence of the 'greenhouse effect', radiation resulting from ozone loss and the pollution of air, soil and water are matters that are sure to attract attention and uncommitted conferences on cause and effect can serve to maintain the illusion that the problems can perhaps be solved, thanks to production growth and new technologies, without direct repercussions for everyday life.

The other view of the question is that people will have to make some definite sacrifices if the extermination of species is to be resisted and wildlife is to be spared and given a reasonable chance of survival. It is not sufficient merely to keep the inanimate environment clean and unpolluted: valuable territory must be made available for the preservation of animals and plants. There are, of course, other possible methods of conservation: threatened species could be kept in botanical gardens, zoos and gene-banks. But if we want to retain the dynamic ecosystems in which nature constantly regenerates itself, then the necessary space must be made available. This applies not only to exotic tropical rain-forests but everywhere. Even in densely-populated areas, a considerable variety of species can be supported if suitable small reserves are set aside in good time, especially if these reserves can be interconnected by corridors. Even small plots of wild nature can have their uses. The importance of all this, however, is that the inhabitants of densely-populated regions must be prepared to make sacrifices for a policy directed towards long-term benefits, and unfortunately, there is little interest for policies of that kind.

But probably the most important obstacle is that it is difficult to discuss the value of nature and to formulate the necessary measures in specific concrete terms. One of the first intergovernmental gatherings at which experts in the field of conservation expressed concern about the deteriorating condition of the natural environment was a conference organised by UNESCO in Paris in 1968 to discuss the rational use of the biosphere. Even then, the confusion of issues was so great that the participants scarcely knew where to begin. One recommendation was that certain projects should not be carried out until their possible consequences had been carefully considered. In this connection it was observed that such consideration would be more objective if criteria could be found which would enable those factors of the biosphere which cannot (yet) be expressed in monetary terms to be compared with the purely financial-economic factors opposed to them. In The Netherlands, the report of this meeting provided incentive for a World Wildlife Fund study carried out by the Free University of Amsterdam. This book is in part a continuation of that study.

In the epoch-making report on the situation of Mankind which Meadows presented at the Club of Rome in 1972, the approaching end of a number of natural resources is discussed, but no special attention is paid to the depletion of species.
More attention was paid to this subject in the report 'Global 2000 to the President', which was submitted to President Carter in 1980; however, the spirit of this report did not fit in well with the 'Reaganomics' of his successor, and it was pushed aside as being too negative.
The same year saw the publication of the 'World Conservation Strategy', compiled by the International Union for The Conservation of Nature in collaboration with the IUCN and the WWF. This was the first time that both government and non-government bodies were associated with an international document that had conservation as its main theme. Amongst other things, the 'Strategy' went into the relationship between ecology and policy-making and emphasised the importance of protected nature reserves. It was here too that the expression 'sustainable' first appeared, used to convey the idea that no commercial exploitation of a natural area should be allowed to cause the loss of its natural attributes.
The same theme was discussed at the third congress of the IUCN on reserves and protected areas, held in Bali in 1982. Considerable emphasis was placed on the role that protected areas could play in sustainable development, but there were some who thought the claims exaggerated.

Immediately after the congress, the biologist Marius Jacobs expressed his doubts in an article in which he pointed out that the possibilities for administering a reserve on a economic basis are really quite limited. 'It is facile enough to raise expectations among development-hungry people, particularly at the expense of plants and animals', he wrote. 'Any illusions that tropical rain-forests can be exploited on a permanent base (otherwise than through seed-collection) is misleading.' And then in conclusion: 'We can be reasonably sure that any opening in the defense of nature will be widened by exploiters, any promise of 'utilization' will result in claims under the most far-fetched pretexts.'

A breakthrough to government leaders did not really occur until the United Nations, under pressure of public opinion, set up the World Commission on Environment and Development, also known as the Brundtland Commission, from the name of its chairwoman. Its report was published in 1987 with the title 'Our Common Future'. At the same time the UNEP also went to work and formed a commission which produced a report entitled 'The Environmental Perspective for The Year 2000 and Beyond'. The following noteworthy sentence occurs in this report: 'As the genetic base of plants, animals and micro-organisms becomes narrower, some genetic material is being irretrievably lost at such a rate that the world could lose one fifth or one tenth of its 5 - 10 million species by the year 2000'.

Despite this disturbing statement, conservation occupies only a very modest amount of space in the report. The report does, however, contain a remarkable pronouncement: 'An international network of protected areas for conserving animal and plant genetic resources of about 10% of the world's land area should be established to reverse the trend towards depletion of species.'

That is three to five times as much as is under protection today!

The Brundtland Report contained a happy message: we were not heading towards an increasing decline of the environment in a degenerated world but towards a new age by means of 'policies that sustain and expand the environmental resource base'. The concept 'sustainable development' became the keyword but no longer only in reference to nature - it was expanded to include human progress. The term had become politically loaded.

Although this report does acknowledge the importance of biodiversity, the living elements in the environment do not really receive the attention they deserve. The discussion of the relationship between conservation and development does not get much further than the recommendation that 'parks for development' be set up with the aim of furthering both the protection of species and development. In general, however, the report does recognize the importance of wild nature. One important recommendation, for instance, is that any activity which causes changes in the soil, water, air or in the flora and fauna of the place in question should be preceded by an Environmental Impact Assessment. This had already been suggested by the Organisation for Economic Co-operation and Development ' to ensure that environmental considerations are incorporated at an early stage of any decision in all economic and social sectors likely to have significant environmental consequences'. Another recommendation in the Brundtland-report worth noting is that the amount of tropical rain-forests under protection should be at least 20%. The present amount is 5%!

The problem that Jacobs pointed out in 1982 has not become less relevant in the meantime. Sustainable management has frequently been used as a pretext for encroaching on nature, but the extent to which protection and exploitation can be combined is often over-estimated, not only in regard to rain-forests but to virtually all ecosystems. This does not of course mean that a well-planned long-term use of nature is not sometimes possible. The circumstances of each situation are peculiar to itself, and only a systematic process of analysis and evaluation will enable us to make the correct decision.

Meanwhile there have been many changes. The environment is now one of the world's main news topics. So the question now is whether the setbacks that wildlife has suffered can be made good quickly enough to ensure the survival of an adequate number of species to maintain life on earth. But whose responsibility is it to tackle this problem?

The first group to come to mind is probably the conservation movement. In recent decades there has been a marked increase in the number of non-governmental organisations of this kind, and not only in industrialized countries. They can be very influential, because their status as 'private charities' puts them in a position of financial and political independence. Perhaps one of their most important tasks is to provide information to a public that has become increasingly estranged from nature. It will be necessary for them to concentrate on living nature and to teach people to think in functions, so that they will come to understand the value of 'wilderness'. And they can let young people see that wild nature is no less absorbing than computer games and space travel. In the third world it can be useful to help local communities defend their natural resources against unsustainable exploitation.

There is also an important role for the business world. It is interesting to note that the International Chamber of Commerce has produced a charter of sustainable development for use in commerce and industry. The charter strongly recommends the preparation of environment-effect reports and advises the use of internal environment accountants. This could eventually lead to the making up of an alternative environment balance sheet, as is already done by some firms. These can provide good indications of a company's environment policy. Unfortunately the charter gives very few guide-lines for applying these recommendations and contains no references to regulations and sanctions, but it is encouraging that such a broadly representative section of the business world should show its willingness to take some account of the environment.

In conclusion, something should be said about the organisations which arrange aid to developing countries. In contrast to earlier expectations, it now appears that in some countries this aid does not bring about a permanent rise in the standard of living because economic growth is immediately cancelled out by a fresh increase in the population. The hunger and want arising from this lead to increased depletion of such natural resources as are still available. Arable ground is reduced by erosion and drought, there is a shortage of wood for cooking and building, a shortage of pasture for the cattle, and gathering the produce of the forest becomes more and more difficult. Recovery from such a situation is scarcely possible: the exhausted natural environment no longer has the capacity to restore the economy. Not only does this lead to hopeless poverty, it can also be the cause of mass migration and even war.

The only solution is not only that aid must be increased considerably and production and population planning improved, but also that restoration and preservation of the natural environment must be an important goal. Maintaining biodiversity is a complex problem, and it has been shown repeatedly that none of the groups involved is able, alone, to prevent a world-wide environment disaster. Is it therefore essential that governments and the United Nations henceforth give absolute priority to nature and the environment.

A lot of meetings and publications have been devoted to the environment in recent times. A number of events from the hopeful early seventies have had their revival twenty years later. There has been a sequel to the first report of the Club of Rome, the World Conservation Strategy has appeared in a revised version, entitled 'Caring for the Earth', and Rio de Janeiro has been chosen a successor to Stockholm for a second world conference on the human environment. It all looks like a refresher course on a grand scale, repeated for the benefit of a humanity which failed to listen properly the first time.

Although the importance of the living environment has received more attention of late, the loss of biological diversity is still suffering from under-exposure. Recent articles press for more scientific information about nature and the integration of these data in social and economic developments. But this will never get beyond generalities unless clear guide-lines are drawn up and adhered to in setting up the necessary apparatus and procedures and in weighing the import of the relevant factors. The new subject of ecological economics, of which function-evaluation is a part, can assist in this.

This book is to some extent a first approach, and the author will welcome any contribution that readers may make towards perfecting the system he describes. I hope that many will respond to this invitation.

M.G. Wagenaar Hummelinck

environmental impact assessment and cost-benefit analysis. An important obstacle to the inclusion of environmental concerns in planning and decision-making is the translation of ecological data into useful information for planners and decision-makers.
What is most lacking is a simple but effective method for (local) planners and decision-makers to decide on the best alternative use of a particular natural area, including the option to conserve it in its natural state.

Current methods of evaluation in decision-making, such as cost-benefit analysis, inadequately reflect the true environmental and socio-economic value of natural resources and ecosystems. The traditional view has often been that natural ecosystems are unproductive areas whose benefits can only be realized by conversion to some other use. As a result, many natural areas have been altered to serve other purposes simply because their value to society cannot be adequately demonstrated and because traditional evaluation methodologies automatically favour short-term, high-value uses of the land. One of the main purposes of this book is, therefore, to contribute to the development of methods which translate environmental data into useful information for environmental planning and decision-making, in a more objective and systematic way.
In order to achieve the conservation and sustainable utilization of nature and natural resources, data on the many possible environmental effects of development projects and land use decisions must be presented to planners and decision-makers in a comprehensive manner.
The concept of environmental function evaluation (which is described in detail in chapter 1.2) is a useful tool in this respect since it concentrates the large amount of ecological data which is relevant to planning and decision-making into a checklist of a limited number of environmental functions.
The main part of this book (chapter 2), deals with a description of the many environmental functions (goods and services) than can be distinguished, with emphasis on those functions provided by the plants and animals of natural ecosystems. In total, 37 main functions are listed, covering a wide range of ecological, social, cultural, scientific and economic values. The most important environmental parameters needed to assess the capacity of a given natural area or ecosystem to provide these functions, are given in Appendix I, including a matrix showing the relation between specific functions and evaluation parameters.
An overview of the types of socio-economic values that can be attached to these functions, and methods for the monetary valuation of some of these functions is given in chapter 3, including several examples.
The practical application of this function-evaluation system is illustrated in chapter 4 by a description of the functions and socio-economic values of three case studies with very different environmental characteristics and socio-economic settings: tropical moist forests, tidal wetlands (illustrated by a case study of the Dutch Wadden Sea) and the Galapagos National

Park. Although these case studies focus on the functions and values of specific natural ecosystems, the function-evaluation system presented in this book can be used as a framework (or manual) to describe the entire scope of interrelations between man and the natural environment. The book, therefore, closes with a brief discussion of the more general application possibilities of function-evaluation as a tool in environmental planning, management and decision-making (chapter 5).

The function-evaluation system presented in this book can help to incorporate arguments for the conservation and sustainable utilization of nature and natural resources more structurally and systematically in planning and decision-making in various ways:

– An important benefit of systematic function evaluation is that it can be used to demonstrate the ecological and socio-economic importance of natural ecosystems and protected areas, and provide guidelines and indicators for their conservation and sustainable utilization. Since protected areas have to compete with alternative land uses, such as urban development, agriculture, and forestry, listing the many functions and demonstrating the economic benefits of protected areas may help to justify their establishment and ensure their continued protection under increasing land use pressure.

– Early in the planning process, it is important to obtain a clear insight into the environmental trade-offs involved in alternative development projects. An instrument which is increasingly applied in this phase of the planning process is Environmental Impact Assessment (EIA). Conventional EIA is often limited to an assessment of the direct effects of a given project on the environmental characteristics of the area. Preferably, however, environmental impact assessment studies should also include an assessment of the environmental functions and hazards affected by the planned activity. More integrative environmental assessment and ecosystem evaluation is especially important to the drafting of environmental profiles and to determine carrying capacity limits as background information for the formulation of sustainable development strategies.

By providing a comprehensive checklist of environmental functions, this book may also serve as a reminder to environmentalists of the points that need to be considered when making independent assessments of projects that involve the use or conversion of natural ecosystems.

– To achieve more balanced decision-making, economic Cost-Benefit Analyses (CBA) and other decision-making instruments should be based on the concept of sustainability and must be adjusted in order to better account for non-monetary values, both social and environmental. Somehow, cost-benefit analysis should account for the fact that natural ecosystems, besides providing marketable resources also perform many ecological functions with indirect but important values to economic productivity and human welfare.

The concept of environmental functions, and the function-evaluation method described in this book, can help planners and decision-makers to obtain better insight into all the costs and benefits involved in land use decisions. If all factors are taken into account, it will often show that sustainable use of natural ecosystems is not only environmentally safer than short-term (over) exploitation, but also economically more sound.
– To structurally implement environmental concerns in planning and decision-making, improvement of environmental assessment methods alone is not enough. In order to make economic planning and decision-making more responsive to environmental concerns, methods must be found to 'internalize' the environmental dimension in economic assessment and accounting procedures. There is a strong need to change conventional economic accounting procedures and new indicators for human welfare are needed in order to provide appropriate incentives for sustainable use of environmental functions. Here too, the function-concept can be useful as an indicator for both environmental quality and quality of life by providing an instrument for measuring the availability and the "full value" of environmental functions to human society.
Only when ecological principles become an integral part of economic and political planning and decision-making is there a chance of achieving sustainable development based on a new kind of environmental economics which integrates conservation objectives and economic interests into one common goal: i.e. the maintenance and sustainable utilization of the functions (goods and services) provided by nature and natural ecosystems.

Trying to understand the multitude of functional interactions between man and the natural environment and integrating all these functions and associated values into a practical and universally applicable evaluation method is clearly quite complicated. Any evaluation method of this scope and complexity will surely need continuous updating. The wide variety of topics covered, and the continuing appearance of new publications on specific aspects, made the task of incorporating all the latest information, and dealing with all sections of the book in the same detail, most difficult. The choice of detail was also a problem when describing the functions (chapter 2) and the evaluation parameters (Appendix I): for some readers, the descriptions may be too detailed; others may have wished to find more information on certain functions or parameters. I am very much aware of these difficulties and welcome constructive criticism to improve future editions.

Basically, there are two reasons for publishing this book now:
Firstly, *to increase awareness about the concept of environmental functions and their importance to human welfare.* Better insight into the many functional interrelations between man and the natural environment may help to create more understanding and awareness about the many benefits which natural environments provide to human society. Greater awareness

about our dependence on a healthy environment and the many implications of environmental degradation is crucial if we are to solve the environmental problems we are facing today. Thinking in terms of functions, instead of the more narrow concept of natural resources, may stimulate a change of attitude towards our natural environment. We now realise that we are not "only" depleting nature's resources (fossil fuels, soil, species) but also destroying many essential services with serious socio-economic consequences (e.g. erosion and landslides caused by deforestation). Knowledge about the many natural goods and services, and the socio-economic effects of their loss, may help to better incorporate the value of the conservation and sustainable utilization of natural ecosystems in planning and decision-making. It is very likely that the recent increase in environmental concern and the subsequent measures taken, notably with respect to atmospheric pollution, are mainly due to the publication of figures on the economic damage of environmental pollution (e.g. acid rain), and reports on the loss of functions previously taken for granted (such as the protective function of the ozone layer against UV-radiation and climate-regulating processes).
Secondly, *to stimulate debate and comments on the proposed method for further development and improvement.* The environmental assessment method described in this book is a first attempt to design a comprehensive checklist of environmental functions and related parameters. It is hoped that anyone who is interested in the subject or is involved in related research (such as land (use) evaluation, (natural) resource assessment and management, resource economics, and eco-development) will share his or her ideas on how to improve the evaluation method presented in this book. Practical examples of the functions and socio-economic values of natural ecosystems and wildlife, as well as other comments on the book, are very welcome and may be sent to the following address: Rudolf S. de Groot, Nature Conservation Dept., Agricultural University Wageningen, P.O.Box 8080, 6700 ER, Wageningen, The Netherlands.

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Chapter 1

Environmental assessment and ecological evaluation: concepts, methods and arguments

Introduction

To facilitate the incorporation of ecological data in environmental planning and decision-making, several methods for environmental assessment and ecological evaluation have been developed over the years. Some of the earliest efforts to describe the value of nature to human society can be traced to conservationists who attempted to convince decision-makers of the need to conserve part of the natural environment as a natural heritage for future generations. Over the years, many arguments for nature conservation (and the sustainable use of natural resources) have been put forward. The arguments most mentioned in some of the early literature (e.g. Mörzer Bruyns (1967), Ehrenfeld (1970), Hueting (1970), Westhoff (1971), Dasman (1975) and Udvardy (1975), are briefly summarized below.

Early efforts to promote biological conservation were mainly based on **sentimentalism**, stressing the need to achieve a certain harmony between man and nature. The **ethical argument** is based on the presumption that all living beings have an equal right to exist, and consequently, man should act as a responsible steward over the natural heritage. The **recreational argument** stresses the value of nature as a source of aesthetic enjoyment and recreative experience which provides many people with an important source of inspiration to cope with daily chores and compensates for daily routines. In 1872, Yellowstone National Park, the first National Park in the world, was established chiefly for this reason. The **educative argument** proceeds from the viewpoint that nature is a source of educational experience which increases man's awareness and understanding of his environment and informs him about his place within the universe. The **scientific argument** sees nature as an almost unlimited source of research opportunities and as a field laboratory, enabling man to explore his environment and to secure his continued existence on earth by further developing the life sciences. The **utilitarian argument** defends nature conservation on the basis that natural ecosystems are suppliers of many resources and essential commodities, e.g. water, food, raw materials, and energy. Finally, the **survival argument** stresses the point that the continued functioning of natural processes is essential to human existence on earth. Disturbance of these processes has negative consequences for the supply of basic goods and services needed for survival and adversely affects human and environmental health. Our knowledge of the effects of disturbances of the natural processes in our environment is still fragmentary. Nature conservation can therefore be seen as a 'health insurance' against unforseeable ecodisasters. Conserving natural ecosystems also maintains the opportunity to discover new functions of the natural environment which may be essential to our survival in the future.

These first attempts to describe and evaluate the importance of nature to man were rather unstructured. Since the early seventies, attempts have been made to provide a more systematic listing of the many benefits of natural ecosystems to human society, and to design methods for assigning values to these benefits. Many titles and reference books on the evaluation of species and ecosystems exist, and in chapter 1.1 a review of environmental assessment methods is given. The function-evaluation system used in this book is described in more detail in chapter 1.2. Within the disciplines of environmental assessment and ecological evaluation, a large number of specific terms and concepts are used. To avoid confusion, some of the most frequently used are briefly described in the glossary to this book.

1.1. Environmental assessment and ecological evaluation methods, a review

Although the terms environmental assessment and ecological evaluation are now in common usage, they are often used and interpreted differently depending on the subject and aim of the assessment or evaluation. Many types of assessments and/or evaluations may therefore be distinguished, including: (1) conservation evaluation, (2) land use evaluation, (3) environmental function evaluation (which can be seen as a combination of the previous two), (4) environmental risk assessment, and (5) environmental impact assessment.

The subject matter may differ for each type of assessment or evaluation. For example, conservation evaluation may concern a single species or involve a certain habitat or ecosystem and may also be extended to the evaluation of entire natural areas (natural parks, reserves, etc.). Land use evaluation may be related to a specific human activity or may involve an assessment of the potential effects of complex land use (development) projects.

Environmental assessments and ecological evaluation may also have different aims. Ecological evaluations aim to appraise and find numerical expressions for certain ecological characteristics. The term 'evaluation' thus by definition includes value judgements, which may range from assessing the conservation value (mainly based on rarity) of certain species or ecosystems to priority ranking of natural areas, based on the thought that some ecosystem characteristics are more important or interesting than others. Land use evaluations aim to determine the potential value of a given habitat for human use. Environmental assessments are usually restricted to making an inventory of the ecological characteristics of a

certain ecosystem or natural area in an objective manner (e.g. landscape ecological studies) or to describe the possible effects of human activities on these characteristics (environmental impact assessment).
Translating information provided by environmental assessment and ecological evaluation into economic (and monetary) information is another type of evaluation which is discussed extensively in chapter 3 of this book.
There is a large amount of literature on the broad subject of ènvironmental assessment and ecological evaluation. Only a few titles on the general topic are listed here for reference Van der Ploeg & Vlijm (1978), Spellerberg (1981), Odum et al. (1983), and Usher (1986).

1.1.1. Conservation evaluation

Conservation evaluation deals with an evaluation of ecosystem qualities per se, regardless of their socio-economic interests. Usually, the purpose of these evaluations is to determine the 'conservation value' of certain species or ecosystems in order to be able to set priorities for their protection. Value judgements are mainly based on criteria such as naturalness, diversity, species richness and rarity (see the table 2.2.5-1). Sites meeting many criteria tend to be more highly valued than sites meeting few criteria. The existence of different conservation criteria and the various ways in which they can be combined, pose problems for the explicit determination of the conservation value of a particular area or ecosystem.
To include information obtained from conservation evaluation in planning and decision making, ranking nature areas according to 'importance' based on a selection of conservation criteria cannot be avoided. To facilitate decision-making, attempts have been made to translate qualitative information into quantitative data, for example by assigning a numerical value to the importance of a given site for a criterion, such as naturalness, diversity, etc. To integrate the data, more or less complicated formulas were developed by some authors to combine these different values into one 'total value' for the area as a whole. This opens up the possibility of drawing maps showing the various number-values of different ecological units in a region, province or country. The idea is that this simplification would facilitate planning since on one map it could be seen which areas are more 'important' (in terms of a higher integrated conservation value) than others.
However, much critism has arisen against these numerical 'environmental mapping' methods which were especially popular in the Netherlands in the late 1970's under the name of 'milieukartering' (for a review of 13 case studies, see Burggraaf, 1979). The main objection is that one cannot simply add figures which represent values of a completely different nature. For example, area A may score 3 for diversity and 7 for uniqueness, making a total of 10 points (whereby a high score is better than a low score). Area B, on the other hand scores 6 for naturalness and 4 for ecological fragility, also adding up to 10. In this case area A and B

score equally high on the conservation list but for very different reasons. Of course, different weight can be given to the importance of each criterion to make more subtle calculations, but the problem remains that numerical calculations cannot adequately account for the different qualities of the areas in question.
Another problem with assigning and integrating numerical values to conservation criteria is that only areas with similar ecological characteristics should be compared.

1.1.2 Land use evaluation

Contrary to conservation evaluation (chapter 1.1.1), this type of evaluation puts emphasis on the 'utilitarian' value of nature. It aims to analyse the (potential) benefits, values and suitability of a given natural or semi-natural area for certain types of human use. Land use evaluation may relate to a wide variety of values and uses, for example the value of species or ecosystems for agriculture, trade, recreation, and science. Consequently, land use evaluations are carried out under a large number of different names such as resource assessment, land capability studies (environmental profiles), carrying capacity studies, etc. It would lead beyond the scope of this book to discuss all these methods in detail here. For more information the reader is referred to the literature, for example Kessler & Ohler (1983), and O'Leary (1986).

1.1.3 Environmental function evaluation

Environmental function evaluation can be seen as an attempt to combine conservation evaluation (the 'ethical approach") with land use evaluation (the 'utilitarian approach"), in order to provide a relatively objective reference system for measuring the importance of natural ecosystems to human welfare. The concept of environmental functions thus includes not only the harvestable goods (i.e. natural resources in the narrow sense) and land use values but also refers to other benefits of natural environments which are less tangible.
Much research has been carried out in The Netherlands on the development of the theoretical concept of ecosystem functions and environmental values, and on ways to include this concept in environmental planning and decision-making. Some early references to the function-concept date back to 1966 when a Dutch Government policy document referred to the 'functions of the rural landscape' (Ministerie VRO, 1966). Other early references from Dutch ecologists describing functions and values of natural systems include Mörzer Bruyns (1967), van der Maarel (1970), and Westhoff (1971). One of the first authors to use the environmental function-concept in an economic context was Dr. R. Hueting, economist at the Division of Environmental Statistics of the Netherlands Bureau for Statistics. Dr. Hueting introduced the function-concept in January 1970

(Hueting, 1970) and since then has written many publications on the (potential) use of environmental functions in economic theory (e.g. 1980, 1984, 1990).
Another pioneer in the field of environmental function analysis is Ir M.G. Wagenaar Hummelinck. As chairman of the World Wildlife Fund-Netherlands, he initiated a working group in 1969 (with Dr. Hueting as one of the participants), to formulate a research plan on the evaluation and, if possible, the quantification of the ecological and economic value of nature to man. This study was carried out by the Free University of Amsterdam between 1971 and 1975 (Bouma & Van der Ploeg, 1975). In 1979, an english version of the results appeared, entitled 'Functions of the Natural Environment, an economic-ecological analysis' (Braat et al., 1979). This scientific report was made available to a broader public by W. van Dieren and M.G.W. Hummelinck by means of the book 'Nature's Price, the economics of Mother Earth' (1979).
An attempt to incorporate function-evaluation in physical planning by van der Maarel and Dauvellier (1978) provided additional views on the possible classification and evaluation of environmental functions.

Outside the Netherlands, a similar line of thought was followed by King (1966), Helliwell (1969), Odum & Odum (1972), Everett (1979), Pimentel (1980, 1984), Thibodeau & Ostro (1981) and Kellert (1983). Often these authors did not explicitly use the term 'environmental function' but used 'environmental or wildlife values' when referring to goods and services provided by (natural) ecosystems. Some important recent references on this subject include McNeely (1988) and Folke and Kaberger (1991).
It would require a book-length document just to summarise all the different interpretations of the concept of environmental functions, and the different ways in which the authors assess the benefits of these goods and services to human society. The function-evaluation method used in this book is partly based upon the work done by the aforementioned authors (especially Braat et al. (1979) and van der Maarel & Dauvellier (1978)), combined with original research on various case studies, and is described in detail in chapter 1.2.

1.1.4. Environmental risk assessment

Nature not only provides many useful goods and services but also presents many hazards to human society, such as extreme weather conditions (e.g. storms and droughts), earthquakes, volcanic eruptions, floods, landslides, and biological hazards such as disease-agents and poisonous plants and animals. When assessing these natural hazards, it must be realised that many of these 'negative functions' of nature are aggrevated by, or even solely caused by human interference. For example the loss of vegetation caused by human activities (such as logging) influences slope stability and weather conditions which may lead to flooding and landslides in areas which were previously free from such 'natural' hazards. A useful handbook on environmental risk assessment is a publication by OAS (1987).

1.1.5 Environmental impact assessment

Environmental Impact Assessment (EIA) attempts to assess the actual and potential effects of human activities on the natural environment. EIA thus studies the impact of human society on the natural environment as opposed to the other four evaluation methods which study the impact of the natural environment on human society, both positive (goods and services) and negative (hazards). Since this book mainly concentrates on assessing the (potential) benefits of the natural environment to human society, EIA methods are not further elaborated in this section. EIA is, however, becoming an increasingly important instrument in land use planning and decision-making, and the application of the function concept in environmental impact assessment is therefore discussed in greater detail in chapter 5.2.

1.2 Environmental function evaluation: the method used in this book

From the literature review given in chapter 1.1, it appears that few studies have attempted to make a comprehensive assessment of the total importance of natural and semi-natural ecosystems to human society. Most of the existing literature on environmental and wildlife values is descriptive and the few methodological studies available only deal with certain aspects of the natural environment (e.g. wildlife, forests, wetlands) or are limited to only some functions (e.g. recreation or the use of certain resources). Also, the classification systems used for environmental functions differ widely. Many of the existing methods which were developed to assess and/or evaluate ecosystem functions have not been tested in practice and often the link between the functions and the parameters or criteria is not very clear, making it difficult to apply the system in practice and to repeat the assessment or evaluation procedure for verification or comparative purposes. Also, the socio-economic valuation of the functions is not very systematic and still lacks clear criteria.
The design of a comprehensive and universally applicable evaluation method was the main purpose of the research for this book. Based on literature, in combination with original ideas, an evaluation method was designed, and tested in a number of case studies (see chapter 4), which translates environmental characteristics into functions (goods and services) provided by natural and semi-natural ecosystems and the wildlife they contain, taking both ecological and economic factors into account.

To analyse the ecological and socio-economic implications of the most important functional interrelations between man and the natural environment in an objective and systematic manner a simplified man-environment model can be used (see Figure 1.2-1.).

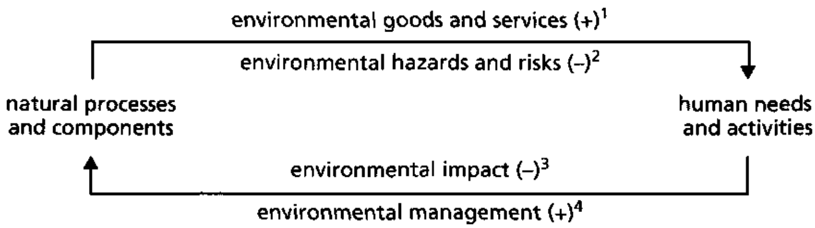
Fig. 1.2-1 Simplified man-environment model

An important element in this 'man-environment model' is the **function concept**. In this book, environmental functions are defined as the capacity of natural processes and components to provide goods and services that satisfy human needs (directly and/or indirectly). Human needs, in turn, may be divided into two main categories: - physiological needs i.e., the need for oxygen, water, food, physical health, and a healthy, unpolluted living environment, and - psychological needs: the need for mental well-being which in turn depends on the availability of opportunities for cognitive and spiritual development and re-creation, the freedom to establish social contacts and to achieve a certain social status (i.e. a meaningful place in society), and the need for a safe future for both present and future generations. According to OAS (1987), something can be considered a necessity if: '...its absence, presence or reintroduction is related to illness, or if the deprived person prefers it to other satisfactions'. Necessities (and desires) vary according to culture, race, age, sex, seasons, climate, education, income levels, etc., which means that the cultural and socio-economic setting should be taken into account when assessing and evaluating the importance of environmental functions to human society. In order to satisfy these needs, human society and individual people engage in all sorts of activities such as agriculture, house-building, industry, transport, recreation, etc. The satisfaction of many of these needs and the performance of many human activities depend on certain environmental conditions. Translating these environmental conditions into terms of functions (and hazards) of the natural environment, instead of the much narrower concept of natural resources, may provide a useful analytical framework for measuring both environmental health and quality of life.

In order to provide a framework for a systematic analysis of the most relevant functional interrelations between man and the natural environment, the arrow in figure 1.2-1 may be elaborated into 4 different assessment techniques: (1) **Environmental Function Evaluation**, which deals with an assessment of the goods and services provided by natural and semi-natural environments (e.g. resources/raw materials, energy, recycling of waste, opportunities for recreation, etc.), (2) **Environmental Risk Assessment**, which involves an assessment of the hazards imposed on human society by natural and semi-natural processes (e.g. drought, storms, floods, earthquakes, volcanic eruptions, etc.), (3) **Environmental Impact Assessment**, i.e. an assessment of the physical, chemical and biological impact of human activities on the natural and semi-natural environment, and (4) **Environmental Management Evaluation**, which assesses the effects of management measures intended to maintain and/or restore natural processes and components (e.g. anti-pollution measures, environmental rehabilitation, sustainable management techniques, etc.). The relation between these four assessment techniques is shown in figure 1.2-2.

Most of this book is devoted to the description and illustration of the first assessment technique (environmental function evaluation) while its use as a tool for environmental impact assessment and environmental management evaluation is also discussed (see chapter 5). Environmental Risk Assessment is another important tool for planning and decision-making which was briefly introduced in chapter 1.1.4.

Fig. 1.2-2 Main elements of a system to evaluate the functional interactions between man and the natural environment



The functional interactions between the natural environment and human society have both positive (+) and negative (-) aspects and can be divided into four types of interactions: (1) Environmental Function Evaluation, (2) Environmental Risk Assessment, (3) Environmental Impact Assessment, (4) Environmental Management Evaluation (for explanation, see text).

Human welfare and the quality of life depend directly or indirectly on the availability of environmental goods and services in many ways. An important aspect of environmental function evaluation is the classification of environmental functions. Four function categories are distinguished, mainly based on Van der Maarel & Dauvellier (1978) and Braat et al. (1979). The following definitions are from the author:
(1) **Regulation functions:** this group of functions relates to the capacity of natural and semi-natural ecosystems to regulate essential ecological processes and life support systems which, in turn, contributes to the maintenance of a healthy environment by providing clean air, water and soil.
(2) **Carrier functions**: natural and semi-natural ecosystems provide space and a suitable substrate or medium for many human activities such as habitation, cultivation and recreation.
(3) **Production functions**: nature provides many resources, ranging from food and raw materials for industrial use to energy resources and genetic material.

(4) **Information functions**: natural ecosystems contribute to the maintenance of mental health by providing opportunities for reflection, spiritual enrichment, cognitive development and aesthetic experience.
In addition, it must be realised that there are probably many unknown goods and services (functions) which are not yet recognised, but which may have considerable (potential) benefits to human society.

The ranking order of the function-categories is somewhat arbitrary. The order used here is taken from an 'environmental perspective', in which case maintenance of essential ecological processes (regulation functions) and suitable living space (carrier functions) provide the preconditions for production and information functions. If the order is determined by the human perspective, it could be argued that the available living space (carrier functions) and resources (production functions) are most important, followed by the regulation and information functions (e.g. Stortenbeker, 1990). Another aspect to be considered is the fact that regulation functions are performed by nature regardless of man's presence and also benefit other species. Carrier and production functions relate to more species-specific environmental requirements, while information functions can only be distinguished because of man's cognitive capacities.
Since human life seems quite impossible in the absence of any one of these function categories, the hierarchy should not be interpreted too strictly. Other rank orders and (sub-) divisions are of course possible and, considering the complexity of the subject (chapter 2 describes 37 separate functions), a completely satisfactory listing and division of functions may never be found.

The capacity of a given natural or semi-natural ecosystem to provide certain goods and services depends on its environmental characteristics (natural processes and components). Ideally, a matrix should be developed showing the relation between environmental characteristics and environmental functions (see Table 1.2-1). The matrix should focus on those characteristics which are important as parameters or criteria for assessing or evaluating the qualitative and/or quantitative capacity of a given area or ecosystem to provide certain functions.
Considering the large number of environmental functions and the enormous variety of environmental characteristics and parameters, it is physically almost impossible to design a matrix which shows all the interactions between environmental functions and environmental characteristics.
Theoretically, many different models of the functions of the natural environment can be constructed, ranging from a model for a large area including all functions and unlimited in time, to one for a specific small area, for only one function and for a short period of time (Braat, et al., 1979). In the first case, data to quantify the variables would be impossible to collect. In the second case, the model is bound to be unrealistic since functions (and parameters) are often interrelated. A choice must therefore be made,

and selecting the appropriate parameters and criteria for assessing and evaluating the function performance of a given ecosystem is essential to the practical application of the proposed function-evaluation system. Another problem in finding the most suitable combination of environmental functions and assessment parameters is the fact that many functions are determined by more than one parameter and that one parameter may influence more than one function.

Table 1.2-1: Relationship between environmental functions and environmental characteristics

Environmental[1] characteristics (as assessment parameters or evaluation criteria)	Environmental functions			
	Regulation	*Carrier-*	*Production*	*Information*
Bedrock/geology (e.g. lithology)				
Atmosphere & climate (e.g. air quality)				
Geomorfology/relief (e.g. sedim./erosion)				
Hydrology (e.g. water quality)				
Soil (e.g. fertility)				
Vegetation (e.g. structure)				
Flora and Fauna (e.g. species diversity)				
Life community (e.g. food chain inter.)				
Ecosystem (e.g. naturalness)				

[1]A brief description of the most important environmental characteristics can be found in Appendix I

In order to design a practical evaluation method and to investigate which parameters are the most important, several case-studies were carried out on various ecosystem complexes. A brief summary of the results of three case studies is given in chapter 4, including the functions and values of tropical moist forests (partly based on a case study of the Darien National Park in Panama, a subtropical pre-montane rainforest), a case study of the Dutch part of the Wadden Sea (an estuarine environment) and a case study of the Galapagos National Park (Ecuador), a volcanic, oceanic island ecosystem.

Since the environmental characteristics of most ecosystems differ from one another, the functions of different ecosystems, such as rainforests, wetlands and volcanic islands will also be quite different. Yet, it is possible to develop a general checklist of parameters that may be used to assess the contribution of a given ecosystem to certain environmental functions. A description of the most important parameters, including information on methods to survey these parameters, is given in Appendix I.

Chapter 2

Functions of the natural environment

Introduction

Human society, for its survival and wellbeing, is totally dependent on the biosphere, the thin layer of air, water and soil surrounding the globe in which life on earth is concentrated. This layer is at most no more than 20 km in thickness, which is not more than 0.3% of the earth's diameter, and provides all the physiological necessities of life, such as oxygen, water, food, and various forms of energy and raw materials. In addition, the biosphere provides many essential services which are indispensible to humanity, such as maintenance of the gaseous quality of the atmosphere, amelioration of climate, regulation of the hydrological cycle, waste assimilation, recycling of nutrients, generation of soils, pollination of crops, maintenance of a vast genetic library, and many other life supporting processes.

The availability of these goods and services (= functions) is largely controlled and sustained by ecological processes operating in natural and semi-natural ecosystems such as forests, grasslands, lakes, oceans, cultivated fields, deserts, ice sheets, and many hundreds of other types of ecological systems which blanket the earth and compose the biosphere. The size of ecosystems may vary from large tracks of tropical rain forests or ice sheets covering hundreds of square kilometers to small isolated potholes of only a few square meters. In various ways, these large and small ecosystems each play their role in regulating and maintaining the 'ecological balance' on earth.

In spite of their vital importance to our survival and wellbeing, we still know very little about the functioning of natural ecosystems, and details on their operation, maintenance, adaptation and evolution are still poorly understood. In order to better incorporate ecological information into the planning and decision-making process, it is essential to increase our knowledge on the many functions provided by natural and semi-natural ecosystems.

Based on the function-evaluation system described in chapter 1.2, the multitude of different environmental functions can be grouped into four main categories, which in turn can be subdivided into 37 separate functions (see table 2.0-1).

Although this list of functions can be applied to the 'total' natural environment, the emphasis of this book is on natural ecosystems as spatial units which can easily be recognised as elements in the planning and decision-making process, also because they are often confined to small, more or less protected areas. However, they are only one, although important, aspect of the total natural environment which consists of both biotic and abiotic processes operating in and between ecosystems which together make up the biosphere. Many of these processes which operate on a biospheric scale fulfill essential functions, such as protection against UV-radiation by the ozone layer or maintenance of the energy-balance and associated climate processes. For such 'diffuse' functions, it is difficult to determine the contribution of individual ecosystems. However, it is very important to be aware of these functions since the combined results of many small-scale land use decisions has a significant effect on the capacity of natural ecosystems to provide these functions, leading to environmental hazards such as acid rain, the decline of the ozon-layer and the enhanced greenhouse effect. Early recognition of these processes and functions, and the role natural ecosystems play in maintaining these functions, is essential for ensuring the long-term integrity of the biosphere.

It must be realised that research on the many functions of the natural environment has only just begun and most of the few remaining natural areas on earth and notably their plant and animal life, contain a vast reservoir of still unknown functions with possible future benefits to human society. The present rapid destruction of natural habitats, notably the primary tropical rain forests, and the extermination of wild species and indigenous people, which depend directly on these natural habitats for their survaival, greatly reduces the opportunity to explore and use this reservoir of potential information with possibly serious consequences for the survival and wellbeing of both present and future generations.

As was explained in chapter 1.2, the capacity of a given natural or semi-natural ecosystem to provide certain functions depends on the environmental characteristics (processes and components) of the area under consideration. Information on these characteristics is important in order to be able to describe a given function and to determine sustainable use levels for certain functions. A description of almost 65 environmental parameters as well as matrices showing the relation between specific functions and these parameters is given in appendix I. In the following chapters, environmental parameters are only mentioned briefly. To fascilitate cross-reference between functions and parameters, the parameters are indicated in the text in bold, and preceeded by the symbol *.

When assessing the environmental functions of a particular area or ecosystem, it must be realized that many environmental functions are interlinked, as is illustrated by the fact that most environmental characteristics (parameters) influence more than one function (see the matrices in Appendix I). Each function is the result of the interactions between the

Table 2.0-1 Functions of natural environment

Regulation functions
1. Protection against harmful cosmic influences
2. Regulation of the local and global energy balance
3. Regulation of the chemical composition of the atmosphere
4. Regulation of the chemical composition of the oceans
5. Regulation of the local and global climate (incl. the hydrological cycle)
6. Regulation of runoff and flood-prevention (watershed protection)
7. Watercatchment and groundwater-recharge
8. Prevention of soil erosion and sediment control
9. Formation of topsoil and maintenance of soil-fertility
10. Fixation of solar energy and biomass production
11. Storage and recycling of organic matter
12. Storage and recycling of nutrients
13. Storage and recycling of human waste
14. Regulation of biological control mechanisms
15. Maintenance of migration and nursery habitats
16. Maintenance of biological (and genetic) diversity

Carrier functions

providing space and a suitable substrate for
1. Human habitation and (indigenous) settlements
2. Cultivation (crop growing, animal husbandry, aquaculture)
3. Energy conversion
4. Recreation and tourism
5. Nature protection

Production functions
1. Oxygen
2. Water (for drinking, irrigation, industry, etc.)
3. Food and nutritious drinks
4. Genetic resources
5. Medicinal resources
6. Raw materials for clothing and household fabrics
7. Raw materials for building, construction and industrial use
8. Biochemicals (other than fuel and medicins)
9. Fuel and energy
10. Fodder and fertilizer
11. Ornamental resources

Information functions
1. Aesthetic information
2. Spiritual and religious information
3. Historic information (heritage value)
4. Cultural and artistic inspiration
5. Scientific and educational information

dynamic and evolving processes and components (structures) of the total ecological sub-system of which they are a part. This means that utilization of one function (especially the carrier and production functions) will most likely affect other functions. The continued availability of most if not all functions therefore depends on the maintenance of the integrety of the entire ecosystems which provide them. Another important fact is that competition between functions automatically brings in the economic aspect since all (relatively) scarce goods and services that satisfy human wants are part of the subject matter of economic theory (see chapter 3). In determining the maximum sustainable use level of separate functions in a geographically limited area, the (potential) competition between functions is an important aspect which should be given due consideration in the assessment procedure. When assessing sustainable use levels of environmental functions it is convenient to make a distinction between biotic versus abiotic and renewable versus non-renewable functions (see Table 2.0-2).

Table 2.0-2 Renewability of environmental functions

	Biotic functions	Abiotic functions
Renewable	Most resources from wild plants and animals	Many regulation functions (e.g. the recycling of nutrients) certain energy sources (e.g. wind/tidal)
Non-renewable[1]	For example: genetic material and certain types of tropical timber	Certain carrier functions such as energy (e.g. fossil fuels) and use of the land for permanent human constructions

[1]Defined as functions which cannot be restored within a reasonable period of time, arbitrarily put here at 100 years.

For renewable functions it is in principle always possible to determine sustainable use levels, for non-renewable biotic functions this is sometimes possible and for non-renewable abiotic functions this is usually not possible. Environmental functions that cannot be used in a sustainable manner are left out of this book altogether (e.g. the conversion of natural ecosystems for permanent human constructions) or are only briefly mentioned. Another important restriction in assessing the functions of a particular natural or semi-natural ecosystem is the fact that some functions are of such a scale and nature that it is practically impossible to quantify the contribution of a given area/ecosystem to such a function. This is especially the case for certain regulation functions. Yet, the cumulative contribution of individual ecosystems is essential for the maintenance of these regulation functions, for example, the loss of genetic diversity or the changes in the chemical composition of the atmosphere are the result of the cumulative effect of many small-scale land use decisions. The existence of these 'unquantifiable' regulation functions should therefore always be kept in mind by the planner and decision maker.
When functions that cannot be used in a sustainable manner, and/or for which quantification is difficult, this will be clearly indicated in the text.

Chapter 2 gives a general description of the many functions that can be attributed to the natural environment. For each function, a brief introduction of the ecological importance will be given, while occasionally examples of the contribution of a particular ecosystem to a certain function are included. To avoid interruption of the text, the most important environmental parameters which are needed to assess and evaluate the function in question are given in a separate box or are only listed with further reference to Appendix I. Methods for evaluating the socio-economic and monetary value of environmental functions are discussed in chapter 3. However, for some functions it seemed useful to also include some information on the socio-economic (and monetary) value in this chapter.

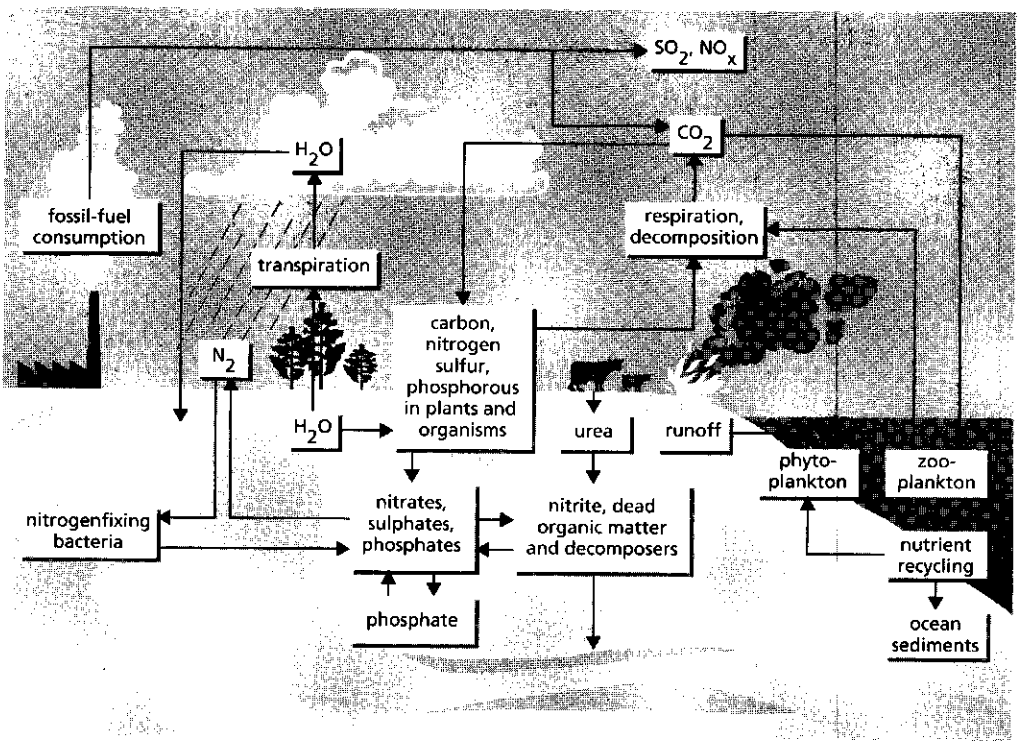
2.1 Regulation functions

The maintenance of the earth's biosphere, as our only life support system in an otherwise hostile cosmic environment, depends on a very delicate balance between many ecological processes. Some of the most important ones are transformation of energy, mainly from solar radiation, into biomass (primary productivity); storage and transfer of minerals and energy in food-chains (secundary productivity); biogeochemical cycles (e.g. the cycling of nitrogen and other nutrients through the biosphere); mineralization of organic matter in soils and sediments; and regulation of the physical climate system. All these processes, in turn, are regulated by the interplay of abiotic factors (such as climate) with living organisms through evolution and control mechanisms (cybernetics).
Individual organisms not only adapt to the physical environment, but by their concerted action in ecosystems, they also alter the geochemical environment to fit their biological needs. The physical and chemical nature of inert materials is constantly being affected by organisms which return new compounds and energy sources to the environment. For example, as is decribed later in this chapter, the chemical content of the sea is largely determined by the actions of marine organisms, as is the very composition of the atmosphere.
New insight into the interactions between the living and inorganic parts of the planet led Lovelock (1987) to the formulation of the hypothesis that the biosphere may be more than just the complete range of all living organisms within their natural habitat of soil, water, and air. According to Lovelock, the Earth's living matter, air, oceans, and land surface form a complex system which is more than the mere sum of its parts: it is a cybernetic system which seeks an optimal physical and chemical environment for life on this planet. The maintenance of relatively constant conditions by active control is described by the term homeostasis, and Lovelock used the word Gaia as a shorthand for this hypothesis. Whether Lovelock's view of our planet as a living organism is correct or not, it is clear that the interactions between the biotic and abiotic components result in a very complex system of processes which influence the conditions for life on

earth (see fig. 2.1-1).

Natural ecosystems play an essential role in the regulation and maintenance of the ecological processes and life support systems on earth. One problem involved in evaluating the contribution of a particular ecosystem or natural area to these regulation processes is the fact that some processes mainly relate to internal regulation of the ecosystem (e.g. certain biological control mechanisms), some relate to external regulation (for example protection against harmful cosmic influences), while others relate to both, for example the prevention of soil erosion by the vegetation. On sloping terrain, this latter process protects both the soil within the ecosystem and prevents erosion and sedimentation further downhill. It entirely depends on the purpose of the evaluation what aspect of a given function is important under the given circumstances.

Fig. 2.1-1 The biogeochemical cycles as examples of important ecological processes operating on a biospheric scale



Source: NASA, 1988

Movements of key elements (carbon, nitrigen, sulfur, phosphorus, and others) through the earth system are critical to the maintenance of life

The many functions that are performed by natural regulation processes often do not directly satisfy human needs, but provide the necessary conditions for a suitable environment. Most of these ecological processes and regulation functions exist independently of man and can be regarded as latent values because only disturbance or removal of the natural ecosystems (for example forests) results in actual damage (i.e. the loss of the functions of the forest).

Regulation functions are usually best performed by undisturbed, natural ecosystems, and in order for man to benefit from these functions, he only needs to ensure the continued existence and integrity of these natural ecosystems and processes. Yet, many human activities cause severe disturbance (physically, chemically and biologically) of the basic ecological processes listed above, sometimes with irreversible consequences, at least within the human lifespan. The loss of regulation functions often leads to great environmental hazards and has serious consequences for environmental and human health, for example soil degradation and erosion, the loss of the protective function of the ozone layer, acidification of the environment, climate change, etc. Because of the indirect benefits of regulation functions they are often not recognized until they are disturbed, but they are nevertheless essential to man's existence on earth.

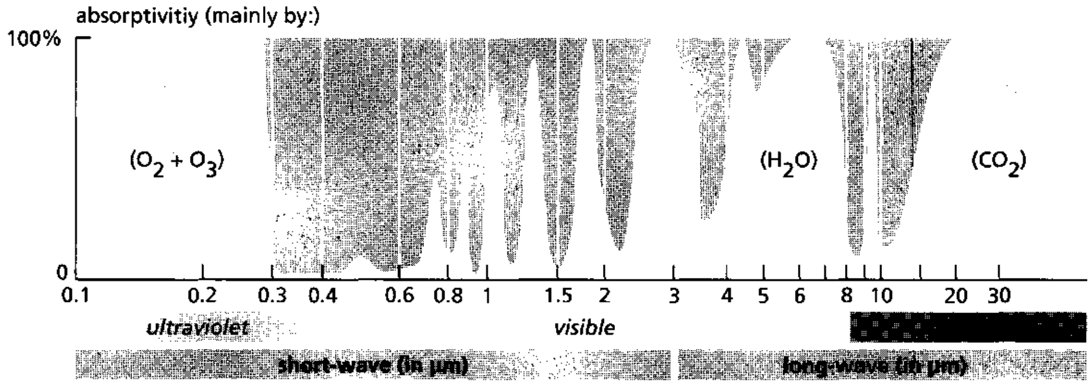
In total, 16 regulation functions are distinguished in this book (see table 2.0-1). The first 9 functions mainly relate to the regulation of the abiotic environment while the other 7 functions deal with biotic regulation processes. Within the group of abiotic regulation functions, the first 5 operate at a 'biospheric scale' (e.g. protection against UV-radiation and regulation of the chemical composition of the atmosphere and oceans). Although it is often rather difficult to quantify the influence of a particular ecosystem on these functions, an indication of their relation with specific natural processes operating in certain ecosystems or natural areas has been given as much as possible.

2.1.1 Protection against harmful cosmic influences

The biosphere is constantly threatened by cosmic influences in the form of (electromagnetic) radiation and solid cosmic particles, varying in size from cosmic dust to large meteors. Much of the extraterrestrial radiation is reflected, scattered, absorbed or filtered by the atmosphere before it reaches the earth's surface. Radiation penetrating the atmosphere is attenuated exponentially by the atmospheric gases and dust to varying degrees, depending on the frequency or wavelength (see Fig. 2.1.1-1). The earth-magnetic field, together with the * **chemical composition of the atmosphere** provide an essential protective shield against several harmful cosmic influences; notably against harmful radiation such as UV.

According to figure 2.1.1-1, UV-radiation is attenuated the most, and visible light the least, which means that photosynthesis, which is restricted to the visible range (optimum by 0.43 u) can continue even on cloudy days (see also chapter 2.1.10). Ultraviolet radiation, between 0.18 and 0.30 microns in wavelength, is extremely disruptive to the life forms that evolved in the absence of these wavelengths. The most important atmospheric gas that is impenetrable to ultraviolet radiation is ozone (Ehrlich et al., 1977). The ozone-layer in the outer atmosphere (especially between 25-30 km of altitude) intercepts about 75% of the incoming UV-radiation (Odum, E.P., 1971).

Fig. 2.1.1-1 Attenuation of extraterrestrial solar radiation by the earth's atmosphere



Source: Fleagle and Businger (1963) in: Nilsson, 1990

Most of the UV-radiation, which is damaging to life, is absorbed by the ozone layer, most of the infrared (long wave) radiation is absorbed by CO_2 (which plays and important role in the so-called greenhouse effect, see chapter 2.1.5).

The role of a particular ecosystem or natural area in this function mainly relates to the influence on the chemical composition of the atmosphere (see also chapter 2.1.3). Some areas such as coastal wetlands and rice-fields emit considerable quantities of chemical substances, such as methane, into the air. These emissions may cause local, and sometimes global changes in the atmospheric chemistry which, in turn, influences the capacity of the atmosphere to intercept cosmic radiation. Also emissions from human activities affect the chemical composition of the atmosphere (see box 2.1.1-1). The quantitative influence of a given geographically limited area to this function is difficult to assess and, inspite of its importance, this function is therefore often not considered in the planning and decision-making process

2.1.2 Regulation of the local and global energy balance

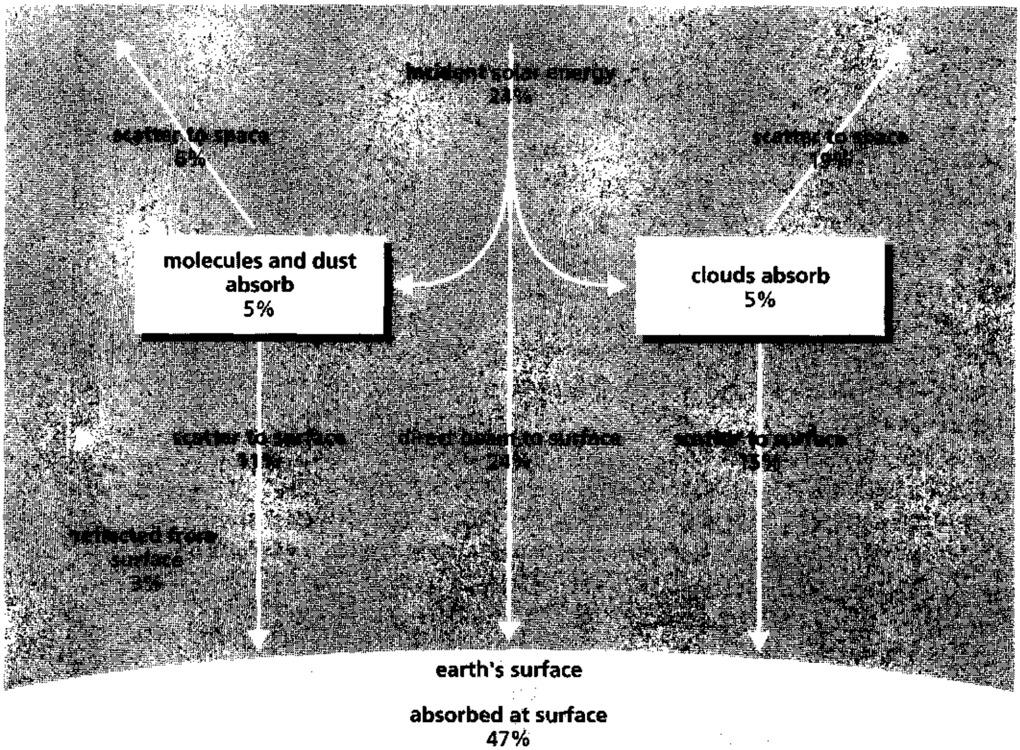
The variety of manifestations of life are all accompanied by energy changes. The main energy source for the maintenance of ecological processes and life on earth is the sun, and the transformation of solar

Box 2.1.1-1 Human impact on stratospheric ozone

The function of the ozone-layer as a'cosmic shield' is increasingly being threatened by the exhaust of pollutants (e.g. chloro-fluorocarbons, so-called cfk's) from airplanes, spray-cans, etc. As a result, the ozone concentration in the stratosphere is declining and a'hole' in the ozone-layer has recently been discovered over the Antarctis, at an altitude of 30 km and with the size of north and south America together. It is believed that, by the year 2020, the ozone-concentration may have declined by 15-20% which would have negative effects on agricultural production and human health (e.g. an increase in the occurrence of skin-cancer) (Nilsson, 1990).

energy into heat and kinetic energy (e.g. wind- and ocean-currents) is important to the functioning of the biosphere in various ways. The absorption of the sun's rays by land and water results in hot and cold areas, ultimately leading to the flow of air which may drive windmills and perform work such as pumping of water against the force of gravity. The oceans are vital parts of the global energy system. By heating up unevenly, depending on the geographical situation, the radiant energy from the sun is transformed into the motions of air and water which in turn distribute this energy over all regions of the world. The energy-balance of the earth is depected much simplified in figure 2.1.2-1.

Fig. 2.1.2-1 Simplified model of the earth's energy balance



Source: Ehrlich et al. (1977)

Figures represent global annual averages

The energy balance is important to many other processes in the biosphere, notable the climate system (see chapter 2.1.5), the local and global dispersal of plants and animals, and the general physiology (through influencing evapotransipration) and structure of ecosystems.
As was the case with the previous function, the contribution of separate ecosystems to this function is difficult to quantify. Some of the most important processes and parameters involved in regulating the global energy balance are atmospheric chemistry, clouds, albedo and photosynthesis by green plants (see box 2.1.2-1). Thus, by altering the concentration of atmospheric gases (e.g. through industrial processes) and by changing the albedo of the surface (for example by removing the vegetation), man may induce local or even global changes in the energy balance of the earth which, in turn, influence the climate system, sea-currents and other functions of the biosphere.

Box 2.1.2-1 Some environmental characteristics (parameters) which influence the local and global energy balance

Evidently, the most important parameter is the * **sun**. Extra terrestrial sunlight reaches the earth's atmosphere at a rate of 1,200 kcal/m²/hour (= 338 W). Of this energy, at most 67% (or 804 kcal/m²/hour) may reach the earth's surface at noon on a clear summer day (Odum, 1971). On average about 50% of the incoming solar energy reaches the earth's surface where it takes part in various energy transformations (see also Appendix I.6.2). Of the incoming light-energy, about 25% is reflected by * **atmospheric aerosols** (dust, molecules, etc.) and * **clouds** while another 25% is absorbed by these same atmospheric constituents (see figure 2.1.2-1). Of the incoming solar-energy which reaches the earth's surface, on average 3% is reflected again. The reflective property of a surface or substance is called it's * **albedo**. Another portion of the energy that reaches the surface is absorbed by the melting and sublimation of ice or snow, or the vaporization of water. Only a tiny fraction is captured and transformed into chemical energy by the process of * **photosynthesis** in plants (see chapter 2.1.10)

2.1.3 Regulation of the chemical composition of the atmosphere

A certain optimum mixture of gases in the atmosphere is essential to most living organisms on earth. The particular mixture of gaseous compounds which makes up the earth's atmosphere, and which in common use is called 'air', has many functions. As we have seen in the previous chapters, the atmosphere is substantial enough to protect the organisms on earth from a variety of harmful cosmic particles and forms of radiation that reach the planet from the sun and from space. At the same time the atmosphere is transparant enough to permit an adequate amount of life-giving sunlight to penetrate to the surface. Acting as a thermal insulator, the atmosphere keeps the earth's surface much warmer, on the average, than it would be if there were no atmosphere (the so-called 'greenhouse effect', see chapter 2.1.5).
In addition to these functions, the atmosphere serves as a reservoir for many gases and colloidal particles (aerosols) many of which are essential to living organisms. Carbon (C), oxygen (O), hydrogen (H) and nitrogen (N) are the four elements required in greatest quantity by living

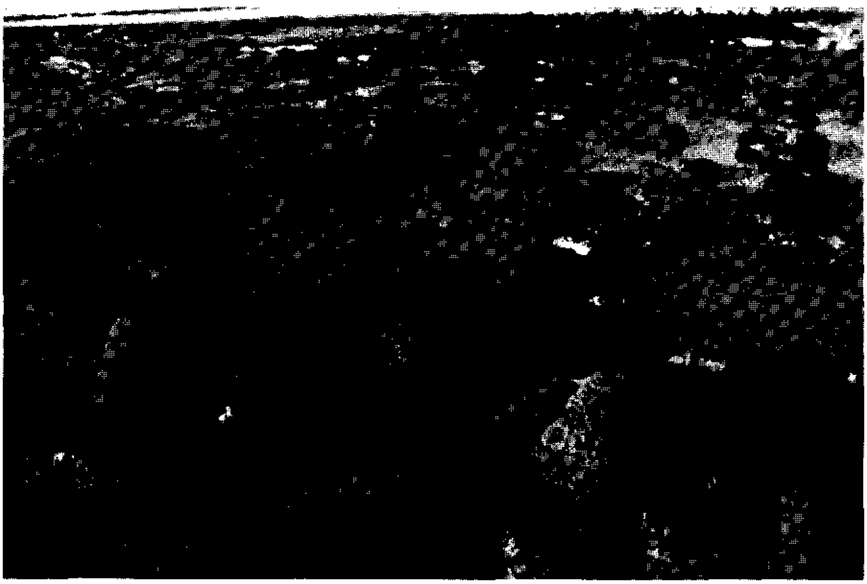
organisms. The atmosphere provides the main reservoir of one (N), the most accessible reservoir of two others (C, O), and an essential link in the continuous recycling of the fourth (H, in the form of H_2O = water). (Ehrlich et al., 1977).The average composition of 'clean' air in the earth's atmosphere is shown in appendix I.2.1.
The suitability of the atmosphere for the support of life depends on the availability of these chemical elements and nutrients in appropriate forms and quantities (i.e. the air-quality). The principal processes which influence the chemical composition of the atmosphere are the * **hydrological cycle** (see fig. 2.1.5-3.), * **winds**, * **volcanic activity**, * **weathering**, and the activity of life communitities, notably * **photosynthesis** and * **respiration**. Although regulation of the chemical composition of the atmosphere is an essential function, often the quantitative contribution of a limited geographical area to this function is difficult to assess. On the following pages, emphasis will be placed on those processes and parameters which can be related to specific ecosystems or natural areas.

Within the scope of this book, it is quite unfeasible to discuss the recycling mechanisms for all atmospheric gases in any detail. Because of their importance to many ecological processes and to the functioning of the biosphere, only some important processes involved in the oxygen and carbon-dioxide cycles are briefly discussed below. It is thereby important to realise that there is a strong correlation between the production and consumption of O_2 and CO_2: for every mole of oxygen removed from the atmosphere, a mole of carbon dioxide is added (Ehrlich et al., 1977). However, since the total concentration of CO_2 in the atmosphere is 700 times smaller than the total concentration of O_2, the effect of a change in the concentration of these chemical elements is 700 times stronger for CO_2 than for O_2. During the past 60 million years shifts in biotic balances (photosynthesis and respiration) coupled with variations in volcanic activity, rock weathering, sedimentation and solar input have resulted in an oscillating steady state in CO_2/O_2 atmospheric ratios (Odum, 1971). Since the middle of the last century, man has begun to upset this balance: by burning the stored organic matter in fossil fuels, through deforestation, and by agricultural practices that increase the decomposition rate of humus. More information on the disturbance of the chemical balance in the atmosphere and some consequences for the proper functioning of the biosphere can be found in chapters 2.1.5 (climate regulation) and 2.1.13 (on storage and recycling of human waste). Some important parameters involved in the oxygen and carbon-dioxide cycling which can be related to specific ecosystems are briefly described in 2 separate boxes.

(1) Regulation of the oxygen concentration in the atmosphere
Oxygen is an essential element for the maintenance of life on earth, and the current oxygen concentration of 21% in the atmosphere is optimal: a lower concentration would cause problems for larger animals. On the

other hand, an increase of the oxygen concentration by only 4% would cause even wet vegetation to burn (Lovelock, 1987). Some important processes in regulating the oxygen concentration in the amosphere are photosynthesis, respiration/decomposition, fire and weathering/sedimentation (see box 2.1.3-1). Photosynthesis is the only oxygen-producing mechanism while the others remove oxygen from the atmosphere. Especially algae communities in the oceans produce a large excess of organic matter and thereby release oxygen. Some of the earliest living organisms capable of converting sunlight to chemical potential energy were probably stromatolites, a type of blue-green algae. Figure 2.1.3-1 shows a stromatolite colony on the shore in South Australia, which is very close in structure to the fossil remains of similar colonies from 3 billion years ago. It was only when oxygen appeared in the atmosphere that the evolution of 'higher' organisms really took off some 2-3 billion years ago.

Fig. 2.1.3-1 A stromatolite colony on the shore in South Australia



Some of the earliest living organisms capable of converting sunlight to chemical potential energy were probably stromatolites, a type of blue-green algae

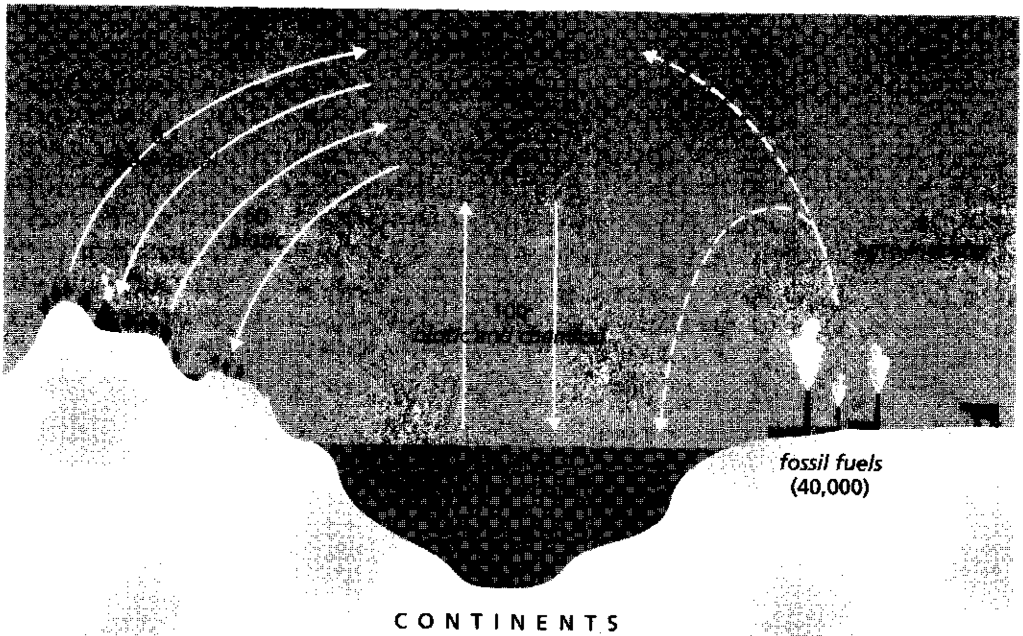
(2) *Regulation of the carbon dioxide concentration in the atmosphere*
CO_2 is an important gas for photosynthesis in green plants. Another important function of CO_2 is its influence on the earth's temperature by acting as a greenhouse-gas (see also chapter 2.1.5 on climate regulation). Some processes that are involved in the production, storage and recycling of carbon-dioxide are photosynthesis, respiration, fire and absorption by the oceans.
Some of these processes can be related to specific ecosystems and natural

areas and thus serve as assessment parameters for the influence of these areas on this function (see box 2.1.3-2). Some quantitative data on the major reservoirs and recycling mechanisms is included in table 2.1.3-1 and fig. 2.1.3-2.

Box 2.1.3-1 Some environmental processes (parameters) involved in adding or removing oxygen from the atmosphere

* **Photosynthesis** (see also Appendix I.8.1)
Through photosynthesis, organic matter is produced from atmospheric carbon dioxide and water while gaseous oxygen is released. In formula, photosynthesis is written as: $CO_2 + H_2O \rightarrow H_2CO_x + O_2$. For every metric ton of dry organic matter produced, there is a net gain of about 1.1 metric tons of oxygen (Ehrlich et al., 1977). In the early history of the Earth there was essentially no atmospheric oxygen, and all molecular oxygen in the atmosphere today is most likely of biological origin (Ehrlich et al., 1977). Only after the evolution of the first photosynthetic organisms, oxygen was brought into the atmosphere while, at the same time, the CO_2 concentration was lowered.
* **Respiration** (consumption and decomposition of organic matter) (I.8.2)
During consumption and decomposition of organic matter, the reverse process from the one described under photosynthesis occurs. This is called respiration. Plant matter is broken down into carbon dioxide and water again by the metabolic processes of the plants themselves, of animals and of microbes. Respiration uses up molecular oxygen just as rapidly as new plant material and oxygen are being produced, thus returning carbon dioxide to the atmosphere. The balance between the two processes is not exact and in geological history there were times of excess organic production which has resulted in the build up of oxygen in the atmosphere to the high levels of recent geological times, and this, in turn, has made the evolution and continued survival of the higher forms of life possible (partly after Odum, 1971)
* **Fire** (burning of organic matter) (I.2.9)
By burning the stored organic matter in fossil fuels and living vegetation (deforestation), additional carbon dioxide is brought into the atmosphere while oxygen is removed. By the present rate of burning of fossil fuels oxygen is probably removed faster from the atmosphere than it is being replaced.
* **Weathering and sedimentation** (I.3.5)
There is an ongoing debate about the possible depletion of the pool of oxygen in the atmosphere caused by the balance or imbalance between weathering and sedimentation of highly insoluble iron sulfide (FeS_2). If there is an increase of sedimentary $CaSO_4.H_2O$ at the expense of FeS_2, then a steady drain on atmospheric oxygen could be the result. There is evidence that this phenomenon was actually occurring during the Permian period about 250 million years ago, but how much oxygen depeletion occurred is unclear and controversial (Ehrlich et al., 1977)

Fig. 2.1.3-2. The global CO_2 cycle



Source: Odum, 1975

Estimates of amounts of CO_2 in three major compartments (atmosphere, oceans, and fossil fuels), and flux rates (as shown by arrows) between compartments. Figures are in 10^9 tons of CO_2

Table 2.1.3-1 The major reservoirs and recycling mechanisms for carbon dioxide
(in 10^9 ton carbon, world average)
After: Hougton & Woodwell (1990) and WRI (1990)

	Reservoir	Release of carbon (into atmosphere)	'fixing' of carbon (from atmosphere)
Vegetation and life communities	560	50.0 (respiration) 2.0 (deforestation)	102 (photosynth.)
Soil-communities	1,500	50.0 (decomposition)	
Fossil fuels	5,000	5.6 (burning)	? (fossilization
Man (excl. burning fossil fuel)	?	0.1	?
Oceans	36,000	100.0 ('evaporation')	102 (absorption)
Atmosphere	735	–	–
Total[1]		207.7	204

[1]In total there is more carbon released into the atmosphere (207.7 billion ton) than removed (204), resulting in a net increase in the atmosphere of 3.7 billion ton carbon per year

As table 2.1.3-1 shows, in addition to natural sources such as life communities on land and in the soil, carbon dioxide is released during burning of fossil fuels, especially coal (combustion of coal releases 40% more carbon-dioxide than burning of natural gas), burning of plastics, which are made from oil-products, and cutting and burning of forests. As a result of these human activities, the carbon dioxide concentration in the atmosphere has increased from approximately 270 ppm (the pre-industrial concentration) to more than 350 ppm today (WRI, 1990), an increase of about 25% in only 150 years.

In absolute terms this rapid increase is less dramatic since the total molecular fraction of CO_2 in the atmosphere is only about 0,03% of the total volume of atmospheric gases (Appendix I.2.1). Although the amount of CO_2 injected into the atmosphere by man's agro-industrial activities is yet small compared to the total CO_2 in circulation (see Figure 2.1.3-2), it is beginning to have a perceptible effect because the atmospheric reservoir is small and the larger oceanic resevoir is not able to absorb the new CO_2 as fast as it is being produced by man (Odum, 1971).

Box 2.1.3-2 Some environmental processes (parameters) involved in adding or removing carbon-dioxide from the atmosphere

*** Photosynthesis and chemosynthesis (I.8.1)**
For every metric ton of dry organic matter produced by green plants 1.5 metric tons of CO_2 is removed from the atmosphere (Ehrlich et al., 1977). In a hypothetical world without plants, the chemical composition of the atmopshere would be 99% CO_2 (and 1% Argon, see appendix I.2.1). Also certain baceteria are able to fix CO_2. One unique group of chemosynthetic bacteria is being seriously considered for life-support systems in spacecraft because on a weight basis they would be very efficient in removing CO_2 from the spacecraft atmosphere.

*** Respiration** (consumption and decomposition of organic matter) (I.8.2)
During consumption and decomposition of organic matter, the reverse process from the one described under photosynthesis occurs. This is called respiration. Plant matter is broken down into carbon dioxide and water again by the metabolic processes of the plants themselves, of animals and of microbes, thus returning carbon dioxide to the atmosphere. If CO_2 was not continuously produced by respiration and breakdown of organic matter, the plant cover on earth would exhaust the atmospheric supply in a year or so (Simmons, 1981).

*** Fire** (burning of organic matter) (I.2.9)
By burning the stored organic matter in fossil fuels and living vegetation (deforestation), additional carbon dioxide is brought into the atmosphere.

*** Absorption by the oceans** (I.4.2)
The most important process responsible for removing considerable quantities of CO_2 from the atmosphere is the absorption by oceans. It is estimated that thus far, the oceans were able to absorb about 50% of the CO_2 produced by man (Ehrlich et al., 1977, Pimentel et al., 1980)

(3) *Regulation of some other important gases*

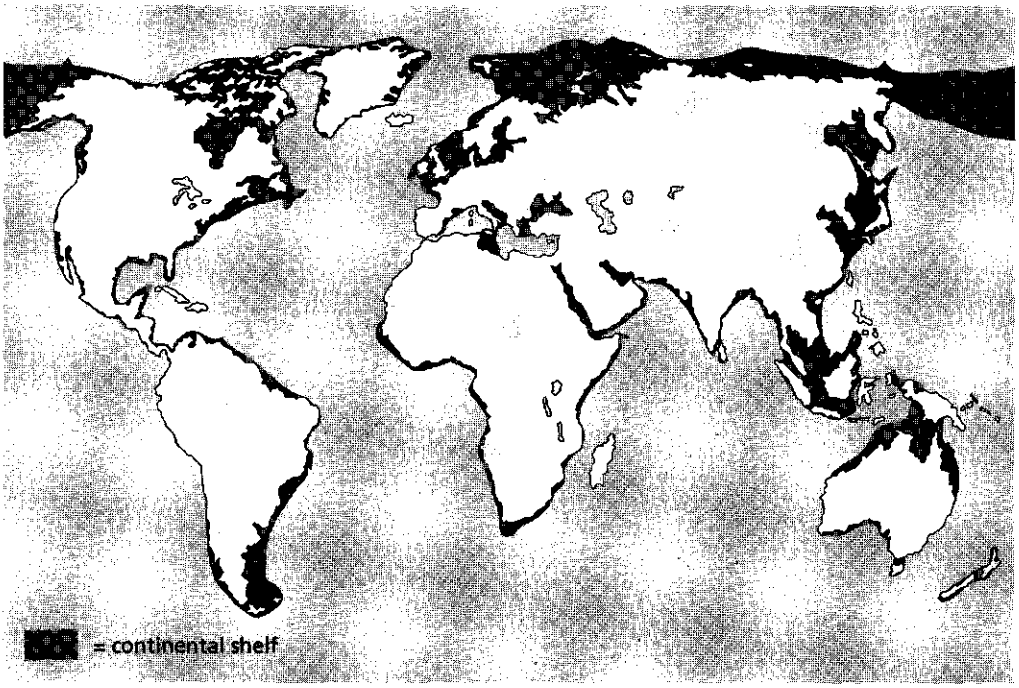
Besides CO_2, many other gases in the atmosphere influence the energy balance and thereby the local and global climate on earth (see 2.1.5). An important so-called greenhouse gas is methane (CH_4). Methane is, among others, produced by certain bacteria through reduction of either organic or carbonate carbon during decomposition. Methane bacteria are obligate anaerobes which decompose organic compounds with the production of methane. In areas with high concentrations of methane bacteria (e.g. swamps, rice-fields, etc.) the production of methane may have a noticable influence on the atmospheric concentration of this gas, which belongs to the so-called 'greenhouse gases (see chapter 2.1.3).

2.1.4 Regulation of the chemical composition of the oceans

Sea water is a complex mixture of living and dead organisms and dissolved or suspended inorganic compounds. Chemically, oceans consist of 96% water, 3.5% salt and the remaining 0.5% consist of sodium nitrate and trace-elements. The chemical composition of the oceans is strongly influenced by living organisms, and without life, the oceans would consist of about 85% water, 13% salt and 2% trace elements (Lovelock, 1987). The average depth of the oceans is 3,200 meters, although there are trenches as deep as 10 km. The total volume of water is around 1.2 billion cubic kilometres. Collectively, the oceans form a reservoir of dissolved gases which helps to regulate the composition of the air which we breathe and provides a stable environment for marine life.
Especially the shallow waters on the continental shelves of the oceans, which occupy an area as large as the African continent (see Fig. 2.1.4-1), may be crucial to the homeostasis of our planet. These areas are essential in regulating the concentration of many chemical elements in the sea (as well as in the air and on the land). Here carbon is buried, a process which sustains oxygen in the air, and here is the source of many other gaseous and volatile compounds essential for life. Unfortunately, most of the pollutants brought into the air, water and soil by agriculture, industry and other human activities, eventually end up in these shallow coastal waters. Thus far, the regulating mechanisms in these areas have been able to buffer the negative impact of these pollutants to some extent, although many coastal seas are suffering badly. It is not clear what the risks are when we disturb this key area of the biosphere even further. Possibly there is a certain threshold beyond which the system will break down.

In principle it is possible to assess the quantitative contribution of a given (coastal) area to the recycling of certain elements, although the impact on the total chemical balance of the oceans will usually be minimal. Yet, the cumulative impact of all coastal areas combined is significant. Some mechanisms involved in the regulation of several elements in the oceans are described below.

Fig. 2.1.4-1 The continental shelves of the oceans.



Source: Lovelock, 1987

These regions, which occupy an area as large as the African continent, may be crucial in the homeostasis of our planet

(1) Regulation of the salt-contents in the oceans

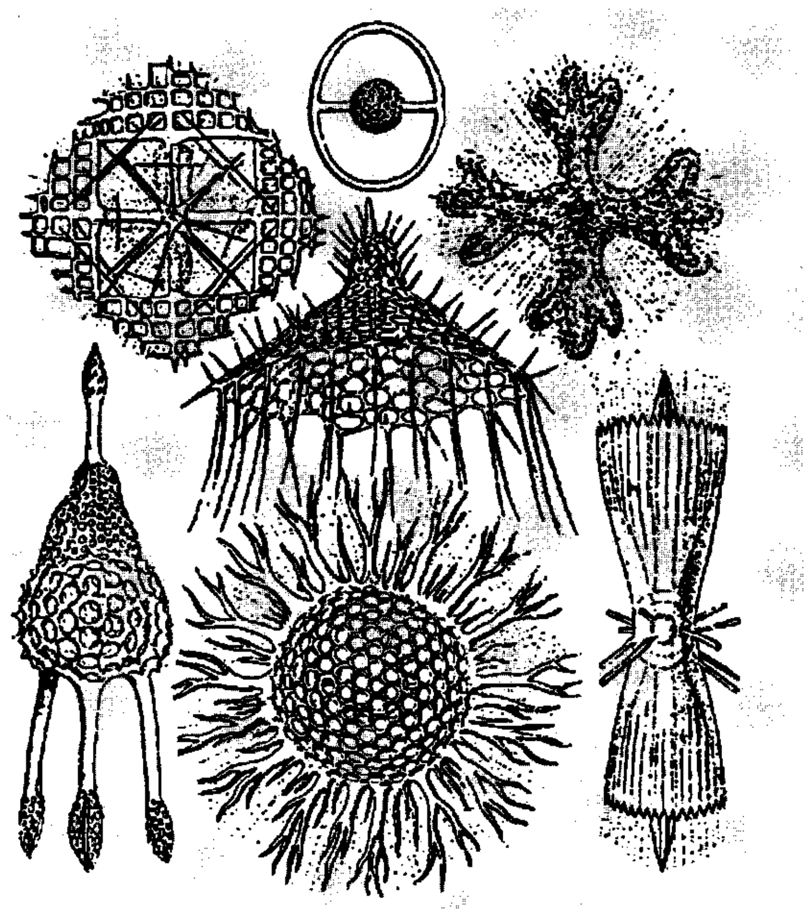
The word 'salt' describes a class of ionic compounds of which sodium chloride (common salt) is only one example. Of the 3.4% salt in sea water, 90% is sodium chloride. Other types of salts are magnesium, sulphate, calcium, bicarbonate, phosphate, and nitrate. The regulation of the salt-content of the ocean is an essential and intricate process which is influenced by many different mechanisms (see box 2.1.4-1). Although the details of these processes still have to be investgated further, they illustrate the intricate interrelations between living organisms and the abiotic environment. The disturbance of such processes by human activities may lead to unknown ecological hazards. Because they consume large amounts of (micro)organisms, the slaughter of whales for example, could disturb the balance of the * **food chains** in large parts of the oceans. This, in turn, could have repercussions on the chemistry and physics of the oceans.

Box 2.1.4-1 Some processes (parameters) which influence the salt-concentration in the oceans

Salt-adding processes: Basically, there are two processes that **add** salt to the sea: (a) One mechanism involved is the * **continental runoff** from rain-water and rivers, washing small amounts of salt from the land into the sea. The surface waters of the oceans evaporate and later fall on the land as rain, but salt, a non-volatile substance, is left behind and accumulates in the sea. This input of salt from continental runoff is calculated at 540 megatons each year (Lovelock, 1987). (b) Another mechanism is * **volcanic activity**: the plastic rocks of the Earth's hot interior at times well up and push through the ocean floor. This undersea volcanic activity adds magnesium and other salts to the sea.

Salt-removal processes: In spite of the continuing processes which bring salts into the sea, the salt content of the sea has not changed very much since the oceans came into being about 4.5 billion years ago. This raises the question what salt-removal processes are at work to maintain the salt-concentration at 3.4%, or in any case well below the critical level of 6%, above which most aquatic life-forms cannot survive. Salt removal processes are less well understood than salt-adding processes. Several processes which are most likely involved are described below.
(a) The (positive) sodium-, magnesium- and calcium-ions may be removed as part of the * **rain of debris** that falls constantly to the sea bed where it becomes part of the sediment. Such a regulation mechanism has been found to exist for the control of the concentration of silica and calcium. Silica is the main constituent of sand and quartz and one of the most abundant elements in the earth's crust. Yet, less than 1 percent of the silica-bearing minerals washed into the sea is retained in the surface waters. The explanation for this phenomenon is the presence of countless single-celled micro-organisms (protozoa, algae, phyto- and zoo-plankton) in the sea. Of special importance in this respect are the *coccolithopores* (with cells of calcium carbonate), and diatoms and radiolarians which are types of algae with skeletal walls made of silica (see fig. 2.1.4-2). When these micro-organisms die, they cause a constant rain of skeletons which sink to the ocean floor, building up great beds of chalk and limestone (from coccoliths), and silicate (from diatoms), adding about 300 million tons of silica to the sedimentary rocks each year (Lovelock, 1987). This biological process is flexible, since the diatom-population grows and shrinks depending on the amount of available silica, thus actively controlling the silica-concentration in seawater. A similar process could be at work to control the concentration of other (positive) salt-ions in the sea.
(b) An entirely different mechanism is needed to account for the removal and disposal of the negative chloride and sulphate ions. One suggestion is that water trapped in isolated sea-arms, such as the Persian Gulf, shallow bays, and landlocked lagoons * **evaporates** more rapidly than it enters from rivers and rain, thus causing a net-inflow of sea-water. Salts will crystallize out in vast * **deposits**, which will eventually be overlaid and buried by natural geological processes. Great beds of salt which are of this origin are found beneath the continental shelves all over the world, and also in various locations below and at the surface of the continents. The only problem with this explanation, according to Lovelock (1987, p.93), is that it may account for the average level of salinty of the oceans staying within tolerable limits, but not for the absence of large and lethal fluctuations. Apparantly there must be some kind of regulation-mechanism which reacts to variations in salt-concentrations, similar to the one described above for silica, by actively stimulating the formation of shallow bays and lagoons. There are two possible explanations for how this could function. One is the * **building of coral reefs** which often close off bays and lagoons and, eventually, may lead to island formation. The other links the sedimentation of skeletons of micro organisms (see a.) to under-sea volcanic activity and sea-floor spreading. Due to increasing pressure and insulation as a result of the continued sedimentation of skeletons, the temperature under the zone of sedimention increases. Eventually the heat is intense enough to melt the rock of the sea floor and lava poors out. This process could stimulate the formation of volcanic islands and, consequently of lagoons.

Fig. 2.1.4-2 Deep-sea radiolaria



Source: Drawings from the Challenger expedition
from Haeckel, History of Creation, vol. 2. (in: Lovelock, 1987)

These tiny micro-organisms may play an important role in the regulation of the silica concentration in sea water

Two other examples of regulation mechanisms that control the concentration of the chemical composition of the sea are the recycling of dimethyl-sulphide and methyl-iodide.

(2) Regulation of the recycling of dimethyl-sulphide
Scientists have found that rivers continuously wash off more sulphur from the land into the sea than could be accounted for by * **weathering** of sulphur-bearing rocks, the sulphur extracted from the ground by plants, and the amounts emitted into the air by the burning of fossil fuels. Each year hundreds of millions of tonnes could not be accounted for. It has been suggested that the missing compound could be dimethyl sulphide which is carried from the sea to the land via the atmosphere. In order to

rid themselves of an excess of unwanted substances, many organisms turn these chemical elements into gases or vapours by adding methyl groups (a process known as methylation). Many marine algae, including the seaweeds, are able to produce dimethyl sulphide in large quantities. This process mainly takes place in the sea around the continental shelf and in inshore waters rich in living matter. Here one finds certain algal seaweeds wich are extremely efficient in extracting sulphur from sulphate ions and converting it to dimethyl sulphide. One of these algae is *Polysiphonia fastigiata*, a small red organism which lives attached to the large bladder-wrack (*Fucus vesciculosus*) to be found on most sea shores. The smell of dimethyl sulphide, in dilute form, is typical of the sea. The * **biological methylation** of sulphur appears to ensure a proper balance between the sulphur in the sea and that on the land. Sulphur is one of the environmental constituents needed for the maintenance of living organisms. Without this recycling process, much of the soluble sulphur on land would have been washed off into the sea long ago and would never have been replaced (after Lovelock, 1987). Dimethyl-sulfide is also one of the so-called 'greenhouse-gases' (see chapter 2.1.5).

(3) Regulation of the recycling of methyl-iodide
A process similar to the recycling of sulphur brings back iodine from the sea to the land. Iodine is a life-essential element necessary to enable the thyroid gland to produce the hormones which regulate the metabolic rate of most animals. Certain species of kelp, notably *Laminaria*, have the capacity to gather iodine from the sea and to produce large quantities of methyl iodide. These algae grow in inshore waters and they used to be harvested, dried and burnt to extract iodine from the ashes (Lovelock, 1987).

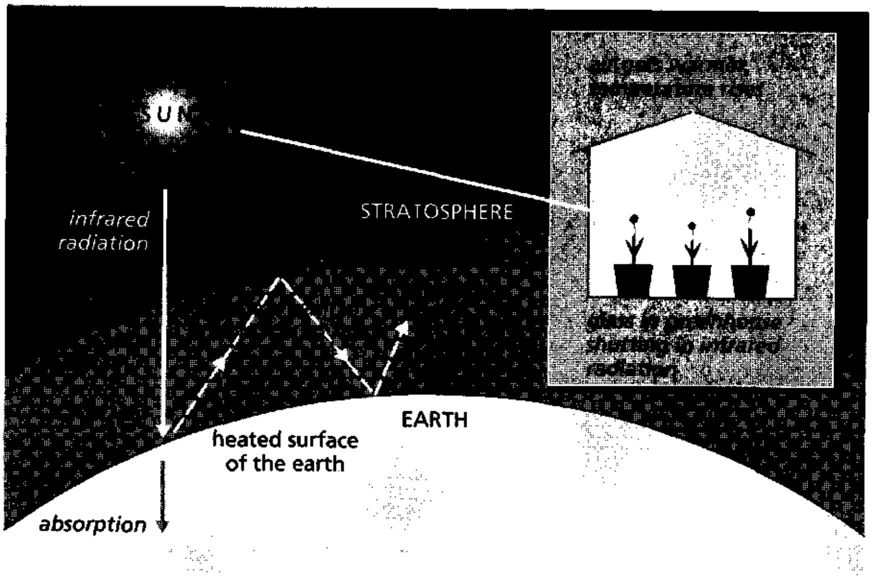
2.1.5 Regulation of the local and global climate

Climate influences many aspects of life and, in case of man, it is important to many activities (agriculture, recreation, etc.) and even influences cultural differences between people living in different climatic zones of the earth. The climate is described by a large set of variables, including temperature, precipitation, humidity, air-turbulence, cloudiness, sunshine, etc.
Many factors influence climatic conditions, both locally and regionally. Local weather and climate are determined by the complicated interaction of regional and global circulation patterns with local topography, vegetation, albedo, configuration of lakes, rivers, and bays, and so on. The global climate is also influenced by changes in solar output and in the earth's orbit, and by the chemical composition of the atmosphere.
When studying the implications of certain human activities for climate, it is important to account for the scale problem. Depending on the scale of the land use intervention (e.g. deforestation, agriculture) or other human

activity, effects may have very different implications for local, regional and global climate conditions.
On the following pages, some regulation mechanisms for temperature, precipitation and wind (air turbulence), being three of the most important climatic parameters, are briefly described. The relation with specific types of land use or ecological processes operating in certain ecosystems is indicated as much as possible.

(1) Regulation of temperature (heat balance)
Life on earth can only exist within a relatively narrow temperature range between certain minimum and maximum values of about -50 °C and +70 °C. In the course of the evolution of the earth, the average temperature has remained remarkably constant, between 10 and 20 °C. This is quite strange, since the sun's output of energy has increased by at least 30% since the 3.5 billion years of life's existence on Earth (see Appendix I.2.6). Thirty percent less heat from the sun would imply a mean temperature for the Earth well below the freezing point of water. If the Earth's climate were determined solely by the output from the sun, our planet would have been in a frozen state during the first 1.5 billion years of life's existence. We know from the geological record that no such adverse conditions existed (Lovelock, 1987). In early times, when the sun was dimmer than today, the presence of certain * **atmospheric gases** such as ammonia and, more importantly, carbon dioxide served as the gaseous greenhouse that kept the planet warm. After evolution produced photosynthesising organisms they began to replace carbon dioxide with oxygen. By lowering the (natural) greenhouse-effect through reduction in carbon dioxide concentrations this process possibly counter-balanced the effects of the increase in energy output by the sun, thus helping to keep the temperature on earth relatively constant. Also other atmospheric gases have major effects on climate, notably nitrous oxide (N_2O), methane (CH_4), ozone (O_3) and chlorofluorocarbons (CFC) These so-called 'greenhouse gases' are essentially transparant to incoming short-wave solar radiation but, like glass, they absorb infrared heat re-radiated from the earth's surface and re-emit long-wave radiation and are thus able to influence the earth's climate (see figure 2.1.5-1). This greenhouse effect of certain atmospheric gases means that an increase in these gases tends to result in a reduction in the rate of loss of the earth's heat to the atmosphere which could lead, eventually, to a worldwide increase in temperature of the biosphere as a whole (see Box 2.1.5-1).

Fig. 2.1.5-1 The Greenhouse Effect



Source: Adapted from various sources.

Another important factor, besides the chemical composition of the atmosphere, is the * **type of surface cover**. Different types of surface-cover have different influences on micro-and macro-climatic conditions. For example, the vegetation cover, by intercepting solar radiation and through evapotranspiration has a strong influence on land temperatures and clearing of forests results in raised land temperatures. Sand deserts produce huge pockets of hot, dry air causing droughts in neighbouring areas, ice deserts have a strong cooling effect on the atmosphere. Large water masses adjacent to land buffer temperature fluctuations, making daily temperature ranges smaller, winters milder and summers cooler. In general, ocean-atmosphere interactions are probably a major factor in the regulation of the global climate. Generally speaking, vegetated areas and oceans have a buffering influence on climate conditions while unvegetated land areas induce more extreme climate conditions.

Also * **relief and altitude** influence climatic conditions. With increasing altitude temperatures drop (on average ca 0.5 °C/100 m). As a result, clouds which are forced to ascend cool off and are therefore less able to hold moisture. Relief and altitude thus influence the amount of precipitation on a local and sometimes regional scale.

Box 2.1.5-1: On some causes and effects of man-induced global climate change

*** On the causes**
Natural fluctuations in the composition of the atmosphere do occur, but in recent times man has significantly increased the concentration of many of the so-called 'greenhouse-gases", due to burning of fossil fuels, deforestation, production of aerosol-gases for spray-cans, airplane propellants, etc. Carbon dioxide (CO_2) has increased by about 25% from pre-industrial levels (see chapter 2.1.3) *while the concentration of other greenhous gases such as nitrous oxide* (N_2O), *methane* (CH_4), ozone (O_3) and chlorofluorocarbons (CFC'$_s$) has been increasing even faster recently. If present trends continue, the combined concentrations of atmospheric CO_2 and other greenhouse gases would be equivalent to the radiative effects of a doubling of CO_2 from pre-industrial levels (before 1850) possibly as early as the 2030$_s$.
In addition to the increase in atmospheric CO_2, the capacity of the biosphere to absorb carbondioxide is decreasing. Deforestation and subsequent desertification reduces the overall rate of photosynthesis carried out by green leaves so that less carbon dioxide is removed from the atmosphere. The burning off of forests, moreover, has the additional effect of increasing carbon dioxide levels in the atmosphere. The role of the vegetation, oceans and other biological and geophysical processes in buffering 'greenhouse gases' is discussed in more detail in chapter 2.1.3.
As a result of the increasing concentrations of these greenhouse gases, it is now believed that in the first half of the next century a rise of global mean equilibrium surface temperature between 1.5 and 4.5 °C could occur, which is faster than any temperature rise in man's history (UNEP, WMO, ICSU,
1985). The observed increase in global mean temperature during the last 150 years (about 0.75 °C) is shown in fig. 2.1.5-2
*** On the effects**
Such a drastic and rapid change in climatic conditions as expected from the greenhouse-effect would cause many problems for the proper functioning of natural ecosystems and for human society. Some expected effects include, melting of the polar ice-caps and continental glaciers, changes in sea-level, world-wide shift in climate and vegetation zones, disturbance of the 'natural balance' in ecosystems, disruption of agricultural production, etc. (Boer & de Groot, 1990).
It must be realised that the debate about man's impact on the greenhouse-effect is rather complicated because, while man is increasing the CO_2 content of the atmosphere, certain processes may counter-act the warming effect, such as increasing concentrations of particles in the atmosphere from volcanic activity and human actions (through industry, burning of forests, etc.). This reduces overall atmospheric clarity which has the opposite effect of cooling the earth. Also changes in air humidity and cloud-formation are complicating factors.

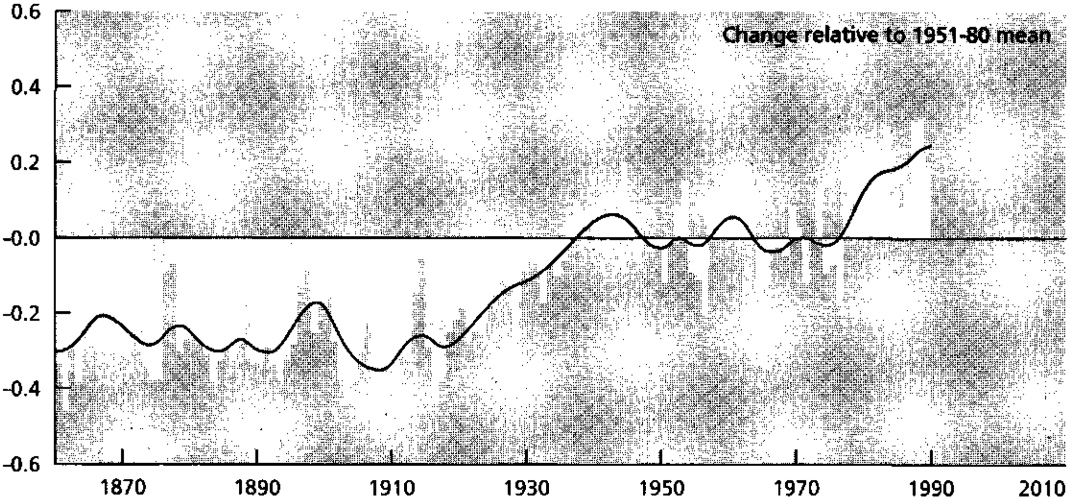
(2) Regulation of precipitation and humidity (including the hydrological cycle)

99.3% of all water on earth is stored in oceans and ice caps, and on average only about 0.0001% (about 13,000 km^3) of the total amount of water on earth is found in the atmosphere as water vapour (see table 2.1.7-1). This water vapour has a period of turnover of about one week to nine days (Mesarovic and Pestel, 1974). Only a small part of the total amount of water on earth takes part in the hydrological cycle (see fig. 2.1.5-3), which is mainly driven by the energy provided by solar-radiation through evaporation, condensation, cloud formation, freezing, melting and sublimation. The cycle includes all three physical states of water: liquid, solid (ice and snow), and gas (water vapour).

Fig. 2.1.5-2 Increase in atmospheric carbon dioxide and temperature since 1850

a

Global average (land + sea) temperature change in °C



b

Concentration (ppmv)

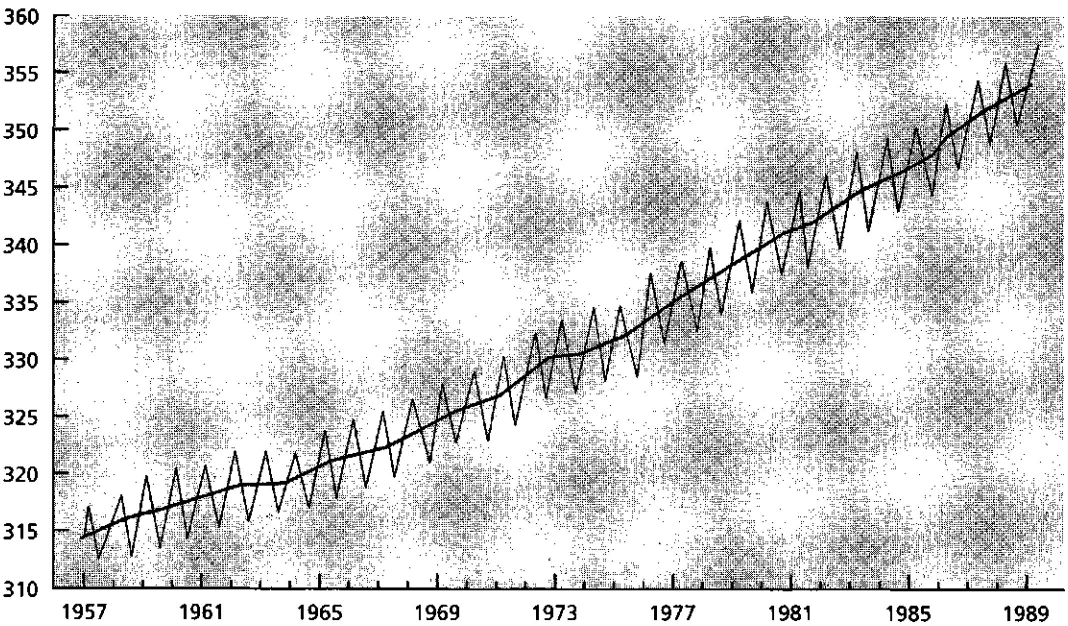
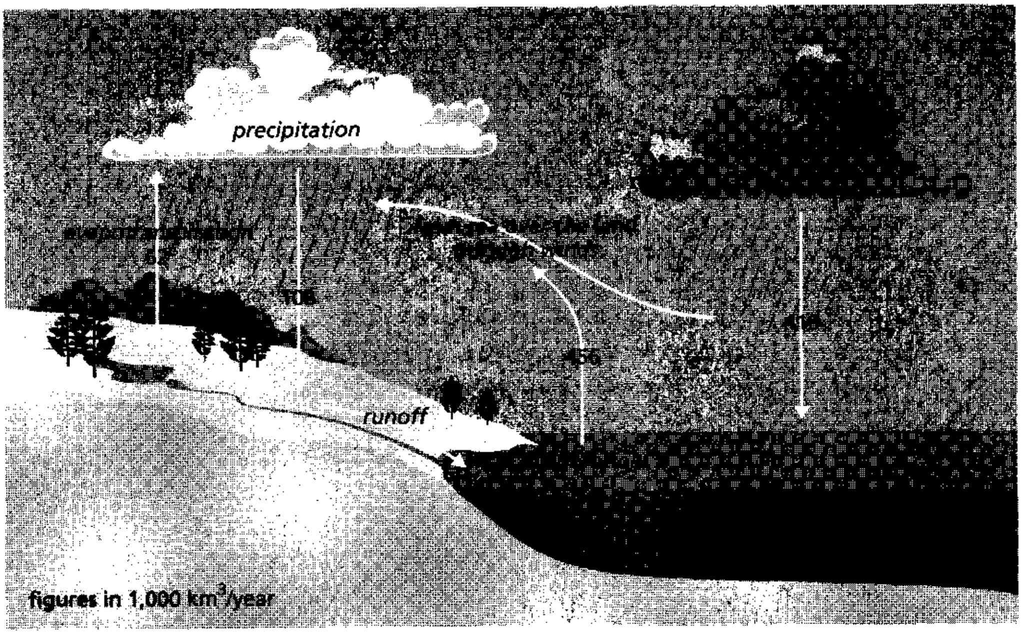


Fig. 2.1.5-3 Simplified scheme of the hydrological cycle



Source: Data from Budyko, 1974, in: Ehrlich et al., 1977

About 90% (410,000 km^3) of water which evaporates from the oceans is returned directly to the oceans through precipitation, the other 108,000 km^3 falls on the continents as rain or snow (Dasmann, 1976). About 62,000 km^3 of the water which has fallen on the continents is returned to the atmosphere through transpiration by the vegetation or evaporation from un-vegetated areas Each year, 2,000 km^3 is stored in ice-caps, mainly in the Antarctics and Greenland, and only about 43,000 km^3 enters rivers, lakes and groundwater-reservoirs through runoff (after: Mesarovic and Pestel, 1974).

In spite of the relatively small amount of water in the atmosphere, it is an essential factor in the hydrological cycle, in the cycling of chemical nutrients and in shaping climates. The vertical and horizontal movement of air masses and atmospheric water, either as vapour or as liquid water droplets and ice cristals in clouds, to a large extent controls climate and weather (which in turn has a strong influence on land use and other human activities). Also many natural ecological processes are influenced by precipitation and air moisture. Without the continuous cycling of water in the atmosphere, rivers and groundwater-reservoirs would soon be dried up. Only places with a certain minimum amount of available water can sustain life. Those places which receive most rainfall, in combination with favourable temperatures and humidity, support the most abundant combination of life-forms culminating in the most species-rich ecosystems of all:

the tropical rain forests.

Some environmental parameters influencing precipitation
Several landscape-features and processes are involved in regulating the amount of water in the atmosphere, mainly by influencing evaporation and (evapo)transpiration. For example, air masses lying over * **seas and other large bodies of water** pick up large quantities of water which is evaporated from the surface (on average about 456,000 km^3), when they move inward over the continents, much of this water is released again as precipitation. Also mountains (i.e. the * **topography** in general) influence the occurence and distribution of rainfall over large areas. The * **type of surface covering** is another parameter which has a large influence on the amount of precipitation. Transpiration of water by plants adds water vapour to the atmosphere. Because on the continents it is difficult to distinguish between the contributions of evaporation from small bodies of water and transpiration by the vegetation, these two terms are often lumped together as evapotranspiration. Each year, about 62,000 km^3 of water-vapour is brought into the atmosphere above the continents through evapotransipration (see fig. 2.1.5-3). Because the * **vegetation cover** has a strong influence on the formation of rain clouds, clearing of forests results in raised land temperatures and strong thermals which hold off light rain clouds making rainfall more erratic and less frequent over the cleared areas. For example, after deforestation of a densely vegetated area in the Amazon basin a reduction of rainfall by 20% has been observed (see chapter 4.1.1). Also from Indonesia there are many examples of climatic changes caused by deforestation (UNDP & FAO, 1982).

(3) Regulation of air turbulance/storms
Air turbulence (i.e. winds) can serve various purposes, for example as distribution medium for animals and plant-seeds, as a source of energy (which can be tapped by windmills), as creator of wave activity and sea-currents, as a dispersal mechanism for moisture and pollutants. However, air turbulance must remain within certain limits; too much wind can cause great damage, for example from storms and associated flooding.

Some environmental parameters influencing air turbulance
The type of * **surface cover**, notably the height, structure and density of the vegetation, is one of the main (local) factors influencing air turbulance. Deserts, oceans and forests show great differences in their impact on air tubulance. For example, cyclones and hurricanes only originate above large open areas (oceans, deserts), vegetated areas on the other hand reduce wind speeds (windbreak function).

2.1.6 Regulation of runoff and flood-prevention (watershed-protection)

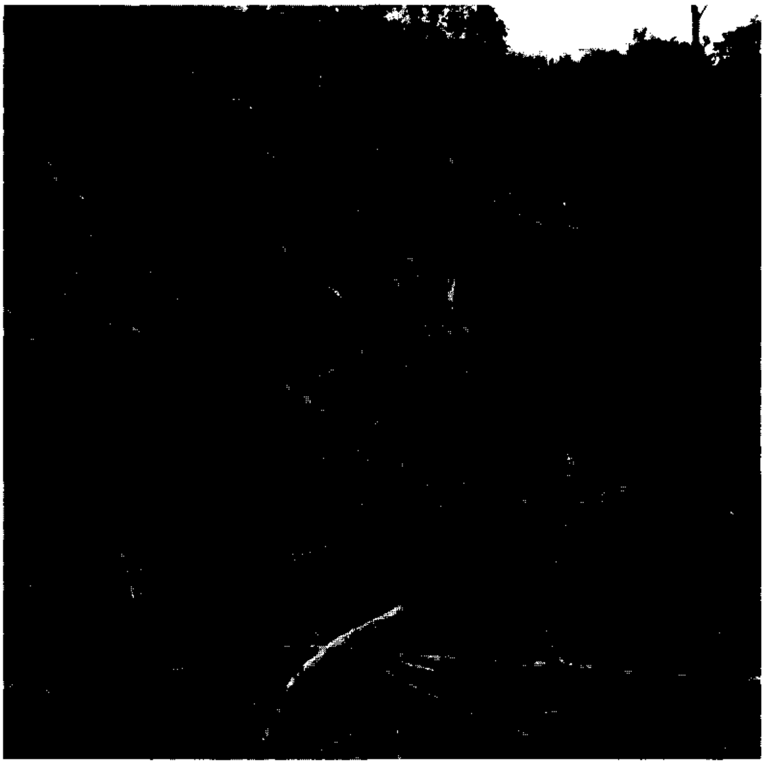
Depending on the balance between precipitation and evapotranspiration (see chapter 2.1.4), a large portion of the water which falls on the continents as precipitation (rain, snow, etc.) finds its way back to the oceans, either as surface-runoff or in underground waterflows. The amount of runoff varies widely from continent to continent. For example, in South America the average runoff is 16,600 km^3/ year, in Australia only 380 km^3/year (Ehrlich et al., 1977). The amount of runoff is a measure of how much water is potentially available for human use such as household, agricultural and industrial uses (including dillution and removal of wastes), and for other functions which are performed by flowing water, such as transportation-medium and recreational uses. A regular distribution of water along the surface is quite essential, since too little, as well as too much runoff can present problems. For example, soil erosion and siltation (which is discussed in more detail in chapter 2.1.8) is often caused by excessive runoff from sloping land. Rapid water runoff can also cause increased flooding in the lowlands.

Some environmental parameters influencing runoff, river discharge and flooding
The runoff characteristics of catchment-areas (= areas from which rainfall flows into a river or lake) are affected by many variables such as * **slope**, * **soil-depth**, * **-texture**, * **humus contents**, and the * **heigth, structure and densitiy of the vegetation cover**, as well as * **leaf area**, and * **root system**. Together, these parameters determine the capacity of a given ecosystem to prevent water-runoff and reduce flooding.

(1) Prevention of runoff on hillslopes
The vegetation plays a particularly important role in regulating the flow of water at the surface and buffering effect on extreme water levels. Especially on hillslopes, the vegetation prevents or reduces flood-damage and soil-erosion while at the same time reducing the danger of prolonged droughts further downhill in the watershed area. In general it can be stated that the higher the * **vegetative biomass** the greater the capacity to reduce runoff (both by providing a physical barrier and through transpiration of excess water). For example, Pimentel, et al. (1980) calculated that water runoff on bare slopes is 10 to 25 times as great as that on slopes covered by vegetation. In Malaysia it has been shown that the peak runoff per unit area of a forested catchment is about half that of rubber and oilpalm plantations, while the low flows are roughly double (Daniel and Kulasingham, 1974). Many agricultural systems in valleys depend for their water supply on this natural irrigation system which enables the vegetation to take in sufficient amounts of water during longer periods of time, thus enhancing the productivity.

(2) *Regulation of river discharge*
Along river-banks, riparian forests buffer extremes in the discharge of rivers and regulate the channel flow. An experimental watershed in Southern Calfornia, San Dimas, for example, produced a flow of 49,300 m^3/day before the removal of the riparian vegetation; afterwards the flow almost doubled to 86,300 m^3/day (Simmons, 1981). Riparian vegetation also traps silt from the watershed.

Fig. 2.1.6-1 Protective function of forest on hillslope



(3) Flood prevention

Also in less mountainous areas, vegetation and soil conditions have an important influence on buffering extremes in water-runoff. Wetland areas, for example, store water during the spring-melt and during storms. The water is then released gradually into the waterways, smoothing the flood peak. Wetlands also trap erosive silt. Together these functions prevent both damage to the stream bank and local flooding (Thibodeau and Ostro, 1981) (see also chapter 4.2).The blanket peats on British uplands, for example, are extremely deep and retentive and reduce flood peaks in this unforested catchment (Simmons, 1981).

(4) Stormprotection

Other ecosystem-complexes such as sand dunes and coral reefs provide a buffer against storms and the associated flooding events in coastal areas.

2.1.7 Water catchment and groundwater recharge

The total amount of water on earth is about 1.3 billion km^3, most of which is stored in the oceans and ice caps (see table 2.1.7-1). About 0.6% is found in the soil and groundwater-reservoirs. It has been estimated that an additional amount of water, approximately equal to that in the oceans may be bound in chemical or physical combinations in the rocks of the earth's crust (Dasmann, 1976).

Table 2.1.7-1 Storage of water on earth
Compiled from: Mesarovic and Pestel, 1974, Dasmann (1976), Ehrlich et al.(1977), Simmons (1981)

	Volume (1000 km³)	(%)
Total	**1,357,710.00**	
Oceans	1,320,000.00 [1]	(97.220)
On continents		
Frozen in ice caps & glaciers	29,100.00	(2.140)
Groundwater	8,300.00	(0.610)
(of which 50% deeper than 800 m)		
Saltwater lakes and inland seas	104.00	(0.008)
Freshwater lakes	125.00	(0.009)
Soil moisture (above water table)	67.00	
Average in rivers and streams	1.27	
In atmosphere (vapour and clouds)	13.00	

[1] Ehrlich et al.(1977) give 1,370,000,000 km³

Water which is not evaporated or transported by surface runoff (see chapters 2.1.5 and 2.1.6) infiltrates into the ground. Here it becomes part of the groundwater flow and may reappear in springs or as base flow in streams. This groundwater reservoir maintains the flow or level of these bodies of surface water during the dry season when surface runoff is no longer available. Groundwater-recharge is also important to maintain the water table in the soil and to keep soils saturated, to maintain meadows or marshes which depend on high groundwater levels, and to provide soil water in dry seasons or to feed deeper-rooted plants.
Part of the deeper groundwater may remain for long periods in underground storage (aquifers). Some of this deep groundwater is tapped by wells, which usually is a non-sustainable form of use since recharge of deep groundwater is very slow or non-existant.
Of the environmental characteristics which influence water catchment and groundwater recharge, vegetation- and soil-properties are probably the most important (see below). Together they determine the capacity of a given ecosystem to prevent water-runoff and store water, either at the surface or as groundwater. Because of their structure and high contents of organic matter, litter- and peat-rich soils have a great capacity to absorb water and gradually release excess water to the surrounding ecosystems. They are often important recharge areas for groundwater-reservoirs. Inland wetlands, for example, form an important mechanism for the control of the groundwater flow and in some situations recharge aquifers

(Thibodeau and Ostro, 1981, see also chapter 4.2. on the importance of wetlands for this function).
Forested mountains are often critical water catchment areas because they may accumulate snow during the winter, from which the melt forms a major source of water for lowland areas (Simmons, 1981).

Some important parameters influencing water catchment and groundwater recharge
As with the previous function (2.1.6), some important properties of the vegetation in relation to watercatchment are * **heigth, structure and density,** * **leaf area,** and * **root-system.** Important soil properties influencing the permeability for water and the capacity to (temporarily) store water are * **structure** (porosity) and * **humus-content.** Vegetation- and soil-conditions thus have a strong influence on catchment hydrology and on groundwater recharge. Paving over of important watercatchment areas may therefore seriously disturb this function, leading to extremes in water availability, both high (i.e. extremes in runoff after periods with much precipitation) and low (i.e. absence of runoff and lowering of groundwater tables after dry periods).

2.1.8 Prevention of soil erosion and sediment control

Of all the earth's resources, the one we take most for granted may be the soil. It is everywhere around us, easily accessible and easily wasted. Soil is a resource of delicate balance, complexity, and frailty and of crucial importance to the production of food and many other important crops. In the past, degradation and loss of topsoil has contributed to the downfall of such ancient civilizations as Mesopotamia. According to Brown (in: Ehrlich, 1985) 'Civilization can survive the exhaustion of oil reserves, but not the continuing wholesale loss of topsoil'. Today soil conservation is equally essential to our survival and deep, rich soils should be treated as a non-renewable resource.
Yet, in spite of its importance and vulnerability, this resource is treated with astonishing carelesness and it is believed that one-third of the earth's cropland is eroding faster than nature can replace the soil (National Wildlife Federation, 1985). The average rate of topsoil loss is 6-8 times the natural rate of soil formation (see chapter 2.1.9). The tolerance level at which most American farmlands, for example, are thought to be able to replace eroded soil is estimated at 12 tons per ha, which is a layer no thicker than a dime (National Wildlife Federation, 1985). About 1/3 of the original topsoil of agricultural land in the USA has already been lost to erosion (Pimentel et al., 1980), and world-wide, due to over-exploitation of the vegetation (e.g. through deforestation) and the soil (through agricultural practices), each year about 10 million hectares of arable land is lost as a result of soil degradation and erosion annually and about 10% of the land surface of the planet has been transformed by human activities from forest and rangeland to desert (WRI, 1990).

Soil erosion may be caused by runoff of excess water or by the force of the wind. Prevention of soil erosion is important in various ways. First of all, of course, because the loss of fertile topsoil on arable land reduces agricultural productivity and increases the need to apply additional fertilizer. Depending on various environmental parameters such as climate, inclination and bedrock, soil erosion may eventually lead to desertification which is largely an irreversable process. Many secondary effects are also important such as sedimentation of waterways, resulting in the pollution of water resources by soil sediments, the destruction of freshwater biota, and the reduction of the life span of dams and reservoirs due to siltation of the lakes, leading to extra costs for dredging operations. Some further examples of the effects of soil erosion are given in box 2.1.8-1.

Some environmental characteristics (parameters) influencing soil erosion
The * **steepness** of the hillslopes is an important parameter influencing the vulnerability of the soil to erosion in mountaineous areas. Two other important factors influencing the sensitivity of the soil to erosion are the ***% of vegetation cover**, the * **root system,** and various poperties of the soil, such as * **depth,** * **texture,** and * **humus content.**

Maintaining natural vegetation near cultivated land or planting shelterbelts, windbreaks, fencerows, and hedgerows in areas where the natural protection by vegetation was lost, can reduce erosion considerably. Also the planting-system of the crops themselves is important. For example, soil erosion on agricultural land with row-crops may range between 40 and 290 tonnes of soil/ha/year. In contrast, a heavily forested area loses only 0.004 to 0.02 tonnes/ha/year. (Pimentel, et al., 1980). Erosion from maize croplands and oilpalm plantations can be 11 times higher than from primary rain forest, from vegetable croplands 34 times higher, and from bare soil 45 times higher (Myers, 1988).

Box 2.1.8-1 Some examples of the effects of soil erosion

An important effect of soil erosion in agricultural areas is the reduction or total loss of productivity.
Even if the land is not competely lost due to erosion, as the soil gets thinner less food can be harvested from it. A 15 cm loss of soil will reduce crop yields with 40 percent (National Wildlife Federation, 1985).
In mountainous areas the siltation of aquatic systems causes many problems. Runoff carries soil into waterways and lakes, where it clogs drains, kills fish, destroys habitats and carries herbicides and pesticides into drinking water. Many examples are available on the problems that siltation causes to reservoirs created to produce hydro-electrical power. For example, in the river Oi in central Honshu (Japan), a barrage and electricity works were built at the end of the Meiji period around 1910, without proper attention to the state of the surrounding mountains. Erosion has been so severe that by 1955 the whole lake was silted up (upto ca 1 m below the surface) and the generators were running only on the runoff-water. This would not have happened if the watershed had been properly reforested after the dam was built and the plant started operating (Vas Nunes, in lit. 1987). Another effect associated with soil erosion caused by water-runoff is the increased danger of land slides in mountainous areas.

2.1.9 Formation of topsoil and maintenance of soil fertility

Soils develop in widely different climatic regions under various kinds of

plant cover and from all kinds of parent material (bedrock).
Consequently, there is an enormous variety of soil. Some 15,000 different soil types have been identifed in the USA alone, and perhaps there are hundreds of thousands worldwide. They differ on the basis of the kind of rock that weathered into clay and sand to form the soil, the mix of organic matter in it, the amount of water, the texture and the age. There are the rust red soils of the tropics and the dark brown soils in more temperate climates. There are places where the soil is 60 meters deep and places where it is but a thin film overlaying rock. Living soil is full of air passages that let oxygen, carbon dioxide and nitrogen circulate. A well-aerated soil may be almost half airspace by volume. Films of moisture cling to the surfaces of the particles of sand and clay, forming micro-habitats that nurture a vast array of bacteria, fungi, viruses and protozoans. A cubic cm of soil can contain literally billions of micro-organisms, creating suitable living conditions for many other living creatures: worms, ants, moles, mites, springtails, nematodes, etc. (National Wildlife Federation, 1985).
The topsoil is the uppermost part of the soil in which there is a high biological activity and a relatively high amount of organic material.

Healthy soil has many functions and is important to man in various ways. A healthy topsoil is of great importance as life support system for all terrestrial life communities. It provides a habitat to many organisms with essential roles in the food chain, notably decomposers.
Formation of top soil and maintenance of soil-fertility is especially important for the maintenance of agricultural productivity. Crops grown on the more fertile soils give higher yields and are healthier when fed to live stock and man (Dasmann, 1976). Topsoil forms a medium for the storage and recycling of many important nutrients, and, on a global scale, can be considered a huge chemical factory. The top soil is also an important element in the regulation of the water balance (see chapter 2.1.6).

Soil-formation is usually a very slow process. Soils are usually generated at a rate of only a few centimers per millenium. Under ordinary farming conditions, topsoil can be formed at the rate of 0.6 tons/ha/year or about 2.5 cm every 100 years. This in contrast to the rapid rate at which topsoil is lost annually: in many areas it is being eroded away in rates of several cm per decade or even faster (Ehrlich, 1985, see also chapter 2.1.8). After erosion, soil formation takes considerably longer; it has been estimated for example that regeneration of eroded soil from bedrock takes 100-400 years per cm topsoil (Stortenbeker, 1987).
The suitability ('health') of the soil for human use, such as agriculture, is determined by many factors, among others the nutrient and organic matter content, texture, water-holding capacity, aeration, depth and profile (see appendix I.5 for more detailed information on soil characteristics).

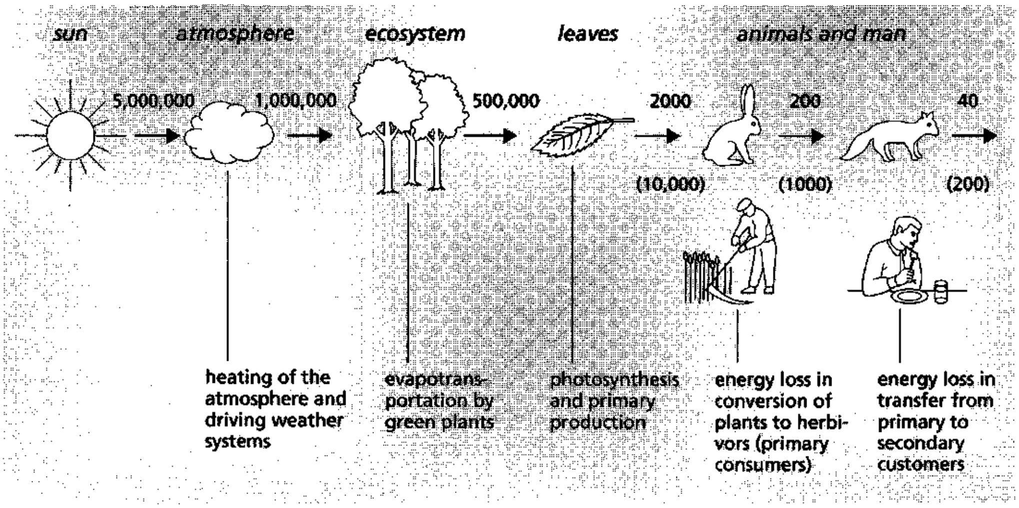
Some environmental characteristics (parameters) influencing the formation of topsoil and maintenance of soil fertility:
The * **vegetation cover** plays an important role in producing and maintaining a fertile layer of top soil. Through * **production of litter**, plants provide much of the organic material needed for the maintenance of soil fertility while at the same time protecting the soil from drying out and from wind- and water erosion. Also the activity of the * **root system** is an important factor. The vegetation thus has a strong influence on soil formation and, depending on the type of vegetation, the original substrate may be radically altered. Another important process is * **bioturbation**. This process relates to the physical activity of the
soil-fauna. Moles, earthworms, burrowing crickets and insect larvae all tunnel through the earth, moving vast amounts of soil, rearranging it, compacting it and opening up air and water passages. Their digging makes the habitat suitable for organisms which are important to the decomposition process. * **Decomposition** is probably the most important process in building up soils and maintaining soil fertility. Organic matter, such as leaves and crop residues, and the nutrients they contain are constantly recycled through the concerted action by many organisms such as ants, insects and wood-eating larvae (mechanical decomposition) and fungi, algae, earthworms, nematodes, protozoa, etc (chemical decomposition) (ODNRI, 1987). More information on the decomposition-process can be found in chapter 2.1.11. while some important biochemical *processes involved in the recycling of nutrients in the soil such as* nitrogen-fixation and nitrification are discussed in chapter 2.1.12.
A less conspicuous process which influences soil-fertility is the * **transportation of dust through the atmosphere**. Many fertile European soils are derived from past aeolian depositions (e.g. löss) which originates among others from Northern Africa (notably the Sahara), and this process still continues today. It may well be that part of the fertility of European soils depends on the continuing soil-erosion in Africa. Other important factors, are the parent material or * **bedrock** on which the soil is formed, and climatic conditions such as * **precipitation** and * **temperature** which influence the * **weathering** of this material.

2.1.10 Fixation of solar energy and biomass production.

Most biological processes which are needed to maintain the life-functions of living organisms, such as growth, self-duplication, and synthesis of complex chemical substances, are accompanied by energy transfers. Only green plants and certain bacteria are able to convert abiotic energy (i.e. solar radiation and chemical energy) into organic matter and other elements which are vital for life. These organisms are therefore called autotrophic or primairy producers and the very basis for practically all other ecosystem functions is the solar fixing ability of plants and algae. The biomass produced by green plants is consumed by other organisms, mainly herbivoric animals. It is then passed on further in the food chain to carnivors. The biomass produced by herbivors and carnivors is called heterotrophic production. All other life on earth depends on the energy fixed by these autotrophic organisms, and the biomass thus formed provides the structural basis for the build-up of ecosystems.
Basically, two types of bio-energy fixation can be distinguished, photosynthesis and chemosynthesis. Photosynthesis is the process whereby CO_2 and water are transformed into carbohydrates (CH_2O) under influence of sunlight. Chemosynthesis is a process whereby bacteria obtain their energy from the chemical oxidation of simple inorganic compounds. For example by converting ammonia to nitrite, nitrite to nitrate, sulfide to

sulfur, or ferrous to ferric iron (Odum, 1971). Photosynthesis is mainly found in green plants, while also some bacteria are able to photosynthesise. Figure 2.1.10-1 gives a generalized picture of the solar energy flow in kcal/m²/year through an ecosystem.

Fig. 2.1.10-1 Solar energy flow in kcal/m²/year through an ecosystem



Source: Odum, 1975a

NB: The figures in parenthesis represent levels for man-subsidized (cultivated) ecosystems

The input of sunlight to an ecosystem averages 3,000 kcal/m²/day (or 1 million kcal/m²/year), which is about 20% of the incoming solar radiation in the atmosphere, the rest is lost to heating the atmosphere and driving weather systems (see chapter 2.1.5). This figure is a very crude approximation since there is an enormous variation in total radiation flux (input and output) within different layers of the ecosystem, as well as from one season or site to another on the earth's surface. Of the sunlight which reaches the green plants about 50% (500,000 Kcal/m²/year) is used for evapotranspiration, the other half is used for Gross Primary Productivity (GPP = the total amount of energy fixed in living organisms, mainly green plants). Through metabolic activities of the plants themselves and by heat loss, the GPP is reduced by 50% or more to the Net Primary Production (NPP = total amount of 'green' biomass or standing crop of plants). Some conservative estimates of the Net Primary Production of major ecosystem types have been given in appendix I.8.1. Estimated mean values for large areas show that production varies from 3 gr. organic matter/m²/year in 'extreme' deserts to 2,200 g/m²/year in tropical rain forests and 3,000 g/m² per year in swamps and marshes. The total Net Primary Production of biomass in the world is estimated at 160-180 billion ton organic matter (dry weight) per year which is 10 % of the total standing biomass. The amount of biomass produced is equivalent to about 1018 Kcal per year (Whittaker, 1975). Due to consumption of the plant-biomass by herbivors, which in turn are eaten by other animals, most of the energy fixed in the plants is eventually released again as heat radiation. Thus, only a small portion of the GPP ultimately results in Net Community Production (NCP). This surplus may be used by man, and many human uses of natural resources (for food, building material, fuel, etc., see chapter 2.3) totally depend on the energy fixed by natural systems. As a general rule, it has been suggested that man should not harvest more than 30% of the GPP or 50% of NPP to ensure the continued proper functioning of the natural ecosystems involved. It has been calculated that man already uses about half of all the net primary production on earth.

As an example, Table 2.1.10-1. gives figures for Gross Primary Productivity, Net Primary Productivity and Net Community Production for a man-dominated system (an Alfafa field in the USA) and a natural mature rain forest in Costa Rica.

Table 2.1.10-1 Annual production and respiration as Kcal/m²/year in cultivated ('pioneer') and natural climax exosystems

	Alfafa Field (USA) *		Mature Rain Forest ** (Puerto Rico)	
Gross Primary Production (GPP)	24,400		45,000	
Autotrophic Respiration (Ra)	- 9,200		-32,000	
Net Primary production (NPP= GPP-Ra)	15,200	(62%)	13,000	(29%)
Heterotrophic Respiration (Rh)	-800		-13,000	
Net Community Production (NCP=NPP-Rh)	14,400	(59%)	0	(0%)

after: * Thomas and Hill (1949), ** Odum and Pigeon (1970)

Table 2.1.10-1, shows that in natural climax communties heterotrophic respiration (i.e. the consumption of the plant-biomass by herbivores, carnivors, and parasites) equals the Net Primary Production leaving very little or no Net Community Production. In cultivated ecosystems, herbivors, carnivors and parasites are kept out of the system as much as possible by fences and pesticides in order to be able to harvest a maximum amount of the Net Primary Production. Thus, natural ecosystems maximise Gross Primary Production, to provide food for as many organisms as possible, while in man-dominated systems the Net Community Production is maximized for human consumption at the expense of the other consumers in the system.

Some ecologists use the total amount of solar energy which can be fixed by an ecosystem in a given time period (= Gross Primary Production (GPP)) as an integrative measure of the life-support value of ecosystems (e.g. Gosselink et al., 1974; Costanza et al., 1989). This measure is presumed to be representative for the total amount of 'useful work' that can be performed by the system and would thus replace the need to evaluate the other functions separately. This is a rather strong over-simplification, but it is true that as long as mankind is unable to copy the natural process of bio-energy fixation efficiently, this function of nature is essential to the maintenance of human life on earth. A discussion of the use of GPP as an integrative measure for the overall functioning of an ecosystem can be found in chapter 3.3.1.

Some environmental characteristics influencing energy transformation and biomass production
Several parameters can be used to measure the capacity of a given ecosystem for energy transformation and biomass production, notably * **primary production,** * **biomass (standing crop),** * **Leaf area index (LAI),** and amount of * **chlorophyll.**

2.1.11 Storage and recycling of organic matter

Every year approximately 100 billion tons of organic matter is produced on earth by photosynthesis (see chapter 2.1.10). Organic matter consists of chemical compounds which contain carbon (C). Other important characteristics are the energy bound in carbohydrates, protein and other vital elements stored in organic compounds. Organic matter forms the basic element of life and is continuously used, recycled and stored. The (almost) complete breakdown and recycling of the biomass produced by autotrophic organisms is one of the most important features of the biosphere. The disruption of this process through the removal of organic matter from the recycling process by man through industrial cropping, deforestation, etc., is graveley threatening vital balances in the biosphere (Odum, 1971). Organic matter on earth is stored in living organisms (i.e. as biomass), as dead organic matter (in litter, detritus and humus), in sediments, and as fossilized material (e.g. coal and oil) (see table 2.1.11-1)

Natural systems contribute in various ways to the storage and recycling of the organic matter produced on earth (including the organic waste produced by man, see chapter 2.1.13).

Table 2.1.11-1 Distribution of organic matter on earth (in billion tons dry weight)
Source: Whittaker (1975), Whittaker & Likens (1975) van der Maarel & Dauvellier (1978), WRI (1990)

Total	9,015,481	+
1)Biomass (mainly plants)	**1,841**	
in terrestrial ecosystems	1,837	
in marine ecosystems	4	
2)Dead organic matter	**12,500**	
detritus (in water environments)	10,000	
litter, humus, peat (on land)	2,500	
3)Sediments (99,8%)	**9,000,000**	
4)Fossilized material	**1,140**	+
Coal	1,000	
Oil	140	
Gas	(120)	*

* in billion m^3

Some environmental characteristics influencing the storage and recycling of organic matter

Some important biotic and abiotic processes involved in storage and recycling of organic matter are * **consumption and respiration**, and * **decomposition** (see appendix I.8 for details). Also the * **quantity of humus** on an area or volume basis is often used as an indicator for the rate of decomposition in terrestrial ecosystems. The average quantity of organic matter degraded per hectare in terrestrial ecosystems is about 4,000 kg dry matter per year (Pimentel, et al., 1980). Some idea of the intense metabolic activity that accompanies microbial decomposition is obtained by observation of the increase in temperature in the substrate. Well-known is the heat generated in an artificial compost pile. In the rapidly accumulating sediments of Lake Mead, which was formed by the huge Hoover Dam in the Colorado River (USA) it was found that the temperature of the bottom was as much as 6 °C above that of the adjacent water; at least part of this heat was the result of the immense populations of microorganisms which were doing their best to break down the organic matter washed into the lake caused by the man-accelerated erosion in the watershed (Odum, 1971). In general, aquatic ecosystems, especially estuaria and wetlands are better able to decompose large amounts of organic matter without negative side-effects (such as eutrophication) than terrestrial ecosystems (see, for example chapter 4.2 on the wetland case study).

* **Fire** is another mechanism by which organic matter is 'respired'. Where climate seasonally inhibits the activity of soil organisms, as in boreal coniferous forests, unmineralized organic matter piles up on the forest floor; here fire may play a vital role as decomposer-mechanism. (Simmons, 1981). Also in savanna and other grassland ecosystems fire is an important factor in the recycling of organic matter.

Organic matter which escapes consumption, decomposition or fire is stored in * **sediments** and, eventually may be * **fossilized**. Since the beginning of the Cambrian period (600 million years ago), a very small but significant fraction of the organic matter produced is burried and fossilized. About 300 million years ago an especially large excess production of organic matter formed the fossil fuels that made man's industrial revolution possible. Most of the organic matter that does escape decomposition becomes deposited in aquatic sediments; this is why oil is only found in areas that are, or once were, covered by water (Odum, 1971). Since fossilization is a very slow process the quantitative contribution to storage and recycling of organic matter on human time scales is not very important.

2.1.12 Storage and recycling of nutrients

Life on earth depends on the continuous recycling of about 30-40 of the 90 chemical elements which occur in nature (Simmons, 1981). Those chemical elements which are most important to life are called nutrients. Some of the more important nutrients are carbon (C), hydrogen (H), oxygen (O), nitrogen (N), sulphur (S), and phosphorus (P). Other, so-called macronutrients, are calcium, magnesium, potassium, sodium, and chlorine. In addition, a large number of essential trace elements are needed, including for example iron and zinc.

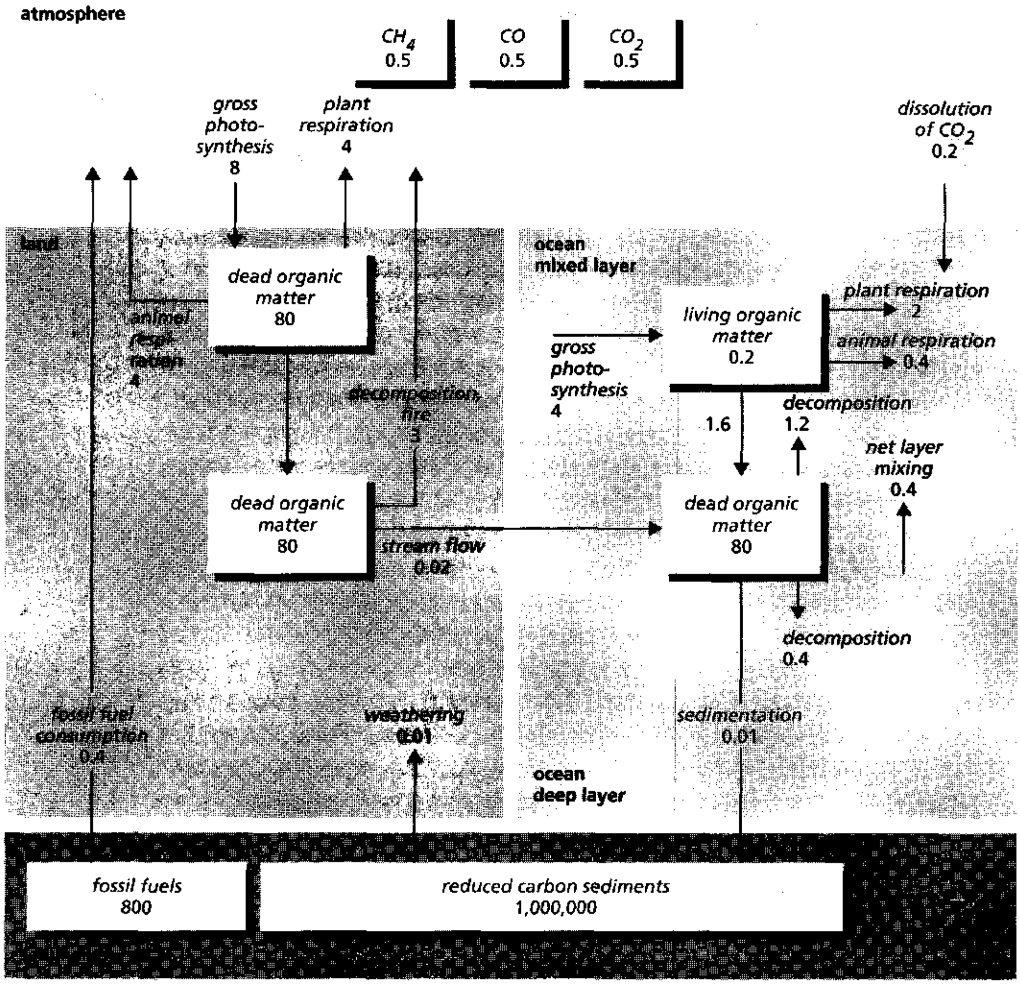
The availability of these chemical elements is often a limiting factor to the growth and occurrence of certain life forms or certain environmental functions. Constant cycling of these nutrients, through so-called biogeochemical cycles, is therefore essential for the maintenace of life on earth (see figure 2.1-1).

Especially mineral elements with sedimentary cycles, such as phosphorus, calcium and magnesium, may impose checks upon the population size of species if they are in short supply For example, in natural land- and freshwater ecosystems, phosphorus is often a limiting factor to growth, while in salt water ecosystems nitrogen generally limits biological productivity.

An important function of recycling mechanisms is not only that they maintain the availability of nutrients but also act as natural purification systems which prevent the accumulation of excessive amounts of nutrients brought into the environment by human activities (see chapter 2.1.13). It is important to recognize in this connection that the same elements and compounds that serve as nutrients for some organisms are often toxic for other organisms, or at too high concentrations also for the same organisms. For example, molecular oxygen (O_2) is toxic to anaerobic organisms and, at high enough concentrations, even to mammals. Ammonia (NH_3) is an important source of nutrient-nitrogen for many plants but is toxic to man. Hydrogen sulfide (H_2S) is a nutrient for certain types of bacteria but is extremely toxic to mammals (Ehrlich et al., 1977).

In natural ecosystems, the flow of nutrients is conserved as much as possible and input and loss are usually small compared with the volume which circulates within the system, notably in terrestrial systems. In a forest, for example, minerals originating from the rocks enter the soil, become part of the tree, decend at leaf-fall, are mineralized by the soil fauna and flora and then are again available for uptake by the tree. A stable system, such as a forest, retains most of its essential elements circulating them within the soil-vegetation subsystem, and losses to runoff are balanced by inputs into the system, as shown by figure 2.1.12-1 for calcium.

Fig. 2.1.12-1 The calcium cycle for an oak-pine forest in New York



Source: Whittaker, 1975

Note: Numbers in boxes are pools (g/m^2); unboxed numbers are flows (g/m^2/yr), The circled number (1.8 g/m^2/yr) is net uptake into net accumulation of organic matter. In the soil boxes the upper compartment is exchangeable calcium; the lower total calcium. Input from precipitation and weathering equals loss plus net accumulation.

If nutrient pathways as shown in figure 2.1.12-1 are disturbed, for example by the destruction of the vegetation (e.g. by clear-cutting or catastrophic fire), then there is a rapid loss of mineral elements from the (eco)system leading to eutrophication of surrounding ecosystems, notably rivers and lakes. After disturbances, successional species, such as shrubs and small trees play an important role in restoring the cycling function and the retention of nutrients. This, however, may take a long time, for example between 60-80 years in northern hardwood forests (Likens et al, 1978).

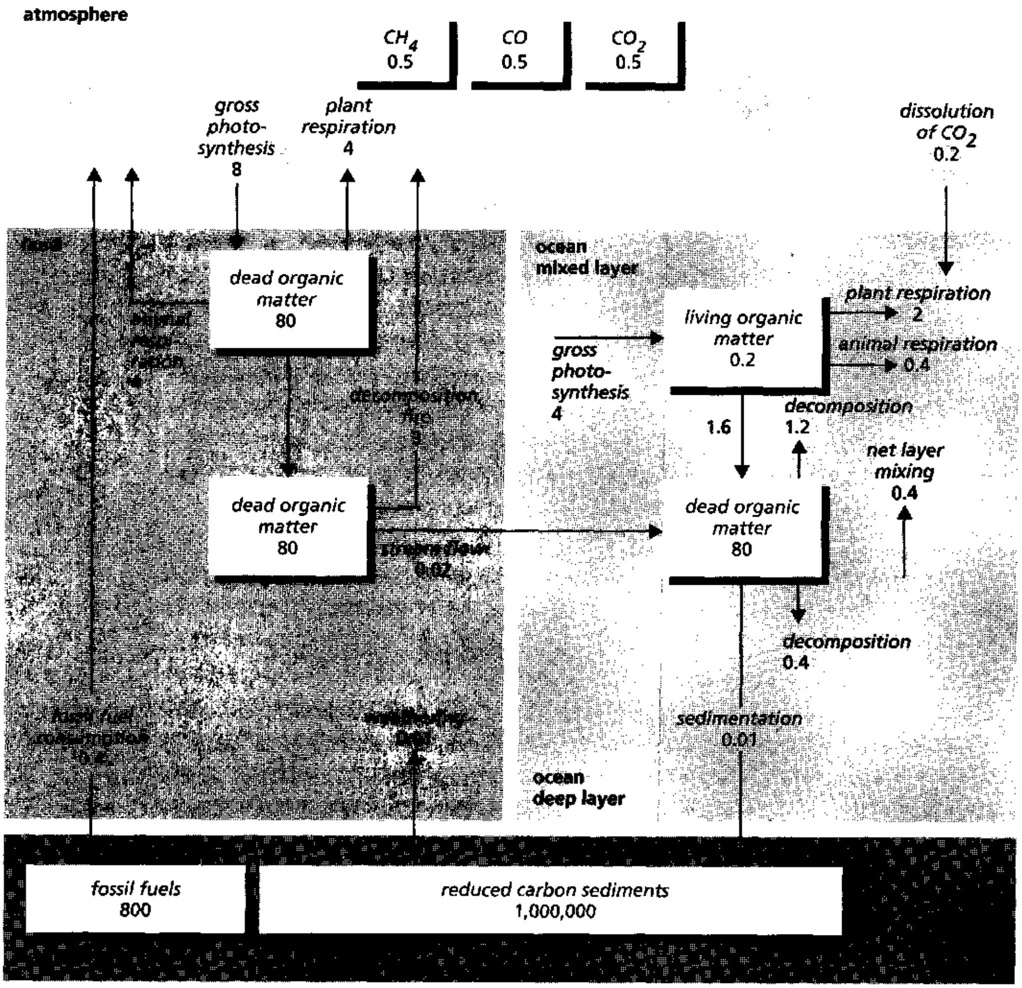
The recycling mechanisms of six important chemical elements (carbon, oxygen, hydrogen, nitrogen, sulfer and phosphorus) in local and regional ecosystems are briefly discussed in the following paragraphs. Although the cycles of the different elements are discussed here separately, it must be realised that most are tightly linked both chemically and biologically, which is especially true for the cycles of carbon, oxygen, and hydrogen.

Some environmental characteristics influencing the recycling of nutrients
As fig. 2.1.-1 shows, there are many processes involved in regulating the cycling-mechanisms of the various nutrients which are related to either physical transport or chemical transformations. Most nutrient cycles which operate at the scale of local or regional ecosystems are part of global cycles.
The principal agents of physical transport are the * **hydrological cycle**, including * **surface runoff** (see chapter 2.1.5), * **winds**, and * **ocean currents**. * **Geological movement**, especially the upward and downward motions at the boundaries of tectonic plates and geological uplifting on continents, and * **volcanic activity** may add or remove large quantities of chemicals to/from the biosphere. Also * **movement of organisms**, for example, fish-eating birds that deposit their excrements on land, provides a significant pathway by which nitrogen and phosphorus are transferred from the sea to the land. Fish such as salmon, that feed mostly in the ocean but migrate up freswater rivers to spawn and die, perform a similar function, as do the ocean-caught fish consumed by man on the continent (Ehrlich et al., 1977).
The principal agents of chemical transport are * the **sedimentary cycle**, whereby nutrients are mobilized when water comes in contact with rock, and the * **chemistry of the atmosphere.** Rainwater is slightly acidic, having absorbed some atmospheric carbon dioxide to form weak carbonic acid: $H_2O + CO_2 \rightarrow H_2CO_3$, and $H_2CO_3 \rightarrow H^+ + HCO_3^-$. The pH of rainfall in areas free of industrial pollution is around 5.7. This slight acidicity is enough to fascilitate greatly the dissolution of many minerals present in exposed rock - a process called * **weathering**. Through wind- and water * **erosion** most of the products of the weathering reactions eventually reach the sea, either as dissolved ions or as suspended solids. The chemistry of life (i.e the passing of nutrients through the * **food chain**, notably the activity of * **soil comunities**) is another important chemical transformation process in biogeochemical cycles. * **Decomposition**, * **photosynthesis** and * **respiration** are only three of a vast number of chemical transformations taking place in living organisms.

(1) Storage and recycling of carbon
Carbon is the connecting element for all organic matter on earth, the pools and flows in the carbon cycle are shown in figure 2.1.12-2.

As figure 2.1.12-2 shows, many processes are involved in the storage and recycling of carbon, including photosynthesis, respiration, decomposition, fire, combustion of fossil fuels, absorption (dissolution) of atmospheric CO_2 by the oceans, sedimentation and fossilization. (see appendix I for further details on these processes). Because of its importance as a greenhouse-gas, the storage and recycling of CO_2 is discussed in more detail in chapter 2.1.3.

Fig. 2.1.12-2 **Pools and flows in the global carbon cycle**



Ehrlich et al., 1977.

(2) *Storage and recycling of hydrogen*

Hydrogen (H) is a very important reducing agent and therefore takes part in many chemical reactions and is found in many chemical forms: water (H_2O), biomass (CH_2O), methane (CH_4), hydrogen sulfide (H_2S), etc. Especially its capacity to form water (H_2O), together with oxygen, is an essential function of hydrogen since most organisms on earth require a certain amount of water, both in their external environment and as physiological medium. The hydrological cycle is dealt with in chapter 2.1.5 while the pools and flows of water at the surface are discussed in appendix I.4. The recycling of the other chemical forms of hydrogen is discussed under the elements with which hydrogen forms chemical bonds, for example carbon, nitrogen and sulfur.

(3) Storage and recycling of oxygen

Oxygen is found in many different chemical forms and reservoirs such as the atmosphere (O_2, O_3, CO_2,), water (H_2O), biomass (CH_2O), and sediments: ferrous oxide (FeO), ferric oxide (Fe_2O_3), and sulfate (SO_4). Because of these different chemical forms, the recycling of oxygen is closely linked with the carbon and water cycles, mainly through processes operating in life communities such as photosynthesis and respiration. One important chemical form is atmospheric oxygen which is discussed in chapter 2.1.3.

(4) Storage and recycling of nitrogen

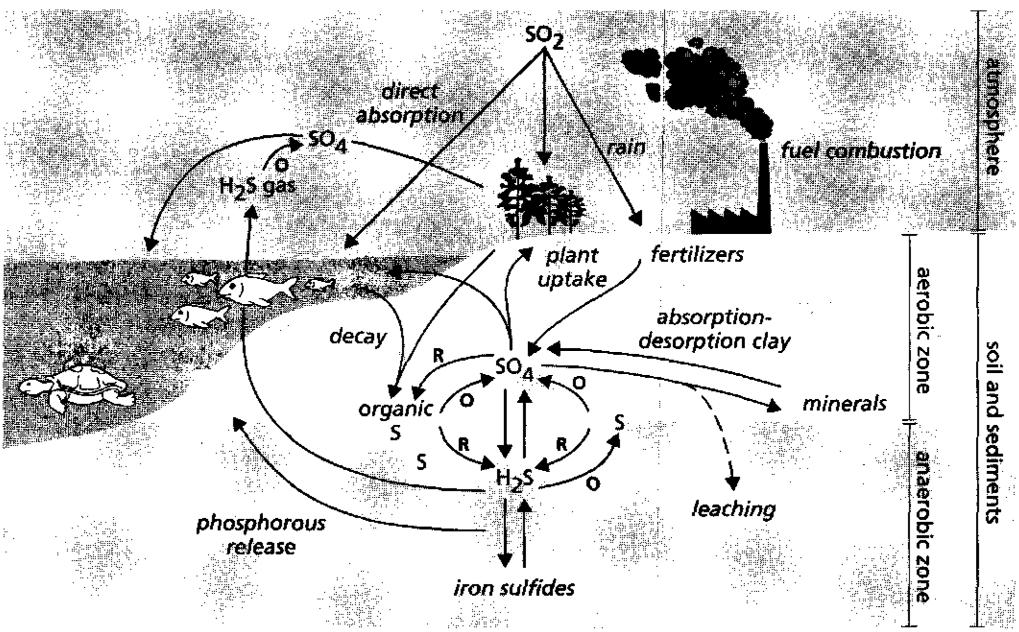
Nitrogen occurs in the natural environment in various chemical forms which are all part of the natural nitrogen recycling processes (see Appendix I.9.). Human activities are bringing extra amounts of various types of nitrogen into the environment which are, to some extent, 'neutralized' by these recycling processes. For example, emissions of nitrogen-oxides (NO_x) from the combustion of fossil fuels amounted to about 20 million metric tons in 1980 (WRI, 1990). Although this amounts to more than 10% of the biological rate (Söderland and Svensson, 1976), most of it is incorporated in the natural biological nitrogen cycle. Especially wetlands are able to recycle large amounts of nutrients. For example the 'treatment capacity' of tidal marshes for nitrogen has been estimated between 365 (Thidodeau & Ostro, 1981) and 2,715 kg (Gosselink et al., 1974) nitrogen per ha/year. The purification capacity of the Great Meadow Wetland (USA) in yearly average of pounds (lb)/acre/day is for all forms of nitrogen 0.89 (Thibodeau and Ostro, 1981).
The fixation of nitrogen (N) by terrestrial ecosystems may serve as an example of the (economic) importance of natural recycling mechanisms. Each year an estimated 140 million tonnes of nitrogen is removed from the soil in crop production world wide. Some biological processes involved in the nitrogen cycle can return some of this N to the soil, notably through fixation of atmospheric nitrogen by certain plants and nitrification of ammonia by certain bacteria (see Appendix I.9.4. for details). Thus, more than 90 million tonnes of this deficit is made up for by biological nitrogen fixation, which thereby also represents a considerable economic value. Certain plants are particularly effective in fixing atmospheric nitrogen and some can be used as nitrogen-fixing crops in agro-forestry projects to rehabilitate degraded soils (see chapter 2.2.2.).

(5) Storage and recycling of sulfur

The complexity of the sulfur cycle, like that of nitrogen, arises mainly from the large number of oxidation states the element can assume. An important chemical form of sulfur is SO_2 (sulfur dioxide), a colourless, toxic gas. The natural concentration of sulfur-dioxide in the air is 0.0002 ppm. Macroscopic plants remove about 2% of sulfur dioxide annually from the atmosphere (Pimentel et al., 1980). However, this natural recycling process cannot cope with the excessive injection of sulphur oxides into the atmosphere by man which amounted to about 60 million metric tons in 1980 (WRI, 1990). Together with nitrogen oxides, the increase of atmospheric sulfur is the main element causing the so-called 'acid rain' leading to acidification of lakes, disturbance of the soil chemistry and damage to the vegetation.

The problem of acid precipitation (rain, snow, etc.), caused by excessive injection of sulphur and nitrogen oxides into the atmosphere, is a clear illustration of the effects of the disturbance of the natural recycling mechanisms for these chemicals. Acid precipitation is not only causing damage to natural ecological systems and processes, but also to human health and to the economy. Loss of productivity and the expenses of mitigation measures (for example to repair the damage to cropland, forests and buildings), cost billions of dollars each year.

Fig. 2.1.12-3 Storage and recycling of sulfur



Odum, 1971

The sulfur cycle linking air, water and soil. The center 'wheel like' diagram shows oxidation (O) and reductions (R) that bring about key changes between the available sulfate (SO_4) pool and the reservoir iron sulfide pool deep in soils and sediments. Specialized micro-organisms are largely responsible for most of the transformations. Primary production accounts for the incorporation of sulfate into organic matter, while animal excretion is a source of recycled sulfate. Sulfur oxides (SO_2) released into the atmosphere by burning of fossil fuels are an increasing problem (e.g. acid rain)

The sulfur cycle is important for various reasons: - sulfur has an essential role in the structure of proteins, - the main gaseous compounds of sulfur are toxic to mammals, - sulfur compounds are important determinants of the acidity of rainfall, surface water and soil, and -the possibility that sulfur compounds may play a role in influencing the amount of molecular oxygen in the atmosphere in the very long term.

(6) Storage and recycling of phosphorus (P)
Phosphorus is required in quantities only about one-tenth as great as nitrogen, nevertheless phosphorus is absolutely essential to the metabolism of most living organisms. Apart from its importance to the chemistry of life, phosphorus is also used in detergents, animal-feed supplements, pesticides, medicines, and a host of industrial applications (Ehrlich et al., 1977) Phosphorus probably is the limiting nutrient in more circumstances than any other element because of its scarcety in accessible form in the biosphere.
Two chemical properties of phosphorus are responsible for this natural scarcety, which is much more acute than one might expect from the size of the total phosphorus pool in sedimentary rocks. One is that phosphorus does not form any important gaseous compounds under conditions encountered in the environment. The second is the insolubility of the salts fromed by the phosphate anion PO_4= and the common cations Ca^{++}, Fe^{++}, and Al^{++}. The lack of gaseous compounds deprives the phosphorus cycle of an atmospheric pathway linking land and sea and thus slows the closing of the cycle to the very sluggish pace of sedimentation, uplift, and weathering. That phosphate forms insoluble compounds with constituents of most soils retards its uptake by plants and slows its removal and transport by surface water and groundwater (Ehrlich et al., 1977).

2.1.13 Storage and recycling of human waste

Unspoiled air, water and soils are essential to the proper functioning of both natural and cultural systems. To a limited extent, natural systems are able to maintain a healthy environment by storing and recycling certain amounts of organic and inorganic human waste (contaminants). However, due to man's excessive use of the natural environment as a free dumpsite, the proper functioning of these recycling mechanisms is seriously threatened, disturbing the chemical balance in the soil, atmosphere and oceans in many ways.
The disturbance of the natural chemical balance is becoming clearly visible now and leads to many environmental problems such as acid rain and acidification of soil and water, eutrofication of lakes and waterways (due to exessive use of fertilizer), increase of ozone in the lower atmosphere and decrease of ozone in the stratosphere, the possibility of climate change due to an enhanced greenhouse-effect, and many other local and global problems related to pollution.

Especially for certain non-biodegradable chemicals (e.g. pesticides), heavy metals and radioactive waste, tolerance levels of living organisms are very low. Nature's capacity to 'recycle' these elements is very slow and usually only consists of isolation and dispersal mechanisms which may reduce the concentration of these elements but do not remove them from the environment. They usually accumulate in organisms and sediments only to enter the environment again at some later point in time and then often in much higher concentrations. For example, pesticides and heavy metals, after having passed through the food chain, accumulate in sediments or in the mud on the bottom of rivers and lakes. The concentration of these elements in the environment is thereby (temporarily) reduced, provided the speed of emission does not exceed the storage capacity of the natural environment. Due to changes in environmental circumstances (e.g. extreme weather conditions or more gradual changes in climate) or direct effects of human activities (for example construction works and dredging), these accumulated amounts of dangerous elements may be 'activated' again and subsequently enter the food chain in much higher concentrations.

Some environmental charateristics influencing human waste recycling
Some processes involved in the storage and recycling of human waste are dilution in * **air**, in the * **hydrological cycle**, and in * **waterreservoirs.** Also * **decomposition,** * **evaporation,** * **dissolution** and transport by * **wind,** * **water,** and * **food chains** (animal consumption), are important, as well as incorporation in * **bio-geochemical cycles.**

Some examples of nature's capacity to deal with human waste are briefly described below. Certain types of human waste, particularly radioactive waste and thermal pollution from industrial plants, are not discussed here because there are no natural biological storage or recycling mechanisms to reduce the concentration of these pollutants in the environment. Some considerations concerning the disposal of solid human waste can be found in box 2.1.13-1.

Box 2.1.13-1. Physical aspects of waste disposal

Apart from the direct disposal of chemical elements into the environment, human society also produces large amounts of solid waste. A still increasing number of garbage dumps, nuclear waste dumpsites and many other forms of storage of human waste are scattered over this planet, both on land, underground and in the sea. Because of the physical aspect of solid waste, the use (or better abuse) of natural ecosystems as dumpsites for human waste should be discussed under the category carrier functions (chapter 2.2). However, since this type of use will usually greatly alter the original ecosystem, this function cannot be utilized on a sustainable basis in natural ecosystems and is therefore not further discussed in this book. Since most solid waste also contains chemical substances which often enter the environment at some point in time and then may disturb natural regulation processes, proper guidelines should be developed for the careful selection of areas which are most suitable (or least unsuitable) for dumping solid human waste.

(1) Storage and recycling of organic waste and nutrients
Much of the organic matter produced by man is directly or indirectly dumped into the seas, waterways, wetlands and other aquatic ecosystems. Many kinds of micro-organisms (notably bacteria) work together in the breakdown process of organic matter. Especially aquatic ecosystems can recycle relatively large amounts of organic matter (and the associated nutrients, see next section) without negative side-effects. Another example is provided by dunes: water which contains too high concentrations of organic matter and nutrients may be infiltrated into (coastal) sand dunes. Depending on the porosity of the sand, sand dunes act as a filter and the water collected beneath is to some degree purified.
Because the recycling of organic matter and nutrients has already been treated in chapters 2.1.11 and 2.1.12 respectively, this function is not further discussed here. However, it is interesting to note that man-made sewage disposal systems largely depend on the activity of anaerobic and aerobic micro-organisms which have been harvested by man from the natural environment to break down the organic waste produced by man.

(2) Storage and recycling of chemical pollutants (excl. nutrients)
As a result of many human activities, such as industry, agriculture, traffic, and household activities, large quantities of about 50,000 different chemical compounds are produced annually. Eventually, most of these chemicals end up in the air, water and soils. Some of these chemicals also occur naturally in the environment and, depending on their concentration, are even essential as nutrients to certain organisms. For example CO_2, which is produced by combustion of fossil fuels and burning of vegetation, is needed by green plants for photosynthesis (see chapter 2.1.10). The storage and recycling of these 'natural' chemical pollutants, such as CO_2, nitrogen and sulfur-dioxide, is discussed in chapter 2.1.12. A separate problem is presented by the increasing amounts of synthetic chemicals which enter the environment. These are new substances which are usually non-biodegradable and not amenable to participate in exisiting biogeochemical cycles. Because of the absence of natural recycling mechanisms these chemicals continue to accumulate over long periods of time. Some of the more persistent, and therefore dangerous chemicals are chlorofluorocarbons (CFC's), which belong to the category of substances which are depleting the ozone-layer and which contribute to the greenhouse effect, and polychlorobiphenils (PCB's).
To some extent, natural systems are able to deal with some of these chemical pollutants, however, for most synthetic chemicals natural mechanisms by which these may be removed from the food chain, or may be converted to less harmful forms, are absent. As explained above, 'purification' processes for non-biodegradable waste are usually no true recycling mechanisms, they only re-allocate the problem in space and/or in time, and man should therefore prevent as much as possible these elements from entering the environment.

(3) Reduction of oil-pollution

Discharges of oil from fossil deposits into the natural environment pollute surface- and groundwater, and soils. In laboratories it has been shown that certain bacteria can break down oil, a function which is already employed in practice, for example in combatting oil-spills at sea.

(4) Storage and breakdown of pesticides

Pesticides can have a profound effect on many ecological processes and functions. Depending on the type of pesticide, they are more or less persistent and residues of certain pesticides can be found in practically every living organism on earth, from penguins in the Antarctic and polar bears near the North Pole to the milk of nursing mothers in Europe and the USA. Some types of pesticides degrade when residues are exposed to sunlight, moisture and acidity or other physical factors. Also biotic mechanisms, especially micro-organisms, play important roles in the breakdown of certain pesticides. The rate of degradation of those pesticides which can be broken down by biological and/or physical mechanisms depends on the specific pollutant and complexity of the mechanism, and may vary from 2-5 days to 15 years or more. For example, diazinon, an organophosphate insecticide, can be degraded by bacteria in 5 days (Pimentel et al., 1980). Studies in the field have shown that some soil microbes can consume up to 99 percent of the DDT sprayed on the soils within a few weeks (National Wildlife Federation, 1985). An important neutralisation process for organic pesticides is absorption in the peats at wetland surfaces.

(5) Storage and recycling of heavy metals

Although heavy metals, such as iron (Fe), lead (Pb), and copper (Cu) are not easily recycled, there are some mechanisms that can immobilize these elements, thereby rendering them temporarily harmless. One natural immobilization-mechanism for metal-ions in the soil is a process known as * **chelation** whereby a complex chemical formation is formed with metal ions, keeping the element in solution and, thereby, nontoxic, as opposed to the inorganic salts of the metal. Glycine, an amino acid is such a so-called chelator, which is often added to soils which are used for cultivation to neutralise unwanted effects of metal-ions (after Odum, 1971). Another neutralisation process is absorption in wetlands. The peats at the wetland surface can absorb significant amounts of lead and copper and possibly also mercury, magnesium, cadmium and zinc (Thibodeau & Ostro, 1981). However, this only means a temporary immobilization and little is known about the long term effect or retention time of these substances in wetlands .

(6) Abatement of noise-pollution

Another serious threat to the quality of the human environment is noise pollution. If we define noise as 'unwanted sound", then noise pollution is unwanted sound 'dumped' into the atmosphere and should be considered along with other forms of air pollution. Even a comparatively low level of noise such as crowd, highway, or radio noise interferes with human conversation and causes stress, both emotional and behavioral. High intensity sound, such as that emitted by many industrial machines, traffic and aircraft, when continued for long periods of time, is not only disturbing to man (and probably other vertebrates), but may permanently damage hearing (Odum, 1971). The unit for measurement of sound is the decibel (db), and the area of human hearing extends in intensity from 0 to greater than 120 db, at which point the intensity causes physical discomfort. Ordinary conversation registers between 30 and 60 db, while noise under a jet airplane at takeoff may rise in excess of 160 db. In general, 85 db can be considered the critical level for ear damage, and inquiries have shown that people begin to complain when unwanted noise levels in residential areas reach 35 to 40 db (Odum, 1971).

Some environmental characteristics influencing noise-abatement
Parameters to determine the suitability of natural systems or certain species for reducing noise levels are, among others, the * **vegetation density and height** and the * **amount of litter.**

Plants are efficient absorbers of noise, especially noises of high frequency. Dense evergreen hedges, or a closed forest of hundred meters wide, for example, have a capacity to absorb 10 dB. A practical application of this function is the use of plants along highways to reduce the noise-level in the surroundings. A 15 m wide band of vegetation, consisiting of an inner strip of dense shrubs and an outer band of trees can be quite effective (Odum, 1971).

(7) Filtering of dust particles
Dust particles limit the passing of light, both in the air and in aquatic ecosystems. In addition to reducing overall atmospheric clarity, dust particles hinder (human) sensory perception and are often contaminated with heavy metals, biocides, radio-active material, etc. Dust particles are brought into the air by natural phenomena, such as volcanic eruptions and fire, and by human activities, such as household activities (heating), industry, agriculture, and traffic. Also cutting and burning of forests brings dust into the atmosphere while at the same time reducing nature's capacity to filter dust particles from the air. The vegetation plays an important role in the removal of dust particles from the atmosphere. Forests, for example, may trap 30-70 tonnes of dust particles/ha/year. The amount of atmospheric dust in forested areas is approximately 500 particles/m^3, in open landscape 5,000/m^3 and in industrial areas more than 10,000/m^3 (van der Maarel & Dauvellier, 1978). In general, high growing vegetation intercepts 30-40% more airborne particles than low growing vegetation (Van Drunen et al., 1986).

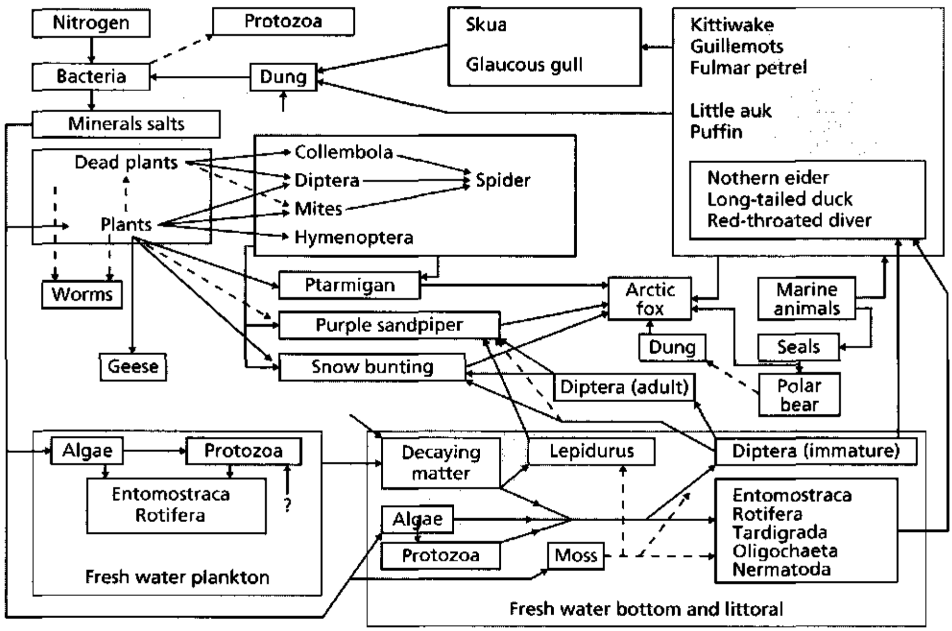
Some environmental characteristics influencing filtering of dust
Important characteristics (parameters) influencing the capacity of the vegetation to intercept aerosols are * **height and roughness** and the * **leaf area index**, which is a measure for the total surface area of the leaves.

Fig. 2.1.13-1. Illustration of artificial air purification contraption

2.1.14 Regulation of biological control mechanisms

This function relates to the capacity of natural ecosystems to maintain a certain biological balance or homeostasis through biological control of biotic processes, similar to the maintenance of the chemical balance in the atmosphere and oceans (functions 2.1.3 and 2.1.4). As a result of millions of years of evolutionary processes, the biotic communities of natural ecosystems have developed many interactions and feed-back mechanisms which enable the community to maintain more or less stable life-communities and to prevent the outbreak of pests and diseases brought in from outside. There are an almost infinite number of interactions between the species within food chains and food webs. An example of a simplified food-web for Bear Island (Spitsbergen) is given in figure 2.1.14-1.

Fig. 2.1.14-1. Example of a simplified food-web (Bear Island, Spitsbergen)



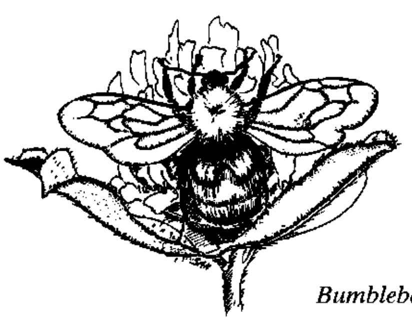
Source: Collier et al., 1973

Especially the life communities of climax ecosystems such as rainforests have developed intricate biological regulation mechansism which can contribute to stabilising both their internal and external environment. Ideally, for each species it's * **role in this food web** should be assessed in order to determine its suitability and importance in regulating certain biological processes which influence food production, human health or other environmental aspects which are important to man. Two biological control mechanisms which are of special importance to food production and maintenance of human health are the control of pests and diseases, and pollination-mechanisms.

(1) Biological pest control

Natural predators and parasites play an important role in pest-control, whereby a 'pest' may be defined as an uncontrolled increase in numbers of one species in an otherwise balanced ecosystem. According to Ehrlich (1985), natural ecosystems control more than 95% of all the potential pests of crops and carriers of disease to human beings. At the same time it must be noted that natural ecosystems also are the source of these 'harmful' species whereby man usually is the trigger that turns these species into pests by upsetting the natural balance. By maintaining natural elements in agricultural areas a certain 'biological balance' can be maintained which helps reduce damage caused by insect pests. Scrub communities bordering cultivated land, for example, have a regulating influence on the outbreak of pests in the neighbouring crop- or grasslands since they provide shelter to many predators (birds, insects) which feed on species which are potentially harmful to the crops. Common songbirds, for instance, may catch upto 675 insects every day or between 100,000 and 250,000 each year (Dieren & Hummelinck, 1979). Another good example of the importance of these natural regulation mechanisms is the role of snakes and frogs in Asian rice fields. Only after decimating the numbers of snakes (for their skin and blood) and frogs (as delicacy in restaurants) did their role in the food chain become clear: the numbers of mice, rats and other pests, which were controlled by the snakes and frogs, increased dramatically. In Sabah (Indonesia), recent studies suggest that high densities of wild birds in commercial Albizia plantations limit the abundance of caterpillars that would otherwise defoliate the trees. For nesting, the birds require natural forest which occur near the plantations (McNeely, 1988). Also many micro-organisms in streams and rivers (upto 1 million bacteria/milliliter) play an important and beneficial role to man since they destroy many pathogenic enteric viruses (Pimentel et al., 1980).

(2) Regulation of pollination
Pollination is essential to many plants for reproduction, including commercial crops. Insects are the most important group of pollinator species. Without this service of wild pollinators, in particular bees, cultivation of most modern crops would be impossible or their productivity could only be maintained with enormous investments in artificial pollination procedures. To maintain this service of nature, it is essential to conserve at least a minimum of natural habitat in the vicinity of cultivated lands for the reproduction of these pollinator-species. In modern agriculture, bees are already especially raised in captivity for pollination of plants grown in greenhouse-cultivation. An interesting example from the past is the recently discovered role of the now extinct Dodo (*Raphus sp.*) in the ecology of Mauritius (see box 2.1.16-1).



Bumblebee pollinating clover

2.1.15 Maintenance of migration- and nursery habitats

Many animal species show migratory behaviour and have separate habitats for resting, feeding and breeding both in time and/or in space. Some conspicuous animal movements are those of birds and mammals, notably ungulates and whales, which migrate over large distances between feeding and wintering areas, and the areas where they breed and raise their offspring. Also fish, reptiles, amphibians and many insects (for example butterflies and grasshoppers) show migratory behaviour. Why animals migrate has been subject to much discussion, but now it is generally believed that the various migration patterns were evolutionarily established by selecting the strategy which ensures the highest individual survival and reproduction. Apparently, the cost of hazardous migration to favourable wintering areas are lower than the costs for survival in the breeding area under harsh conditions during the non-breeding season.
Most ecosystems provide food and shelter to migratory animals which spend only part of their life cycle in that ecosystem. Many marine organisms, for example, depend to a large extent on estuaria and mangroves for reproduction while spending the rest of their lives in open sea. Disturbance and destruction of ecosystems that are important breeding areas for migrating species will have serious consequences for these species and thereby for the functioning of other, sometimes remote ecosystems. The network of protected areas, which man is slowly establishing to safeguard the remaining biological diversity on earth, should therefore always include all 'functional areas' (e.g. breeding, feeding and resting habitats) of the species involved (see chapter 2.2.5). In view of the fragmentation of the landscape caused by human activities (urbanisation, cultivation, road-construction, etc.), attention should also be payed to the corridor-function of natural habitats. Certain ecosystems, such as rivers, riparian forests, and hedgerows, are often essential corridors which enable organisms to move from one habitat to the next. This corridor function may become even more important in the future considering the expected changes in climate conditions (see chapter 2.1.5). A changing climate may force plants and animals to seek for new habitats after the climate in their present range of distribution has become unfavourable. More research on migratory and reproductive behaviour of certain key-species is needed, since knowledge on the complex interrelationships between life communities of different and sometimes widely separated ecosystems is still quite fragmentary which makes it often difficult to assess the importance of a given area for this function.

(1) Providing a feeding and resting habitat to migrating animals
Estuarine and other ecosystems with a high net-biomass production (usually pionier communities) are especially important as feeding and resting habitats for migrating animals.

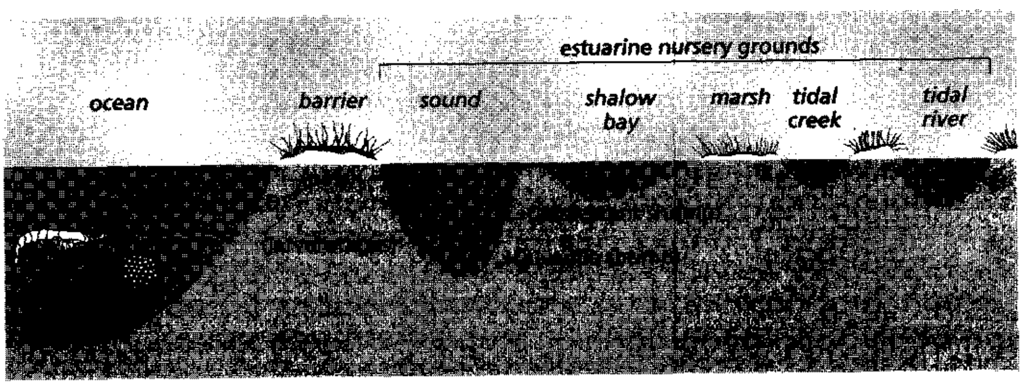
Some environmental characteristics influencing the suitability of an ecosystem as migration habitat The importance of a given ecosystem or natural area for this function may be deduced from the * **number of migratory species** of which over 1% of a regional or global population depends on this area for feeding and resting. For example, to determine the international importance of wetlands for migration, Scott (1980) mentioned two criteria: (a) the area should regularly support 1% (being at least 100 individuals) of the flyway or biogeographical population of one species of waterfowl, (b) the area should regularly support either 10,000 ducks, geese and swans, or 10,000 coots, or 20,000 waders. In general it can be said that the higher the * **net-production of biomass**, the more migratory species can be supported by a given ecosystem.

(2) Providing a nursery habitat

The importance of a given ecosystem as nursery area is related to the dependence of the life communities of other ecosystems on the area in question as a place for breeding and reproduction. Usually this function is investigated only for species which are commercially important such as fish and crustaceans. For example, in Europe North-sea fisheries depend to a large extent on the Wadden Sea as nursery area for many commercial fish-species (see chapter 4.2).

Some environmental characteristics influencing the suitability of an ecosystem as a nursery habitat
An important parameter for measuring the value of a given ecosystem or natural habitat as 'nursery' may be the * **number of breeding species** of which over 1% of a local, regional or global population depends on this area for reproduction (see appendix I.7.1 and I.7.2).

Fig. 2.1.15-1 Life history of shrimp that use estuaries as nursery grounds



Source: Odum, 1971

2.1.16 Maintenance of biological (and genetic) diversity

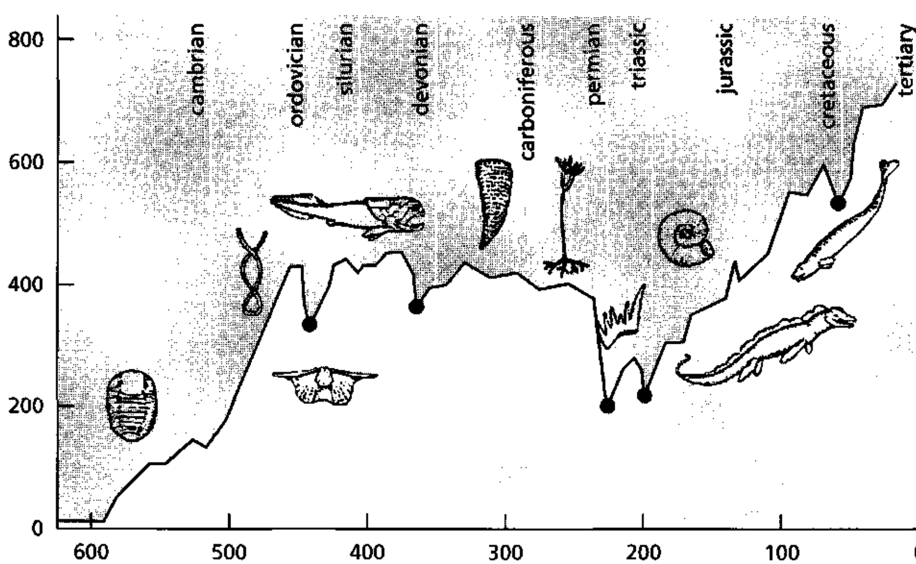
Ultimately, the maintenance of biological diversity on earth depends on the continuous evolution of the genetic material which determines the characteristics of individual organisms. Because of the many interrelationships between species (plant-animal interactions, predator-prey relations, symbiosis, pollination, etc,) the continuous evolution of new varieties and species is essential for the maintenance of the vitality of species and the functioning of entire life communities and ecosystems (see also chapter 2.1.14).

By providing living space to wild plants and animals, natural ecosystems are essential to the maintenance of the biological and genetic diversity on earth. Natural ecosystems can thus be seen as a 'storehouse' of genetic information. In this 'genetic library' the information of environmental adaptations acquired over 3.5 billion years of evolution, is stored in the genetic material of millions of species and subspecies.

The existing biological and genetic diversity is being used by man for many different purposes, such as food, medicinal use, crop improvement, pest-control, industrial products, energy sources, etc. In chapter 2.3 some current uses of wild plants, animals and micro-organisms are described. Future improvements in harvesting and producing food, medicines, and other essential resources will depend on the continuous selection, improvement and crossing of wild strains to maintain fitness of existing cultivated species and on the discovery of new species and properties. We still have to identify most of the species, and their properties, which are still living in the wild and their continued survival may be essential for man's future prosperity.

Biological diversity has increased slowly over time, set back occasionally by mass extinctions (see figure 2.1.16-1). Since the last mass extinction at the end of the cretaceous period some 65 million years ago, diversity has slowly increased to its present all-time high. However, it is now declining again at an unprecedented rate as a result of human activity.

Fig. 2.1.16-1 Evolution of biologic diversity on earth



Source: Wilson, 1989

The distribution of many species is restricted to biogeographical zones and within these zones their occurrence is often limited to specific habitats and ecosystems. Protecting representative samples of the most important habitats and ecosystems is therefore essential if we want to maintain the genetic diversity on earth. By destroying natural habitats, and the plants and animals that live there, we are not only loosing unique life-forms that evolved over millions of years, but we are also disturbing the natural balance on earth with unknown consequences. A tragic example is the extinction of the Dodo. Only recently, it was discovered that this bird played un unexpected but important role in the ecology of Mauritius (see box 2.1.16-1).

Some environmental characteristics influencing maintenance of biological diversity
The importance of a given ecosystem for the maintenance of biological (and genetic) diversity may be deduced from several parameters, notably the * **species diversity** and the number of * **endemic** and * **rare/endangered species and subspecies.**
a. Diversity of species and sub-species: The total biological diversity on earth is still unknown. To date, about 1.5 million species have been actually recorded and named (see App.I.7.1). However, it is thought that of the insects only about 10% has been identified and Erwin (in: May, 1988) believes that there may be 30 million tropical arthropods alone! Recent estimates, therefore, put the total at between 5 and 30 million species, and a much greater number of sub-species and varieties (Ehrlich, 1985, May, 1988). Especially the number of sub-species gives a good indication of the genetic variation and speciation (evolution) processes operating in a given ecosystem.
b. Number of endemic and dependent species and subspecies: An important parameter for selecting the most important habitats and ecosystems for the maintenance of biological diversity is the number of species and subspecies of which a significant percentage of the world population (e.g. 25% or more) depends on a given natural area for its survival. In extreme cases, this dependence may be 100% for endemic species and subspecies. Examples of such centers of endemism are oceanic islands and other isolated habitats, such as mountain tops, old volcanic craters, coral reefs, etc. One example of an area with a high percentage of endemism is the Galapagos Archipelago (Ecuador), which is discussed in more detail in chapter 4.3.
c. Number of rare and/or endangered species: Some species are naturally rare, for example endemic species which occur in a small area. However, as a result of human activities, both through habitat destruction and direct harvesting or killing of wild plants and animals, many species have become rare or endangered. To maintain the remaining biological (and genetic) diversity on earth, special care should be taken to save rare and endangered species from extinction (see box 2.1.16-1). To monitor the situation with respect to threatened species, so-called red data books on certain species-groups such as mammals, birds, amphibians, reptiles, fish and flowering plants (Angiosperms) are published regularly by the IUCN.

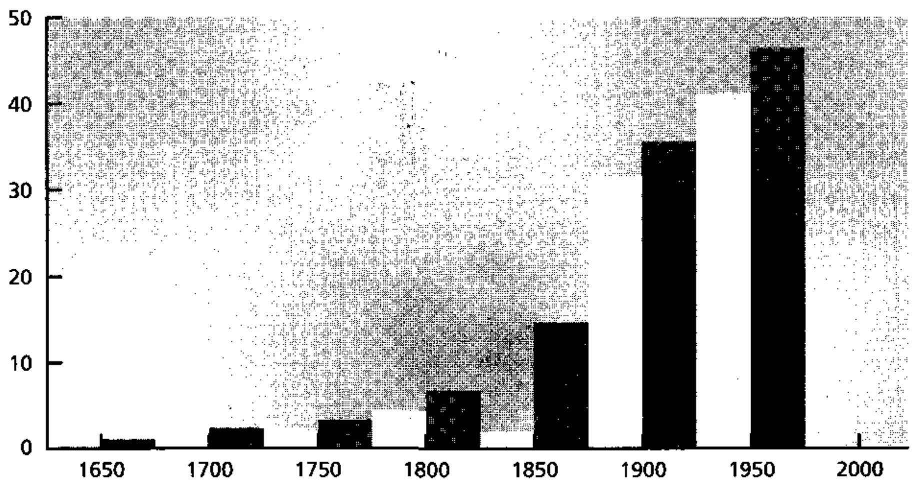
Dodo

Box 2.1.16-1 Extinction of wild plants and animals: rate, causes and some effects

Although extinctions have occurred throughout the evolution of life on earth, the rate at which species have been exterminated during the last 300 years has increased dramatically (see figure 2.1.16-2). As a result of hunting, pollution, habitat destruction and landscape fragmentation, many species have become extinct. It is estimated that since the year 1600 AD, man has eliminated at least 150 species of mammals and birds and unknown numbers of reptiles, amphibians, fishes, invertebrates and plants (Meyers, 1979). It has been estimated that the destruction of rainforests leads to the loss of 2,000 to 6,000 species per year, most of which without ever having been recorded by man. In Europe, already 11,000 native plant species have become extinct, while for the USA the number of lost plant species is put at 20,000 and 2,000 in the Sowjet Union. In addition to those species already lost, it is estimated that at least 25,000 plant species are threatened with extinction (Spellerberg, 1981), a number which will have increased to 40,000 by the turn of the century. By the year 2,000 the total species-loss may have accumulated to about half a million species.

At this rate of extinction, some biologists fear that the genetic diversity will soon decline below the level of the last mass extinction some 65 million years ago. Extinction of populations is often just as important as extinction of species because once most of the genetic variability is removed from a species by the extinction of most of its populations, its chances of survival are severely compromised. When a species disappears, also the food-web of which it was a part may be seriously disrupted. For example, the seeds of the Calvaria-tree on the island of Mauritius can only germinate after they pass through the digestive system of the now extinct dodo. After this bird disappeared early in this century, no seedlings of the tree germinated and only recently this crucial role of the dodo in the Mauritius-ecosystem was discovered. Now turkeys are being introduced to take over the role of the dodo (Libbenga, 1990). Apart from the threat to the continued proper functioning of ecosystems and life communities through extinction of species, opportunities for man to benefit from the known and unknown functions of these vanishing species are also lost forever.

Fig. 2.1.16-2 Rate of species extinction since 1650



Source: From Ziswiler, 1967

The number of exterminated mammal forms (white bars) and bird forms (black bars) over the last three hundred years. Each bar represents a 50 year period.

2.2 Carrier functions

All living organisms need a certain amount of space in accordance with their particular environmental requirements. The natural suitability of a given area or ecosystem to provide space and a suitable substrate or medium for certain physical needs, such as shelter or dispersal, depends on many factors such as the amount of available space, soil structure, and bedrock stability. Together, these environmental characteristics determine the physical carrying capacity of the environment for a particular organism or type of use.
Although all organisms require a certain amount of space to satisfy particular needs, this chapter only deals with those carrier functions which are important to man. In principle, all types of human use of the (natural) environment which require space such as habitation, cultivation, industry and engineering, transportation, recreation and nature protection, can be considered (potential) carrier functions of the natural environment. Unfortunately, the use of carrier functions by human land use usually involves a significant alteration of the natural environmental conditions. Especially when the use involves permanent infrastructure such as buildings and roads, changes may become irreversable leading to permanent loss of other functions of the ecosystem in question.
It must also be realised that the use of carrier functions is usually exclusive. For instance, space occupied by agriculture for crop growing or pastures for cattle breeding cannot simultaneously be used for other purposes, and usually goes at the expense of all or most other functions of the original ecosystem including regulation, production and information functions. Consequently, the use of certain carrier functions is one of the main causes of the loss of natural habitat. For example, over 30% of the land surface of the earth has been converted to cropland and pastures (FAO, 1976).

Apart from providing a check-list of environmental functions, another objective of this book is to provide guidelines for the sustainable use of goods and services of natural and semi-natural ecosystems. Therefore, when describing the capacity of natural ecosystems to provide certain carrier functions, the emphasis is on those functions which do not permanently alter the physical, chemical and/or biological characteristics of the original ecosystem and which do not exclude the use of other functions. Following this presupposition, possibilities for sustainable use of carrier functions in natural ecosystems are very limited since, with the exception of establishment and management of protected areas, most human activities that require space cause great alterations of the original ecosystem.

Bearing in mind all the above-mentioned problems and reservations, it must be acknowledged that human society cannot avoid occupying space. If a human population is to sustain itself, it needs a certain amount of space to satisfy essential survival needs such as food- and fuelwood production. Pimentel et al. (1984) estimate that a person in the tropics requires at least 0.2 ha for food-production and 0.4 ha for fuelwood production. Thus, the demand for space will increase as long as the human population continues to grow and activities such as urbanisation, cultivation, industry, waste disposal, transportation and recreation continue to expand.

Apart from ecological parameters, such as the suitability of the soil to provide arable land, the suitability of the natural environment for a particular carrier function may also be deduced from the amount of resources, energy, labour and capital needed to make use of this function, for example to improve the soil structure through drainage for agriculture or settlements. The more energy, resources and money need to be invested in infrastructure and regulatory activities, the less suitable the natural environment apparantly is for a particular type of land use (or carrier function).

On the following pages, only those carrier functions will be discussed which are potentially compatible with the conservation and sustainable use of the other functions of natural ecosystems. These include the (small scale) use of natural ecosystems as living space for indigenous people, some types of cultivation, certain forms of energy conversion, recreation and tourism, and management of protected natural habitats.

2.2.1 Human habitation and (indigenous) settlements

An important function of the biosphere is the provision of suitable 'living space'. Today, over 5 billion people are inhabiting the earth, all living under widely differing circumstances, ranging from settlements of indigenous people living in small communities of a few hundred people or even less to large cities and metroplitan areas with millions of inhabitants. In industrialized nations, the use of the natural environment for habitation usually means that the original ecosystem is completely removed to make place for concrete, steel and asphalt. This type of habitation is usually permanent, leaving very little room for natural elements. At the other end of the spectrum are indigenous people who occupy very little space for habitation and utilise natural materials for their often semi-permanent constructions. These indigenous settlements leave the natural environment largely intact and can be considered as the only form of sustainable use of the natural environment for habitation.

From the parameters listed below, it follows that some areas are more suitable than others to provide space for (sustainable) habitation. Sites for the first human settlements were 'naturally' chosen in the most suitable areas, notably coastal areas where the terrain is flat and where sufficient water and resources are available to sustain the community. Other ecosystems which provide suitable conditions for indigenous habitation are tropical forests and savannah-type habitats.

Examples of indiginous settlements which are in harmony with their natural environment are still available although many native cultures are rapidly disappearing and with them, the knowledge how to make sustainable use of the natural habitat they lived in.

Some environmental characteristics influencing the suitability for human habitation
The physical carrying capacity (or suitability) of the environment for human settlements is determined by various factors including the * **inclination**, the * **stability of the substrate** (soil, bedrock), and the absence of hazardous geological and surface processes such as volcanic eruptions, earthquackes, floods, and avalanches. Also * **climatological conditions** have an important influence on the suitability of a given area for habitation.

2.2.2. Cultivation

This function relates to the capacity of the natural environment to provide arable land and a suitable substrate or medium for the cultivation of plants and animals. Basically three types of cultivation can be distinguished: crop growing, animal husbandry and aquaculture.
Most arable land is already used and at present, the total area under cultivation for crop growing on earth amounts to 1.4 billion hectares or 0.28 ha per capita (WRI, 1990), while about 3 billion hectares is being used for animal husbandry (Oldfield, 1984). No information was obtained on the total surface area used for aquaculture.
The use of natural ecosystems for cultivation usually means the destruction of the original ecosystem, and since the most suitable areas have been taken into production already long ago, much of the land now under cultivation is not very suited for this purpose. Also the cultivation techniques applied are often not in accordance with the characteristics (potential carrying capacity) of the land which leads to soil degradation and erosion: about 10 million hectares of arable land is lost due to soil degradation and erosion each year (see chapter 2.1.8). To avoid further misuse and to develop more sustainable cultivation practices, land use for cultivation should take better account of the carrying capacity of the soil and other environmental factors influencing the suitability of the land for cultivation (for some specific parameters, see the description of the respective types of cultivation below).
Man continuously attempts to increase nature's capacity to produce food and other resources by manipulating the limiting environmental conditions through the input of labour, energy, machinery, fertilizer, irrigation measures, etc. The (un)suitability of a given area for cultivation can thus also be deduced from the amount of resources, energy and labour needed to cultivate the land (or to use the water environment for aquaculture). This can be done by calculating the total amount of energy input (natural and artificial), allowing for the loss of energy due to harvesting methods, storage and transportation, and comparing this with the output of the harvest. On the following pages, only those types of cultivation are briefly

described which can be utilised in a sustainable manner in natural or semi-natural ecosystems.

(1) Crop growing

The main purpose of crop growing is food-production. Of the estimated 350,000 plant species on earth, thus far man has learnt to use about 3,000 plant species for food, but at least another 75,000 plants known to have edible properties are not being seriously exploited. In total only about 150 species are cultivated to the extent that they are widely traded (Fitter, 1986). Of the 30 major world crops, the great majority of people today are actually fed by only about 7 plant species: wheat, rice, corn/maize, potato, barley, sweet potato, and cassava (Oldfield, 1984), which illustrates the dependence of modern agriculture on the continuous input of wild genetic material to maintain the genetic viability of these crops (see chapter 2.3.4). Crop-plants may also have other uses besides food, for example for the production of vegetable oils for lubricating and other purposes (e.g. jojoba- and rape seed oil), as ornamental plants, or as raw material to produce energy. By using certain hydrocarbon- and sugar-producing plants, it is possible to establish bio-energy plantations and produce petroleum and gasoline from biochemical energy (plant oils and sugars) (see chapter 2.2.3).

Although crop growing can have many negative effects on the natural environment, cultivation of some crops can reduce the pressure on harvesting wild species. Jojoba oil, for example, can serve as an economic substitute for the use of sperm oil and may also lessen the harvesting impact on slow-growing carnauba palms (*Copernica cerifera*) in Brazil, and on Mexican candilla wax shrubs (*Euphorbia antisyphilitica* and *Pedilanthus pavonis*). These hard wax-producing, wild plants have suffered from over-exploitation in the past (Oldfield, 1984).

Some types of crop growing which, under proper management, are more or less compatible with conservation objectives are briefly dealt with below.

(Shifting) agriculture: Agricultural practices range from intensive permanent cultivation of mono-cultures with large inputs of human and fossil energy, fertilizer and pesticides to shifting agriculture where the natural vegetation, usually forest, is cleared after which the soil is cultivated for 2 or 3 years. If the cleared patch is small enough and the surrounding forest is largely left intact, the natural vegetation may return after the cleared area has been abandoned again. When carefully planned, shifting agriculture is one of the few types of crop growing which may be compatible with nature conservation objectives.

Agro-forestry: Another cultivation method which is increasingly being employed in areas with poor environmental conditions is agro-forestry. Under agro-forestry management certain food-crops are planted mixed with trees to maintain nutrient recycling and protect the soil from erosion

and degradation. Important crop-species for agro-forestry are legumes because of their capacity to fix nitrogen. With proper management, also some natural values may be maintained, or even enhanced when agro-forestry is employed in formerly degraded areas.
(Selective) forestry: With selective harvesting methods, some types of timber-exploitation may be possible on a sustainable basis in semi-natural areas, especially in buffer-zones surrounding more strictly protected natural areas.

Some environmental characteristics influencing crop growing
The suitability of a given area for crop growing depends on a wide variety of environmental parameters whereby the specific requirements vary depending on the type of crop. On a local scale important environmental parameters include the * **soil depth,** * **soil-structure/texture,** * **humus content** * **fertility,** * **slope,** * **drainage** of the land, and * **water availability.** On a larger scale, environmental parameters for cultivation are related to climate conditions such as * **temperature,** * **precipitation,** * **humidity,** and * **amount of solar radiation/energy** which all influence plant growth. By combining a number of these climate variables it is possible to make a division into agro-climatic zones based on the length of the growing season. Plant growth is not only dependent on the amount of solar-energy fixed through photosynthesis but is also influenced by external energy subsidies such as * **air movements** and energy generated by * **evapotranspiration.** One way to approximate the suitability of a given site to support cultivation is therefore to determine the net energy balance (see also chapter 2.1.2).
Apart from the suitability of the substrate and climate, another important environmental factor influencing crop-output is the * **genetic viability.** Most of the cultivated species need regular infusions of wild genes to maintain their productivity and resistance against diseases. Efforts to maintain the genetic viability of cultivated plants (and animals) through input of wild genetic material and genetic manipulation are essential for the maintenance of the productivity of cultivated stocks. This is, however, an 'external' factor which depends on the maintenance of biological diversity and the availability of genetic material in natural habitats. More information on the dependence of cultivation on these functions can be found in chapters 2.1.16 and 2.3.11, respectively.

(2) Animal husbandry

Both domesticated and wild animals are reared by man to produce meat, eggs, milk, cheese, hides, wool and many other products. The animals used are mainly domesticated species such as cattle, sheep and goats but may also include wild species such as crocodiles, butterflies, ostriches and kangaroos. Basicaly four types of animal husbandry can be distinguished: - farming domesticated animals, - farming 'wild' species (wildlife farming), - game ranching, and - pastoralism. Only the latter two may be applied in (semi-) natural areas on a sustainable basis. Farming domesticated animals usually involves complete alteration of the original ecosystem and is therefore not further discussed here. Wildlife farming is a special case which is briefly explained in a separate box (2.2.2-1).
The environmental parameters which determine the suitability of a given area for animal husbandry are largely identical for those that influence crop growing with the notable exception of the availability of forage and animal feed in the form of grass, trees (leaves) or other types of * **edible plant material.**

Game ranching: With game ranching animals are kept within semi-natural areas where management aims to optimize the natural productivity without artificial inputs. The numbers of animals harvested are limited to sustainable yield levels. In some protected areas harvesting large numbers of certain species may even be necessary to maintain a certain balance. Game ranching can thus be seen as intermediate between hunting (whereby natural stocks may be decimated) and wildlife farming, whereby wild species are taken out of their natural environment to increase their numbers in an artificial way. An example of succesful game ranching is the management of vicuna's in Peru. These animals are kept in their natural environment in a semi-domesticated state and provide a valuable source of income for the people of the Andean plains.

Pastoralism: This type of animal husbandry refers to the herding of (semi) domesticated animals in more or less natural environments. It is usually practiced by nomadic people in areas with poor environmental conditions which makes it necessary to regularly change locations to make optimal use of the scarce amount of water or forage for the animals.

Box 2.2.2-1 Wildlife farming

With dwindeling populations of wild species, man has recently begun to 'farm' wild animal species for many different purposes. Many furs now come from chincilla-, mink- and fox-farms. Crocodile-farms produce, among others, leather, and butterflies are now bred in captivity, mainly for ornamental purposes. Also the green sea turtle is raised in captive stocks. Silkworm-breeding (sericulture) can also be considered a form of wildlife farming. The Chinese and Indian tasar silk industries are based on the use of wild Antheraea silkworm species which feed primarily on wild but economically useful timber trees (Oldfield, 1984). Also apiculture (bee-keeping), and ericulture (keeping insects that secrete biochemicals) should be mentioned here, as well as breeding exotic fish in capitivity for the aquarium trade. However, for most wild animal and plant species, captive breeding/cultivation has thus far proved to be impossible or impractical.
For some data on the economic importance of wildlife farming, see chapter 3.3.2.

(3) Aquaculture

Aquaculture refers to the farming of aquatic organisms, including fish, molluscs, crustaceans and aquatic plants. Cultivation methods vary from intensive farming requiring auxiliary inputs and capital, such as salmonid cage-farming, to extensive rearing systems, such as mussel culturing, which are to a great extent run by natural processes (Folke and Kautsky, 1989). Aquaculture has always been important in China and Japan but this type of cultivation may become increasingly important world wide (see table 2.2.2-1). Today, about 200 species of fish are reared in 136 countries with a total yield of over 12 million tons which could be 20 million in the year 2000.

Table 222-1 Average aquacultural production in 1987 (x 1,000 metric tons)
Source: WRI (1990)

	Freshwater fish	Diadromous fish	Marine fish	Molluscs	Crustaceans	Other*	Total
Afrika	60	x	x	x	x	x	60
N & C America	207	86	x	191	52	x	536
S. America	17	4	x	2	80	9	112
Asia	4,915	391	245	1,760	349	3,146	10,806
Europe	148	237	6	645	3	x	1,039
USSR	262	27	x	x	x	3	292
Oceania	x	2	x	27	x	2	31
World Total	5,609	747	251	2,625	484	3,160	12,876

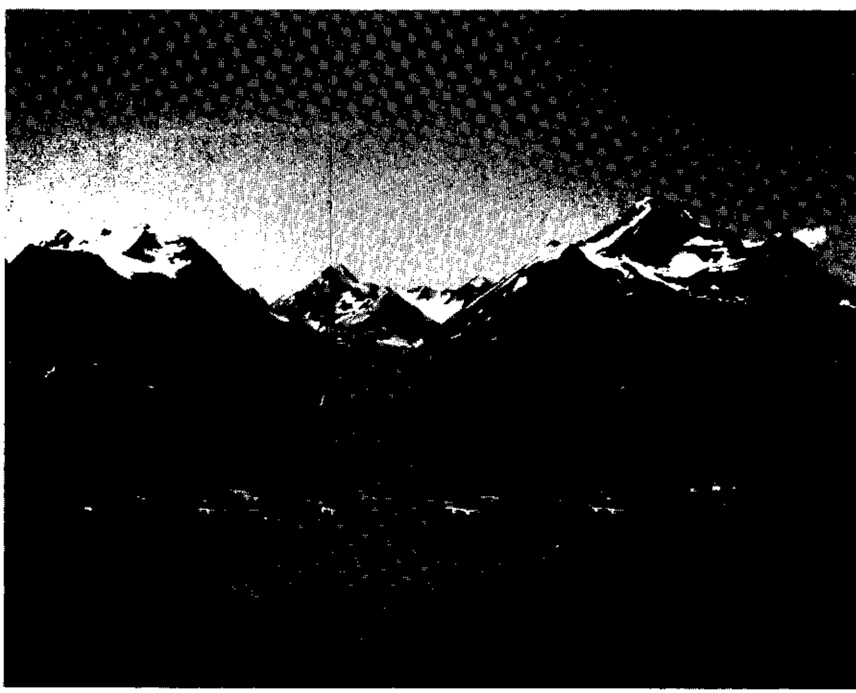
x = total production less than 1,000 tons or data not available
* = frogs, turtles and aquatic plants

The sum totals for each region are minimum estimates since data from many individual countries are not available. As the table shows, aquaculture is mainly practised in Asia where China (5.6 million tons) and Japan (1.2 million tons) are by far the largest producers. In North and Central America the USA is the largest producer (438,000 tons) while in Europe Spain (265,000) and France (226,000 tons) take the lead (WRI, 1990). Aquacultural food production has grown considerably during the last decades and now accounts for some 14% of the total world harvest of aquatic organisms which was about 90 million tons in 1987 (WRI, 1990). Production of biomass through aquaculture is expected to increase five to tenfold by the year 2000 (WCED, 1987). Especially in Africa and S. America there seems to be a large potential for aquaculture. In order to develop a sustainable aquaculture industry, culturing has to be carefully dimensioned to the capacity of the ecosystem to support aquacultural production, while environmental degradation, for example eutrophication from cage farming, should be prevented.

Some environmental characteristics influencing aquaculture
Important environmental parameters for assessing the suitability for aquaculture are the * **water quality** and the natural * **food chain interactions**, especially with respect to the availability of nutrients and animal feed. Also hydrological processes, such as fluctuations in * **river-discharge**, * **tides** and **currents** are important, as well as the * **temperature regime** in the aquatic environment.

Fish-cultures: Some important species of fish used for aquaculture are - carps, barbels, tilapias, and other freshwater fishes, - diadromous fishes such as sturgeons, river eels, salmon, trout, and smelts), and - marine fishes, including flounder, halibut, redfishes, milkfish, and catfish. Aquaculture with fish can be carried out in several ways: (a) Fish-farming in ponds and lagoons. In Benin, West Africa, fish are caught from shallow lagoons that are managed in order to maximise the growth of the algae and other plants on which they feed. Marine fish farms are found in some coastal estuaries and deltas in the Philippines, especially for the milkfish (*Chanos chanos*). Fish-farming is also practised in some shallow Scottish lochs (Fitter, 1986). (b) Cage farming. With cage-farming, fish are concentrated in net pens and the high fish densities are maintained by artificial food inputs. Floating net cages used in fish farming are of various sizes and types, designed for a production ranging from 1 to more than 150 tonnes per cage. Since high fish densities are artifically maintained, medical treatment, chemical treatment as well as vitamin supplements in the feed are often necessary. Cage farming of fish has a processing structure which resembles modern intensive meat production. Cage farming adds to eutrophication due to nutrient input through the supplied feed (Folke and Kautsky, 1989) and pollution as a result of chemical treatment. Care should therefore be taken not to damage natural proceses in the surrounding area.

Fig. 2.2.2-1 Salmonid cage farm in Norway



Molluscs: Use of molluscs for aquaculture includes both fresh- and marine species such as oysters, mussels, scallops, clams and squids. As an example, the mussel-culture is described in some detail below. Wild mussels (*Mytilus edulis L.*) live attached to various substrates and under favourable conditions they can attain very high biomasses per area in

nature. Favourable conditions are provided by man in an artificial way through long-line rearing units. A typical mussel rearing unit covers an area of about 1,500 m^2, and will produce 80-120 tonnes of mussels, including shells, after 14-17 months of growth (Folke and Kautsky, 1989). Mussels filter plankton from the water as currents pass through the rearing unit, and thus no supplementary food is needed. Mussel-rearing represents a more or less self-regulated extensive aquaculture system that is, to a large extent, integrated with the natural marine ecosystem. Since no feed is added and nutrients are removed when mussels are harvested, mussle culturing may even counteract negative effects of other human activities, such as eutrophication (Folke and Kautsky, 1989).
Crustaceans and other animals: Well-known crustaceans used for aquaculture include crabs, lobsters, shrimps, and prawns. Other animals which may be reared through aquaculture are for example frogs and turtles.
Plant-aquaculture: Many types of seaweeds are suitable for cultivation. For example kelp is the source of many useful products and is cultivated in various parts of the world. In Japan the aquatic fern *Ceratopteris pterioides* is cultivated as a spring vegetable (Fitter, 1986).

2.2.3 Energy conversion

This function relates to those sources of energy found in nature which depend on local environmental conditions for the conversion of the original energy source into energy that can be used by man. These are usually diffuse energy sources as opposed to other sources of energy which can be 'harvested' directly from nature such as fossil fuels, fuel for nuclear energy, and fuelwood and biomass. Most of these latter energy sources are discussed in chapter 2.3.9. Conversion of energy from diffuse sources, which require much space and a suitable substrate or medium, include solar energy, wind energy, hydro-power, tidal energy, and geothermal energy. Also the temperature differences caused by inversion in aquatic systems can be used as a source of energy by man. The production of biochemical energy from plants should also be considered a carrier-function since it is only commercially feasible in large plantations.
The separation between energy from point-sources and diffuse sources into carrier and production functions is somewhat arbitrary since, for example, conversion of fossil fuels and nuclear energy into electricity takes place in factories which also require space. However, the conversion of energy from diffuse sources is restricted to particular sites where the appropriate environmental conditions are present (solar radiation, wind, water-currents, etc.), as opposed to energy obtained from point sources where the mined or harvested material is usually transported and conversion takes place far away from the source.
As with most carrier functions, utilization of the energy from diffuse sources requires much space which is then occupied permanently and therefore natural ecosystems are generally not very suitable for the use of

this function. Since this book focusses on the functions of the living components of natural ecosystems, only biochemical energy and fuelwood plantations are discussed here in some detail. Some information on abiotic energy sources is included in box 2.2.3-1.

(1) Fuelwood plantations

A large percentage of the world population still depends on fuelwood and special fuelwood plantations may be a solution to the energy problem in many developing countries where firewood is still the most important energy source (see chapter 2.3.9). With sustainable management practices, also many natural values such as wildlife habitat, could be maintained or even enhanced when fuelwood plantations are planned in now treeless, mountaineous tropical areas where they could also help reduce the negative effects of deforestation such as runoff and erosion. Environmental parameters to assess the suitability of a given area for fuelwood plantations are similar to the requirments for cultivation of food crops (see chapter 2.2.2).

(2) Biochemical energy (plant oils and sugars)

Green plants capture solar energy by converting it into energy-rich organic compounds such as sugar and hydrocarbons. Some plants produce such quantities of these chemicals that they can be harvested and refined or converted into fuel. Two of the most important ways in which plant biomass can be converted into fuel are cultivation of particular oil- or latex-producing plant species to produce hydrocarbons ("gasohol"), and cultivation of sugar-producing plants followed by extraction and fermentation of the sugars to ethanol.

Hydrocarbon (gasohol): Hydrocarbon producing plants include, among others, guayule, some *Euphorbia* spp. (particularly *Euphorbia tirucalli* from Brazil, and *Euphorbia lathyrus* from California), members of the milkweed family (*Asclepiadaceae*), and tumbleweed (*Salsola pestifer*), a pest species of arid lands. Production of hydrocarbons in Malasya from the rubber species *Hevea brasiliensis* is currently averaging the equivalent of about 25 barrels of oil per hectare annually.

Sugar (ethanol): Many plants are able to convert solar radiation into energy-rich sugar, for example maize (*Zea mays*), sorghum (*Sorghum bicolor*), sugar cane (*Saccharum officinarum*), and cassava (*Manihot esculenta*). At present, sugar cane is the most promising sugar- producing species used for fermentation to fuel alcohol. One ton of sugar cane can yield 90 kg of sugar or 30 liters of alcohol. In recent years, Brazil has been the world's largest sugar cane producer, producing 6-8 million tons per year. The use of ethanol as a fuel oil has some advantages over petroleum; when added to gasoline, it increases fuel octane ratings and reduces engine knock, thus obviating the need for lead additives. Ethanol-powered engines produce smaller quantities of other pollutants, and ethanol also produces 18 percent more power than gasoline (Oldfield, 1984).

In the past, biomass conversion and industrial energy plantation experiments have received little attention or financial support in comparison with the massive expenditures on nuclear power. Yet the potential for energy production from renewable plant populations is an important possibility for replacing (limited) fossil fuel stocks and radioactive material for nuclear power plants. However, it must be realized that these 'gasoline-plantations' require large amounts of space. For example, to produce 13 million barrels/day (the total gasoline consumption of the industrialized, non-communist countries in 1985) would require something in the order of 80 million ha of land for sugar cane plantations, which would destroy large areas of natural habitat.

Box 2.2.3-1 Some abiotic energy-sources and their dependence on natural carrier functions

(1) Conversion of solar energy: The amount of energy received from the * **sun** is by far the most powerful and most abundant source of energy available to man. The earth receives a daily amount of radiation-energy from the sun of 4.2 x 10^{15} kWh (see Appendix I.2.6). Expressed in coal-units, the amount of energy received each year from the sun is equivalent to the heat-energy of 185 thousand-billion tons of coal, which is about 185 times the total proven reserves on earth (see chapter 2.3.9). In 1988, the total energy consumption on earth was equivalent to 12 billion tons of coal (or 8 billion metric tons of oil) (WRI, 1990) which was only about 0.00006% of the solar radiation input, illustrating the enormous potential of this energy source to satisfy human energy needs. The amount of solar radiation received locally depends on various environmental factors (such as latitude and the associated day-night rithm) and the weather-conditions, notably the * **cloudiness**. For example, the Sahara has a maximum annual radiation input of 2,600 kWh per m^2, the southern part of the USA receives an annual solar energy-input of on average 1,800 kWh per m^2, and northern Germany of only about 1,000 kWh per m^2. For most of the biosphere the radiant energy input is about 1,500 Kwh per m^2 per year which equals 3,000 - 4,000 kcal/m^2/day (Odum, 1971).
Basically, two processes are available to convert solar radiation into useful energy: photovoltaics and thermal technology. Photovoltaics, which converts sunlight directly into electrical energy using semiconductor devices, and thermal technology which uses mirrors to focus the sun's light onto coated steel pipes which contain a fluid. The fluid is heated and passes through a heat exchanger to generate steam for electric turbine generators (WRI, 1990).
(2) Wind energy: The kinetic energy generated by air turbulance may be converted into usable energy to man by means of windmills, windturbines or other devices which are able to convert kinetic energy.
(3) Hydro-power and tidal energy: Flowing water, tides and wave activity represent a considerable amount of energy which can and is being used by man to generate electricity. (a) Hydro-electricity from rivers provided almost 7% of global energy consumption in 1988, equivalent to about 565 million metric tons of oil (WRI, 1990). North America and Europe had, by 1980, tapped 59 and 36 percent of their large-scale hydropower potential, while Asia had developed just 9 percent, Latin America 8 percent, and Africa 5 percent. The worldwide potential is estimated to be well over 100,000 megawatts (WRI, 1990). (b) The potential kinetic energy available through tidal movements, which are caused by the gravity-forces in the solar-system, is 1/60,000 the amount of energy received from the sun (Mesarovic & Pestel, 1974). This is 35 billion kWh/day or an equivalent of 3 billion tons of coal. A problem with the utilisation of hydro-power from rivers and tidal energy, is that large constructions and engineering projects (such as hydro-electric power dams) are needed which require large amounts of space. The full development of hydro-power potential may therefore be problematic due to the negative environmental effects.
(4) Geo-thermal energy: Heat released by sub-surface volcanic activity can provide a useful source of energy. It can be utilized directly by using the hot water from geysers, or by converting the heat in hot air and steam, which escapes from vents, into electricity. The amount of energy transported from the hot inner core of the earth to the surface amounts to about 400 billion kWh/day (Mesarovic & Pestel, 1974) or 37 billion tons of coal-equivalent. The world production in 1987 was about 35,000 gigawatt-hours or 0.3% of the total world production of electricity (WRI, 1990).

Table 2.2.5-1 Some parameters for determining the conservation value of a particular area or ecosystem
Source: modified after Usher (1986), Spellerberg (1981)

Parameter	Relative importance*
Diversity (of species and/or habitats)	(12,2)
Rarity (of species and/or habitats)	(11,3)
Representativeness	(10,2)
Area size needs/minimum critical ecosystem size	(9,9)
Naturalness/heritage value	(8,9)
Scientific value	(8,4)
Ecological fragility/species vulnerability	(8,3)
Uniqueness/endemicity	(8,0)
Threat of human interference	(8,0)
Wildlife reservoir potential	(7,4)
Potential value	(5,0)
Management factors	(4,8)
Position in ecological geographical unit	(4,7)
Replaceability	(3,8)
Amenity value/aesthetic qualities	(2,8)
Recorded history	(2,0)
Educational value	(1,5)
Availability	(0,7)

* The mean importance values calculated are based on Margules and Usher (1984), who asked expert panels (with a maximum of 14 members) to give relative weights to each criterion.

In addition to the ecological and scientific value of a given ecosystem or natural area, there are many functions and associated values that can be attributed to protected areas. For example, apart from their role in conserving the remaining biological diversity on earth, by providing a safe habitat for many rare and endangered species, they also safeguard stocks of wild relatives of domesticated species and maintain the continuous evolution of genetic material which is important for agriculture, forestry, and medicine. They may provide watershed protection and serve as water-catchment-areas, thus safeguarding the supply of drinking water and irrigation schemes. Protected areas influence (local) climate conditions and often provide a buffer against desertification. Protected areas may also provide many resources. For example, the Chitwan National Park in Nepal provides nearly a million dollars worth of thatch grass each year, the only source of such house-building material in the area (Press Release IUCN World Conference on National Parks and Protected Areas, Bali, Oct. 1982). Also firewood and other forest products, including some of the wildlife, may be harvested from protected areas. The value for recreation and tourism should also be mentioned as an important productive use value of protected areas. Natural areas often simultaneously protect special geological or anthropological features, such as megaliths, archeological and cultural sites. Protected areas are important for education and research and can be used as a scientific yardstick for monitoring both short and long-term changes in the biosphere, such as the effects of climate change.

The combined socio-economic value of all these functions, together with the conservation-argument and intrinsic values attributed to natural areas, more than justifies the inclusion of protected areas in the planning and decision-making process as a serious alternative for other types of land use. Depending on the local situation, protected areas may provide a combination of functions and the checklist provided in this book can help to make a systematic overview of the many functions and socio-economic values of protected areas.

2.3 Production functions

Natural and semi-natural ecosystems provide many resources which range from oxygen, water, food, medicinal and genetic resources to sources of energy and materials for clothing and building. Over time, man has learned to manipulate the biotic productivity of natural ecosystems to provide certain resources in greater quantities than available under natural conditions. When discussing the contribution of nature to biotic production functions, a distinction must therefore be made between products taken directly from the 'wild", like fish, tropical hardwoods or other so-called 'minor' forest products, and products from cultivated plants and animals.
In this book, production and resource functions are limited to those goods which are produced naturally and for which man only needs to invest some time and energy to harvest them. As soon as he begins to manipulate the environment to increase or change the natural productivity (e.g. by applying fertilizer and pesticides and supplying animal-feed), the function of nature is not so much the supplying of the resource itself, but rather to provide space and a suitable substrate or medium to produce these goods. Therefore, products from agriculture and animal husbandry are discussed under the category 'carrier functions' (see chapter 2.2.2). However, even production-systems which are totally dominated by man, such as factory-farming, often still depend on the presence of the cultivated animals and plants in the wild to maintain the genetic viability of the stocks. When animal feed, fertilizer and genetic material are harvested in the wild, these resources do belong to the category of naturally produced goods which are discussed in chapters 2.3.10 and 2.3.4 respectively.

Within the category of production and resource functions, a distinction should further be made between the use of **biotic resources** (i.e. products from living plants and animals) and **abiotic resources** (i.e. mainly sub-surface minerals). An important difference between biotic and abiotic resources is their renewability. Generally speaking, biotic resources are renewable within a reasonable period of time (a notable exception being tropical hardwoods which take many decades or even centuries to grow), while most abiotic resources are not renewable, although it may be possible to recycle them.

If utilized in a sustainable manner, nature could provide many of the biotic resources in perpetuity. However, the consumptive nature of the use of these resources and the short-term interests of the market economy make them vulnerable to over-exploitation. In addition, many of nature's resources are considered 'free' goods and as such have no monetary value in conventional economic accounting procedures (see also chapter 3). Consequently, they are being exploited until it becomes too expensive to obtain the resource and transport it to the market place. The exploitation level at which natural resources become 'un-economical' thus often exceeds the sustained yield level and carrying capacity of the ecosystems providing them. The non-sustainable use of wild resources has seriously endangered a large number of animal and plant species, and several species have already become extinct (see box 2.3.0-1).

Box 2.3.0-1 Some considerations concerning (non)-sustainable use of wild species and natural productivity

Most biomass on earth is ultimately derived from the solar energy fixed by green plants (see chapter 2.1.10). To what extent the total biomass production of an ecosystem may be used by man (for food, fuelwood, timber, etc.) depends on the degree to which the ecosystem uses the energy stored in this biomass for its own metabolism. In biological communities which are in a steady state, most of the Gross Primary Production is used for respiration by the members of the life community and is recycled very quickly. Mature or climax ecosystems, notably those with large biomasses or standing crops, such as rainforests, require so much autotrophic respiration for maintenance that Net Community Production is very low or even zero at the end of the annual cycle. In order to maintain a certain balance in ecosystems from which products are harvested by man, not more than one-third of the gross primary production should be harvested (see 2.1.10). When more biomass is harvested, the self-maintaining mechanisms of the eocystem will be disturbed, leading to degeneration of the system and decline of species numbers.

Of the many examples which are available, the over-exploitation of whales is maybe best documented. Whales are harvested primarily for their edible oil which is used to make margerine and cooking oils, and secondarily for their meat. Often, exploitation has focussed on one species until the numbers are so low that harvesting becomes 'uneconomical'. Hunting then shifts to another species, etc. This sequence occurred with the blue-, humpback-, and fin whales, which have suffered strongly from overharvesting. Due to their widespread occurrence the point where harvesting became too expensive luckily left a few individuals to recover the world population but at present all three are still endangered. Species which have a more localised distribution, such as the Dodo, were not so fortunate. A classic example is the Great Auk (*Pinguinus impennis*). This seabird was hunted for its meat and eggs until it became extinct in 1844. Another tragic case is the Passenger pigeon (*Ectopistes migratorius*). Whereas an estimated 3 billion Passenger pigeons existed in the North American continent at the time of the arrival of the first European colonists (possibly 25-40 percent of the total U.S. bird population at that time), by 1915 not a single individual remained (Oldfield, 1984).

Apart from resource depletion, over-exploitation of a resource often causes other negative effects as well. For example, logging of tropical timber causes habitat destruction, erosion, desertification, and pollution.

It should therefore be stressed here that when deciding to utilise the production functions of the natural environment, due account should be taken of these so-called 'external' effects. Resource exploitation should aim to conserve the natural biota that provide these resources and should be limited to sustainable yield levels as much as possible. Since natural ecosystems support many other organisms besides man, and perform many functions simultaneously, the capacity of natural ecosystems to provide resources on a sustainable yield bases is often very limited.
It is quite impossible to discuss the enormous amount of resources (biotic and abiotic) provided by the natural environment, both directly and indirectly, in any detail. This book therefore gives a brief overview of the most important categories of production functions with some illustrative examples.

2.3.1 Oxygen

The vital function of oxygen for human (and most other) life is obvious. The present concentration of O_2 in the atmosphere of about 21% is sufficient to sustain (human) life, although the range between acceptable upper and lower limits is quite small and may easily be disturbed (see chapter 2.1.3). Because the atmospheric reservoir of oxygen is very large compared to the fluxes of oxygen between the various environmental compartments, the availability of oxygen does not seem to present any major problems in the near future. A more problematic factor is total air quality. Since oxygen is consumed by man through inhalation of air, the quality of the air as a reservoir and transport-medium for oxygen is very important. Unfortunately air-quality does present reasons for concern and clean air is becoming increasingly scarce. For example in some large cities, such as Paris and Tokyo, clean air, and thereby oxygen, has become so scarce that additional oxygen is supplied through artificial devices. In the spring of 1991, Mexico City installed 25 'casetas de oxigeno': a type of telephone-booth where breathless people can inhale oxgen for about 2 US$ per minute. Because of the altitude (more than 2,000 m above sealevel), air is thin in Mexico City and 3 million cars and many industrial complexes are competing for oxygen and pollute the air.
The capacity of a given area or ecosystem to contribute to the availabilty of atmospheric oxygen depends on the net-oxygen production, which in turn depends on the balance between production and breakdown of organic matter (see below). This is why, for example, (undisturbed) tropical rain forests have a neglegible effect on the oxygen-concentration of the atmosphere since all the organic matter produced is almost immediately consumed or decomposed. Deforestation, either by large forest-fires or by logging, thus has a negative impact on the oxygen-concentration in the atmosphere since large amounts of organic matter are 'consumed' (i.e. burnt) at the expense of atmospheric oxygen (while carbon dioxide is released).

In healthy aquatic systems oxygen-production exceeds the consumption. For example, a pond measured by Odum (1971) had a gross production of 8 gr O_2/m^2/day and a community respiration of 6 gr O_2/m^2/day, leaving a net-oxygen production of 2 gr O_2/m^2/day. Also algea-communities in the oceans maintain a continuously high net community production and thus high oxygen production.
Apart from aquatic systems, the most important life communities in terms of oxygen-production are pioneer-communities since they produce an excess of organic matter. However, their net-oxygen producing effect is often temporary and declines when the community approaches the climax stage.

Some environmental characteristics influencing oxygen-production
The net-oxygen production of a life community depends on the balance between production of organic matter. Through * **photosynthesis**, oxygen is released into the atmosphere while * **consumption (respiration)** and * **decomposition** of organic matter removes oxygen from the atmopsphere. Only when production of organic matter exceeds the rate of consumption and decomposition is there a net-release of oxygen to the environment.

2.3.2. Water

Water is needed by man in many ways; for example for drinking, household needs, irrigation, industry, and recreation. In this chapter only the use of water as 'harvestable' resource is taken into account. Non-consumptive uses, such as the use of water for recreational purposes, fall under the category of carrier functions and are discussed in chapter 2.2. Some parameters which influence the availability of (fresh) water are listed below in small print.
According to WRI (1990), the total amount of available renewable freshwater resources (which is the average annual flow of rivers and aquifers generated from endogenous precipitation) is about 7,690 m^3/per capita. Due to pollution, however, this is reduced to about 7,000 m^3 according to Mesarovic and Pestel (1974). The actual total consumption of water per capita per year was 660 m^3 in 1990 which was mainly used for agriculture (69%) and industry (23%). There is a wide variation in per capita consumption with the USA taking the lead with over 2,000 m^3/capita/year (WRI, 1990). The current average withdrawl of freshwater from the hydrological cycle is about 10% of the total amount available. However, if all people would consume the USA-average, the total world consumption of water would be 10,000 km^3/year (based on 5 billion inhabitants), which is almost 25% of the available amount of unpolluted fresh water cycling through the biosphere.
Since precipitation and also the surface- and groundwater-reservoirs are unevenly distributed over the planet, there are large differences in regional and local availability of water which makes the situation even more complex. For example, of the 40,000 km^3 of renewable fresh water

available per year, Brasil receives about 13% (5,200 km^3) and Egypt less than 0.005% (2 km^3) (WRI, 1990).

Locally water shortages are already occurring, and due to population growth, increased industrial activity and increased needs for irrigation-water, the total world consumption of water may soon exceed the quantity of circulating water on earth. Man would then have to begin to use (deep) groundwater stock or to desalinate sea-water on a large scale. If the available water is to be used in a sustainable manner, we will have to investigate the consequences of the extraction of water from the reservoirs and of the interruption of the water-cycles for the natural ecosystems on earth. In those areas where human society depends on groundwater and surface water-reservoirs, fresh water should be considered a non-renewable resource. Recharge of aquifers is naturally slow, and often hampered by the paving over of recharge areas, leading to the collapse of over-pumped aquifers such as the Ogallala Aquifer in the USA and the Nubian Aquifer in Libya (WRI, 1990). In many parts of the world human water use already considerably lowered groundwater-tables and reduced the volume of surface water reservoirs (e.g. lake Balaton in the Sowjet Union). Another problem is the salinization of soils due to increased use of water for irrigation.

Some environmental characteristics influencing water-availability

The total * **water-reservoir** on earth is about 1.3 billion km^3, most of which is stored in oceans, ice caps and as groundwater. Only a very small portion (about 125,000 km^3 or 0.009%) is found in freshwater lakes (see table 2.1.7-1). Sea-water and much of the groundwater is not directly suitable for human consumption, whereby many of the groundwater-reservoirs must be considered non-renewable resources because recharging is very slow or absent.

To avoid depletion of groundwater reservoirs and lakes, man mainly depends on water which moves in the hydrological cycle (about 550,000 km^3, Dasmann, 1976) through * **evaporation**, * **precipitation**, * **runoff** and * **river discharge**. Most of the water being cycled is directly returned to the oceans (through precipitation) or stored in ice-caps, leaving only about 43,000 km^3 of fresh water directly available for human consumption. Another important parameter to assess the capacity of a given area/ecosystem to provide water for human use is * **water quality**. The quality requirements differ for different types of use (see box 2.3.2-1).

Box 2.3.2-1 Water quality requirements for different types of use

The required minimum standards of water quality vary for different types of uses (functions). For example, quality-requirements are different for water used for drinking, industry, households, irrigation, recreation and as a wildlife habitat. Over the years, minimum standards have been developed for the most important substances occurring in water. Table 2.3.2-1 lists a few of 50 selected indicators.

The quality of the water returned to the environment after human use is often very bad and heavily imposes on natural purification processes to maintain an acceptable quality which is important both for renewed human use and for other functions, notably as a wildlife habitat and for recreational use. In many parts of the world the quality of especially drinking-water is far below required standards and near heavily populated areas it becomes more and more necessary to apply costly and energy-consuming purification procedures.

Table 2.3.2-1 Water quality requirements for different types of uses (figures from WRI, 1990)

Element	Drinking	Wildlife	Recreation	Irrigation	Industry
Dissolved Oxygen	?	2-4 mg/l	?	?	?
Biol. Oxygen Demand (BOD)[1]		< 6.5 mg/l	?	?	
pH[2]		6.5 - 8.5			
Faecal coliforms[3]	0	?	?	?	?
Dissolved mercury	< 0.001 mg/l	?	?	?	?
Dissolved lead	< 0.05 mg/l	?	?	?	?

[1] Rivers can be said to be seriously polluted if more than 6.5 mg of oxygen would be required to oxidize the organic matter in a liter of water (see also Appendix I.4.6).
[2] Lower pH values in waterhave negative effects on wildlife and lead to increases in the dissolved concentrations of heavy metals including lead and cadmium
[3] Faecal coliforms are most commonly associated with the faeces of animals and humans. This measure is used as an indicator for the presence of other pathogenic organisms which are more difficult to observe and measure.

2.3.3. Food and nutritious drinks

Most of man's nutritious needs are satisfied by plant and animal resources, either from wild, domesticated or cultivated species. Only very few food-items, such as table salt, do not originate from biological sources.
Although today most foods are derived from cultivated plants or domesticated animals (see chapter 2.2.2), still a substantial part of our nutrition comes from wild plants and animals. Natural ecosystems are an almost unlimited source of edible plants and animals, ranging from game- and bushmeat, fish and fowl, to vegetables, fungi, fruits, and such exotic items as birdsnests and sponges.
Many societies still depend to a large extent for food and nutrition on wild plants and animals, and this is especially true for villagers and tribesmen in non-industrial countries in the tropical world. For example, in Africa over 80% of the diet of 740 African tribes surveyed depended largely on wild animals and plants (Fitter, 1986). But also in the industrialized countries substantial amounts of food are directly harvested from the wild. In the U.S.A. alone, yearly more than 4.3 million metric tonnes of wild plants and animals are harvested, including fish (representing over 80% of the harvest), game mammals, game birds, maple sirup, tree nuts, blueberries and algae/plankton (Pimentel, et al.,1980). In Britain, such wild fruits as bilberries, watercress and mushrooms add important variety to rural diets, and every September countless people go out to the country hedgerows to pick blackberries from the wild bramble (*Rubus fruticosus*). In continental Europe many species of edible fungi are gathered and sold in local markets; one of the best known is the underground truffle (*Tuber spp.*), harvested with the aid of specially trained dogs (Fitter, 1986). Some important food-items directly harvested from nature, and examples of the species which provide them, are briefly described on the following pages.

Some environmental characteristics influencing the availability of food
To assess the suitability of a given ecosystem or natural area to provide plants and animals as food-resource, and to avoid over-exploitation, several parameters should be taken into account, such as the * **occurrence of edible plants and animals**, * **population size** and * **population dynamics**, and * **food-chain interactions** of the species involved. Also the total amount of * **standing biomass**, and the * **biomass production** is important.

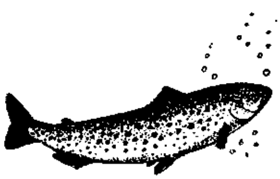
(1) Meat and eggs

Apart from harvesting fish, which is a major source of food to modern man, only few remaining tribes of hunter-gatherers and pastoral peoples still largely depend on wild animals for food. Most major animal taxa contain animals which are edible in one way or another (see box 2.3.3-1 for some examples).

Box 2.3.3.-1 Some examples of wild animals harvested for food

NB: Most information is taken from Fitter (1986) and Oldfield (1984), unless indicated otherwise
Mammals (game- or bushmeat/game utilization): Meat from wild terrestrial game-animals or 'bushmeat' provides less than 1% of the total world meat production today. Species of mammals which are still harvested from the wild for their meat include among others primates, whales, sea cows and manatees, horses and their relatives, wild pigs, and cattle and their relatives such as hippopotamus, eland, yak, oryx, gazelle and mouflon.
Birds (poultry): In most countries wild birds still provide eggs and meat (game-birds) to many people, although in the developed world collecting eggs from wild birds has been almost completely replaced by the production of eggs from the domestic fowl (*Gallus gallus*). Some wild bird species which are primarily caught for their meat are phaesants and turkeys, guinea-fowl, ducks and geese, pigeons, parrots
songbirds, shorebirds (for example sandpipers and plovers in Guyana), puffins (for example on Iceland), gannets which provide salted 'gugas' on the Hebridean islands, and frigate birds which are a source of meat on the Cocos/Keeling islands in the Indian Ocean. Especially in Mediterranean Europe many songbirds are still captured for their meat (and also to be kept as 'singing pets'). In Cyprus alone, up to ten million birds are shot, netted or limed annualy. Colonial nesters, such as gulls, auks and penguins, are the most important sources of wild eggs. In Irian Jaya it is the magpie goose (*Anseranas semipalmata*) and on Sulawesi maleo fowl (*Macroephalon maleo*) which provide eggs. Also eggs from wild *Phasianidae* are collected in many parts of the world.
Reptiles: Reptiles provide both meat and eggs. Marine turtles are an important human food source. Their flesh sustained many ship-crews in the tropical oceans during the time of discovery; together with their eggs they are still an important, if overexploited, source of protein for coastal populations in the warmer parts of the world. For example, the green sea turtle (*Chelonia mydas*), which is still hunted for meat, eggs and oil, is now an endangered species. River turtles have long been important sources of meat and eggs for local people in South America, but these too have been overexploited.
Land tortoises are also used for meat and oil; a famous example being the Galapagos tortoise (*Testudo elephantopus*), which was killed by the hundreds of thousands by whalers, sealers, buccaneers and fishermen for several centuries causing the extinction of 3 of the original 15 sub-species (see chapter 4.3).
Snakes, lizards and iguana's are important items of diet in China and elsewhere in Asia, the Pacific and in Latin America.
Amphibians: Many people, especially the French and Swiss, have acquired a taste for the flesh of the edible frog *Rana esculenta*, which is only one of numerous instances where amphibians are harvested for food.
Fish: The principal source of wild animal food is surely provided by marine organisms, especially fish and shellfish. Fishes, both marine and freshwater, are human food throughout the world. For the main bulk of our fish supplies, we still rely on wild fish. The annual world-catch of marine fisheries is estimated at 80 million metric tons (both fish and shellfish) in 1987 while freshwater-

fishery in that year amounted to over 10 million metric tons (WRI, 1990). In the early 1980'ies, marine fishery alone represented which about 25% of the total world meat production.
Some of the most important marine fish species are plaice, salmon, trout, cod, haddock, herring, mackerel and tunafish. Some of the most important freshwater food fishes are carp, catfish, salmon, eel, and tilapia.
Major lake fisheries are found in the great African lakes (Victoria, Chad and Nyasa), with various species of *tilapia* as the main catch. In both Africa and Asia the major river systems and their flood plains, such as the Mekong in South-East Asia and the Congo in central Africa, provide vital additions to local protein supplies.
Invertebrates: The three major invertebrate groups that contribute to the human diet are crustaceans, molluscs and arthropods. Most of the marine invertebrates fished for human consumption are ***crustaceans***, and among these, shrimps are almost certainly the world's most valuable wild animals. The total annual value of the exports of fresh and frozen shrimps from India, Indonesia, Mexico and other developing countries is one billion US$. Indeed, for countries like Panama, Pakistan, and Madagascar shrimps are the main source of foreign exchange. Other crustaceans which are harvested for human consumption are krill (*Euphausia superba*), a shrimp-like crustacean of the southern oceans (and an important element in the natural food chain), crayfish, lobster, crabs and prawns, and branchyopods, for example *Lingula* in Japan. Marine molluscs eaten include bêche-de-mer or sea slugs (Australia), abalones and ormers, oysters, and Cephalopods (squids, octopuses, etc.). Land molluscs eaten include the Roman snail (*Helix pomatia*) in Europe, and the Giant snail (*Achatina spp.*) in Africa.
Several species of arthropods are valued by man for food, such as termites, which have a very high nutritive value. For example, one sample of lightly roasted wingless termites in Zaire proved to be 44% fat and 36% protein. Also the large fat larvae of moths or beetles are regarded delicacies in some parts of the world. Another source of food provided by arthropods is honey.



Rainbow trout

(2) Honey

Honey is collected both from wild bee-colonies and from 'domesticated' bees. Two honeybees, *Apis melifera* and *A. indica*, are among the remarkably few domesticated invertebrates. However, they are domesticated only in the sense that they can be induced to nest in artificial hives, where they are more easily exploited.

(3) Vegetables

Today, as in the past, most of the world's human population is sustained by vegetable rather than animal foods. Of the estimated 350,000 plant species on earth, roughly a quarter (about 80,000 species) are believed to posess food value for humans. The most important plants which provide vegetables are now cultivated, but a few are still collected in the wild. Seaweeds are an important group of plants still harvested from the wild. They are eaten, raw or cooked in many developing countries, but also in industrialised countries such as Japan and Wales (Great Britain). Koreans in particular eat large amounts of kelp, mostly dried. Around Lake Chad,

waterleaf (*Talinum triangulare*), a weed-species with a high protein and vitamin B12 content, is eaten as a green vegetable.
Wild palms yield both salads and edible oils. In Brazil, for example hearts of palm are eaten, which by the way entails the destruction of the entire tree. In South-East Asia, Papua New Guinea and Venezuela, sago is still produced from wild palms. In Africa, the leaves of the baobab (*Adansonia digitata*) are cooked and eaten (Fitter, 1986)

(4) Grains
Grains provide important vitamins and are a staple food in many parts of the world. The seeds are usually ground to make, for example, bread and tortillas. Grains may also be fermented to produce alcoholic drinks (see further). Grasses of the genus *Saccharum* provide sugar and sugar-syrup (molasses) (Fitter, 1986). The most important plant-group providing grains is the *Gramineae*-family (grasses), and many species used for this purpose are now cultivated. For example wheat, barley, rye, oats, rice and corn (maize) are all the seeds of grasses. An example of the use of wild grasses is the harvesting of the seed-heads of the eel-grass *Zostera* (*Potamogetonaceae*) from the delta of the Colorado River, at the northern end of the Gulf of California in Mexico, by the Sori Indians, who grind them into a flour to make tortillas (Fitter, 1986).

Bread wheat

Emmer

(5) *Fruits*
Nature provides a multitude of edible fruits, which are an important source of vitamins and other vital food-elements. Some of the most important edible fruits are apples, pears, plums, cherries and berries, citrus fruits, grapes, bananas, papayas, kiwi, and less well-known fruits such as tomatillo, tuna (the fruit of the *Opuntia*-cactus), kumquat, and loquat. Most fruits are now also cultivated but many are still collected in the wild, particularly many kinds of berries (blackberries, cranberries, etc.).

(6) *Nuts*
In Iran and Afganistan about 60,000 tons of pistachio nuts from wild *Pistachia vera* trees are harvested and exported each year. Brazil is appropriately the major producer of Brazil nuts (*Bertholletia excelsa*), harvested from natural forests in the Amazon basin. Most of the hazelnuts (*Corylus americana*) on the American market are gathered from wild plants (Fitter, 1986).

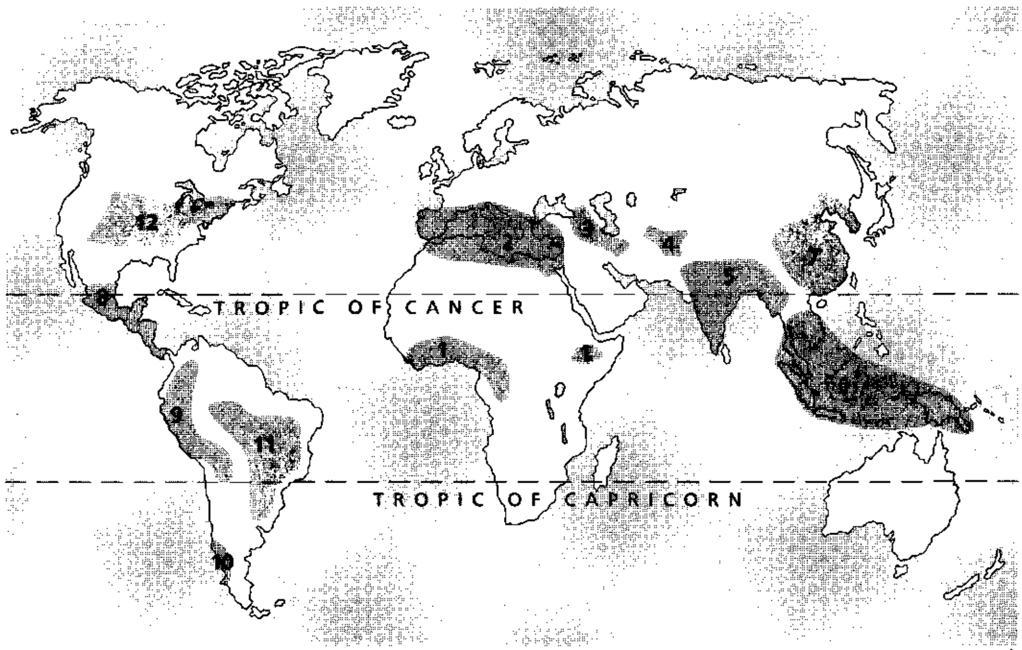
Box 2.3.4-1 Genetic engineering: opportunities and risks

Through genetic engineering man may be able to create new species and varieties, but his 'raw materials' will always be the natural genetic diversity of wild plants and animals. Some techniques include cross-breeding, transplantation, and artificially induced mutations or polyploids.
According to the World Commission on Environment and Development (WCED, 1987), biotechnology will have major implications for the environment. The products of genetic engineering could dramatically improve human health. Researchers are finding new drugs, new therapies, and new ways of controlling disease vectors. Energy derived from plants could increasingly replace non-renewable fossil fuels. New high-yield crop varieties and those resistant to unfavourable weather conditions and pests could revolutionize agriculture. Integrated pest management will become more common. Biotechnology could also yield cleaner and more efficient alternatives to many wasteful processes and polluting products. New techniques to treat solid and liquid wastes could help solve the pressing problem of hazardous waste disposal (Elkington, 1986). These new technologies blur the traditional distinction between agriculture, industry, and research services.
Agriculture has already virtually become an 'industry' in developed countries. New techniques of tissue culture and genetic engineering could soon generate plant strains able to fix nitrogen from the air, a development that would drastically affect the fertilizer industry, but that would also reduce the threat of pollution by agrochemicals (WCED, 1987). The chemical and energy industries are moving increasingly into the seed business, providing new seeds that meet specific local conditions and requirements - but specific fertilizers and pesticides may also be needed.
With improved techniques both the application possibilities and the risks of genetic engineering increase. The need for caution when introducing a new technology is reinforced by the experience of the Green Revolution, which, despite formidable achievements, raises concern over increased dependence on relatively few crop strains and large doses of agrochemicals. New life forms produced by genetic engineering should be carefully tested and assessed for their potential impact on health and on the maintenance of genetic diversity and ecological balance before they are introduced to the market, and thus to the environment (WCED, 1987). It must also be realized that genetic engineering can never replace natural selection and evolution processes. Therefore the need to conserve the biological and genetic diversity in natural habitats is even more urgent: 'It would be grim irony indeed if, just as new genetic engineering techniques begin to let us peer into life's diversity and use genes more effectively to better the human condition, we looked and found this treasure sadly depleted' (WCED, 1987).

(1) Wild genetic resources and agriculture

The gene pool resources of wild relatives of the world's commercial food crop species exist in centers of genetic diversity or so-called 'crop gene centers', which were first recognized by the Russian plant explorer and breeder V.I. Vavilov in the 1920's (see Fig. 2.3.4-1). These centers of crop genetic diversity store a vast array of genetic resources and have long been the traditional source of useful genes for crop improvement programs. These regions contain both the natural habitats of the wild ancestors of most commercial crops and the traditional agro-ecosystems in which most of the domesticated plants originated and became genetically diversified.

Fig. 2.3.4-1. Presumed centers of origin of cultivated species



Legend (including some examples)

1. Ethiopia-West Africa (barley, coffee, african rice)
2. Mediterranean (asparagus, lettuce, olive)
3. Asia minor (cherry, carrots, pea, wheat)
4. Central asiatic (apple, grapes, pear, spinach)
5. Indo-Burma (cucumber, lemon, orange)
6. Siam, Malaya, Java (banana, grapefruit, asian rice)
7. China (mandarine-orange, peach, tea)
8. Mexico-Guatemala (beans, corn, tomato)
9. Andes (cacao, peanut, potato)
10. Southern Chili (Chilean-potato, strawberry)
11. Brazil-Paraguay (cashew, hevea, pineapple)
12. United States (sunflower, blue-, cranberry)

In spite of the importance of these gene-centers to the maintenance of the genetic variability of most agricultural crops, development within the regions concerned has accelerated tremendously during the last half century. The natural habitats and traditional agricultural systems that have maintained the world's wild and primitive gene resources for thousands of years are now being increasingly converted to urban, industrial, or other more intensive forms of land use. Many of the genetically important wild species are threatened and there is a general agreement that many more parks and protected areas are needed to ensure the conservation of these resources. For example, the Amazon region is undergoing rapid economic development, and as early as 1976 the International Board for Plant Genetic Resources classified the gene center in Brazil as a priority area in critical need of conservation (Oldfield, 1984). In addition, the Green Revolution and other modern agricultural practices led to the development of monocultures of genetically uniform, high-yielding seed stocks, which has also had a detrimental effect on the survival of valuable gene resource populations. Apart from the loss of valuable crop gene resources, this has also resulted in some genetically based epidemics leading to reductions in crop productivity (Oldfield, 1984).

The genetic resource base of most crop species is very small. Many crops are genetically impoverished, and therefore very vulnerable to diseases. For example, all soja-plantations in the world are derived from 6 plants that were collected in one location in Asia. The entire coffee-culture in Brazil originated from 1 plant (IUCN, UNEP, WWF, 1980). World food production depends almost entirely on the genetic integrity of only 7 crop plant species, and three species alone - corn, wheat, and rice - produce approximately two-thirds of the total world grain crop. This is a rather dangerous situation and the fate of millions hangs precariously on the balance between the genetic viability of these three crops and their diseases and pests (Thimoty, 1972). Or, as Ehrlich (1973) put it: 'There is no such thing as mankind going on without wildlife. If you lose your genetic diversity, you are out of business of high yield agriculture permanently'
In order to maintain the productivity of many food crop plants, wild germ plasm must continuously be imported from their centers of origin to 'top up' the domesticated species to reduce their susceptibility to rapidly evolving predators and diseases in their present areas of cultivation. The contribution of genetic material from wild relatives of commercial crops is manyfold, and primitive crop cultivars are still being introduced into modern agro-ecosystems. The third world in particular holds many crop varieties whose genetic traits, such as high yield or resistance to pest or disease, are essential to maintain agricultural productivity (see figure 2.3.4-1 and box 2.3.4-2).

Box 2.3.4-2: Some examples of the application of wild genetic resources in agriculture

Disease resistance
An important aim of genetic manipulation of cultivated crops is resistance to pests and diseases. Many cultivars of West African rice have been used as sources of resistance to extremely virulent races of rice blast. Modern wheat cultivars have received disease resistance genes from wild relatives, such as *Agropyron spp.* A wild wheat from Turkey saved the US prairies from an epidemic of stripe rust in the 1960's, and genes from Ethiopia protect California's barley from yellow dwarf disease (IPS News Feature, October 18, 1982). Other examples of commercial crops which depend on regular input from wild genetic material include, potato, sugarcane, cotton, tomato, tobacco, and many fruits. The use of rootstocks of wild relatives of commonly grafted species, such as grape, citrus, peach, and pistachio, has often solved serious pest and disease problems. Forage grasses, used for livestock production, have also profited from improved disease resistance by the incorporation of genes from wild species (Harlan, 1976).
Maintenance and increase of productivity
By applying various techniques of genetic engineering, the world crop output per hectare has increased considerably. Of course not all the credit can be given to genetic infusions since application of extra fertilizer, improved machinery, and better farm practices must also be considered. But improved farming techniques alone accomplish nothing without genetically adapted varieties of crops to take advantage of them (Meyers, 1983).
Other applications
Wild germplasm resources have also been utilized for a host of other applications. A prominent *concern has been that of extending the present range of adaptation and distribution of preferred*

agricultural species. This is usually achieved by locating and incorporating of genes that control tolerance to either inadequate or excessive rainfall or humidity, heat, cold, and saline or other adverse soil conditions, and genes that confer resistance to pests and diseases (see above). Other uses of crop gene resources include increase in uptake of fertilizers or water, improved photosynthetic efficiency, earliness, thornlessness (in cultivated bramble fruits), alterations in storage or harvesting properties, and improvements in nutritional value.
Within a few years, agricultural experts hope to introduce a nitrogen-fixing capacity into several major crop plants, thus reducing their need for chemical nitrogen fertilizer that now costs the world's farmer US $ 15 billion a year (Meyers, 1983). Breeding for dwarf stature, one of the most important characteristics of the modern high- yielding varieties, has also been achieved in wheat through the use of wild *Agropyron* derivatives. In the near future it may be possible to use germplasm from crop weed relatives to transfer herbicide resistance to cultivated crop varieties (Oldfield, 1984).

(2) Wild genetic resources and animal husbandry

Wild animal species can be used directly as sources of food (see chapter 2.3.3) or indirectly as breeding stock for the genetic improvement of closely related, domesticated species. Through crossbreeding with wild relatives, domesticated breeds may be able to increase productivity or to improve pest resistance or hardiness.

Also many of the rare, primitive breeds of livestock have characteristics that may be useful to improve more modern breeds, for instance their resistance to diseases and insect pests. The N'Dama cattle of Nigeria in West Africa are well known for their high degree of tolerance to sleeping sickness (trypanosomiasis), as are the West African shorthorns of the Gold Coast (Ghana). The N'Dama breed is rare and the West African shorthorn is in danger of extinction primarily because it is no longer preferred for meat production in its homeland. Yet both breeds may be of value for increasing the resistance of cattle in areas infested by the tsetse fly, the vector for the trypanosomes which cause sleeping sickness (Oldfield, 1984).

Wild relatives not only played an important role in the evolution of domesticated species because they were the original donors of their genetic characteristics, but they also function as sources of heritable traits derived from occasional spontaneous crossings between domesticated and wild animals. Some traditional agricultural peoples still encourage and exploit such crosses. For example, the Tsembaga in New Guinea rear domesticated sows and only castrated males; they release their sows into the forest to be inseminated by feral boars. The Naga of Assam place salt-licks in the forest to attract wild gaur bulls to inseminate their gayal cows. And in Sri Lanka and Assam, matings between wild bulls and domesticated cows of the Asiatic buffalo (*Bubalus bubalus*) are tolerated (Oldfield, 1984).
Unfortunately, during the course of the domestication process, many of the wild progenitors and other close relatives of most domesticated species have been hunted or harvested to the point of extinction, or they have been replaced ecologically by their genetically altered descendants. The Aurochs (*Bos primigenius*), the European ancestor of domesticated cattle, became extinct in 1627 due to hunting, habitat conversion and competition with cattle. The same happened to the Tarpan (*Equus*

caballus ferus), the European wild horse which became extinct in 1851 (Oldfield, 1984).
Many of the primitive (semi-)domesticated species and varieties have also become endangered or extinct. Of the originally 119 different cow-races, 9 have become extinct and 44 are threatened with extinction. Of the 73 pig-races once recorded, now only 31 remain. The genetic impoverishment of the variety of cultivated species causes great concern, and in 1990, the FAO decided to allocate 206 million dollar to install a databank on threatened cultivated species.

(3) Wild genetic resources and medicine
The use of genetic material from wild plants and animals has been, and still is important for improving the effectiveness of medicines and for developing new applications. Also the efficiency of existing procedures for extracting medicines can be improved with genetic engineering. For example, genetic improvements have led to a 55-fold increase in the production processes of penicillin (Meyers, 1983). More information on the use of wild genetic material in medicine can be found in chapter 2.3.5.

(4) Wild genetic resources and industry
Industrial applications of genetic resources, through crop improvement and genetic engineering, are manyfold. Rubber, for example, is now largely obtained from *Hevea* species which are cultivated in plantations. Through artificial selection and crossing, the yield has increased from about 225 kg/ha in the late 1890's to up to 3,000 kg/ha today (Oldfield, 1984). The genetic viability of this valuable crop may well depend on the future of the survival of wild *Hevea* gene pool sources in the Amazonian rainforests which are severely threatened by human activities.
Development of crops for oil and hydrocarbon production ('gasohol', see chapter 2.3.9) will require genetic improvement of current domesticates and exploitation of new germplasm resources for producing more sugar. For this reason, endangered species and subspecies within genera that contain oil-bearing plants, such as *Asclepias, Solidago, Rhus,* and *Cirsium*, should receive special attention (Oldfield, 1984).

2.3.5 Medicinal resources

Nature contributes to the maintenance of human health in many ways: by providing chemicals that can be used as drugs or which may be used as models to synthesize these drugs. Animals are used to test new medicines or may even serve as medical tools (such as medicinal leeches (*Hirundo medicinalis*) which are applied to reduce blood pressure), or as student specimens: two species of frogs, the bullfrog (*Rana catesbeiana*) and the leopard frog (*R.pipiens*), have been harvested from the wild for decades to serve as laboratory specimens for students in the medical and health sciences. It was recently estimated that roughly 9 million frogs are used

annually in the United States for research purposes (Oldfield, 1984). Also soil minerals and earth heat contribute to human health by providing opportunities for therapeutic mud- and thermal baths.
In this chapter, three of the most important types of medicinal uses of resources provided by natural ecosystems are described, illustrated with some examples. The suitability of a given species or environmental feature for medicinal use mainly depends on its * **biochemical properties**, and its * **role in the food web**. Thus far, only a small part of the enormous variety of wild plants and animals has been studied and it is very likely that future research will reveal many more medicinal resources.

(1) Drugs and pharmaceuticals
Many wild plant and animal species (and micro-organisms) contain active biodynamic compounds which can be used by man for medicinal purposes. Active biodynamic compounds include alkaloids (e.g. ephedrine, reserpine, rescinnamine, deserpidine, cocaine), cardiac glycosides, morphine, quinine, penicillin, saponins, resins, and menthol. Despite attempts by the pharmaceutical industry to synthezise these and other substances the drugs which are used today are still predominantly derived from plants, animals and micro-organisms, either wild or cultivated. For example, more than two-fifths of the prescriptions in the United States contain an active ingredient derived from a higher plant (25%), bacteria (13%) or animal (3%) (Fitter, 1986). Apart from technical difficulties, another reason why natural ingredients play such a prominent role in modern medicine is that they are cheaper than the synthesised products.
A wide array of biochemicals are now used (see box 2.3.5-1), but many unknown medicinal properties of wild plants and animals still await discovery. For example, a comprehensive drug development program in the USA revealed 2,591 plant species, 525 marine animals and 800 species of terrestrial arthropods that demonstrated anticancer activity (Oldfield, 1984). When investigating the medicinal properties of plants and animals, the use of traditonal knowledge (folklore) is an invaluable source of information.

Box 2.3.5-1 Medicinal drugs from wild plants and animals: some examples

NB: Most information provided in this box was obtained from Oldfield, 1984, unless indicated otherwise.

a. Medicinal properties of plants
Two examples of plants with active medicinal compounds are the red periwinkle and ginseng. Researchers discovered the anticancer activity of the red or Madagascar periwinkle (*Cantharanthus roseus*) which was initially investigated as a possible treatment for diabetes. However, interest in natural sources of anticancer drugs actually began with the success of two alkaloid drugs extracted from the Red periwinkle: vincristine sulfate and vinblastine sulfate. These natural alkaloids are often referred to as the first modern anti-cancer drugs, and vincristine now plays a major role in curing or effecting extensive remissions of acute childhood leukemias. Also Hodgkin's disease and various other types of cancer can be treated with these drugs. Probably the most well-known U.S medicinal plant in the USA is American ginseng (*Panax quinquifolium*), a native species of the

northern deciduous forests. Ginseng is used routinely by a great number of more or less healthy individuals for stimulation, added energy, and a sense of wellbeing. Widespread belief in the curative powers of ginseng still prevails in China, where it has been used for centuries. Extraction of ginseng for commercial sale has occurred primarily at the expense of wild populations, many of which were exterminated or severely depleted throughout the northeastern woodlands where they once thrived (before ginseng was brought into large-scale cultivation).

b. Medicinal properties of terrestrial animals

Although wild terrestrial animals have yet to be extensively studied as sources of drugs, many of them already have established pharmaceutical potential and some poisons and venoms have been chemically isolated and screened.

Snakes: several snake venoms, notably cobra (*Naja spp.*) and vipers (*Viperidae*) are noted for their cardiac and analgesic effects.

Toads: Toad poison compounds have been traditionally valued in Chinese medicine for their cardiac, anaesthetic, and anti-inflammatory effects. Marinobufagin, a poison from the giant marine toad (*Bufo marinus*), is noted for its cardiac and analgesic effects. Powdered toad skin was a highly recommended treatment for congestive heart failure and difficult breathing.

Rhino: Nearly all of the peoples of south and east Asia believe that various rhino products possess medicinal, magical, or religious powers. Although it is commonly believed that the Chinese and other Asian cultures use rhino horn principally as an aphrodisiac, only the penis and testicles have been widely valued for this purpose (as have the same anatomical parts of tigers and deer). In China and other parts of Asia however, the horn (and to a lesser extent, the hooves) is valued for its potent fever-reducing action; it is also prescribed as an antidote for snakebites, for its cardiotonic effects, and as a treatment for boils. Many other parts of the rhino are used as well, including the skin, dried blood, bones, meat, fresh dung, and even the urine. However, as Oldfield (1984) points out: 'the correlation between the specific part of the human body treated and the part of the rhino anatomy employed, however, leads one to believe that most of the prescribed uses of these rhino products are based primarily on superstition rather than on established medical grounds'.

Terrestrial arthropods: Extracts of 800 species of terrestrial arthropods (insects, spiders, crustaceans, millipedes, and centipedes) showed some anticancer activity. The more promising compounds included isoguanine and isoxanthopterin from the Asian butterflies *Prioneris thestylis* and *Catopsilia crocale*, respectively, and dichostatin from the Taiwanese stag beetle (*Allomyrina dichotomus*). The active constituents were concentrated in the wings of the Asian butterfly (*C. crocale*) and in the legs of female stag beetles. It is of interest that early studies of butterfly wing compounds enabled some of the advances in anticancer chemistry which facilitated the synthesis of methotrexate, a synthetic cancer chemotherapeutic drug currently in clinical use in the United States.

c. Medicinal properties of marine fauna

Apart from medicines derived from plants and terrestrial animals, many drugs or drug compounds are extracted from marine fauna. Although some marine products have been used medicinally for a very long time, exploration of the oceans for useful pharmaceutical substances is a relatively recent activity, and many novel pharmaceuticals have been obtained from marine animals during the last few decades. One well known product is fishliver oil. Oil from codliver is commonly used in vitamin A and D therapy. It is also the major ingredient in a soothing ointment used for diaper rash, chafing, and other minor skin irritations. Recent research has uncovered toxic compounds from poisonous sea animals that possess anti-cancer, anti-microbial, anti-viral, cardioactive, and neurophysiologic properties. Many of these substances possess chemical structures unlike those found in any terrestrial species. An example is the Carribean sea sponge (*Cryptotethya crypta*), which produces compounds which have proved useful in treating viral-infections (notably herpes) and certain types of leukemia.

Various other marine animals provide compounds which show anticancer activity, for example coelenterates (e.g. *Stoichactis kenti*, a sea anemone of Tahiti), nudibranches (e.g. sea hares of the Indian and Australian Oceans), and substances from echinoderms (e.g sea cucumbers of Hawaii and Australia). In Asia sea cucumbers are frequently marketed for various medical treatments.

Other novel drugs from marine organisms include tetrodotoxin which is 160,000 times as potent as cocaine for blocking nerve impulses, and is currently used in Japanese clinics a sa local anaesthetic and muscle relaxant for patients with terminal cancer and neurogenic leprosy. This drug compound has been extracted from certain puffer fish, porcupine fish, and ocean sunfish; it has also been isolated from a California newt, a goby from Taiwan, and some Central American frog species.

d. Medicinal properties of microbes

Many micro-organisms can either cure or cause disease. The bacterium *Clostridium tetani*, for instance, causes tetanus, while another, *Clostridium botulinum*, causes botulism (National Wildlife Federation, 1985)

Yet, many pharmaceuticals are still derived directly or indirectly from microbes. The primary contribution of microbial drugs is their role in the development of antibiotics, the largest therapeutic drug catagory.

Among the families of the true bacteria, only members of the Bacillus family (*Bacillaceae*) have yielded useful antibiotics. *Streptomyces* bacteria of the *actinomycetes* have been by far the most important sources.

Recently, 58 percent of the antibiotics derived from natural sources have been obtained from *Streptomyces* species, with an additional 9 percent from other bacteria. Although some antibiotics can be produced more cheaply by artificial synthesis, it is usually more practical to use the biological machinery of the bacteria for production. Even in the industrial synthesis of antibiotics, the provision of chemical models of compounds originally isolated from micro-organisms is necessary as a first step (see 2.3.5.2).

Apart from antibiotics, vitamins, vaccines, diagnostic agents, enzymes, and some medicinal alkaloids are also manufactured directly or indirectly by employment of microorganisms.

e. Medicinal properties of fungi

The use of green and blue moulds for their antibiotic properties probably originated in the Orient more than 3,000 years ago. Chinese, Egyptian, and Indian physicians commonly employed moulds (and yeasts) on open wounds, inflammations, boils and other infections, and on skin afflictions such as eczema, as long ago as 1,000-2,000 B.C. Today most of the penicillin antibiotics used worldwide are obtained from genetically improved strains of two species of soil fungi: *Penicillium notatum* and *P. cheysogenum*. Penicillin and other natural or synthetic penicillin derivatives are used to effect cures in cases of viral and bacterial infections.

Madagascar periwinkle

(2) Chemical models

Besides providing active medicinal compounds, a second major reason for the sustained demand for natural drug products is that they often serve as chemical 'blue prints' for the development of related synthetic drugs. Because the chemical structures of natural, pharmacologically active compounds are usually very complex, their chemical synthesis is unlikely to be achieved without the use of such natural model compounds. Cocaine, from the tropical shrub *Erythroxylum coca*, for example, provided the chemical structure used for the synthesis of procaine and other related local anaesthetics. Similarly, semi-synthetic penicillin derivatives were obtained by studying the natural molecule. Other examples include morphine and codaine, alkaloids from opium poppies (*Papaver* somniferum and P. bracteatum), which have been used to develop synthetic pain-killers. Many drug researches believe that the provision of these blueprints or chemical models for the development of synthetic products is the most important function of newly discovered medicinal plant compounds. However, such artificially derived drugs have seldom exceeded the effectiveness of their natural parent compounds (Oldfield, 1984).

(3) Test-animals or assay organisms

Medicine and the pharmaceutical industry also heavily depend on wild animal species as research models, for drug testing and development, and for other types of biomedical research. Although many test-animals are now specially raised for this purpose, wild animals are frequently still used (see box 2.3.5-2).

Box 2.3.5-2 Some important medicinal test-animals taken from the wild

NB: Most information provided in this box was obtained from Oldfield, 1984, unless indicated otherwise.

a. Primates

No group of biomedical research animals is more important to mankind than the non-human primates. The principal biomedical research value of non-human primates is because of their physiological, biomedical, morphological, and embryological similarities to humans. For example, the drug-induced reactions of non-human primates very closely mirror those observed in humans. The chimpanzee (*Pan troglodytes*) in particular has been used extensively in behavioural studies and in psychology. Certain primate species have also served as valuable models for observing human diseases, as well as the study of reproductive physiology, arteriosclerosis and other chronic degenerative diseases, mental health, malnutrition, and drug metabolism and drug abuse. Baboons (*Papio spp.*) have been particularly valuable for dental research and experimental surgery. Although some of the primates used for research purposes are obtained from captive breeding populations, many species cannot be successfully reared in captivity. During the late 1950's and the 1960's, hundreds of thousands of primates were imported annually into the United States for biomedical research and drug testing purposes. The tropical countries have historically been the principle source of these invaluable species. However in recent years, the use of primates for research purposes in the United States and most other industrialized countries has declined significantly due to inflationary costs coupled with lack of availability of primates from tropical countries that have recently imposed export bans. As a result, there is a slowing down in the development and testing of new medicines.

b. Armadillo

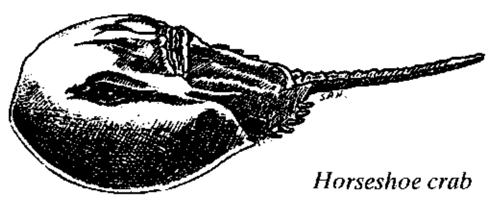
The study of leprosy (*Mycobacterium leprae*), long a mysterious human disease, has recently been facilitated by experimental induction of the disease into the 9-banded armadillo (*Dasypus novemcintus*). Another pootentially useful trait of this species is that it regularly produces four genetically identical offspring from a single fertilized egg. It is hoped that study of reproduction in the (wild) armadillo may help to improve the understanding of 'twinning' in humans and domestic animals, and thus contribute to the understanding of some of the problems associated with monozygotic, multiple births.

c. Birds

Treatment of cardiomyopathy, a disease caused by the overdevelopment of heart muscles, is being aided by studies of the extensive flight capabilities of albatrosses (*Diomedea spp.*) and the storm petrel (*Hydrobates pelagicus*).

d. Horseshoe crab

One of the most important assay organisms discovered in recent years is the horseshoe crab (*Limulus polyphemus*). Limulus is not a crab, but rather a distant relative of the spider. Horseshoe crabs may become an invaluable replacement for rabbits in biological assays for endotoxin, a fever-producing and sometimes fatal toxin produced by gram-negative bacteria. In order to prevent this toxin or the deadly bacteria from entering the bloodstream of patients, an appropriate assay organism is used to detect their presence in all pharmaceutical and medical supplies or equipment destined to enter the bloodstream (e.g., intravenous solutions). The cost of each rabbit screening test has amounted to US$ 10-75 in recent years; moreover, most of the test animals either die or are sacrificed after testing. In contrast, the 'blood' cells (amoebocytes) of the horseshoe crab can be taken repeatedly from the same wild animals. The limulus assay is 10-15 times less expensive than the rabbit assay; thus, it has been projected that a firm that conducts around 150,000 tests each year might save US$ 1 million annually. More important, the limulus assay is believed to be at least 5-10 times more sensitive than the rabbit test. The recent discovery of the limulus assay demonstrates the potential usefulness of wild animal species to medicine, especially since horseshoe crabs have not yet reproduced in captivity and therefore must still be harversted from wild populations.



Horseshoe crab

2.3.6 Raw materials for clothing and household fabrics

Until comparatively recently, most of mankind's needs for clothing, footwear, bedding and furnishing depended virtually entirely on natural resources provided mainly by fibers from plants and animals. Both plant and animal fibers are more and more obtained from domesticated or cultivated stock rather than from their wild relatives or ancestors.

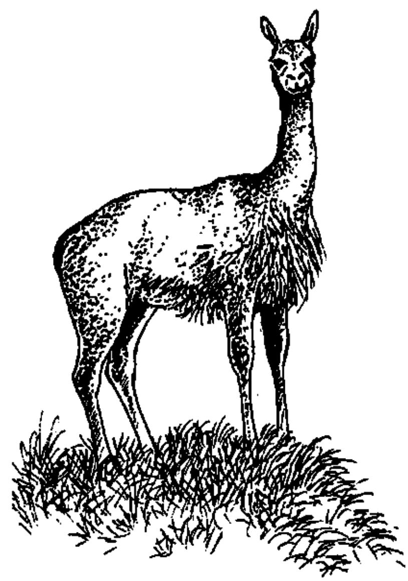
(1) Raw materials (fibers) from animals

Raw materials for clothing and household fabrics from animals include wool, silk, fur, skins and hides (leather). Silk is obtained from the cocoons spun by larvae of either domesticated (*Bombyx morio*) or wild silkworm moth's (*Antheraea spp.*) (see also chapter 2.2.2 on sericulture). Wool is provided by sheep and, in South America from llamas (*Lama glama*) and alpacas (*L. pacos*). The most sought after and valuable fleece known - one far more valuable than that of the Persian lamb or karakul - is that of the vicuna (see box 2.3.6-1).

Since fur, skin and hides, especially from wild animals, nowadays can be considered luxury items, trade in these animal products is discussed in more detail in chapter 2.3.11 (ornamental resources).

Box 2.3.6-1 On the use of the vicuna for fleece

The vicuna (*L. vicugna*). is a shy, camel-like relative of the alpaca. The vicuna of the Andean plains are very fast runners and as they are extremely difficult to hold down for shearing, they could not easily be domesticated. As a result, wild populations have been decimated for their valuable fleece (to make fashion coats and other clothing) which cost around US$ 55/kg in the late 1960's. One meter of vicuna cloth, however, may require the fleece of a dozen animals. Demand for vicuna cloth and pelts during the 1950's brought this species close to extinction. At the beginning of that decade, the total population was estimated between 100,000 and 400,000 individuals, but by the 1960's, only about 15,000 animals remained (Oldfield, 1984). Today this endangered species is recovering as a result of the establishment of wildlife reserves in Peru and strict protection against poachers.



Vicuña

(2) Raw materials (fibers) from plants

Fibers obtained from plants include linen, cotton, jute, hemp, and sisal (from *Agave sisalana*). Plant fibers can be used for many purposes, for example as raw material for the production of textile, rope, canvas, and baskets. Stout grasses, such as bamboo and rattan, are also used for rope- and basket-making and other household items such as brooms and furniture (see also 2.3.7).

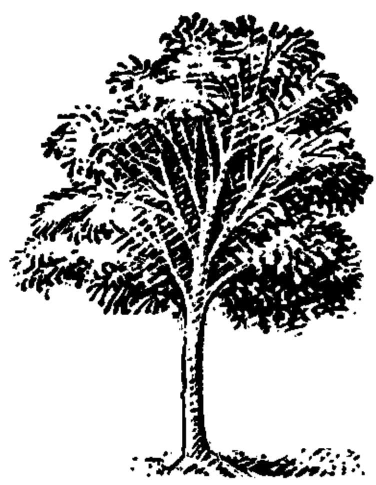
2.3.7 Raw materials for building, construction and industrial use

Nature provides many materials for building, construction and industrial manufacturing such as wood and strong fibers from certain grasses. A few of the more important ones provided by wild plants and animals are briefly described below. Some minerals and other non-biological building and construction materials are listed in box 2.3.7-2 at the end of this section.

(1) Wood

The biomass produced by trees provides the greatest concentration of woody (lignified) cell wall material which may be used by man for instance for construction purposes, manufacturing, handicraft, and energy-conversion. Worldwide, about 3.2 billion m^3 of wood is consumed annually. About half of this wood is used for fuel and for charcoal making (see chapter 2.3.9) and the other half for industrial purposes (lumber, plywood, posts, beams, chipboard, paper, etc.). Industrial applications can be separated into the uses of timber and pulpwood:

Timber: About 700 million m^3 of hardwood is produced in non-tropical countries (mainly USA, Canada, Sweden, Finland, France and W.Germany) and 750 million m^3 is hardwood from tropical countries (WRI, 1990). Although some timber is produced on plantations, most timber is extracted from natural closed forests, especially in tropical areas (see box 2.3.7-1). Because most tropical hardwood species grow very slow and are widely dispersed in the natural forest, they are extremely vulnerable to over-explotation and sustainable use of the natural forest for this resource is difficult, if not impossible. An example is true mahogany (*Swietenia spp*), found in the West Indies and from Mexico to the Amazon Basin. This hardwood species has been harvested in large amounts for furniture and other industrial uses. Due to over-harvesting the species became commercially extinct in the early 1980's (Oldfield, 1984).



Mahogany

Pulpwood: Pulpwood is used for paper-making (e.g. deluang paper from *Broussonetia* (Jacobs, 1982), paperboard, packaging, containers, particle-board, fiber-board and waste-paper. It is even used to make textiles and clothing (2.3.6). In 1974, the worldwide consumption was 263 million m^3 of which ca 10% originated in the tropical rain forest (Steinlein, 1982 and Myers, 1979).

Box 2.3.7-1 Deforestation estimates for closed tropical forests

Recent studies covering several key countries suggest that deforestation in the tropics may be much worse than was previously thought. Until recently, the most authoratative estimate of annual deforestation in the tropics was 11.4 million hectares, based on a 1980 FAO assessment of tropical forestry research, literature and surveys (FAO, 1988). Several recent studies show that deforestation is much higher in Brazil, Costa Rica, India, Myanmar (formerly Burma), the Philippines and Viet Nam. Forest clearing also increased sharply in Cameroon, Indonesia, and Thailand. The new studies examine loss of closed forest, defined by FAO as 'land where trees cover a high proportion of the ground where grass does not form a continuous layer on the forest floor'. They do not examine open forests, in which trees are widely spaced. If these new studies are accurate, the world is losing up to 20.4 million hectares of tropical forest annually - almost 80% above the FAO's 1980 estimate. The additional amount represents an annual forest loss of the size of Panama (WRI, 1990).

(2) Stout grasses

In the developing world not just timber but also other natural building materials, such as bamboo and other stout grasses, continue to be of vital importance. In China and Japan bamboo, formerly used mainly for house-building and firewood, is now used in a wide range of products, from plywood and plastics to furniture and other durables, not to mention its use as food and medicine. In total, over 1,300 past and present uses of bamboo have been identified. In the developed world the use of thatch for roofing has become a luxury, but in Iraq whole houses are still made from reed (*Phragmites australis*), which is also still harvested for thatching both around the Neusiedlersee in Austria, and in parts of England, Ireland and The Netherlands. Various sedges, especially *Cyperus papyrus* and *Scirpus spp*, are widely used in Afrika for thatch and matting (Fitter, 1986).

(3) Rattan

Rattan is a climbing palm of the Genus *Calamus* (*Lepidocaryoideae*), with long thin many jointed pliable stems, and is much used for furniture making and other building and construction purposes. There are at least 150 species of rattan of which over 2/3 are useful (see chapter 4.1 for more information).

Box 2.3.7-2 Minerals and other non-biological building and construction materials

Natural minerals and other non-biological resources can be used for building and construction and have many other industrial uses as well. Often they support entire industries such as the steel-industry and agro-industry (production of fertilizer). Since the emphasis of this book is on the sustainable use of functions of the living part of natural ecosystems, and because non-renewable resources cannot generally be used in a sustainable way, only a few examples are briefly listed below for the sake of completeness.

Metallic minerals: Nature provides many metallic minerals, ores and nuggets which are or can be used as raw materials for the manufacture and synthesis of products in many industrial processes. For example bauxite (the chief source for aluminum), gold, silver, platinum, copper, iron, lead, tin, uranium, manganese, etc.

Non-metallic minerals include sediment materials (such as clay, sand, limestone, gravel), rocks/pebbles, marble, asbestos, salts, oil, diamonds, etc. Some applications are: the use of quartz-sand for glas blowing, and clay for pottery. Oil, apart from being an important energy source, is

also used as raw material for the plastic-industry.
Atmospheric chemicals: There are many chemicals in the air, some of which may have (potential) industrial applications, for example hydrogen, methane, nitrogen, neon, helium argon, and krypton. In Appendix I.2.1 further details are provided about a few of these elements. Thus far, this large reservoir of elements has hardly been tapped by man, in fact many of these elements are added to the atmosphere as waste-products of industrial processes. Development of recycling and extraction procedures could make better use of many of these elements while helping to maintain a 'healthy' mixture of these elements in the atmosphere.

2.3.8 Biochemicals (other than fuel and medicines)

Wild plants and animals provide a wide array of biochemicals or biodynamic compounds. These can be used by man for many different purposes, for example in the automobile and cosmetic industry, for the production of paint, plastics and (bio)-pesticides, and also in electronics and space-industry. The very important use of biochemicals in medicine was discussed separately in chapter 2.3.5., while the potential for developing 'gasoline plantations' was mentioned in chapter 2.2.3.
Natural biochemicals include latex (rubber), gums, oils & waxes (e.g. beeswax), essential and volatile oils, resins, tannins, alkaloids, dyes, stains, syrups, incense, and pesticides/insecticides (repellants and pheromones). Because of their industrial potential, many biochemicals which until recently were harvested from the wild are now (also) obtained from cultivated plants and animals.
Biochemicals and their uses for industrial purposes are so numerous and varied that details cannot be provided here. A few examples of some important natural biochemical products and their applications are given below.

(1) Natural rubber (latex)
Latex is a milky fluid of tropical plants and comes in various types: rubber, gutta-percha (a tough, greyish-black plastic substance from various Malayan trees, e.g. *Sapotaceae*), and caoutchouc (unvulcanized rubber from *Dyera willughbeia*) (Jacobs, 1982). The use of latex was first discovered by ancient American cultures and, according to Templeton (1978) natural rubber was the world's most important industrial crop in 1978, with applications in a wide range of industries.
Many kinds of articles can be fabricated from rubber, varying from hard, strong structural materials to soft, yielding, comfortable materials. Natural rubber is used as a shock absorber, in transmission belts, hoses for transporting gases and liquids, clothing to keep out rain or to control the figure, sport goods, paints, plastics, and even pharmaceuticals. Above all, tyres are the chief outlet for rubber, especially heavy-duty and radial tires for the automibile and aviation industries (Polhamus, 1962, and Templeton, 1978). Few people realize that 95-98 percent of the rubber in the tires of the Columbia Space Shuttle is natural rather than synthetic rubber

(Oldfield, 1984). Natural rubber constitute about a third of the total world rubber supply, and demand for natural rubber is high because it is more versatile than synthetic rubber.

Today virtually the entire world supply of natural rubber is derived from genetically improved Para rubber trees (*Hevea brasiliensis*) which are now grown in plantations. Yet, the economic future of this valuable crop may well depend on the future of the survival of the wild *hevea* gene pool sources in Amazonian rain forests. In addition to the *hevea* rubber tree, approximately 2,000 plant species are known to contain elastomers. The most important alternative to the *hevea* rubber tree is guayule (*Parthenium argentatum*), a native American member of the *Compositae* (Oldfield, 1984).

(2) Gums

Gums are viscous secretions of some trees and shrubs that harden on drying but are soluble in water (contrary to resins). Gums are used to stick paper together, to stiffen linen, and for various other applications.

(3) Oils, waxes

Many plant species, and a few animal species, can provide oils, glycerides and other hydrocarbon compounds (long-chain alcohols) which can be extracted, processed, and refined for use as fuel oils, lubricants, waxes, rubber additives, synthetic fibers, plastics, cosmetics, or other industrial raw materials. Although many oils and waxes are now produced synthetically, a few hydrocarbon products derived from plants or animals cannot be easily duplicated by petrochemical substitutes. For example, sperm whale oil and its recently discovered economic substitute, jojoba oil (*Simmondsia chinensis*, *Simmondsiaceae*), are essential industrial raw materials.

Sperm oil and jojoba oil are not actually oils per se, but rather liquid wax-esters. The possibility of displacement of these unique natural products by synthetic products is remote, since the chemical structure of these liquid waxes cannot be easily synthesized commercially and they are superior in many of their most important industrial applications. One of the best types of wax is produced by carnauba palms (*Copernica cerifera*) in Brazil. Other hard wax-producing plants are the Mexican candilla wax shrubs (*Euphorbia antisyphilitica* and *Pedilanthus pavonis*). Since the plant must be sacrificed for wax production, these wild species have all suffered from overexploitation in the past (Oldfield, 1984)

Box 2.3.8-1 Economic importance of natural oils

Sperm oil and spermaceti (hydrogenated sperm oil) provide a hard wax which has superior qualities as an anti-rust and anti-corrosion lubricant. Since the 1940's, sulfurized sperm oil has been the premier lubricant to reduce friction in heavy-duty industrial macinery and automobile transmissions. It is so valuable as an industrial lubricant that, like rubber and certain timber products, it has been stockpiled in the USA in the event of a national crisis. Jojoba oil is used in furniture-, auto-, and shoe-polishes, carbon and stencil paper, insulating materials, and film coatings for fruits and vegetables, as well as for a myriad of other industrial uses of carnauba wax and spermaceti (Oldfield, 1984).

(4) Essential and volatile oils

Essential and volatile oils produced by plants are mainly used for perfums, soaps, toothpaste and incense, but often also in flavouring (chapter 2.3.3) and medicine (2.3.5). Most are obtained from tropical plants, such as camphor from *Cinnamomum camphora*, cloves from *Eugenia caryophyllus*, lavender from *Lavandula officinalis*, and scented wood and aromatic oils from sandal wood (*Santalum spp.*). Conifers and oranges too produce an essential oil called terpene (Jacobs, 1982, Oldfield, 1984, Fitter, 1986).

(5) Tannins

Tannins are polyphenols obtained from oak-galls and various tree-barks (e.g. mangrove trees). They can be used in preparing ('tanning') leather, making ink, plywood glues, particle board adhesives, oil well drilling muds, anti-oxidants, etc. (Oldfield, 1984).

(6) Resins

Resins are adhesive inflammable substances insoluble in water and secreted by most plants. Some examples are benzoin (a fragrant aromatic resin of an East Asian tree of the genus *Styrax*), dragon's blood (from *Daemonorops*), turpentine (from *Pinus*), camphor (from *Dryobalanops*), and amber, a yellow translucent fossil resin (partly after Jacobs, 1982). The main application of resins is in wood laminating. They may exude naturally or upon incision especially from fir- and pine-trees. Resins can also be made synthetically by polymerization and can then be used as or in plastics (Sykes, 1982).

(7) Dyes

Nature provides many types of dyes, both from herbs and trees such as red sandal wood.

(8) Alkaloids and toxic chemical compounds

The study of natural alkaloid and toxic chemical compounds has revealed many useful applications of these substances, for example in medicine and in the production of natural pesticides and repellants. Many tropical species produce chemical compounds which act as natural insecticides by repelling insects which might otherwise feed upon those plants. Some of these compounds offer great promise as biodegradable insecticides that would increase world food production at no cost to the environment (WWF-US, 1983). Many toxic chemical compounds with insecticidal properties are still extracted from plants for the manufacture of pesticidal products, for example from flowers of the pyrethrum daisy (*Chrysanthemum cinerariaefolium*). Natural biochemicals may also serve as the basis for synthesising pesticides. For example, the study of physostigmine, a medicinally useful alkaloid obtained from the poisonous calabar bean (*Physostigma venenosum*) of tropical West Africa, led to the synthesis of new methyl carbamate insecticides (Oldfield, 1984).

(9) Environmental hormones

Organic compounds, especially those released into the environment during decomposition, frequently combine with trace metals in the environment to form hormone-like substances which have profound effects on the growth of other organisms in the ecosystem. These extracellular metabolites and many of the 'waste products' of decomposition are important chemical regulators which provide a mechanism for maintaining the equilibrium in ecosystems and help to explain the succession of species. Although species living on decaying matter (saprotrophs) seem to play a major role in the production of environmental hormones, algae also excrete such substances (Fogg, 1962). The waste products of higher organisms, and leaf and root excretions may also be important in this regard (Odum, 1971).

Environmental hormones may be inhibitory, as in the case of the 'antibiotic' penicillin (which is produced by a fungus), or stimulatory, as in the case of various vitamins and other growth substances, such as thiamin, vitamin B12, biotin, histidine, uracil, and others, many of which have not yet been chemically identified (Odum, 1971).

(10) Pheromones

Pheromones are substances secreted by animals in minute quantities and basically serve two purposes: to attract partners for reproduction and as an alarm-mechanism. Both properties may be used for pest-control purposes. An example of the application of the first property is the use of sex-pheromones to combat flies. Periodical emissions of sex-pheromones, in combination with a light-source, attract flies to a trap where they are electrocuted. An example of the application of the second property is the use of alarm-pheromones of leaf-lice in combination with small quantities of Pyrethrum, a conventional insecticide. Lice, which are usually quite slow-moving insects become very active due to the alarm-pheromone and during their frantic movements quickly come in contact with the poison (Odum, 1971).

2.3.9 Fuel and energy

Nature provides an almost limitless array of energy (re)sources which may be used by man. They can be grouped according to their origin and renewability: (a) Abiotic, renewable: solar radiation, wind-energy, hydropower (tidal-movement and flow of rivers), geo-thermal energy, (b) Abiotic, non-renewable: nuclear energy, (c) Biotic, renewable: fuelwood, organic matter, animal power and biochemicals (hydrocarbons, ethanol, etc.), (d) Biotic, non-renewable: fossil fuels (oil, coal, natural gas).
In addition to these energy sources which can be directly used by man, there are many other forces at work on earth, such as tectonic movement, gravity, and volcanic activity. All these forms of energy are essential to the functioning of the biosphere as a global ecosystem and benefit human existence in one way or another.
The current total world energy consumption is estimated at 8 billion metric tons of oil-equivalent (or 12 billion tons of coal) per year (WRI, 1990). It is curious to note that from all the energy sources available to man the only two that are basically non-renewable (nuclear energy and fossil fuels) take such a prominent place in the energy-supply, especially in the industrialised countries. About 88% of the total world energy consumption is based on fossil fuels and nuclear energy (see box 2.3.9-1). However, their short life span, together with the environmental risks associated with these non-renewable energy sources, forces man to look for other more lasting or renewable resources which, when utilized in a sustainable manner, can be used indefinitly.
In this chapter only those energy resources are discussed that can be extracted directly from the natural environment. For the utilization of some energy sources such as solar radiation, wind-energy, geo-thermal energy and hydro-power, large constructions and engineering projects (such as hydro-electric power dams) are needed which require the availablity of a 'suitable' substrate and vast amounts of space. This is also true for the utilization of biochemicals, which will have to be produced on large plantations. Therefore the utilization of these abiotic renewable energy-sources is discussed under the carrier functions (chapter 2.2.3). Below, the biotic, renewable energy sources are discussed in some detail, followed by a brief section on non-renewable energy sources (box 2.3.9-1).

(1) Fuelwood and charcoal
The total amount of wood harvested for energy-use, either through direct burning (for cooking, heating or power production) or through the production of charcoal, is estimated at ca 1.7 billion m^3 per year (WRI, 1990). In many parts of the world, harvesting firewood outstrips the wood-production leading to deforestation and the associated problems such as soil-degradation and erosion. The real energy crisis confronting the greatest proportion of the human population is the daily search for firewood to cook their food and heat their homes.

Fuelwood: The principal and sometimes only source of fuel for perhaps one-quarter of the world's population is fuelwood (Hallsworth, 1982). Although only about 10 percent of the North American timber harvest is used for fuel, nearly 30 percent of the European, about 75 percent of the Asian (exclusive of the Soviet Union), and 90 percent of the African and Latin American harvests are consumed solely for cooking and heating of homes. About 80 percent of the housholds in all of the developing nations depend on firewood as their primary source of energy; if desert and wood-poor regions are omitted, this rises to over 95 percent (Oldfield, 1984).
Charcoal: Conversion of wood to charcoal is an essential process for many industries in petroleum-poor nations. Although much of the original biomass of the wood is lost, the charcoal has a much greater energy content and provides smokeless heat. Some species are more suitable for charcoal production than others. Hawaiian species and varieties of *Leucaena*, for example, have proved especially valuable for charcoal production. They produce a very dense wood and provide more heat upon burning (Oldfield, 1984).

(2) Organic matter

In addition to wood-biomass, organic matter such as litter, peat and dung can, after drying, be used as fuel.
Peat: In Ireland, for example, peat resources provide about 8 percent of the country's commercial energy demand (WRI, 1990). It can be argued, however, that the renewal time for peat is so long that, for practical reasons, peat should be considered a non-renewable resource.
Litter and dung: Since harvesting dung from wild animals is usually not feasible, the use of organic matter for fuel is largely limited to litter (both from natural ecosystems and residues from agricultural crops) and dung from domesticated animals. One side-effect of the shortage of fuelwood (see above) is that crop harvest residues and animal manure (dung), which were once used to replenish nutrients on cultivated land, are increasingly being used as substitutes for firewood. Fuel from dung is especially significant in arid or severely deforested areas. Over the long run, this diversion of animal fertilizers will decrease food production capabilities. However, for the people now inhabiting severely deforested areas, the location of fuel for cooking and heating is more important than safeguarding the possibilities for future food production.

(3) Animal power

Many wild species have been domesticated by man to provide draft power, to hunt other animals (e.g. cormorants for fishing) or to do other work. The pig-tail macaque (*Macaca nemestrina*), for example, has been trained to serve as coconut picker (Oldfield, 1984). Cheetahs, ospreys, hawks and falcons, and even sea-diving cormorants have been tamed and used to track or catch other food animals, and some are still used for these purposes.

Where motorized vehicles are either too expensive to buy and maintain or are inappropriate for the prevailing terrain, animal traction will probably remain the predominant form of power for cultivating, harvesting, and transporting agricultural produce.
Semi-domesticated water buffalo, camel and dromedary, llama, reindeer, elephant, and yak have been, and are still being used as draft animals to drive milking, threshing, and irrigation equipment (Oldfield, 1984).

Box 2.3.9-1 Some non-renewable biotic and abiotic energy sources

NB: Data provided in this box is taken from WRI (1990) unless indicated otherwise

a. Fossil fuels
The most important source of energy used by man thus far are fossil fuels such as oil, coal and natural gas. Although these energy resources are the result of different histories of biogeochemical transformation, they all originate from dead organic matter. Together they account for 88% of the world's total energy consumption.
Oil: Oil is still the world's major fuel, supplying 38% of world energy. Oil is found in the form of petroleum, oil shale, and tar sands. The proven reserves amount to 140 billion metric tons which at present consumption rates (about 3.4 billion metric tons per year) would last a little more than 40 years.
Coal: Coal is the second largest fuel source used today, supplying some 30% of global energy. There are different types of coal, including lignite, subbituminous, bituminous, and anthracite, which represent different ages (listed here from youngest to oldest), and differ in terms of origin of the plant material they are derived from. They also have somewhat different chemical compositions (Ehrlich et al., 1977). The proven reserves amount to over 1,000 billion metric tons which should be enough to last for another 200 years.
Natural gas: Natural gas is relatively abundant globally with proven reserves totalling 112 billion m^3. Natural gas now covers 20% of global energy consumption. With future consumption expected to rise sharply, the life span of these reserves is estimated between 50 and 60 years.
b. Nuclear energy (fission and fusion)
The energy trapped in nucleii of certain elements (e.g. uranium, plutonium, hydrogen) may be used as fuel for nuclear power plants. One radioactive element used as fuel for nuclear power plants is uranium. However, because it contains only 0.72 per cent of the active isotope U235 (Lovelock, 1987), large quantities of the raw material are needed to provide sufficient radioactive material for operating a nuclear power plant. At present, about 5% of global energy is provided by nuclear power. No data were obtained on the ratio between available resources (e.g. uranium and plutonium) and present consumption rates. Although nuclear fission is a natural process, and stood at the beginning of our solar system, the manipulation of this type of energy by man bears considerable risks for both environmental and human health.

2.3.10 Fodder (animal feed) and fertilizer

In many parts of the world, agriculture and animal husbandry depend on natural ecosystems for fodder and fertilizer.

(1) Animal feed (fodder)
Natural ecosystems provide animal-feed in a variety of forms, ranging from grass and leaves (stripped from tree-branches) to krill: tiny planktonic crustaceans which are harvested as cattle-feed. Leaves, in particular, are an important source of animal-feed. It has been estimated that over 90% of the foliage of forests is potentially usable as an animal-feed

additive or substitute. Nectar produced by plants to attract bees, which in turn are used by man to produce honey, could also be seen as a type of natural 'animal feed'.

(2) Fertilizer

Fertilizer is needed for improvement or regeneration of agricultural soils after a harvesting cyclus. Plant litter can be used as mulch (= mixture of wet straw, leaves, etc.) to protect roots of newly planted trees or as fertilizer and improvement and regeneration of agricultural soils. Compared to chemical fertilizer, organic fertilizer is much better for the maintenance of the soil structure and biological activity in the soil. Organic fertilizer is therefore still important as a source of nutrients and for soil-improvement, both in traditional agriculture and modern agro-industrial cultivation. Organic fertilizer is provided in the form of animal excrements (dung, guano), plant litter and mulch (see box 2.3.10-1). Seaweed is also harvested for this purpose. When harvesting organic matter from natural ecosystems, care should be taken not to distrub natural recycling mechanisms; as a general rule not more than 10% of the natural productivity should be harvested by man.

Box 2.3.10-1 Some examples of natural organic fertilizer

a. Animal excrements: Especially in developing countries, animal-excrements (dung, guano) are frequently used as a source of much needed manure for fertilizing crop plants. However, from the perspective of world trade, seabirds such as gannets and cormorants provide the most important commercial sources of natural fertilizer. Conservation and management of seabird populations and their prey have increased the Peruvian guano production tenfold between 1900 and 1971, from 20,000 tons to over 200,000 tons annually. On islands off the south and southwestern coasts of Africa, breeding colonies of gannets have yielded an average of nearly 4,000 tons per year from 1961-1972 (Oldfield, 1984).
b. Plant-litter: Accumulated dead plant material (litter) may be harvested by man as natural fertilizer. There is a large variation in litter production between the various ecosystems, and the amount of litter decreases with increasing latitude and/or altitude. Litter fall decreases from approximately 2,000 grams per m^2 per year in the tropics to just over 200 grams per m^2 per year in northern temperate latitudes or on mountain tops.
c. Mulch (compost): Animal excrements, plant litter and dead bodies of plants and animals are eventually decomposed to form humus (see chapter 2.1.11). As with litter-production, there is a large difference in the amount of humus produced by different ecosystems. In humid tropical ecosystems there is a large production of dead plant and animal material (see above); however, the humic substances are taken-up rapidly by the natural ecosystem leaving little to be harvested by man. Although there is less dead organic matter available in cold-climate ecosystems, the breakdown of this organic matter is very slow, and therefore ecosystems in temperate climates offer better opportunities to harvest mulch for fertilizing purposes than tropical ecosystems.

2.3.11 Ornamental resources

The use of wild plants, animals and abiotic resources (such as precious minerals and stones) for ornamental purposes is extensive and varied. Nature provides many kinds of raw materials which are used for fashion and clothing (notably animal skins and feathers), handicrafts (e.g. wood and ebony for carving), and objects of worship (i.e. products associated with cultural, tribal and religious ceremonies). Wild plants and animals are also collected and traded as pets or for decoration (e.g. ornamental plants) in private households or to supplement the collections of zoological and botanical gardens. Many plants and animals and their products are used and traded as souvenirs, or as collectors items. Examples include orchids, butterflies, aquarium fish, birds, feathers, skins, and ivory. As Fitter (1986) points out: 'To many people, furs, feathers and other luxury clothing, together with refinements and adornments, such as perfumes and jewelry, are essential to their being satisfied with their appearance, and they will go to great lengths to maintain their self-respect through ornamentation, often at the expense of basic material needs'. On the next few pages, 6 categories of ornamental resources are described in more detail, illustrated with some examples, namely fashion and clothing, handicraft and artisan work, precious materials and jewelry, trade in live plants and animals, and souvenirs, tourist curios and collecters items.

For many reasons, ornamental resources are very vulnerable to over-exploitation (see box 2.3.11-1) but, if well regulated, it should be possible to harvest many of the desired products and species on a sustainable basis. Considering the high prices which are payed for most of these ornamental species, sustainable use of this resource could provide an important source of foreign exchange to the countries involved and could help to ensure the protection of the habitats where these species occur.

Box 2.3.11-1 On wastefulness and dangers of the use of natural ornamental resources

An important problem with the use of wild plant and animal species for ornamental purposes is the fact that there is a strong tendency to over-exploitation because consumer prices depend on the perception of the rarity of the object. Frequently, when consumers perceive the uniqueness or rarity of a particular species or one of its products, they are willing to pay much higher prices than they would for other goods that are less unique or rare although equally good. This phenomenon, which is also reflected in the price of art works, for example, causes prices to go up when the supply goes down, leading to a spiral that only ends when the supply is dried up, that is when the species concerned have become very rare or extinct.

A well-known example is the trade in ivory. The great value of ivory as raw material for artisan work, as investment and as a tourist curio provides a strong incentive for the slaughter of elephants. In 1976 consumer nations imported more than 1.25 million kg of raw ivory obtained from an estimated 72,300 elephants, and nearly 1 million kg in 1977 from about 56,200 elephants. It was estimated that about 40% of this ivory came from poaching. As a result, many animals which produce ivory are threatened, not only the African elephant, but also the Asian elephant and the Atlantic and Pacific Walruses. Walrus populations in Alaska have been officially protected since 1972. Yet, the number of animals killed anually in Alaska increased from 1,500 animals in 1979 to an estimated 5,000-6,000 in 1980 (Oldfield, 1984). If a sustainable yield of raw ivory is to be achieved in the future, the trade in ivory must be better regulated, and depleted elephant (or walrus) populations and their natural habitats must be better protected.

Also, the live animal trade is generally very wasteful of the species which support the industry because the profit margins are so great that the tremendous waste involved can easily be 'afforded'. Due to the large scale of the trade in ornamental plants and animals, many local populations suffer greatly under the harvesting practices so that entire species have become endangered or extinct.

(1) Fashion and clothing

Nature provides a wide array of raw materails which can be used for fashion and clothing, such as furs and skins (from mammals and reptiles) and feathers from birds (see box 2.3.11-2 for some examples).

Box 2.3.11-2 Some examples of the use of wild animals for fashion and clothing

a. Mammals: Especially the large spotted and striped cats, many seals, and sea- and river otters have been, and still are valued for their fur and as a result, many of them have become endangered. Many of the spotted cats, particulary the snow leopard, clouded leopard, and cheetah, were already threatened by the fur trade as early as the 1950's. Despite signs of depletion, great numbers of spotted cats were continually harvested throughout the 1960's for export to the United States and Europe. The number of animals killed in 1968 alone amounted to 1,300 cheetahs, 9,600 leopards, 13,500 jaguars, and 129,000 ocelots (Oldfield, 1984). As the economically preferred species became increasingly scarce and were put under protection, the smaller cats such as ocelot, margay, bobcat, and lynx became more intensively sought.

In the late 1920's and early 1930's, there was a real fur-craze which had considerable consequences for the populations of the wild chincilla (*Chinchilla laniger*) in South America. During that period, European furriers could obtain as much as US$ 100,000 for a single coat from wild chincillas. Demand for chincilla furskins became so great that trappers completely exterminated chinchilla populations in the lower altitudes of the Andes Mountains, and by 1943 only a few isolated colonies remained. Since then chinchillas have been domesticated and are now bred in captivity to meet the consumer demand for fur coats (Oldfield, 1984).

b. Birds: Also birds were, and still are much sought after by the fashion industry, mainly for their feathers. Some species which are now endangered because of the use of their feathers are the Chinese egret (*Egretta eulophotes*), the Japanese Crested Ibis (*Nipponia nippon*), and the Short-tailed Albatross (*Diomedea albatrus*) (Ziswiler, 1967).

c. Reptiles: Crocodiles, alligators, caimans and many species of lizards and snakes have been and still are being captured in the wild and killed to provide skins for fashion and clothing. During the 1950's, as many as 12 million snakeskins were exported from India and over 350,000 from Indonesia. Indonesia also exported more than 270,000 iguana skins (Oldfield, 1984)

(2) Raw materials for handicraft and artisan work

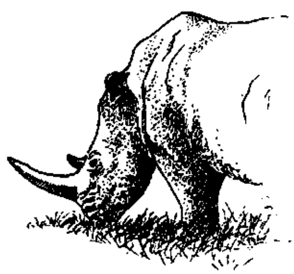
The diversity of artisan work and handicrafts produced by man is almost limitless, as is the number of natural materials used, ranging from wood (for wood-carving) and plant fibers (for ornamental basket making) to rock (for stone-carving) and minerals (for dyes and glass-making). Ivory has been used as raw material for carving and production of artifacts since paleolithic times, and is still being used for such purposes by most cultures today. Many of the handicraft items and artworks produced from natural materials have become highly valued as jewelry or are sold as tourist curios (see further).

(3) Precious materials and jewelry

Nature provides many precious and semi-precious materials with special value for adornment or financial investment. Many minerals found in the earth's crust possess great attractiveness as adornment and therefore fetch high prices, such as silver, gold, diamonds, and many other precious stones. Valuable animal-products are, for example, pearl, coral, conches, mother of pearl, ivory, bones, tusks, teeth, claws, horns, etc. Ivory is not only used for carving (see above), but it is also in great demand as jewelry and for adornment of jewelry boxes. Ivory has even been collected and hoarded as a guarantee against inflation. In times of monetary instability, highly durable ivory tusks and art pieces are sometimes valued more than gems, paintings, and valuable antiques. As a result, prices for raw ivory have steadily increased. The wholesale value of raw walrus ivory climbed to US$ 55/kg by 1981, and raw elephant ivory rose from about US$ 6/kg in the 1920's, to US$ 110/kg in the 1970's (Oldfield, 1984).

Box 2.3.11-3 The rhinoceros horn: functions, values and (effects of) exploitation

The horn of rhinoceros is a special case and is collected for various reasons: it is supposed to have certain medicinal powers (see chapter 2.3.5) and is used for adornment, especially in Yemen where special daggers called jambias are preferably made out of rhino horn. In part this may be attributable to the mystique of the rhino as a powerful, aggressive animal. The more expensive daggers with ornately carved handles encrusted with silver or gold retail for 300 US$ - 13,000 US$ each. Because of these properties, the horn of rhinoceros is much asked for and since there are not many rhinoceros left their horns are very valuable (in 1970 the total world population of five species was estimated at 70,000, in 1987 this was reduced to approximately 11,500). Because of the high demand, the price for rhino horn climbed from ca US$ 30/kg in the early 1970's to US$ 600/kg in 1979; a single horn of the black rhinoceros was worth US$ 19,000 in 1987. As a result there are now only ca 4,000 black rhinoceros left in the wild and if current poaching trends continue this species will be extinct in 10 years (IUCN Bulletin Vol. 18, 1987, No. 4-6).



White rhino

(4)Ornamental use of live animals

Many animals are captured live to be kept as pets in private households, to expand collections of zoological gardens or to be used as circus attractions. Although efforts to breed animals in captivity for these purposes are increasingly successful, and in the case of zoological gardens may even contribute to increasing the population of some endangered species, the trade in live animals depends to a large extent on the capturing of wild animals in their natural habitat.
When interpreting figures of trade in wild animals, it must be realised that for each animal sold, many more have died during capture, on transport or in the pet-shops. For example, for every 1-2 birds which survive their journey, 5 die during capture and transport due to stress and disease. The death rate during transport of the more delicate species typically exceeds 80 percent. Even under the best conditions for transport and subsequent captivity, death rates are seldom lower than 40 percent for any one species (Oldfield, 1984). Moreover, since many birds, such as parrots, nest in holes or cavities in trees, and since the natives often cut down the trees to obtain the nestlings for export, the harvesting process further contributes to the decline of such species by destroying potential future nest sites.
Species captured for this purpose can be found in almost all major animal groups such as butterflies, fish, birds, amphibians, reptiles, and mammals (see box 2.3.11-4). As usual, the rarer the species, the more fashionable it is to own a specimen, and therefore the higher the price the consumer is willing to pay.

Box 2.3.11-4 Some examples of the value of trade in wild animals for ornamentatal use

a. Birds: As many as 100 million wild birds are traded annually, and trade in wild birds has increased rapidly during the last decades, while supplies have steadily decreased. As a result, prices for many species, particulary the rare, unusual, or protected species, have skyrocketed. For example, endangered Little Blue (Spix's) Macaws or Indigo (Lear's) Macaws recently sold for at least US$ 10,000 each. The Hyacinth Macaw (*Anodorhynchus hyacinthinus*), is one of the most valuable but not one of the most threatened macaws. In 1979, individuals sold for US$ 1,500-8,000, with one advertisement asking US$ 25,000 for a pair. The Golden-shouldered Parrot (*Psephotus c. chrysopterygius*) is in such great demand that birds are regularly smuggled out of their native Australian habitat. Since the current price of a single bird (US$ 10,000) is several times that of the maximum possible fine (US$ 3,000), smugglers find that the potential gains far outweigh the potential losses (Oldfield, 1984).
b. Fish: Yearly, millions of mainly tropical fish are sold for the ornamental aquarium trade. For example, in 1978, the United States imported more than 260 million tropical fish with a declared import value of US$ 17 million (Oldfield, 1984).
c. Reptiles and amphibians: Worldwide, a great variety of reptiles and amphibians are collected, both legally and illegally, for the live trade. In 1970, the United States imported more than 1 million frogs and toads, over 70,000 salamanders, nearly 1.4 million turtles and tortoises, more than 200,000 lizards, about 110,000 crocodiles, and almost 32,500 snakes - about 2.8 million animals in all. The two most commonly imported species are leopard frogs (*Rana pipiens*), animals which are also used for training students in the biomedical sciences and red-eared turtles, which are common children's pets. Just like the cage-bird trade, trade in live reptiles and amphibians is usually very wasteful; as few as 30-40 percent survive transport. For some species, only 1 percent of the animals survive their first year of captivity (Oldfield, 1984).

Greater bird of paradise

(5) *Ornamental plants*

Many wild plants are collected for landscaping, to be used as dry-flowers, indoor-decoration or other types of ornamentation. In Europe, mainly African succulents and Asian orchids are traded. In the USA, many species of cacti are, often illegally, harvested from the wild, such as the Arizona barrel cacti (e.g. *Echinocactus horizonthalonius*) and the tree-like saguaro (*Carnegiea gigantea*). Examples of plant families that provide woody ornamentals include *Rosaceae* (roses, ornamental pear, cherry, plum and apple trees, and *Spiraea*) and *Ericaceae* (rhododendrons, madrone, azaleas, heathers, salal, and manzanita). Although many of these species are propagated or grown from seed, a significant proportion of the trade consists of plants harvested in the wild. Moreover, excessive seed collecting from wild populations may adversely affect the population densities of some species, such as Pachypodium, an Old World succulent. In addition to commercial plant harvesters, tourists and private collectors also contribute to the decimation of ornamental plant populations in the wild (Oldfield, 1984).

(6) Souvenirs, tourist curios and collectors items

The trade in souvenirs and curios account for some of the more bizarre and often wasteful uses of wildlife. Tourist curios include artefacts made from mammals, stuffed birds, reptiles, and other animal groups (see box 2.3.11-5). Many invertebrate species are also popular collectors items, for example coral, sponges and marine shell pieces.

Box 2.3.11-5 Some examples of the use of wild plants and animals as souvenirs and tourist curio's

a. Mammals: Souvenirs from mammals include, elephant feet waste paper baskets, elephant or gnu-tails for fly swatters, and leopard or cheetah heads for trophies. In many cases these items are 'by-products' obtained from animals that were harvested or poached for other purposes. Some animals, however, are harvested directly to be stuffed or preserved for tourist souvenirs or items of trade. For example, Gorilla's, have been (and still are?) poached for their heads and hands which fetch high prices as tourist curios, such as gorilla-hand ash trays. In Alaska, the penis bone ('oosik') of male walruses is sold as tourist curio.

b. Birds and reptiles: Stuffing birds is also quite profitable. For example, stuffed birds of paradise sell for US$ 215.- . Also young sea turtles, crocodiles and caimans are preserved or stuffed for sale to tourists (Oldfield, 1984).

c. Exotic marine shells are in the greatest demand and consequently fetch the highest prices. Valued shells include the *cowries, tritons, conches,* helmet shells, *and other colourful tropical species.* Most of these are obtained from reefs and shore areas of Hawaii, the Philippines, East Africa, and Papua New Guinea. The shells of the giant marine clam (*Tridacna gigas*) are so large (up to more than 110 kg) that they are frequently sold in the United States and Europe as wash basins. Shells of some land-snails are also valued. The green tree snail (*Papustyla pulcherrima*), for example, is appreciated by collectors and is often used in valuable art-pieces for its beautiful green color. In Cuba, the attractive Polymita snail shells are collected. Extensive collection of the last mentioned species is contributing to the decline of the rare Cuban Hook-Billed Kite which depends primarily on Polymita snails for food (Oldfield, 1984).

d. Butterflies are also very popular with tourists and collectors. To illustrate the quantities involved, in Taiwan 20 million butterflies are caught annually, and in Brazil perhaps as many as 50 million each year (Oldfield, 1984). The wings are removed from most specimens and are used for decorating candles, making butterfly plaques, or replicas of well known art pieces and other artistic designs. Some of these butterfly 'paintings' sell to tourists for hundreds of dollars. Other butterfly species are collected primarily to be sold as pressed specimens to butterfly collectors all over the world. Japan is the primary importer; however, the United States and many European countries are also major importers.

Especially in demand are birdwings, members of the swallowtail family found in Australasia and Southeast Asia, which are among the largest and some of the most beautiful butterflies in the world. A male Queen Alexandra's birdwing (*Ornithoptera alexandrae*) has an average wingspan of 20 cm. The most prized birdwings (they sell for US$ 1,000 and more) exist only in isolated areas of New Guinea and some of its neighbouring islands. Unfortunately, excessive harvesting, coupled with the destruction of their forest habitats, is depleting many tropical forest populations. Now that populations of some of the more valuable species are depleted, more attention is being paid to raising them on 'butterfly ranches', small areas planted with their larval host plants (*Aristolochias*) and their favourite adult nectar plants. Some birdwing ranches have already been established in Papua New Guinea, and they are producing superior specimens for collectors while simultaneously helping to reduce harvesting pressures on wild populations (Oldfield, 1984).

2.4 Information functions

As we have seen in the previous chapters, natural ecosystems are important for maintaining essential ecological processes (chapter 2.1), and they provide space (2.2) and many resources (2.3) needed to sustain most human activities. In addition, natural ecosystems provide almost unlimited opportunities for spiritual enrichment, cognitive development and re-creation. Nature is a source of inspiration for culture and art, and provides many opportunities for (environmental) education and research. Or, as Forster (1973) put it: '...natural environments provide a highly inspirational and educative form of re-creative experience, with opportunities for reflection, spiritual enrichment and cognitive development through exposure to life processes and natural systems'.

Some types and examples of information functions are described in the following five paragraphs. As with regulation functions, information functions are usually best performed when nature is left untouched as much as possible. In fact, the information value of natural areas was, and is often the main reason for establishing protected areas.

2.4.1. Providing aesthetic information

Many people enjoy the special scenery of natural areas and landscapes, and many natural areas are protected partly or mainly for this purpose. Although methods to analyse the aesthetic value of landscapes and scenic features exist, it is difficult to evaluate this function objectively since the appreciation of the scenery is a highly personal experience. Also, both personal and societal views as to what constitutes a desirable environment changes with time. Many people seem to feel most comfortable in a half-open, so-called park landscape: a constrasting landscape with open spaces bordered by medium-dense vegetation. Possibly this preference supports the theory that the evolution of man took place in this type of environment which provided both resources (game in the open areas) and protection (by the more densely vegetated parts of the landscape). Spectacular landscapes such as mountains, deserts, and polar regions also provide scenery which attracts many people. However, most people usually only stay for short periods of time in these areas as essentially they are quite inhospitable to human life.

Aesthetic information is probably more important to us than we may realise and has a considerable influence on the quality of life. Some examples of the concious and sub-concious 'use' of aesthetic information are briefly presented in box 2.4.1-1.

Some environmental characteristics influencing the aesthetic qualities of the landscape

Parameters which can be used to assess the importance of a given area to this function include, of course, the * **aesthetic quality** which, in turn, depends on a combination of certain features such as the * **topography,** * **vegetation cover** (structure, height, etc.), and the * **integrety or naturalness** and * **diversity** of the scenery.

Box 2.4.1-1 Some examples of the importance of aesthetic information to man

Housing: Most people find it more enjoyable to live in an aesthetically pleasing environment then to have to live in or near run down urban areas or industrial complexes. Much effort therefore goes into 'landscaping' (= imitating natural scenery) urban and rural areas. Although this often contributes little to increasing the natural values of the area, since often exotic plant species are used or because the elements are too small and fragmented, it does give an indication of the importance which people attach to this function. The value which people place on living in an aesthetically pleasing environment is also reflected in the price of real estate which is much higher when the house is located in a scenic, (semi-) natural environment (see chapter 3).
Scenic routes: Another example of the importance of aesthetic information from the (natural) landscape of taking 'scenic routes' when going on short day- or weekend trips. Just for the sake of the scenery people sometimes make considerable detours when visiting family, amusement parks or other destinations. Sometimes there is no specific destination and people simply go for a drive through the countryside to enjoy the scenery. In many countries, 'scenic roads' are indicated with special signs for this purpose.
Recreation and tourism: For many recreational activities (such as hiking) or vacation trips, the aesthetic quality of the natural environment plays an important role in the selection of the area of destination (see also chapter 2.2.4 on recreation and tourism). As a result of increased affluence and mobility, more and more people are able to experience nature's variation in landscapes by visiting remote areas that differ strongly from the environment one is used to in every-day life. Especially in the richer industrialised countries, where nature has been largely destroyed (which is no coincidence by the way), people spend large sums of money on short vacations to exotic places, whereby the aesthetic quality of the landscape in the area of choice plays an important role. As soon as the natural scenery of these tourist attractions becomes spoiled (by pollution, construction works or by the presence of too many visitors), the area loses its attractiveness and visitor numbers go down.

2.4.2. Providing spiritual and religious information

Many people feel the need to experience a certain continuity in their environment and to understand their place in the universe. Undisturbed natural areas provide a certain measure for this orientation in time and space. Most people, for example, tend to become emotionally attached to the landscape they experienced during their childhood. Disturbance of these landscapes due to development is often felt as a personal loss. Also the notion that our ancestors observed the same landscape (or even a single tree) a few centuries ago is an important spiritual experience to many people. Going back further in time, knowledge of the development (evolution) of life, especially human life, contributes to a sense of continuity and understanding of our history and place in the universe, and may lead to a certain feeling of one-ness (unity) with nature.
For these, and other reasons natural areas provide an important source of spiritual enrichment which is expressed by a general reverence for nature and respect for the intrinsic value and right of existence of all life on earth. This respect may be translated into an ethical, or religious attitude towards nature. An ethical (or religious) attitude may be directed towards nature in general or may focus on certain elements such as forests or particular species of animals or 'holy' trees. Some societies even approach

running water with considerable reverence, for them it is the visual source of life and therefore seen as a living entity itself. In many traditional societies, the spiritual and religious ties to the natural environment can be traced back into their cultural system. It is reflected in social customs (taboos) to ensure a responsible attitude towards nature.

The spiritual/religious information provided by nature, and expressed by man through ethical behaviour and the recognition of intrinsic values (see box 2.4.2-1), is difficult to measure. One possible parameter could be the * **maturity or age** (see appendix I.6.2) of the vegetation which makes up the structural part of a given natural area or ecosystem. The presumption thereby is that the older the ecosystem (i.e. the trees), the more likely it is to have special spiritual or religious meaning to certain people or communities (see also the next function on historical information).

Also, the presence of sites or features of special religious and/or spiritual interest is important. Many indigenous cultures attribute religious/spiritual values to certain natural phenomena and use certain natural areas or elements for religious or spiritual customs and rituals (sacred sites). In modern societies, the distance between man and nature has diffused the ties with the natural environment which makes it more difficult to determine the degree to which respect for nature and other living beings is reflected in people's attitudes and behaviour.

Box 2.4.2-1 Environmental ethics and intrinsic values

All life on earth is part of the same evolutionary process (or subject to the same 'creative force') and without the fellow-creatures that share the same (mysterious) origin and have the same (unknown) destiny, man would be very lonely indeed, in a world without boundaries in time or space. By becoming the most powerful and destructive agent on the planet, man has now become responsible for the survival of all other creatures on earth. They too have a right to live and most of the major religions have a philosphy expressing the need for man to respect other living organisms and take responsibility ('stewardship') for nature. According to Rolston (1986) there are two kinds of environmental ethics: the humanistic or anthropocentric ethic where '...the concern for the environment is entirely subsidiary to a concern for humans, who are helped or hurt by the condition of their surroundings"; the other type is the naturalistic ethic which "... is directly about nature. It holds that some natural objects, such as whooping cranes, are morally considerable in their own right, apart from human interests, or that of some ecosystems. Perhaps the Great Smokies, have intrinsic values, such as aesthetic beauty (sic!), from which we derive a duty to respect these landscapes'.

The concept of 'intrinsic value' is used to stress the point that nature has an inherent value, regardless of the (other) values it has for man and even regardless of the presence of man. This statement is less straightforeward than it seems since existence or intrinsic values can only be perceived in the presence of a cognitive conciousness. Thus, both types of ethics described by Rolston entirely depend on the presence of human mental powers. Without man, these values would not exist which, by the way, is true for all information functions. The example of the intrinsic value of the Great Smokies given by Rolston, which is related to its aesthetic beauty, shows how much even intrinsic values are related to human perception. Apparantly, many people **need** the natural environment as a source of inspiration and outlet for moral and ethical considerations. In that sense, the possibility to attach intrinsic values to nature can be seen as a function of nature (and not as a reflection of human altruism), which fulfills a basic human need (see also chapter 3.1.2).

2.4.3 Providing historic information

There are certain (natural) areas or specific landscape elements, such as trees, to which people attach emotional or heritage values and the destruction of these elements is experienced as a personal (or collective) loss. The historic value of natural areas or elements should therefore be accounted for in the planning and decision-making process.

For example, the historic information-value of old trees is an important reason for conserving these landscape-elements. Apple and peer-trees, for example, can become 200 - 300 years old, and some trees which still stand today were likely to have been planted in the year Beethoven was born (1770). Elm-trees can grow for 500 years or more and some may have started to grow when Columbus was still a child. Certain oak-trees live 1,500 years or longer and the few that reached this age could tell use from the days of the Roman empire. In the Sierra Nevada in the USA some mammoth-trees are 4,000 years old and the Monkey-bread tree in Afrika and Australia can reach the respectable age of 5,000 years. They started growing in times when in Europe people were still living in the stone-age. One of the oldest living trees is a swamp-cypres on the graveyard of Santa Maria el Tule in Mexico, which was planted about 6,000 years ago. Its base has a circumference of 31 meters and it is as old as the first findings of the wooden plough in Europe and the first copper-tools in Egypt.

Fig. 2.4.3-1 Approximately 800-year old Olive-tree, Krete

Some environmental characteristics influencing the historic information value of the landscape
The importance of a given area for this function may be deduced from the presence of * **archeological sites** or * **special historic elements**. The * **maturity or age** of single landscape-elements (such as individual trees) or entire ecosystem complexes (such as tropical rainforests), can provide an important source of historic information.

2.4.4. Providing cultural and artistic inspiration

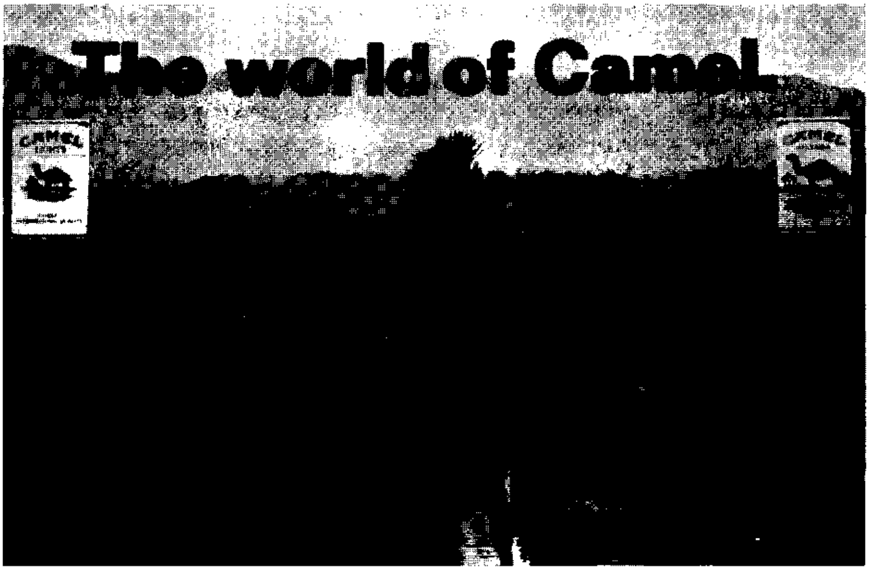
Without nature, life would be very dull indeed or, as Van Dieren & Hummelinck (1979) state: 'There is hardly any province of culture to which nature does not give shape or inspiration'. Many books, magazines, films, photographs, television programmes and other media- forms use nature as a motive and source of inspiration. Nature is an important motive in paintings, sculptures and popular art. Many cultures have been enriched by allusions to wild animals such as elephants, tigers, monkeys, deers, and others in their folklore, music and dance. Many nations use natural motives as symbols in their national flags or monetary units. For example the bald eagle is the national symbol of the USA while the condor is depicted on the coins of several Andean nations. Nature is also used as a motive in industrial design and many shapes used in architecture and fashion are based on examples (models) found in nature. Also to advertising nature is an important source of inspiration, ranging from advertising for mineral waters and health food to cigarettes, cars, banking and computers.

Since almost any feature in the natural environment may serve as a source of inspiration for cultural or artistic activities, it is quite impossible to list the relevant parameters for assessing the potential value of a given area or ecosystem for this function. It is however possible to assess the actual use that is being made of a particular site for this function by listing the 'end-products' (films, books, paintings, etc.) that use the area as a motive.

2.4.5 Providing educational and scientific information

Awareness and understanding of the functioning of natural processes and components in our environment can substantially contribute to a more responsible attitude of people towards their environment and fellow creatures. Nature and natural areas provide many opportunities for nature study, environmental education, and basic and applied scientific research. A better understanding of basic processes, components and functions of the natural environment is essential to maintain and improve the quality of life and may well be crucial to our long-term survival. In addition to basic scientific research, studies in (semi-)natural ecosystems may yield important information for direct practical application, such as the discovery of new medicines and bio-technological applications. In order to develop improved strains of cultivated plants and animals, a better insight

Fig. 2.4.4-1 Nature and advertising



into evolutionary processes is needed. Also monitoring of natural processes to detect changes in our environment, and development of methods for conservation management and sustainable use of the remaining natural and semi-natural ecosystems on earth depend on the continued presence of representative, largely undisturbed natural ecosystems.
A few of the possible uses of natural ecosystems for scientific research and (professional) education are briefly described below. Recreational nature study is described in chapter 2.2.4.

Some environmental characteristics influencing the availability of educational and scientific information
As with the previous function, the potential use of natural processes and components for education and research is almost limitless. Some general parameters for assessing the suitability of a given area for education and scientific research would include biotic and abiotic diversity, rarity and uniqueness of habitats, species and abiotic features occurring in the area, the representativeness of the life communities and the presence of indicator species or processes. To facilitate the evaluation procedure, the many factors which influence the value of a given area for this information function may be integrated into one general * **information value.** The potential value for research and education of a given site is, of course, also influenced by other factors such as the * **accessibility** and viscinity to research institutes and urban areas.

(1) Providing information for natural science classes
The importance of this function is illustrated by the increasing number of natural science classes in schools, environmental education centers, educational field excursions, and the amount of textbooks and materials used for environmental education purposes. In addition, the engagement of voluntary workers employed in the maintenance of natural areas or landscape management should be mentioned here. Nature also provides many

study-'materials' which are used in natural science classes, such as Leopard frogs (*Rana pipiens*) for training students in biomedical sciences (see also chapter 2.3.5).

(2) Providing information for basic scientific research
The importance of nature to basic science is almost impossible to quantify; an almost endless list of science-disciplines deals with aspects of the natural environment ranging from geological research, to ecological studies and behavioural sciences, management research and expeditions for new biochemicals. Thousands of researchers produce a yearly flood of publications based on studies conducted in natural areas, and in recent decades, the (potential) usefulness for scientific research has frequently been put forward as a reason for the creation of parks and other protected areas. Gartlan (1975) argues that all tropical forests that are managed as national parks, because of their low attractiveness to tourists, must be seen as research institutions. The major theme of UNESCO's Man and Biosphere Reserve Programme is the promotion of scientific research within national parks and reserves (Doherty, 1977). While many of the values associated with parks have been assessed, so far their actual research productivity has largely escaped evaluation. According to Burnett (1986), citation analysis is a useful tool for evaluating the scientific value of protected areas, both in terms of defending their status as reserves and in clarifying the relationships of the many, often competing functions and values within the reserved landscapes. It must be realised, however, that citation analysis only gives an indication of the past and present use of the area for research, but it does not say much about the potential value for scientific research.

(3) Providing information on environmental changes (indicators)
Animals and plants are living indicators of environmental characteristics such as climate, soil conditions, etc. By means of their regions of distribution they define areas where environmental conditions are uniform or similar (Muller, 1974) and thus provide information about these environmental conditions. Monitoring changes in life communities (e.g. species composition, species diversity and relative abundance of species) can usefully be employed to measure the nature and extent of impacts on that community of environmental changes, either man-induced or natural. In the same way that communities can act as indicators, some groups of organisms or single species are good bio-indicators for environmental change through changes in their condition, distribution or population size. Plankton, for example, can be used as an indicator for water quality, lichens for air quality, and plants for nutrient levels in the soil. Some animals may serve as indicators for changes in the weather. Box 2.4.5-1 gives some more examples of bio-indicators.
In addition to monitoring individual species, measurement of key ecological processes which are particularly sensitive to certain chemicals may also

provide an early warning system for ecosystem stress. For example, an early indication of possible disruption of the natural balance by pesticides can be obtained by measuring changes in the biological nitrogen fixation and nitrification rates in soils (ODNRI, 1987).

One advantage of monitoring bio-indicators and ecological processes is that combined effects and effects with a long 'incubation-time' can be traced whereas chemical analysis of soil or water only show short term effects of single pollutants. Sites which can serve as reference area for monitoring long-term environmental changes are therefore very valuable and must be protected and maintained.

Box 2.4.5-1 Species as bio-indicators: requirements and some examples

Some species of animals and plants may be indicators by their absence or presence. Usefulness as an indicator is dependent on the narrowness of the ecological niche or valency. Good indicators are species which have narrow tolerances to physio-chemical factors but nevertheless have a wide distribution. Species with narrow tolerance limits are called stenotopic species which are strictly bound to a particular biotope (stenoecious). For example, antarctic fish of the genus *Trematomus* are only able to survive in a narrow range of temperatures between - 2.0 °C and + 6 °C (Spellerberg, 1981).

Eurotopic species, on the other hand, can exist under a great variety of conditions and are therefore less suitable as bio-indicators (Muller, 1974). Some types and examples of useful bio-indicator species are listed below:

Lichens: The sensitivity of lichens to air pollutants led to the study of their use as indicators and they are now used to monitor air-pollution. The most suitable types are foliose forms such as *Hypgymnia physodes* which is especially sensitive to mercury and is widely distributed throughout Europe (Spellerberg, 1981). Another lichen, *Parmelia physodes* is highly sensitive to various emissions, such as SO_2. In concentrations of 0.11 mg SO_2/m^3 of air this lichen usually disappears (Muller, 1974). Its pattern of distribution therefore produces a mosaic which can be used in mapping the effects of air pollution from towns and industrial areas.

Plants: Some higher plants are also suitable for monitoring air pollution due to their sensitivity to pollutants such as sulphur, fluoride, and chloride (Spellerberg, 1981).

Reptiles: Snakes have a good potential for use as pollution indicator species. Like birds-of-prey and other top carnivors they are particularly vulnerable to adverse effects caused by bioaccumulation of pesticides and other harmful chemicals that have entered the food chain. However, unlike birds, they are usually sedentary and seldom roam further than a few kilometers during their entire lifetime. Thus, they may be among the most reliable of vertebrate indicator organisms, because there is less likelihood that they will migrate from contaminated to uncontaminated areas, or vice versa (Oldfield, 1984).

Invertebrates: In the marine environment, various species of bivalve molluscs and macro-algae have proved to be efficient and reliable as biological indicators for the study of trace metal pollutants in water and sea sediments. Probably the best known of these indicator species is the edible mussel *Mytilis edulis*, a species widely distributed throughout temperate waters and of which a wealth of knowledge has accumulated regarding the content of trace metals in its tissues in various waters and its mechanism of metal uptake (Oldfield, 1984).

(4) Providing indicators for biogeochemical prospecting

Many plant species are very useful as indicators of particular minerals and could be used in the search for new ore bodies, for example typical serpentine-, zinc- and copper-plants are known (Muller, 1974). In gold prospecting one of the greatest problems is that very large amounts of soil must be collected in order to obtain a representative sample of the precious metal which may be present in a given locality. In the case of suitable indicator plants much smaller samples need to be taken by the prospector since the root systems are capable of 'sampling' a large volume of the soil. In Wales, the grass *Festuca rubra* contained as high as 95 ppb (parts per billion) of gold in their leaves (dry weight), while 40 percent of the other species evaluated also contained gold concentrations which were significantly elevated over the background concentration (3.42 ppb) (Oldfield, 1984).

(5) Providing models (information) for biotechnological research
This type of research concentrates on finding answers to concrete problems such as food production, development of medicines and new industrial applications. Especially for the development of new medicines, study of wild animals can be rewarding (see also chapter 2.3.5). For example, the Vicuna, a high-altitude adapted species has scientific value as an animal research model for the study of blood transport of oxygen and body temperature regulation in extreme high altitude environments (Oldfield, 1984). Natural ecosystems surely contain a vast reservoir of as yet unknown possibilities for biotechnological applications, notably through genetic engineering and medicinal research (see chapters 2.3.4 and 2.3.5).

Chapter 3

Socio-economic value of environmental functions

Introduction

Once the many functions provided by natural and semi-natural ecosystems have been identified and described (see chapter 2), the contribution of these goods and services to human welfare can be analyzed. As has been shown in the previous chapter, human welfare and the quality of life depend directly or indirectly on the availability of environmental goods and services in many ways. A world devoid of natural ecosystems and all the goods and services they provide seems quite unthinkable, and it is therefore quite strange that the dependence of human welfare on natural processes and components is not reflected more strongly in planning and decision-making procedures (for a discussion, see chapter 5).
To make environmental values and constraints an integrated factor in planning and decision-making, this chapter presents some methods and examples of ways to assign socio-economic and monetary values to these functions. The term socio-economic is used in the title of this chapter to indicate that the values discussed go beyond the more narrow interpretation of the subject matter of economic theory, which is mainly limited to monetarised market economics (see box 3.0-1). An integrated economic assessment of the benefits of natural areas should also include non-monetary values of goods and services that contribute to human welfare.

In spite of the many problems that still exist when transforming environmental data into economic data, such a transformation is of crucial importance if we want to bring economic development more in harmony with the capacity of nature to sustain the needs of a still growing human population. Practical tools are needed to determine the 'full value' (economic, monetary, social and ecological) of natural areas and the functions they provide. Since environmental functions are defined as the capacity of the natural environment to provide goods and services that satisfy human needs in a sustainable manner (see chapter 1.2), the function-concept can serve as such a tool by providing a common indicator for both environmental quality and quality of life.

Ideally, the socio-economic value of any good or service (either man-made or natural) should be determined by the degree to which it contributes to human welfare. Human welfare, in turn, depends on the degree to which both collective and individual human needs are met, whereby these human needs should be defined in the broadest sense possible, i.e. not limited to material prosperity provided by marketable goods and services, but also including environmental, physical and mental health, employment (or better: a meaningful place in society), social contacts, material prosperity and a safe future (see Table 3.0-1).

Table 3.0-1. Types of values that can be attributed to environmental functions

	Ecological values [1]		Social values [2]		Economic values [3]		
Environmental Functions	Conservation value	Existence value	Health	Option value	Consumptive use value	Productive use	Employment
Regulation (16)							
Carrier (5)							
Production (11)							
Information (5)							
TOTAL for ecosystem or natural area							

[1] The ecological value of environmental functions can often only be described in qualitative terms; quantification will usually only be possible in "natural" dimensions (e.g. number of species, amount of runoff prevented).
[2] Social values may be quantified by setting standards for minimum requirements for the availability of a given function (e.g. air-quality or maximum limits to ensure sustainable harvesting of natural resources).
[3] The economic value of environmental functions may be expressed in their 'natural' dimensions (e.g. quantity of resources harvested), in monetary units (i.e. the value of the resources harvested) or by the number of people employed by activities which depend on a given function.

In chapter 3.1, the various types of values listed in Table 3.0-1 (horizontal axis) are described in more detail. As indicated by the subscript to this figure, these values may be described in qualitative terms, such as the importance of a given regulation function to the maintenance of a healthy environment, or in quantitative terms, for example the amount of available resources or the number of people employed in nature-based industries such as fisheries and tourism. An important element in assessing the socio-economic value of environmental functions is the issue of standard-setting for minimum requirements for maintaining environmental and human health, in order to determine sustainable use levels for each function.

For several types of functions and values, notably those which are of direct economic importance, it is possible to calculate monetary values.

Assessing monetary values of environmental functions is a rather complicated, and somewhat controversial procedure and a more detailed discussion of the possibilities and shortcomings of available methods can be found in chapter 3.2. Also the issue of calculating capital values, through discounting or the use of interest rates, is discussed separately (chapter 3.2.3).

Some examples of the ecological, socio-economic and monetary values of environmental functions are given in chapter 3.3. It should be stressed here that socio-economic evaluation of environmental functions does not necessarily mean placing dollar values on nature and wildlife. As table 3.0-1 shows, the total value of environmental goods and services to human society consists of many different values which are described and quantified by different parameters, of which monetary units are but one element. Furthermore, quantification of the socio-economic benefits of natural areas and wildlife in monetary units must be seen as an addition to, and not a replacement of their many intrinsic and intangible values.

Box 3.0-1 On the subject matter of economics

According to the subject matter of economics, economic planning and decision-making is concerned with 'making choices among scarce, alternatively applicable means that satisfy classifiable human wants' (Hueting, 1980). From this definition, it follows that all scarce means (goods and services) that satisfy human wants are part of the subject matter of economic theory, including (scarce) environmental goods and services. Yet, many economists still mainly focus on conventional monetarised market economics that excludes those environmental goods and services which cannot be traded on the market place and therefore have no monetary value. Fortunately, there is now a widespread agreement that, 'regardless of whether markets exist or not, any environmental function that contributes to human welfare and for which people are willing to pay (either in practice or by proclamation) has an economic value' (Pearce, 1988, pers.comm.). Thus, a wetland, for example, has positive economic value because, if functions such as storm-protection or water purification were not provided by the wetland, they would have to be provided by other means. Similarily, the aesthetic functions of nature have economic value since people would be willing to pay to secure them if there was a market. However, in order to reflect the acceptance of environmental functions as economic goods and services, economic accounting procedures still need much adjustment and there is a need for the development of a new kind of 'environmental economics' which includes monetary-, social-, and environmental values (see also chapter 5.2).

3.1 Types of values which can be attributed to environmental functions

Over the years, a variety of methods have been devised for assigning values to nature and natural resources and there are many titles on this subject. To mention a few: Krutilla and Fisher, 1975, Cooper, 1981, Hufschmidt et al., 1983, Brown and Goldstein, 1984, Johansson, 1987, Barrett, 1988, McNeely, 1988, Pearce and Turner, 1990, Folke & Kaberger, 1991, and this list of publications on resource economics is by no means complete. The multiplicity of ways and means for assessing environmental values is not surprising, because the benefits provided by the many environmental functions are so diverse that methods to measure the socio-economic value of one function may not be appropriate for measuring the value of other functions. For example, the value of a tropical forest as the provider of logs for export of hardwoods is measured in a different way than the value of the forest to the local inhabitants as a provider of their daily living-needs, or the value of the forest for tourism or watershed protection.

Since human society attaches many types of values to the goods and services provided by the natural environment, a number of different methods are required to assess the total contribution of natural ecosystems to human welfare. The major types of values that can be attributed to environmental functions, and the natural ecosystems which provide them, are summarised in table 3.0-1. In the following sections, the various socio-economic values which can be attributed to natural ecosystems will be briefly described, illustrated with some examples.

The total socio-economic value of a given natural area or ecosystem is the sum of the different values listed in table 3.0-1. Within one value-category, the benefits of all functions can be added to arrive at a sum-total for the conservation value, use value, or the contribution to employment of a particular ecosystem or natural area. Since the seven types of values are not comparable, it is impossible to determine one total 'end value' for a given function or natural area and the different types of values must therefore be used next to each other in the decision-making process.

3.1.1 Conservation value

Many environmental functions do not provide direct economic benefits but are nevertheless quite essential to human welfare. The so-called non-use or conservation values are mainly provided by the services (as opposed to the goods) of natural and semi-natural environments such as the regulation and information functions. The regulation functions maintain and conserve the environmental conditions which are necessary for most of the other functions that provide more direct economic benefits. For instance, species without (direct) economic value may play important roles in maintaining the integrity of natural ecosystems that support other species of plants and animals which are harvested for their productive or consumptive use. Information functions of natural ecosystems provide the pre-conditions for activities such as recreation, education and scientific research which have considerable social and economic value.

The functions which together determine the conservation (or 'non-use') value of natural areas are often best performed by undisturbed ecosystems, and are therefore also used as important arguments for conserving these areas in their natural state. Indeed, the conservation value of environmental functions may far outweigh the direct consumptive and productive use values of the other functions of the area or ecosystem in question. Measuring the socio-economic benefits of these environmental services is, however, very difficult and depends on the type of function and on the scale on which it is operating. For example, quantifying the benefits of the watershed protection function of natural ecosystems at a local or regional level is relatively straight forward, while measuring the value of the maintenance of the global carbon cycle would be a 'daunting exercise' (McNeely, 1988).

As a consequence of the problems involved in quantifying the economic and monetary value of the non-use benefits provided by many regulation- and information functions, they are usually not reflected in national income accounts. The non-use benefits of nature are therefore illustrative examples of environmental functions which are considered to be 'free'. As long as no price has been calculated, many vital environmental functions are taken for granted and the role of natural ecosystems and processes in providing and maintaining these functions is not considered in economic planning and decision-making. It is therefore essential to somehow quantify the economic benefits of these non-marketable goods and services. The only way to arrive at some kind of monetary value is the use of so-called shadow prices (see chapter 3.2.2). Ideally, when shadow prices are calculated for a particular environmental function, this value should be added to the market price of the goods or services which depend on the function in question. For instance, the dependence of commercial fisheries on the nursery function of many coastal wetlands and estuaries, or the dependence of agricultural productivity on natural biological control mechanisms should be reflected in the price of the products. This added 'conservation value' on fish and agricultural products should be used for the preservation and maintenance of the environmental functions in question.

Some examples of the non-consumptive use or conservation value of environmental functions to human society are briefly discussed in chapter 3.3. Some references for further reading on non-use or conservation values include: Sinden and Worrel (1979), Oldfield (1984), Peterson and Randall (1984).

3.1.2 Existence value

This type of value relates to the intangible, intrinsic and ethical values attributed to nature. Pearce and Markandya (1987) call this type of value 'existence value', stemming from feelings of stewardship on behalf of future generations and non-human populations. The responsibility people feel towards future generations is also called the 'bequest value' (Krutilla and Fisher, 1975): even if we do not benefit ourselves directly, we do have a responsibility to our children and grand-children to conserve and enhance the evolution of natural ecosystems and biological diversity as much as possible. The bequest value is closely related to the option value discussed in chapter 3.1.4, and to many people saving natural areas and endangered species for future generations is important to their feeling of wellbeing, even if they will never visit the area or see the animal in the wild themselves.

Part of the existence value deals with feelings of stewardship on behalf of non-human populations, reflecting the sympathy, responsibility and concern that some people feel toward wild species and natural ecosystems.

Many people are just satisfied with knowing that the oceans hold whales, the Himalayas have snow leopards, and the Serengeti has antelope, without ever having the intention of visiting these areas or using these species (McNeely, 1988). The intrinsic value ascribed to natural ecosystems and the wildlife they contain, is an important factor in the feeling of well-being to many people and is reflected in an ethical and sometimes religious attitude towards nature. Although ethics is often put forward as the only, or most important argument for nature conservation, ethical behaviour is very much subject to both collective and individual perceptions of man's place in the natural environment, which differ depending on the cultural background, and may change over time. Differences in perception of what is 'natural' and what is not, leads to differences in interpretation of the implications of intrinsic values placed on the natural environment by different cultures. It may therefore be unwise to use the intrinsic value as the only argument for conservation and sustainable use of nature and natural resources. As table 3.0-1 shows, there are many other arguments and values to be considered.

Clearly, accurate economic quantification of existence values attached to natural ecosystems is quite impossible, but the amount of time, energy and money a society or individual people are willing to devote to support nature conservation organisations may serve as an indication. For example, the World Wide Fund for Nature (WWF) alone receives nearly US$ 100 million per year in donations (McNeely, 1988). Also the amount of money donated to special campaigns to save rain forests, whales, etc., is an expression of the willingness to accept our responsibility as 'stewards' over the remaining natural heritage. Yet, even this monetary expression of altruistic (ethical) behaviour is often inspired by a combination of other values, notably the option and conservation values discussed in other chapters in this book.

Although difficult to measure, both in descriptive and in economic terms, the existence value is clearly an important aspect of the socio-economic value people place on natural ecosystems and should be included as such in the decision-making process. Often the existence value is the main justification for preserving natural lands, and dominates all other benefits of wildlife and natural ecosystems in the minds of some people (Pearsall, 1984). In any case it is one of the best means of dealing with problems of inter-generational equity (McNeely, 1988).

3.1.3 Value to human health

Many of the environmental functions described in chapter two contribute, directly or indirectly, to human health. Oxygen, drinking water and food are essential resources to maintain human life. Natural regulation processes contribute to the maintenance of clean air water and soils. Nature provides a large array of medicinal resources and contributes to mental

health by providing a multitude of opportunities for recreation and cognitive development.
The socio-economic importance of this value is evident and the specific contribution of a given ecosystem or function may be expressed in terms of human lives 'saved' or in monetary indicators, such as the costs of medical treatment that would have been needed in the absence of a given function (or the actual loss of life and/or economic damage suffered after a given function is disturbed).

3.1.4 Option value

The option value of natural ecosystems and environmental functions relates to the importance people place on a safe future (i.e the future availability of a given amenity, good or service) either within their own lifetime, or for future generations. This value is therefore sometimes also referred to as bequest value (see also existence value, chapter 3.1.2). The underlying thought of this value was expressed well by Hueting (1984) who stated that '... man derives part of the meaning of existence from the company of others, which in any case include his children and grandchildren. The prospect of a safer future is therefore a normal human need, and dimming of this prospect has a negative effect on welfare'.
One type of option value has been called serendipity value. The serendipity value relates to the potential benefits to human society, of natural processes, components, and species that have not yet been discovered (Schultes and Swain, 1976, Pearsall, 1984, Meyers, 1984). The importance of this serendipity value is shown by the continuous discovery of new functions of natural ecosystems, such as the role of plants in fixing heavy metals in the soil (Baker, Brooks, and Reeves, 1988), and the role of animals as indicators of ecosystem responses to air pollution (Newman and Schereiber, 1984). Wild species may also serve as a source of new domesticates. New breakthroughs in biotechnology suggest that biological diversity may have even greater value in the future than it does at present. Another type of option value relates to the value which people place on conserving natural areas to maintain the option to visit this area in the future. This 'recreational option value' also relates to particular species. Many people, for example, pay donations to conservation programs aimed at saving certain plant or animal species such as whales and elephants, whereby part of the motive to donate this money may be based on maintaining the option to see this animal in the wild (apart from other motives based on the existence value (see 3.1.2). This option value is not necessarily restricted to a person's lifetime. Many people support conservation programs because they want to maintain the option for their children, and future generations in general, to be able to visit undisturbed natural areas. Cicchetti and Freeman (1971) even claim that the option to visit wild areas has values that are independent of the value placed on actually going, such as hope, opportunity, dreams, fellowship, and satisfaction.

(S option price = E(CS) + option value)

Since the future is uncertain, all types of option value can be seen as a means of assigning a value to risk aversion in the face of uncertainty (McNeely, 1988). It is a type of life insurance for access to future benefits from natural ecosystems. It is impossible to say today which species will be most valuable tomorrow, or how much genetic diversity in wild relatives of domestic plants and animals will be necessary to maintain future productivity by crop growing and animal husbandry. To ensure the maximum availability of future benefits of natural ecosystems, the existing diversity of habitats and species should be maintained, and enhanced, as much as possible.

Because of the uncertainty of the future, it is quite difficult if not impossible, to assign a monetary value to the option value of natural ecosystems. This value is considerable, as is demonstrated by an example described by McNeely (1988). In 1979, a new species of maize, called teosinte by the local people, was discovered on a small hillside in Mexico, which was in the process of being cleared. Unlike most types of maize, teosinte is a perennial grass, and Hanemann and Fisher (1985, in: McNeely, 1988) have shown that teosinte may be ascribed a value of US$ 6.82 billion annually for its contribution to creating a perennial hybrid of corn.

It has been suggested that the option value of natural resources should be determined by the maximum willingness (of individuals or governments) to pay for a project which preserves the option to make use of the good or service in the future (see chapter 3.2.2).

3.1.5 Consumptive use value of environmental functions

The consumptive use value of environmental functions relates to the use of natural products which are harvested directly from the natural ecosystem. The consumptive use value of natural ecosystems therefore mainly deals with natural resources in the narrow sense, which are included in the category of production functions (see chapter 2.3).

Relatively few studies have been carried out to assess the importance of the direct use of wild plants and animals to local communities. Yet, the direct dependence of many people on natural ecosystems, notably indigenous people in developing countries, is often considerable, for example for food, medicines, fodder, energy (e.g. firewood), and raw materials for construction and manufacturing (see box 3.1.5-1).

Because these natural products are consumed directly, without passing through a market, consumptive use values seldom appear in national income accounts such as Gross National Product (GNP) or Gross Domestic Product (GDP). However, it is possible to assign a price to these natural resources by estimating the value of the product as if it were sold on the market (through so-called surrogate market techniques, see chapter 3.2). For example, in Sarawak, Malaysia, a detailed field study showed that wild pigs harvested by hunters had an (estimated) market value of some US$ 100 million per year if they would have been sold on the market (Caldecott, 1988).

Box 3.1.5-1 Dependence of local communities on direct consumption of natural resources

In Africa, many rural people depend on harvested species for food. Most of this food is consumed directly without being sold in the market-place. According to Sale (1981), over 50 species of wild animals (ranging from elephants to rodents, bats and small birds) provide animal protein exceeding 90 kg per person per year in some areas in Botswana, corresponding with 40 percent of their diet. Over 3 million kg of meat is obtained annually from springhare alone. In Ghana, about 75 percent of the population depends largely on wildlife for protein. Types of animals consumed include fish, insects, caterpillars, maggots and snails.
In Nepal, Tanzania, and Malawi, firewood (and dung) are used to provide over 90% of the total primary energy needs. In many other countries this exceeds 80% (Pearce, 1987).
In developing countries direct use of wild medicinal plants is an important element in health care (Prescott-Allen and Prescott-Allen (1982), Myers (1983) and Oldfield (1984), although reliable statistics are difficult to obtain (McNeely, 1988).

3.1.6 Productive use value of environmental functions

The most important part of the economic value of a given good or service is probably still its contribution to the (economic) production process which, in turn, consists of many different sectors, such as agriculture, energy conversion, transportation, and industry. Ideally, the dependence of a given production process or economic sector on environmental functions should be calculated. The (market) value of the end-produkt (or service) should then reflect the full costs of the *sustainable* use of these functions, including possible expenditures needed to maintain or restore the function after use. The productive use value then would consist of a combination of conventional market price and shadow pricing techniques (see chapter 3.2).

The productive use value of environmental functions mainly relates to the use of natural resources (i.e. the production functions) and the use of the natural environment as provider of space for carrier functions. Yet, also many regulation functions and information functions contribute to the economic production process but this is usually not recognized and therefore not included in traditional economic accounting procedures.
The productive use value of natural resources is usually the only economic value of environmental functions which is reflected in national income accounts (McNeely, 1988). The dependence of local and national economies on environmental functions, as the sum-total of the dependence of various economic sectors on natural goods and services, often shows to be substantial. For example, Prescott-Allen and Prescott-Allen (1986) concluded that some 4.5% of the gross domestic product (GDP) of the USA is attributable to wild species. The combined contribution of wild harvested resources to the GDP averaged some US$ 87 billion per year over the period 1976 to 1980. The contribution of wild species and ecosys-

tems to the economies of developing countries is usually far greater than it is for an industrialized country like the USA. Timber from wild forests, for example, is the second leading foreign exchange earner for Indonesia (after petroleum), and throughout the humid tropics governments have based their economies on the harvest of wild trees (McNeely, 1988).

Bearing in mind the difficulties and shortcomings in determining 'real' market prices (see paragraph 3.2.1), examples of the monetary value of some commercially harvested natural resources to economic activities, in terms of market prices, are given in chapter 3.3.

3.1.7 Contribution of environmental functions to employment

Not only the monetary value is important as indicator of the dependence of economic production on natural goods and services, but also the way in which such assets influence employment. In many economic sectors, employment depends directly or indirectly on environmental functions. For example people who are employed in the management of protected areas and the guiding of recreational activities in nature. Also jobs held by fishermen and farmers depend on a healthy natural environment and many jobs in industry are in one way or another dependent on environmental functions.

3.2 Methods to assess the monetary value of environmental functions

Since most development plans are mainly based on economic considerations, and since most economic decisions are based on the monetary costs and benefits of the project involved, there is a clear need to express the socio-economic value of natural goods and services in monetary terms. Due to the shortcomings of the present market mechanism in recognising the 'full value' of natural goods and services, many benefits of natural ecosystems are taken for granted and therefore have no 'price' (for a discussion, see box 3.2.1-1). Environmental deterioration and damage to natural ecosystems are therefore often still seen as external effects which need not be accounted for. As a result, natural ecosystems are generally undervalued in economic planning and decision making, leading to over-exploitation and loss of environmental functions.
In chapter 3.1, the different types of values and benefits which can be attributed to environmental functions were discussed. A number of these values can quantified in monetary terms. Table 3.2.0-1 shows the different methods available to calculate monetary values for environmental goods and services which broadly fall into two categories: market pricing (chapter 3.2.1) and shadow pricing (3.2.2). In chapter 3.3.3 the issues of capital value and discounting of environmental functions are discussed.

Table 3.2.0-1 Types of socio-economic values and methods to determine their monetary value

Types of socio-economic value[1]	Monetary valuation methods[2]						
	Market Price	Shadow Price					
		Cost of environmental damage	Maintenance costs	Mitigation costs	Willingness to pay/accept	Property Pricing	Travel Cost
Conservation value		x	x	x	x		
Existence value			[3]		[3]		
Health			x		x		
Option value			x		x		
Consumptive use value	[4]				[4]		
Productive use value	x					x	x
Employment	x						

[1] See chapter 3.1 for an explanation of the various types of values.
[2] Methods to determine market or shadow prices are discussed in chapters 3.2.1 and 3.2.2 respectively.
[3] The existence value could be quantified by these techniques, but it is argued that it is principally wrong to put a monetary price on this value
[4] Natural goods and services which are directly 'consumed' usually do not have a market price. Yet it is argued that they should be included in economic accounting procedures, possibly by means of so-called surrogate market pricing (see chapters 3.1.5 and 3.2.2)

Considering the many difficulties involved in attempting to assign monetary values to nature and natural resources, both practically and emotionally, a constructive dialogue between all parties involved in the planning and decision-making process is essential (see box 3.2.0-1). When critisizing attempts to calculate monetary values for natural goods and services, it must be realised that conventional economic (monetary) data on man-made goods and services are not as hard as the decision-makers make them out to be. For example, expected rates of return of many development projects often turn out to be very different in practice (usually lower, and sometimes negative) and also predictions of macro-economic developments are seldom correct. Even if it proves impossible to arrive at a common measuring standard for both environmental and man-made goods and services, it is still worth-while to discuss the subject, since it is often not so much the end-result itself that counts but the process involved in reaching that end. The discussion could bring ecologists and economists somewhat closer in their approaches to solving the environmental problems of today. A change in attitude of economic and political decision-makers in favour of long-term sustainability is probably more important than construing an artificial yardstick for measuring all economic benefits of environmental functions. We may never be able to quantify the spiritual experience of nature, but at least we should attempt to consider all values of the natural environment in the economic planning and decision-making process.

Box 3.2.0-1 Should nature be quantified in monetary terms?

At some point in the development of economic theory, a decision was made to measure all factors that contribute to economic welfare in monetary terms as an 'objective' yardstick (Giarini, 1980). Today we are still stuck with this pre-occupation with monetary indicators in economic planning and decision-making, and until better instruments are found, translating ecosystem functions into economic values and quantifying the many benefits of environmental functions in monetary terms (where possible) may help to convince politicians and financiers of development projects of the importance and (economic) benefits of the conservation and sustainable use of natural ecosystems. In doing so, however, we face the dilemma of generating prices for the priceless, of quantifying the unquantifiable, of creating common standards for things apparantly unequatable. As Aldo Leopold (1968) put it: 'For those who have experienced the atavistic recall of immersing oneself in wilderness, or felt a kinship with one's hunter/gatherer roots, or stood on ground untrampled but for once in a lifetime, it may have occurred how one could translate these priceless experiences into terms commensurable with the 'al'mighty' dollar'. Yet, what are the alternatives? Kellert (1983) accurately observes that 'Our society tends to be governed by a tyranny of numbers, and to ignore the challenge of empirical measurement is to engender by default decisions inherently biased toward the quantifiable. To the extent, thus, that the process is unavoidable, it seems preferable to quantify all values at risk, regardless of their presumed level of tangibility although the challenge of developing a system to measure all environmental and wildlife values clearly constitutes a formidable task'. Possibly the function-concept can contribute to finding a 'universal value unit' to measure both environmental quality and quality of life.
There are several dillema's in attempting to qualify and quantify the monetary benefits of environmental and wildlife values to human society which are both of an emotional and a practical nature:
Emotional objections. Whereas the description of environmental functions and their benefits to human society can be seen as a rather objective, almost 'clinical' approach to man-environment interactions, attaching monetary values to these functions is quite a different story and evokes many conflicting, sometimes emotional reactions. On the one hand, there are people who view nature as a non-economic frill in the development process, allowing them to make 'free' use of its goods and services while ignoring environmental damages as 'external effects.'. On the other hand, there are people who criticise any attempt to attach monetary values to environmental functions mainly on ethical grounds: nature is 'priceless' and has an intrinsic value which should not be bargained with. However, according to Pearce (1988, pers. comm.) the idea that an experience is 'beyond price' usually means that the person concerned either attaches an infinite price to the experience, which as such remains insubstantial since there is no system of reference, or he or she wants the good or service but is not prepared to pay for it. Pearce admits that some experiences do not translate into monetary indicators but believes that they are far fewer than is generally thought.
Practical impossibilities. As has been indicated in chapter 3.1, the monetary value of environmental functions is but one of many different human value standards and, from an environmental point of view, certainly not the most important. Clearly, translating the many functional interactions between man and the natural environment into monetary indicators is quite impossible and often even undesirable. Especially for some information functions such as the aesthetic and spiritual value of nature, monetary evaluation is a difficult if not impossible procedure. Therefore, there should be room in the economic planning and decision-making process to take account of 'priceless experiences', without having to express them in monetary values.

3.2.1 Market value of environmental functions

The market value of a particular good or service is determined by supply and demand. Ideally, total demand should be an expression of the consumers' willingness to pay for various quantities of a given good or service. The supply should be determined by the (total) costs involved in providing a particular good or service. However, there are many shortcomings in the market-pricing mechanism, especially with respect to the valuation of natural goods and services (see box 3.2.1-1).

When interpreting current market values, it must also be realized that estimates are usually made at the production end (i.e. the landed value of fish, the harvest value of wildlife products, the farmgate value of agricultural products, etc.) rather than at the retail end, where values are much higher. For instance, the estimated production value of cascara-bark of the North American bucktorn (used as laxative medicine) is US$ 1 million per year in the USA alone, but the retail value is US$ 75 million per year (Prescott-Allen and Prescott-Allen, 1986). Bearing in mind these shortcomings, market prices do exist for some environmental functions, notably for production and carrier functions, and some examples are given in chapter 3.3.

Box 3.2.1-1 Some shortcomings of the market-pricing mechanism

From the literature, some of the most important shortcomings of the market pricing mechanisms can be summarised as follows:

Exclusion of external effects: One reason why market prices for both man-made and natural goods and services are inaccurate is because the costs of the 'external effects' (e.g. pollution and environmental degradation) caused by the production or extraction processes are not included. Current methods to determine market prices are therefore very incomplete and reflect only part of the *true social and environmental costs involved in the production and consumption of most goods and services.*

Exclusion of the 'free' works of nature: The market prices which exist for some products provided by nature, such as tropical hardwoods, only reflect the costs of bringing the product to the market place (labour, invested capital), and the profit margin applied. The 'works of nature' as the 'factory' that produces the commodity, are largely ignored. In the case of timber, this commodity could never have been harvested and used by man without the combined ecological processes at work in the tropical forest ecosystem, such as conversion of solar energy into biomass by photosynthesis, and maintenance of biological diversity (including hardwood-species) through delicate inter-and intra-specific relationships. It is somewhat comparable to not accounting for the labour and capital needed to maintain the productivity of a car-factory in the market price of cars. Initially, this would make cars a lot cheaper although scarcety would soon raise prices to astronomic levels because the factories would fall apart and production would stop. If we find it normal for man-made goods and services to include a 'tax' in the market price for maintaing the productive capital, it seems strange that the value of the primary forest as the productive capital (i.e. the 'factory') for tropical hardwoods is largely ignored in the current market price for timber. This seems especially strange when we realise that with a small 'conservation-tax' on naturally-produced goods, in combination with sustainable management techniques, entire ecosystems can be maintained which often provide many additional goods and services, such as protection of watersheds and *recreational benefits.*

Existence of different market places: When attaching market prices to certain goods and services, it must also be realised that there are many different market places with different value standards. For example, some so-called minor forest products may have a very low value (or no value at all) on the international (export) market, although they are very valuable to the national economy or to local communities, notably indigenous people (see for example chapter 3.1.5 on the consumptive use value of environmental functions).

Problems of distribution and equity: The market price usually does not accurately represent the true economic value of a given resource because it does not deal effectively with problems of distribution and equity. Differences in income and access to a given good or service cannot be included in the market price. To ensure a certain degree of access, this problem must be solved by personal subsidies which then distort market prices.

Differences in perception: The willingness to pay for a certain good or service also depends on the value-perception of the (potential) user. For example, California redwoods are valued differently by consumers of scenic beauty than by consumers of lumber products, but no market is available to mediate these claims (McNeely, 1988). There are also different perceptions of value regarding ornamental resources, such as fashion-clothing and collectors items.

Consumers surplus: Another difficulty is presented by the problem of substitution. Where close substitutes for natural goods and services are available, the demand curve will be fairly flat and the use value is determined by the market price of the cheapest alternative. Where close substitutes are not available, there is a 'consumers surplus' over and above the market price. In both cases, the pricing system may severely underestimate the true use value of the natural good or service in question (McNeely, 1988).

3.2.2 Shadow price of environmental functions

Many environmental functions, especially the regulation functions, provide goods and services to human society which are not traded in the market place and therefore do not show in economic accounting procedures (so-called 'free' services). However many of these functions do provide benefits to the economic production process and contribute to human welfare whereby some functions are even essential to human existence on earth. Without, for instance, the capacity of forests to buffer climatic extremes and prevent runoff and soil-erosion, and photosynthesis - the process by which natural ecosystems convert solar radiaton into biomass - human life on earth would be impossible or at least very different from the way we know it today. Those natural products which do have a market value, such as tropical hardwoods and fossil fuels, are also greatly undervalued since, for example, their non-renewability and the 'external effects' of their utilisation (deforestation, pollution, etc.) are not, or only partly, reflected in the current market price (see 3.2.1). Often the true economic value of the functions of nature are only recognised once the function is lost or damaged. Estimations of the economic value of these functions, while they are still intact, would be of great help to ensure the conservation and sustainable utilization of the natural systems which provide these functions.

To better account for the economic value of natural goods and services, methods have been developed to determine so-called shadow prices (e.g. Hueting (1980, 1984), Pearce (1987b), Farber (1987)). Some shadow prices are based on values that can be derived from market prices, such as the economic costs resulting from environmental damage (e.g. erosion, pollution) caused by the loss of environmental functions (see section (1) in this

chapter). Other methods involve an assessment of man's actual and potential willingness to pay for the maintenance of environmental functions which can be seen as a measure for the value which human society attaches to these functions. Maintenance of environmental functions can be achieved by preventing the loss of environmental functions (section 2) and/or the mitigation (restoration and/or compensation) of lost environmental functions (section 3). Methods to determine the willingness to pay for the maintenance of environmental functions or willingness to accept compensation for lost environmental benefits are discussed in sections (4) and (5) respectively. Two additional methods to arrive at shadow prices are the property pricing method (6) and the travel cost method (7).
In spite of the various methods that are available, there are still many difficulties in arriving at realistic shadow prices for environmental functions. However, as long as the conventional market mechanism does not adequately account for the importance of environmental functions to human welfare, constructing shadow prices is essential as they give a better (economic) indication of the value of, and preferences for, the continued availability of environmental functions.

(1) Costs of function loss
Many environmental functions, especially the so-called 'free services' of nature, provide considerable economic benefits which do not show up in economic accounting procedures until they are damaged or destroyed. Some examples of these 'free services' include the protective function of the ozone layer; the contribution of natural pest control and cross pollination in agriculture; the dependence of agriculture and medicine on wild genetic material; the nursery function of wetlands and mangroves to commercial fisheries; and the capacity of natural systems, notably wetlands, to store and recycle human waste.
Disturbance of these functions (due to deforestation, pollution, etc.) leads to environmental problems such as acid rain, ozone-depletion, and (possibly) climate changes. The cost of disturbing the natural processes which provide these functions will be equivalent to the amount of money that would be lost, or not gained, in the absence of the intact functions.
Due to the increase in large-scale environmental problems, data on the economic costs of environmental damage are becoming more readily available (see table 3.2.2-1). A good overview of the subject-matter can be found in Opschoor (1986) and Pearce & Markandya (1987).

Although a direct linking of the economic costs of environmental damage and specific environmental functions is often difficult, it can be argued that, for example, the costs caused by air- and water-pollution at least partly reflect the economic value of the natural functions responsible for maintaining air- and water-quality. In the Netherlands alone, the costs incurred by air- and water-pollution amount to almost 1 billion US$ annually (Opschoor, 1986). Based on the concept of prevented environmental in *cleaning of poisoned soil,* for example, may serve as a measure for the economic value of a clean and fertile layer of topsoil (chapter 2.1.9). In the Netherlands, for example, failure to spend a few hundred thousand guilders on the clean-up of a waste-dump (in Lekkerkerk) before the fill was used for housing, has resulted in the waste of 175 million guilders in repairing the damage afterwards (Vas Nunes, 1987, in litt.). Environmental rehabilitation projects, such as *re- and afforestation*, serve as an expression of the monetary value of (some) of the functions of the intact natural ecosystem.

For example, in the sand dune forest in the Ushiroyachi area not far from Nagoya (Japan), a layer of kaolin (white pipe-clay) was discovered in the 17th century, which enabled Japanese potteries to make the same high grade china ware which they knew well enough from China. The deposit was a shallow layer near the surface, so the forest cover was stripped off and the clay dug up. A whole pottery industry arose, using the wood for fueling the ovens, until both the kaolin and the wood ran out. The resulting waste land began to form dunes and spread in ever widening circles, covering the surroundings like a growing sore. Around the turn of the century the government decided to restore the area by reforestation. But they found that no trees would grow on the steep barren slopes of the dunes. So the slopes had to be terraced before they could be planted. In 1955, the project was nowhere near completion and the money spent was in the order of 5,000 dollars per hectare, probably a multiple of what the china was ever worth (Vas Nunes,1987, in litt.).

Compensation-costs: The costs involved in attempts to compensate the loss of environmental functions can also be used as a measure for the monetary value of the intact function. It can be argued that the monetary value of a given environmental function is equal to the costs involved in replacing the lost environmental function by artificial goods and services, in so far this is possible. Some examples of compensation measures are:
a. Water treatment plants, replacing natural purification processes which have been disturbed. Thibodeau & Ostro (1981) calculated that the capacity of one acre of marsh to remove nutrients, substitutes for plant-construction costs of 85 US$ and annual operation and maintenance costs of 1,475 US$. The total cost to substitute this function (= plant-cost and capitalized annual cost) would be 24,668 US$ per acre (or over 60.000 US$/hectare), at an interest rate of 6%.
b. The costs involved in the construction and maintenance of *artificial fences* on deforested hillslopes to prevent erosion and landslides, can be seen as a measure of the economic value of the original vegetation which provided this function for 'free'.
c. Artificial *devices to improve air quality* in cities and buildings reflect to some extent the price of unpolluted air.
d. The money invested in the creation and maintenance of *artificial recreational areas,* notably those that attempt to imitate or replace natural areas, may serve as an indicator for the economic importance of intact natural areas for this function.

(4) Willingness to pay for the maintenance of environmental functions
Frequently, public preferences for the availability of environmental functions are not adequately reflected by the price of a certain good or service, or by the amount of money which the government is spending on preventive and mitigating measures. The public is often prepared to pay more for environmentally friendly products than the current price charged, or wants more money spent on anti-pollution measures and environmental restoration than the government is actually spending. The concept of 'option value' should also be mentioned here, which relates to the amount of money which people are willing to spend on environmental protection in order to keep the option open to enjoy a healthy environment in the future, either for themselves or for their children (see chapter 3.1.4 and Barrett, 1988, for some examples).
The willingness to pay for measures that prevent or mitigate the loss of environmental functions can be measured by means of techniques such as contingent valuation, hedonic pricing and surrogate markets (for further reading, see for example, Pearce, Markandya and Barbier, 1989, Folke and Kaberger, 1991 and Bojo, 1991).

(5) Willingness to accept compensation for the loss of environmental functions
In certain situations, it is possible to arrive at an estimated shadow price for environmental functions by inquiring about the willingness to accept monetary compensation for the loss of a given environmental good or service. If, for example, pollution impairs water quality and hence affects the aesthetic quality and recreational experience, the value of this non-market loss can, in principle, be measured by the willingness of individuals to accept compensation to tolerate the damage.
Techniques involved in the inquiries needed to assess compensation demand are not further discussed here. A good review can be found in Knetsch & Sinden (1984), who concluded that the compensation demand is usually higher than the willingness to pay for the maintenance of a given environmental good or service (Knetsch, 1988, pers. comm.). This suggests that the willingness to pay for preventive measures can usually only be used as a minimum estimate of the value of an environmental function.
The willingness-to-accept (or willingness-to-pay) approach, seems to be most useful in dealing with situations where there are many similar environmental features, but where no one single lost feature can be shown to have a significant value for particular functional reasons. This is being tested by the Land Use Analysis Division of the Department of the Environment, Canada in the Prairie Pothole regions of Canada where tens of thousands of potholes provide major functions (wildlife habitat, water reservoir, etc.), but where the loss of a single pothole when it is filled in by a farmer is very hard to evaluate on its own. In such circumstances, the approach based on willingness-to-pay for the maintenance of a given pothole, or the willingness to accept compensation for the loss of it, would

give some measure of the perceived value of potholes in general and perhaps especially valued potholes in particular (Manning, 1987, in litt.).

(6) Property pricing

The value of real estate is often influenced by the quality of the natural environment, both in terms of environmental quality in general (e.g. clean air) and specific physical (scenic) features. Usually prices are higher when a given property is located in or near a nature area or a scenic landscape. From a study carried out by Payne and Strom (1975) in Amherst, Massachusetts it was found that the presence of trees around a house appears to have a tangible effect on its marketability. Trees may enhance the value of a property by as much as 20%, with an average increase of 5 to 10%. Several other examples are available of estimates of the contribution of 'nature' to property prices (see for example Pearce and Markandya (1989) and Thibodeau & Ostro (1981)).

(7) Travel cost method

The travel cost method investigates the amount of money people spend, or are willing to spend, for arriving at a particular natural site (Pearce and Markandya, 1989). One of the first references on this method is the work of Clawson and Knetsch (1966), and has since become widely used in the industrialised world, especially the USA (Howe, 1991, Bojo, 1991). This method is more difficult to apply in less developed countries, some examples are given by Dixon and Hufschmidt (1986).

3.2.3 Capital value of environmental functions

The socio-economic value of a given ecosystem or natural area consists of the sum-total of the values of several functions since most natural areas provide various functions simultaneously. Furthermore, it must be realised that natural areas can provide functions in perpetuity, when utilized in a sustainable manner. The calculated annual monetary value must therefore somehow be translated into a capital or net-present value.

(1) Total socio-economic value of the annual return of environmental functions

The 'total value' of a given environmental function to human welfare is determined by a number of values, including non-monetary values, market values, and shadow prices (see the previous chapters). When calculating the total monetary value of a given area or ecosystem, care must therefore be taken not to double-count values. For certain functions both market and shadow prices exist, notably for production and carrier functions. If the shadow price has been calculated correctly, elements contributing to the market price will automatically have been included. Thus, given the choice, the total monetary value of a given function should preferably be based on the shadow price since this gives a more realistic estimation of the full socio-economic costs and benefits of the use of a given function than the market price.

Another factor to take into account when calculating the total annual return is that the benefits from environmental functions should be determined for sustainable use levels. When several functions are used simultaneously, this often means that not all functions can be utilized to their maximum potential but that an optimal mixture should be found to ensure the integrity of the combined functions of the area in question. When all functions and values are taken into account, it will often become clear that sustainable use of a combination of functions provides more economic benefits, especially in the long term, than non-sustainable use of only a few functions (such as logging in tropical moist forests). Myers (1988) calculated, for example, that a **tropical forest** tract of 500 square kilometers could, with effective management, produce a self-renewing crop of wildlife with a potential value of at least US$ 10 million per year, or slightly more than US$ 200.- per hectare. Simultaneously, the area could generate income from tourism and may perform important regulating functions in the form of watershed protection and local climate regulation. Thus, according to the case study presented in this book (chapter 4.1), the total monetary value of the functions of one hectare of tropical moist forest is at least US$ 500.-/ha/year.

For **wetlands**, the most important functions for which a monetary value can be calculated are flood prevention, storage and recycling of human waste, the nursery value, their importance to aquaculture and recreation, food production and the use for education and science. Adding these values for the Dutch Wadden Sea amount to a total of over US$ 6,200/ha/year (chapter 4.2). Of course, values for other wetland-areas may be different.

For the **Galapagos National Park**, total monetary benefits amount to about US$ 140 million per year, based on maximum sustainable use levels mainly from tourism, harvesting natural resources and the value to scientific research. This amounts to an average value of about 120 US$/ha/year (see chapter 4.3).

(2) The capital or net-present value of environmental functions

When interpreting the total monetary value of a given function, natural area or ecosystem, it must be realised that this value only represents the annual return from the respective functions. Since natural areas can provide many environmental goods and services in perpetuity, if utilised in a sustainable manner, the total annual value should somehow be transformed into a capital value to reflect the true economic value of the area or ecosystem concerned. An important reason for calculating the capital value, or net present value (NPV), is to be able to compare the value of the current use of a particular natural area (which may also be 'non-use' when the area in question is a nature reserve) with the monetary returns calculated for projects which aim to develop one or several functions of the area, often in a non-sustainable way. Information on the capital value of the sustainable use of the environmental functions affected by the project should be included in cost-benefit analysis in order to make more balanced decisions concerning the choice between various development options.

In cost-benefit analysis, the present values of future costs and benefits of the intended use of a certain area may be calculated by the formula given by Hueting, (1991):

$$NPV = \frac{B_1 - C_1}{1 + r} + \frac{B_2 - C_2}{(1 + r)^2} + \cdots + \frac{B_n - C_n}{(1 + r)^n}$$

where NPV is the net present value, B_n are monetary benefits in year n, C_n monetary costs in year n, and r is the discount rate.

The use of **discount rates**, in particular, presents a major problem when calculating long-term environmental costs and benefits. Discounting is a practice applied in business economics and is used to estimate the present worth of future benefits. Usually the time-horizon is rather limited: 50 years or less, resulting in (market) discount rates of 10% or more. A discount rate of 10% would mean that one dollar earned 30 years from now acquires a present value of 5.7 cents and only 0.007 cents 100 years from now (Hueting, 1990). An important difficulty in arriving at an acceptable capital value for environmental functions is therefore the choice of discount rate to be used. Discount rates for future benefits of environmental functions found in literature usually range between 5 and 6%. However, using discount rates for calculating the depreciation of the monetary return of the benefits derived from environmental functions has strong principle objections. A discount rate of 5% in effect means that the value of a given function in 30-40 years from now is considered to be close to zero today. However, the benefits of the 'works of nature' will last in perpetuity when used in a sustainable manner, and the 'economic life time' of these goods and services can (or should) not be calculated in the same manner as is customary for man-made goods and services which usually loose their economic value after 20 years or so. Placing discount rates on the functions of natural ecosystems therefore ignores the interests of future generations. Another objection against using discount rates for environmental functions is the fact that human constructions which provide certain goods and services, such as a factory, are replacable while natural ecosystems usually are not.

Although much has been written on this subject (e.g. Bouma, 1974, Stokoe, 1988, Markandya & Pearce, 1988, Hueting, 1990, 1991) a satisfactory solution is not in sight yet.

In so far as the use of discount rates for calculating the future benefits of environmental functions is unavoidable, it should be chosen as low as possible, preferably in accordance with the time it takes for the ecosystem which provides the functions to reach its climax stage. Succession times differ strongly between various types of ecosystems and may range from a few years for certain aquatic or grassland ecosystems to a thousand years or longer for tropical moist forests and over 10,000 years for a bog ecosystem. For practical purposes, it is proposed here to apply a range of discount rates between 1 and 6% for environmental functions provided by natural ecosystems, whereby the higher figure applies to pionier communities and the lower figure to climax communities.

Instead of the use of discount rates, a much better approach to calculate the capital or net present value of environmental functions would be the **'interest-on-capital'** approach. Since natural environments could provide goods and services indefinitely, when utilised in a sustainable manner, it would seem more approriate to consider the annual return in monetary terms as the interest on the capital stock of the natural processes and components that provide these functions. This implies that there is no time-limit to the benefits derived, making the value of the capital immeasurable. Although this is essentially correct, for practical purposes it may sometimes be necessary to estimate a capital or net present value for a given good, service or natural area. At an interest rate of 5%, the capital value of the three case study areas discussed in chapter four would amount to about 2,400 US$/ha for the Galapagos National Park, 10,000 US$/ha for tropical moist forests, and 120,000 US$/ha for the Dutch Wadden Sea.

3.3 Some examples of the socio-economic value of environmental functions

Based on the information provided in chapters 3.1 and 3.2, it is now possible to describe and quantify the socio-economic value of individual environmental functions. In the next four sections, examples of the socio-economic value of individual functions within each major function-category (regulation-, carrier-, production- and information functions) are given. To facilitate cross-reference between this chapter and chapter 2, the number of the corresponding section in chapter 2 is given in brackets after each function-caption.

3.3.1 Some examples of the socio-economic value of regulation functions

As we have seen in chapter 2.1, human welfare largely depends on the maintenance of many regulation processes in the natural environment. Also many economic production processes would be impossible, or much more expensive, without the presence of regulation functions such as, for example, the regulation of runoff by the vegetation on hillslopes and natural purification processes which provide 'free' services saving the rison is difficult to make since biodynamic farming makes sustainable use of the natural possibilities of the land while intensive cultivation systems are not sustainable in the long run because soils become biologically impoverished due to continuous application of chemical fertilizers (and pesticides) and the heavy machines destroy the soil structure and make them susceptible to erosion.

(7) Socio-economic value of bio-energy fixation (2.1.10)

The photosynthetic fixation of solar energy, and the transfer of this energy through green plants into natural food chains, is an essential function of natural ecosystems which stands at the base of almost all other functions of the biosphere. Odum (1975) therefore called this the 'life support function' and suggested the calculation of a monetary value by comparing the amount of energy fixed by a given natural area with the price of energy consumption as reflected in the national accounting systems. Gosselink, et al. (1974) developed a (very crude) method for determining the monetary value of the (biomass)-production capacity of natural systems. Since the rate of primary production is a measure of the energy flow of a natural community, and an index of the useful work that might be accomplished, they used a conversion ratio from energy to dollars (bases on the ratio of Gross National Product to National Energy Consumption) to place a dollar value on any part of the natural environment where primary production can be measured or estimated. In the USA, 10^{16} kilocalories were consumed yearly in the early 1970's to produce a Gross National Product of 10^{12} dollars, so that 10,000 kilo-calories were approximately equal to one dollar. Clearly, this is a very crude method, because the outcome of this calculation (and thus the monetary value of this function) varies with fluctuations of the international economic situation, changes in exchange rates and oil prices, etc. In addition, the value of a unit of energy generated in a natural system may not be directly comparable to a unit of energy delivered in the form of electricity to an industrial plant or home. The natural energy units are, however, essential to life, and Gosselink, et al. (1974) therefore state that the approximation may actually be a gross understatement in dollar terms.

(8) Socio-economic value of storage and recycling of organic matter (2.1.11) and nutrients (2.1.12)

The continuous recycling of organic matter and nutrients is an essential service of natural systems. Wetlands in particular are able to decompose large amounts of organic matter and to store and recycle certain amounts of organic human waste without negative side effects. It has been calculated that waste treatment services provided by marshes in Massachusetts amount to US$ 123,000/ha/year (Oldfield, 1984). The cost of restoring a wetland or rehabilitating a marsh could be even greater (McNeely, 1988). Calculations have also been made for the economic value of the recycling of individual nutrients. For example, one hectare of wetland is able to

recycle an amount of phosphorus which would cost US$ 47,000 if it had to be carried out by artificial purification plants (Oldfield, 1984).
Biological nitrogen fixation in croplands worldwide amounts to more than 90 billion tons/year, representing an annual value of about US$ 20 billion. In addition, 45 million tonnes of industrial nitrogen, worth over US$ 10 billion, are used annually in world agriculture (Pimentel, et al., 1980). Another approach to calculate a monetary value for this function would be to determine the (discounted) monetary value of the damage that would have occurred in the absence of natural recycling processes for organic matter and nutrients (see also next section).

(9) Socio-economic value of storage and recycling of human waste (2.1.13)
By storing and recycling certain types of human waste such as organic matter and nutrients (see above), pesticides and other certain chemical substances (e.g. carbon dioxide), natural ecosystems serve as 'free waste treatment plants'. The preventing and/or mitigating of the negative effects of environmental pollution, has great economic value since it reduces the economic costs of environmental damage and lowers the risks to human health. For example, it has been estimated that in the Netherlands alone, acid rain causes damage to buildings, crops, etc. of about 2 billion Dfl per year .
Noise reduction/abatement is another important function. The socio-economic value of this function can be deduced from, for instance, the investments made in noise-reduction along highways, the value people place on the maintenance of quiet areas for recreation, and the increased property-value in quiet areas.

(10) Socio-economic value of biological pest control and pollination (2.1.14)
Until recently, biological pest control and pollination were seen as 'free' services of nature and therefore had no market value. However for some years now, natural predators of pests and wild pollinators (notably insects) have been commercially cultivated and sold or 'rented' for use in agriculture.
Pest control: Wild enemies of pests help control their depredations on cultivated plants and animals. Biological pest control provided by the natural enemies of pests represents a considerable economic value. In the United States alone, food losses to insects amount to 5 billion US$ per year. Many insect pests can be controlled by other insects, notably by predators and parasites (such as wasps) that attack crop plant eaters. In California, during the period 1928-1979, seven leading biological control projects have reduced crop losses to insects, and have likewise reduced the need for chemical pesticides to an extent of savings worth US$ 987 million, showing an average return on investment of 30:1. In Australia, four biological-control programs are producing benefits that, projected to the year 2000, are expected to exceed the cost of research to develop them

these environmental functions it would be impossible to grow many crops, or only at much higher costs.
Some examples of the socio-economic value of some sustainably cultivated products are given below. At least part of this value can be attributed to natural processes which provide and maintain a healthy substrate. Estimations of the economic value of the contribution of other environmental functions to cultivation, such as genetic resources and biological pest control are given elsewhere in this chapter.
Wildlife farming: Wildlife farming is an important activity in many developing countries. Forest sericulture of tasar silkworm larvae, for example, employs over 100,000 tribal families in tropical India, and it promises employment for nearly 1 million people in temperate areas. Moreover, tasar silk exports from India, the world's second largest producer, amounted to 4.4 million US$ in 1973 (Oldfield, 1984). In developed countries, wildlife farming is becoming increasingly important too. In recent years, the wholesale value of exotic fish raised on Florida fish farms, for example, has toppled US$ 30 million annually in recent years, and the industry supports thousands of people (Oldfield, 1984).
Game ranching/wildlife management: The potential return from wildlife management in tropical forests has been estimated at US$ 200/ha/year (Myers, 1988). The returns from wildlife is far less in drier habitats, though often still exceeding alternative uses. In Zimbabwe's Zambesi Valley, for example, Cumming (1985) estimates that potential gross returns from wildlife utilization amount to US$ 12 per hectare. 'These returns,' he states 'are as good if not better than returns from the best-run commercial beef ranches in the country and the profit margins are probably higher'.
Aquaculture: The total world harvest from aquaculture (both plants and animals) was almost 13 million metric tons in 1987 (see table 2.2.2-1) with a considerable economic value and providing employment to many people, especially in developing countries.

(3) Socio-economic value of natural ecosystems to recreation and tourism (2.2.4)

Recreation is experienced by many people as a reward for professional labour and as a necessary compensation for daily routines. In addition to this intangible value of recreation to man's mental and physical well-being, compared to other carrier functions, recreation may provide the best opportunity to obtain monetary benefits from natural ecosystems in a sustainable manner.
a. (Eco)tourism in natural environments and protected areas is one of the most rapidly growing economic sectors and to many developing countries tourism is one of the major sources of foreign exchange. The economic benefits vary from money spent on travel and lodging, to payment of entrance fees and purchase of local handicraft and other tourist curio's. It has been estimated that US$ 25 billion per year flow from developed northern to less developed southern countries through 'nature- or eco-tourism'

(Sawyer, 1991). In Kenya, for example, tourism is the leading foreign exchange earner, and much of the tourism is based on Kenya's system of protected areas. Using the income from tourism as a measure, it has been estimated that each lion in the Amboseli National Park is worth US$ 27,000 per year in visitor attraction, and each elephant herd is worth US$ 610,000 per year (Western, 1984).
b. The economic value of sport fishing or hunting is usually measured by the value of the whole recreational experience. For example, the market value of a 5-kilogram salmon may represent only a fraction of the value which an individual places on the experience of catching the fish. These values can be considerable; for instance, some 84% of the Canadian population participates in wildlife-related recreational activities in any given year, providing them with benefits they declare to be worth US$ 800 million annually (Fillon, Jacquemot and Reid, 1985).
c. Millions of people yearly 'migrate' to places with a sunny climate, spending most of the time (and money) near beach-resorts, both in developed and less-developed countries. It has been estimated, for example, that this type of tourism brings in about 60 billion US$ to Mediterranean countries each year.

(4) Socio-economic value of protected areas (2.2.5).
Protected areas fulfill a multitude of different functions to human society and represent a wide variety of values (see box 3.3.2-1). However, when calculating the total economic value of protected areas, care should be taken not to double-count values. Since most of the values listed in the box fall under other function-categories, only the costs of managing the area as a conservation site should be included in the overall calculations. As an example, it has been calculated by McNeely (1989), that management costs for tropical forest reserves require on average 2 US$/ha/year (see also chapter 4.1).
Strictly speaking, the costs involved in managing protected areas (maintenance of infrastructure, personnel, etc.) should be substracted from the revenues from the other functions of the area. However, it can be rightly argued that the maintenance of the integrity of tropical moist forests safeguards the continued availability of all other goods and services provided by this ecosystem, thus representing a huge economic value. Furthermore, as long as traditional economic accounting procedures consider the costs involved in managing waste treatment plants and military activities as productive capital, which is thus added to the GNP (see chapter 5.2). It seems justified that management costs of protected areas should also be considered a productive investment and must therefore be added to the sum-total of the economic value of natural ecosystems.

(8) Socio-economic value of (sustainable use of) natural energy resources (2.3.9)

Sustainable use of natural energy resources includes fuelwood, biomass, and animal power. Most of these resources are harvested and used directly (i.e. without passing through a market) which makes it difficult to obtain reliable data on their economic value.

(9) Socio-economic value of natural resources as fodder and fertilizer (2.3.10)

As with natural energy resources, fodder and fertilzer are usually 'consumed' directly without passing through a market-place. An exception is guano. On islands off the south and southwestern coasts of Africa, breeding colonies of gannets have yielded an average of nearly 4,000 tons per year from 1961-1972. The guano from these seabirds was worth twice the economic value of the fish they consumed to produce it (Oldfield, 1984).

(10) Socio-economic value of natural ornamental resources (2.3.11)

Wild plants and animals and their products are valued for fashion, ornamentation, artisan work, investment in precious materials, souvenirs, tourist curios and collectors items. Over the years, trade in wildlife, although often illegal, has generated considerable economic benefits and monetary value (see box 3.3.3-1). However, it must be realised that, especially in the case of ornamental resources, there is considerable danger of over-exploitation as has been pointed out in chapter 2.3.11. Special care should therefore be taken to limit harvesting of ornamental resources to sustainable use levels.

Box 3.3.3-1 Some examples of the monetary value of ornamental resources harvested from the wild

NB: data are from Oldfield, 1984, unless indicated otherwise.

Ornamental live animals: High prices are being paid for rare or unusual reptiles. In 1977, as much as US$ 1 million worth of live tortoises, snakes, and lizards were being extracted annually from Arizona alone. Animal dealers listed prices then at US$ 25 per Sonoran green toad (*Bufo retiformis*), US$ 100-150 for a ridge-nosed rattlesnake (*Crotalus willardi*), and US$ 150-300 for one gila monster (*Heloderma suspectum*). They are all protected species which have been seriously depleted throughout their range and are now treatened with extinction. More common rattlesnakes ranged in price from US$ 10-100, and a common desert gecko for only US$ 2.50.
Ornamental plants: On an international scale, blackmarket trade in illegally harvested cacti from the southwestern USA and Mexico is estimated to be a multimillion dollar business. In the late 1970's, large Arizona barrel cacti (*Ferocactus; Echinocactus*) commanded prices of up to US$ 350 each in New York City; one variety of *Echinocactus horizonthalonius* in Arizona is currently endangered by overcollecting, urban development, and destruction by off-road vehicles. Even the relatively common, tree-like saguaro cactus (*Carnegiea gigantea*), which occurs over much of southwestern Arizona, has become depleted in areas adjacent to some major cities due to its landscaping value for semi-arid urban and residential environments. Saguaros which sold for about US$ 33-40/m in the early 1970's were selling for at least US$ 60-66/m in the late 1970's, while large, crested specimens have reputedly sold for as much as US$ 1,000 each. Specimens of very rare orchid species may even sell for up to US$ 7,000 each.

Souvenirs, tourist curios and collectors items: In a London shell-shop in 1978, shells of the giant marine clam (*Tridacna gigas*) were selling for US$ 80-480 per pair. Collection of beautiful or unique butterflies supports home-industries in some areas of Latin America, Asia, and Australasia. For example, the butterfly trade in Taiwan supports 20,000 people, about half of whom are collectors. In recent years about 20 million butterflies have been caught annually in Taiwan alone, and 1966 exports from Taiwan were valued at US$ 30 million. The Queen Alexandra (*Ornithoptera alexandrae*) and Paradise birdwings (*O. paradisea*) are two of the most prized collector's items in the world. These and other unique and rare birdwings command export prices of US$ 200-1,200 per pair, and demand is already outstripping available supplies. One dealer in England displayed US$ 300,000 worth of Papua New Guinea butterflies for sale in 1976. Some advertisements in the United Kingdom have proposed the purchase of rare and beautiful butterflies as a hedge against inflation; in 1969 one birdwing butterfly sold for US$ 1,875!. A pair (male and female) of rare Rothschild's birdwing butterflies were priced at US$ 850 in Japan.

3.3.4 Some examples of the socio-economic value of information functions

Information functions are an essential element to human welfare and provide many socio-economic benefits. Curiously, information on the economic value of information functions is quite sparce, and in many cases not available, simply because there is no price charged for the goods and services which depend on the availability of these information functions (e.g recreation, books, and films).

(1) Socio-economic value of aesthetic information (2.4.1)
From the examples given in chapter 2.4.1, it may be concluded that an aesthetically pleasing environment is clearly quite essential to our well-being, which is also reflected in the amount of effort and money people are spending on maintaining the aesthetic quality of the environment near their homes or on vacation trips to unspoiled natural landscapes. The advantages of recreation in nature's surroundings are not only that many people derive an income from it but also that those who recreate benefit directly, for example from improved health and a relief of tension (van Dieren & Hummelinck, 1979). It would be interesting to see if a method could be developed to measure the decrease of stress and related socio-economic benefits, from the aesthetic enjoyment and resulting mental refreshment experienced in natural surroundings. The monetary value of tourism to national parks, which is mainly based on the aesthetic value of the landscape, is relatively easy to measure (see chapter 3.3.2) and can often provide a powerful economic justification for conserving biological resources, particularly when protected areas are a primary attraction for visitors to a country. Another indicator for the economic value of an aesthetically pleasing environment is the influence on the price of real estate.

(2) Socio-economic value of spiritual and religious information (2.4.2)
Although difficult to measure in economic terms, the expression of ethical or religious feelings towards nature clearly contributes to the feeling of

well-being of many people and is an essential aspect of human welfare in general (see also chapter 3.1.2 on the existence value of nature). If an economic or monetary measure must be found for this function, a possibility would be to use the amount of money people are willing to give to conservation organisations through membership fees, donations, etc. as an indication of the willingness to pay for conserving natural areas or particular species for more or less altruistic reasons. Worldwide, many organisations collect money from governments and private individuals for the conservation of protected areas or certain species (e.g. whales). It must be realised however that not all money donated for this purpose is necessarily solely for ethical reasons; many people may be aware of the many use-benefits provided by natural areas or may want to keep the option open for a possible future visit to the area. Part of the money is therefore probably also donated for these somewhat less altruistic reasons.

(3) Socio-economic value of historic information (heritage value) (2.4.3)
The importance of this function may be deduced from the amount of energy and money people are willing to invest to conserve certain special historical elements in their environment. For example, the 'information-value' of old trees is considered important by many people, and recently studies are showing the considerable monetary value of these historic landscape-elements.

(4) Socio-economic value of cultural and artistic inspiration (2.4.4)
The contribution of natural ecosystems and their wildlife as a source of inspiration to culture is manyfold, including the use of natural motives in art, photography, film (video), advertising, media, and literature. Each year many films, television-programmes, and books in which nature plays an important role, are produced and their combined economic value is considerable, both in terms of monetary returns and the contribution to employment. The continued availability of this function depends on the conservation of the remaining natural ecosystems and it could be argued that a conservation tax should be placed on the market price of the goods and services which utilise the information value of a particular natural area.

(5) Socio-economic value of educational and scientific information (2.4.5)
Nature provides almost unlimited possibilities for scientific research and educational experiences. A measure for the economic value of this function could be a calculation of the number of scientific expeditions and educational excursions organised in a given natural area, and the amount of money involved in these activities. For example, the use of the Galapagos NP for research is one of its most important functions. Over the years, thousands of scientifc expeditions have been organised and the library of the local research station stores over 4,000 titles. There is an 'expedition fee' charged for research in the park which brings an annual

monetary return of more than 1 million US$/year. Managing the scientific and educational use of the islands provides employment to almost 70 people (see chapter 4.3).
It must be realised that the actual use of a particular function in a given area does not necessarily reflect the full potential (socio-economic) value of the area for this function. With proper management, returns from especially the information functions in natural areas could be increased many times over.

important functions is given, based on the checklist given in table 2.0-1. To avoid lengthy descriptions and overlap with chapter 2, only information related to the specific case study environment is included. For more general information on functions and assessment parameters the reader is referred to the corresponding sections in chapter 2 and appendix I, respectively. More detailed information can be found in three separate case study reports (De Groot, 1986, 1988a, 1988b).

Following the description of the functions of each case study, a section is included on the socio-economic importance of these functions. Where possible, examples of the monetary value of a particular function are also given, based on the methods discussed in chapter 3.2. When calculating monetary values, net annual revenues were used, deducting costs for collecting, transport and maintenance of a certain good or service from the calculated market value or shadow price.

The calculation of the socio-economic value of the functions of a particular case study environment is based on the (maximum) sustainable use or benefits that can be derived from the area, whereby sustainable use is defined as those types and intensities of use which do not basically alter the natural characteristics (especially the biological diversity) of the ecosystem, or which allow the ecosystem to return to its natural state in a relatively short period of time. In practice, this means that the use of many production and carrier functions will not be possible in natural ecosystems.

At the end of each case study, a summary is given of the total socio-economic value, based on the listing of socio-economic values discussed in chapter 3.1 (the horizontal axis in Table 4.0-1). When adding the separate figures in each value-column in Table 4.0-1, it must be realised that it is not always possible to utilise all the functions simultaneously. When adding different values in the rows of Table 4.0-1, care must be taken not to double-count values.

Since natural areas provide goods and services indefinitely, when utilized in a sustainable manner, the monetary value of these goods and services must be seen as the interest on the capital stock, i.e. the natural ecosystems that provide these functions. Thus, the yearly monetary benefits must be extrapolated into the future to arrive at the net present value (NPV). For the case studies presented in this book, an interest rate of 5% is used (for a discussion of the difficult problem of the choice of interest (or discount) rate for environmental functions, see chapter 3.2.3.)

The three case studies presented in this chapter should be seen as general examples or 'blue prints'. The outcome of each case study will be different in other regions, depending on its specific environmental, cultural and socio-economic circumstances. Together with the information provided elsewhere in this book, this chapter can be used as the basis for developing manuals for comprehensive and systematic assessment and evaluation of the functions and socio-economic values of natural ecosystems and national parks or other types of protected areas.

4.1 Functions and values of tropical moist forests

Introduction

The total surface area of (closed) tropical forests is estimated at 1,200 million hectares, of which ca. 900 million hectares are moist (rain-) forests, and 300 million hectares consist of several types of 'dry' tropical forests (Steinlin, 1982, Timberlake et al., 1982). According to Poore (1978), tropical moist forests originally covered about 1,600 million hectares which means that 700 million hectares, or almost 45%, have been converted by man for logging, cultivation, road-construction, housing, etc. Because of the poor soil conditions, much of the converted land is sooner or later abandoned and turned into wastelands and deserts. At present still about 10-20 million hectares (between 1 and 2% of the remaining forest) is still lost each year (WRI, 1990).
The loss of 700 million hectares of tropical moist forest in the past and the ongoing annual conversion of 10-20 million hectares not only means the loss of unique ecosystems which are very rich in life forms, but also causes a drastic change in the environmental situation, both locally and globally, affecting the lives of many people for decades and generations to come.

Fig. 4.1.0-1 Darien National Park, Panama

combustion of fossil fuels, which is one of the main causes of the enhanced greenhouse effect (see chapter 2.1.5). Vegetated areas play an important role in the maintenance of the chemical balance in the atmosphere, in particular in the regulation of the carbon-dioxide balance. Through photosynthesis CO_2 is removed from the atmosphere while respiration and decomposition release CO_2 into the atmosphere. The importance of tropical forests in the carbon-cycle is not so much the carbon circulating through leaves, litter and humus, which is more or less in balance in mature rain forests, but in the carbon of longer residence time locked up in wood. This is estimated at 340×10^9 metric tons which is 41% of all carbon stored in biological systems on earth (Poore, 1978, Min. LNV, 1990). Release of this stored carbon by deforestation and the burning off of forests increases carbon dioxide levels in the atmosphere. It has been calculated that the burning of tropical forests brings an amount of CO_2 into the atmosphere equal to the burning of about 1 million tons of carbon, compared to 5.3 million tons of carbon which is burned by combustion of fossil fuels. The contribution of the burning of tropical forests to the so-called 'greenhouse-effect' is thus estimated between 5-15% (Min. LNV, 1990). Similarily, afforestation could help reduce the concentration of CO_2 in the atmosphere. According to estimations given by UNEP, afforestation of 320-500 million ha (= 2-3% of the total landsurface on earth) is needed to compensate for the current emission of CO_2 by burning fossil fuels and fuelwood and by forest-clearing (Min. LNV, 1990).

Socio-economic value

The economic value of the influence of tropical moist forests on the maintenance of the CO2-balance in the atmosphere is difficult to calculate but is certainly considerable. An indication can be obtained by estimating the costs incurred by the increased greenhouse effect (see next section).

(2) Climate regulation (2.1.5)

Different types of surface covering, i.e. different ecosystems, have a different effect on micro-climatic conditions, influencing for example hydrological conditions (evaporation and rainfall), air turbulence (windspeeds), radiation balance and temperature fluctuations. There are many examples of climatic deterioration caused by deforestation. In Indonesia, for instance, climatic conditions became worse following deforestation in the Karo highlands (South Sulawesi), and in East Java (UNDP & FAO, 1982). *Influence on temperature:* Tropical moist forests, have a low albedo and thus absorb most of the incoming solar energy. Deforestation causes changes in albedo, which rises 10-16% when tropical moist forests are converted to savannas or arable land. As a result, soil temperatures can rise up to 40% (partly after Salati, Lovejoy & Vose, 1983, and Timberlake et al., 1982). Together with reduced cloud formation (see further), changes in albedo thus influences the heat balance in the deforested area which not only changes local climatic conditions but which also has possible consequences for the global climate when the deforested area is substantially large. Simulation models applied in the Amazon basin showed that deforestation could lead to an increase of the local and regional temperature of 2-3°C (Lean and Warrilow, 1989).

Influence on rainfall: Vegetated areas, especially tropical moist forests, have high evapotranspiration levels. In tropical forests 15 - 75% of the water vapour is returned to the atmosphere and this contributes to cloud formation which results in increased rainfall downwind (Salati, Lovejoy & Vose, 1983). About 20-40% of the rain falling on the forest canopy never reaches the ground and is directly evaporated (Min. LNV, 1990). In many tropical areas the main source of rainfall, therefore is not evaporation from the oceans, but local evapotranspiration from the forest (up to an estimated 88% in the Amazon basin). Deforestation obviously has the opposite effect: the increased runoff decreases the amount of water vapour returned to the atmosphere, reducing rainfall in the deforested area and wider surroundings. Research using simulation models showed that in the Amazon basin deforestation could lead to a reduction of the evapotranspiration by 25-30% leading to a reduction of rainfall with 20% (Lean and Warrilow, 1989).

Socio-economic value

Clearing of forests results in raised land temperatures and strong thermals which hold off light rain clouds. This tends to make rainfall more erratic and less frequent over cleared areas, sometimes causing longer periods of drought, which is a disadvantage for agriculture. Continued deforestation may eventually contribute to global climatic changes with considerable economic consequences. For example, Myers (1979) estimates that a temperature increase of only 1°C could decrease US corn productivity by 11 percent and could cut gross income of spring wheat farmers by US$ 268 million (at 1977 prices).

(3) Watershed protection (2.1.6) and watercatchment (2.1.7)

Forests covering a particular catchment area regulate the quality and quantity of water leaving that area and have a buffering effect on extreme water levels further downhill in the watershed area. Vegetation reduces floods during the rainy season and prevents water shortage during the dry season. Watercatchment is also enhanced by the vegetation, especially on sloping land, because it reduces runoff allowing more water to infiltrate into the soil thus feeding underground water reservoirs, rivers and lakes.

Socio-economic value

Agricultural systems in valleys are largely dependent on the natural irrigation system provided by vegetation on hillslopes. Supply of drinkwater, fishery and shipping in many tropical areas also depend on the watershed protection and watercatchment provided by tropical moist forests.

(4) Erosion prevention and soil protection (2.1.8)

The vegetation cover plays a very important role in soil retention and prevention of both wind- and water-induced soil erosion. This is especially so in tropical areas where the soils are often poor and the climate extreme. In mountainous areas the vegetation cover reduces the danger of land slides and prevents or reduces siltation in water catchment areas. Forests

(9) Providing a migration habitat (2.1.15)

Tropical moist forests in Central and South America are important wintering areas for many bird-species in North America: about half of all land birds breeding in North America go to Mexico, the Bahamas, Cuba, and Hispaniola and continued deforestation in these areas will result in major reductions in many species that breed in North America (Terborgh, 1980).

Socio-economic value

This function is mainly of ecological importance for maintaining the integrity of the life communities in the breeding, feeding and resting areas of the migrating animals. In case these animals are harvested by man in any one of these areas there is also an economic value to this function. Furthermore, the migratory behaviour of some bird-species occurring in tropical moist forests provides an important tourist attraction with considerable economic benefits.

(10) Maintenance of biological and genetic diversity (2.1.16)

Tropical moist forests are one of the most species-rich ecosystems on earth. The total number of tropical tree species, for example, is estimated at 50,000. A single tree in the tropical rainforests of latin America has on average 400-600 species of arthropods, about 40% of which are beetles. Thus, this could account for a total of 30 million tropical arthropods alone! (May, 1988). Tropical rain forests in central America are also very rich in bird species. For instance, in one ha. of tropical forest in Costa Rica, 269 species of birds were counted (May, 1988). Recent estimates suggest that all tropical forest ecosystems together may contain even 90% of all species on earth (Min. LNV, 1990). Within the category of tropical forests, tropical rain forests are especially rich in plant and animal species and, although tropical moist forests cover only an area the size of the United States, it has been estimated that they contain almost half the world's species (Timberlake et al., 1982). This diversity of species (and subspecies) is the result of the favourable climatic conditions and the long span of time during which these forests have developed. Some tropical moist forests date back 60 million years and are the oldest ecosystems on earth (Myers, 1979). Here evolution could go its way undisturbed resulting in extreme ecological richness and in complex plant-animal relations. Natural ecosystems thus not only function as a storehouse of useful plant and animal spieces but also allow the continuous changing of genetic material by means of evolutionary processes which produce new organisms and genetic material. Only by conserving biological and genetic diversity in the natural habitat (in situ), as opposed to ex-situ conservation in gene-banks, and zoological and botanic gardens, will species and genotypes of plants and animals be able to perpetuate themselves and express their evolutionary potential.

Socio-economic value

Extinction of wild species and the loss of genetic information is an irreversable process with dramatic environmental consequences and strong ethical implications. Apart from disturbing the biological balance on earth, with unknown consequences, the loss of genetic information represents economic damage of unknown magnitude because of the lost opportunities for both present and future human generations to utilize this resource. A modest estimation of the economic importance of this function would amount to a monetary value that is at least equal to the capitalized value of the present economic benefits of the utilization of wild genetic resources, which is about US$ 800/ha. Because this value is rather speculative and leads to double counting, it is given between brackets in table 4.1.2-1 for reference only.

4.1.2 Carrier functions of tropical moist forests

The use of tropical moist forests for carrier functions usually involves drastic alterations, if not the destruction of the original ecosystem. Yet, apart from timber exploitation, man's interest in the functions of tropical forests thus far mainly focusses on the exploitation of some carrier functions, and many tropical moist forests have been destroyed to provide space for agriculture, plantations, cattle breeding, hydro-electric dams and mining activities. The unsuitability for this type of use is clearly illustrated by the vast amount of energy, resources and money needed to make use of such carrier functions. Sustainable use of carrier functions in tropical moist forest ecosystems necessarily implies great limitations to the type and scope of human activities. Only certain types of cultivation and recreational activities can, in principle, be utilized in tropical moist forest in a sustainable manner, provided these activities are well-managed and integrated in general conservation strategies.

(1) Habitat for indigenous people (2.2.1)

Many tropical moist forests still provide living space and a means of existence to indigenous people. Forest dwelling people have, over the course of thousands of years, developed intimate knowledge of the rain forest and have learned to use it's natural goods and services in a sustainable way. It is therefore especially tragic to see that the way of life of many of these indigenous cultures is threatened, and in many cases has been lost already, by the continuous encroachment of 'civilised' man into their habitat. Much of their land has been taken away for 'development' projects which are often doomed to fail because they do not take account of the natural limitations, leaving a wasteland in places where for thousands of years man lived in harmony with nature.

Socio-economic value

The value of the forest to indigenous people is clearly immeasurable since without it they loose their means of existence and, maybe even more important, their cultural identity. The economic value of this function, in terms of traditional market economics, is very difficult if not impossible to estimate. If an artificial economic (monetary) yardstick must be construed, one possibility would be to calculate a 'gross tribal product', including all benefits which indigenous people derive from the natural forest.

(2) Cultivation (2.2.2)

Cultivation is probably the predominant type of land use in tropical moist forest areas. Depending on the management system, cultivation in tropical moist forests usually results in the complete loss of the original ecosystem. Permanent agriculture and cattle raising are among the most practicised types of cultivation, yet farming is often the worst use of tropical rain forest soils. Most nutrients are stored in the vegetation, not in the soils and when cleared, most tropical forest soils are virtually sterile and very sensitive to erosion. Depending on the environmental and management situation, productivity drops after 2-3 years because the soil is exhausted. When productivity declines, the area is abandoned and the rains and wind turn the area into a wasteland. It has been estimated that about 80% of the current rate of deforestation is caused by conversion for cultivation (Min. LNV, 1990). Some types of cultivation which are more or less sustainable are briefly discussed below.

Shifting cultivation: by cutting only small patches of forest at a time, and allowing the rain forest to regenerate after a few years, it is possible to grow some crops without causing permanent damage to the original ecosystem.

(Agro)forestry: another way of using the forest for cultivation is extensive management aimed at the selective exploitation of one product or a group of products such as wood or so-called minor forest products (rattan, nuts, orchids, latex, etc.). Depending on the management system, the natural forest remains more or less intact. When no active management is involved (such as replanting seedlings), and only the natural productivity is harvested, this function comes under the category of production functions (see further).

Wildlife farming: As with plants (see above), some animal species may be managed in the setting of the natural forest to ensure an optimal productivity of which only the surplus is harvested.

Socio-economic value

Sustainable cultivation in tropical moist forests is very difficult, and may only involve certain types of shifting cultivation or extensive management for selective use of certain resources (timber, wildlife). For lack of better information, it was assumed that an intensity of 10% of the non-sustainable cultivation could produce a sustainable harvest, which would mean an annual return of about 15 US$/ha (see box 4.1.5-1)

(3) Recreation and tourism (2.2.4)

Some important parameters that determine the suitability of a given ecosystem or natural area for recreation are the quality of the scenery and the presence of 'special attractions' (e.g. rare or conspicuous plants and animals). Although it is difficult to generalize, it seems that in terms of the scenery, most people prefer an open forest or a savanna-like landscape with a rich herb layer where the plants and flowers can be appreciated by the visitors (Hallsworth, 1982), and where animals can easily be seen. This would mean that tropical rain forests are not very attractive to most tourists and nature trails will have to be planned carefully in order to enhance the recreational value of the rain forest. With proper management measures it must be possible to make a certain percentage of tropical moist forest areas accessible for tourism in a sustainable way.

Socio-economic value

Recreation and tourism in tropical moist forests could become an important source of foreign exchange, whereby part of the money generated could be used for conservation and sustainable development in the areas concerned. Even though tropical moist forests are essentially not very attractive, because of the humid climate and the rather limited scenic value, international tourism to this type of environment is increasing, especially in Central and South America. As experience with this type of use of tropical moist forests is rather new, data on the economic returns are rather limited. A very crude estimation of the potential sustainable use of tropical moist forests for tourism may be 2,000 visitors per year to a forest park of 50,000 ha, or 0.04 visitors/ha per year. A study of the Galapagos Islands (De Groot, 1988), calculated that each tourist who visited the islands spend on average US$ 1,300 in the country (excluding air fares). Extrapolating these data to tropical moist forests, assuming a 50% reduction in benefits because of lower entrance fees and lower local transportation costs, the contribution to the local and national economy would be US$ 650/per visitor or US$ 26/ha/year.

(4) Nature protection (2.2.5)

The conservation value of a given ecosystem or natural area is determined by many factors, including naturalness, uniqueness, species diversity, and number of rare and/or endemic species. Based on these parameters, tropical moist forests clearly have a great conservation value and a minimum amount of representative samples of all types of rain forests should be included in protected areas in order to conserve at least part of the natural heritage for future generations (see also box 4.1.2-1).

Socio-economic value

According to McNeely (1989), adequate management programmes for tropical forest reserves require an initial capital investment of 5-10 US$ per hectare and a recurrent budget for management costs of 1-3 US$/ha/year (= on average 2 US$). Also, the economic benefits from maintaining the area in its natural state, through appropriate management and regulations, should be mentioned here. To avoid double counting, no figure has been included for this function in table 4.1.5.-1, since these benefits consist of a combination of the values of all other types of sustainable use of the functions provided by the area (for a discussion, see chapter 3.3.2).

Box 4.1.2-1 Criteria for selecting and designing conservation sites in tropical moist forests

In selecting and designing protected areas care should be taken that the size of the area is equal to, or larger than the minimum critical ecosystem size, which is the smallest area in which the whole ecosystem can perpetuate itself (see also appendix I.9.4). According to Timberlake et al., (1982) this is on average 2,500 square km for tropical moist forests. However, the actual minimum size depends very much on the species composition of the forest ecosystem in question, and may vary between 500 and 100,000 km^2. In rich lowland rainforest, most tree species are present at densities of less than one per hectare, and many species at densities as low as 1 tree per 10 hectares. Using the rule of thumb-figure of a minimum viable population size of 5,000 individuals (either plants or animals, see App. I.9.4), a reserve would need to be at least 50,000 ha (500 km^2) for the richest plant habitat. The rarest animals in the forest occur at densities even lower than 1 per 10 ha. Tigers for instance may be as rare as 1 per 20 km^2; a reserve of 10 million hectares would therefore be required to contain a viable tiger population (UNDP & FAO, 1982). Also in view of a possible future climate change it is essential that conservation sites are selected carefully and that they are large enough to allow the occuring species a shift in distribution range to adjust to changing climatic conditions.

4.1.3 Production functions (resources) provided by tropical moist forests

Tropical moist forests contain a very large number of plant and animal species which are (or can be) useful to man. An educated guess with respect to useful plants points to 1 species in about 6 that somehow is known to be useful for non-timber purposes. About 25% of these useful species have medicinal properties, the rest provide other so-called 'minor' forest products such as fruits, gum, etc. (Jacobs, 1982).
In this chapter only the sustainable use of products from the natural tropical moist forest ecosystem is taken into account, which means that they can only be harvested in very small quantities. When assessing the production functions of the tropical moist forest it must also be realised that there is a difference between products taken directly from the primary forest, like wood or bushmeat, and products from cultivated plants belonging to species which have their wild stock in the forest, like rubber, rambutan or kina. In the latter case, the primary forest provides the genetic material which makes it possible to produce a particular product in cultivated areas in large quantities. This product then, falls under the genetic resource function. For a general discussion of the importance of forest resources to indigenous people and local communities, see chapter 4.1.5.

(1) Food, drink and nutrition (2.3.3)
Tropical moist forests provide numerous edible plants and animals. Direct gathering and hunting of such resources is mainly of local importance and includes the collection of fruits, nuts and seeds, sago (from palmtrees, especially the genus Metroxylon, the pith of which yields a kind of starch which is used as food in puddings), fungi, condiments/spices, bushmeat, birds'nests, and honey.

Socio-economic value
Food items from tropical forests, such as fruit and nuts, often have a considerable value, especially on the international market. In a study by Peters, Gentry and Mendelsohn (1989), it was calculated that one hectare of Amazonian forest in Peru produces fruit worth almost 650 US$. After deducting the costs associated with collecting and transport, net annual revenues were US$ 400 (based on 30% transportation costs and US$ 2.50 for wages per man-day). Assuming that 25% of the fruit crop is left in the forest for regeneration, the yearly revenues would be US$ 300/ha.
A field study by Caldecott (1988) in Sarawak, Malaysia, found that if wild pigs harvested by hunters had been sold at the nearest market place, they would be worth an estimated US $ 100 million per year.

Fig. 4.1.3-1 Sago pulp processed by a Penan woman, Sarawak

(2) Genetic resources (2.3.4)

Many well-known food items and industrial raw materials, that were originally harvested in the natural forest, are now cultivated. Primary tropical moist forests function as living gene banks which safeguard a stock of wild relatives of cultivated plants and animals. Wild germ plasm must continuously be imported from the centers of origin to maintain vitality or improve the productivity of the cultivated species, to reduce their susceptibility to rapidly evolving predators and diseases or to breed a more tasty variety.

Contribution to major food crops: Many food crop plants originated in the tropical forests and some key foodcrops depending on genetic material from tropical moist forests are wheat and rice (Timberlake et al.,1982). Banana *(Musa)* and citrus *(Citrus)* are the most traded tropical fruits, which both have their centre of diversity in the Malesian lowland rain forests. Other food crop species which have their origin in tropical moist forests include cacao, coffee, tea, mango, mangosteen, rambutan, durian, lychee, avocado, and peas. Originally these were all minor forest products but are now cultivated.

Contribution to other cultivated crops: Many other products are taken from cultivated species that depend on, or could benefit from wild genetic recources, for example timber, fuelwood, rattan, rubber and other biochemical-producing plants (notably sugar and carbohydrates for producing 'gasohol').

Contribution to medicine: The development of new medicines is also greatly dependent on the availability of wild genetic resources for cultivation of plants and animals with medicinal properties and for genetic manipulation.

Socio-economic value

The value of genetic resources on the world market can only partially be contributed to the remaining natural tropical forests, and is proportionate to the dependence of the cultivated crops on their wild relatives for cross-breeding. As a general rule-of-thumb, 10% of the market value was used to arrive at a monetary figure for the genetic resource function.

Some examples of the economic value of genetic resources of tropical moist forest and their economic importance, are given in the box 4.1.3-1. Based on these examples the contribution of genetic resources to the total value of products derived from cultivated plants and animals which depend on tropical moist forests is at least 3.8 billion US $/year. Tropical moist forests cover about 900 million ha, thus, the genepool value of tropical moist forests would be 4.2 US$/ha/y. If we assume that only about 10% of the genetic potential of tropical moist forests is currently being utilized, the annual potential value would be about US$ 40/hectare/per year.

Cacao tree

Box 4.1.3-1 Some examples of the economic value of genetic resources from tropical moist forests

Contribution to major food crops: According to Oldfield (1984), a reasonable estimate of the contribution of germplasm resources from tropical forests to the genetic supply industry in the US alone is at least 10%, or US$ 160 million per year. For improved crop seeds, the figure would be US$ 114 million. Worldwide, the value of tropical moist forest genetic resources to food crop productivity may be estimated at US$ 2 billion per year (De Groot, 1988b).
Contribution to other cultivated crops: A crude estimation of the total value of other cultivated crops is US$ 12 billion/year, of which 2.6 billion for rubber and 1.2 billion for rattan (De Groot, 1988b). Assuming a contribution of 10%, like food crops, the economic value of wild genetic material from tropical forests to other cultivated crops would be about US$ 1.2 billion per year. Since tropical moist forests make up 75% of the remaining tropical forest area their contribution would be about US$ 900 million per year.
Contribution to medicine: Economic calculations for this function are even more difficult than for food- and other (industrial-) crops. The total value of drugs originating in tropical moist forests was put at US$ 8-10 billion; following the '10%-rule' applied to food- and other cultivated crops, the contribution of genetic material from tropical moist forests to modern medicine could be put at US$ 900 million/year.

(3) Medicinal resources (2.3.5)
The maintainance of human health still predominantly depends on drugs derived from plant and animal species. Each year billions of medicinal prescriptions are written all over the world, of which about 20% find their origin in tropical moist forests (Farnworth et al., 1986). Although today most of the medicinal products from plants and animals are taken from cultivated species, natural tropical moist forest are still essential to the production of these medicines because they safequard the wild stock of genetic information of these species (see also the previous paragraph). However, some 'modern' drugs are still taken directly from the forest. For example, D-tubocurarine, made from the jungle liana *Chondrodendron tomentosum*, is used as a muscle relaxant in surgery. Chemists have so far been unable to produce it synthetically in a form which has all the characteristics of the natural product (WWF-US, 1983). Other examples can be found in chapter 2.3.5.
It must also be realized that we have only just begun to tap the great potential of tropical moist forests (and other natural ecosystems) for providing medicinal drugs. For example, 70% of the plant species so far known to have anti-cancer properties are tropical plants, and the tropical forests contain thousands of species whose potential has not yet even been tested (WWF-US, 1983). The recent discovery of an active substance against leukemia provided by the Rosy Periwinkle *(Cantharanthus roseus)*, a plant from the rainforest in Madagascar, is a good example of the actual and potential use of tropical moist forests for this function (Oldfield, 1984).
Other contributions of tropical forests to medicine and human health include the supply of test-animals (notably monkeys), medicinal leeches *(Hirudo medicinalis)*, and models for drug synthesis.

Socio-economic value
The indigenous inhabitants of tropical moist forests still largely depend on medicines taken directly from the forest. Worldwide, the value of medicinal prescriptions containing drugs originating in tropical moist forests is estimated at US$ 8-10 billion annually (De Groot, 1988b). Since there are about 900 million hectares of tropical moist forest left, the (potential) value of these forests for medicinal drugs would be about US$ 10 per hectare/year. If we assume that only about 10% of the medicinal potential of tropical moist forests are currently being utilized for medicinal purposes, the potential annual value would be US$ 100/hectare/per year.

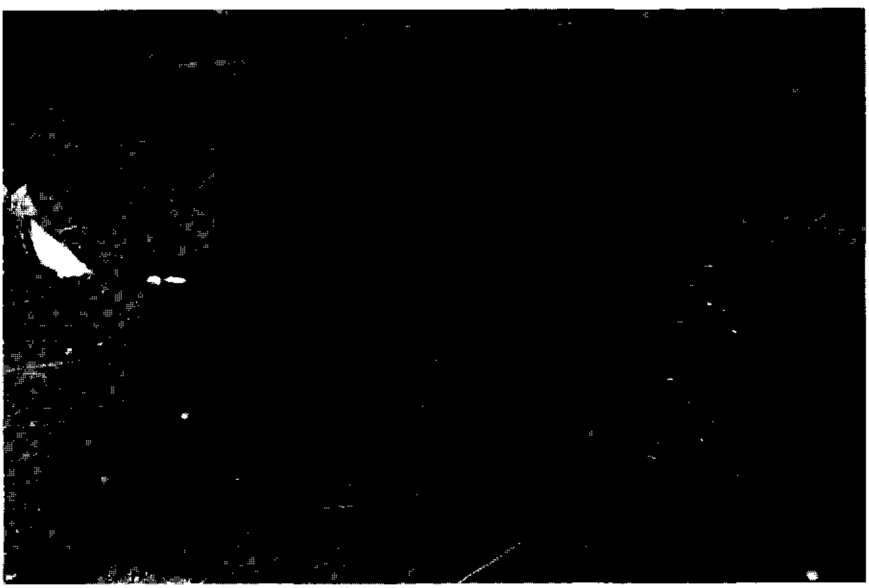
Fig. 4.1.3-2 Medicine-man on Siburut, Indonesia

(4) Raw materials for construction (2.3.6) and manufacturing (2.3.7)
Although today most materials needed for clothing, footwear, bedding and furnishing are provided by cultivated plants and animals or are artificially synthesised, some raw materials are still taken from the natural forest. For example, certain fibrous elements and weaving materials, skins and furs, pulpwood, leaves (for thatch and cottage-manufacturing), and timber and rattan (for construction). When harvested in small quantities many of these resources can be obtained in a sustainable manner and are grouped together under the term 'minor forest products'.
a. Rattan: Rattan is probably the most important 'minor forest product' which is still mainly harvested in the wild. There are at least 150 species of rattan, all belonging to the major group of scaly-fruited palms known as

the *Lepidocaryoideae* (Fitter, 1986), of which over 2/3 are useful. Apart from raw materials (canes) for building and construction purposes, rattan provides edible fruits, leaves (as thatch and for cigarette paper), 'dragon blood' (jernang, used for varnish, red dye, and medicine) and has many other uses (Jacobs, 1982).

Socio-economic value
The worldwide sale of rattan, including harvests from cultivated species, was about 1.2 billion US$/year (Jacobs, 1982, Dransfield in: Sygne, 1981) at a price of US$ 80/ton (Myers, 1979). From these sources it is impossible to distinguish those naturally harvested. Assuming that 10% is harvested from naturally grown plants, this would amount to 0.3 US$/ha/year.

Fig. 4.1.3-3 Orang asli man making roof cover from two species of rattan *Daemonos grandis and Calmus diepenhorstii*, Malaysia Peninsula.



b. Timber and pulpwood: Extraction of tropical hardwood (for timber and pulpwood) is probably the single most important product taken from natural rain forests. The worldwide consumption of timber in 1990 was 750 million m^3 while the use of pulpwood worldwide was 263 million m^3 (in 1974), of which an estimated 10% was provided by tropical moist forests (partly after Myers, 1979 and Steinlin, 1982). Because of the destructive nature of the harvesting process, which usually involves clear-cutting, this logging intensity greatly reduces, if not eliminates the possibility to harvest other forest products and causes the loss of most of the forest's other functions. Selective exploitation of timber in natural rain forests is sometimes possible on a sustainable basis but is very limited and may yield 7 m^3 per hectare per year at the most (= 10% of GPP) (De Groot, 1988). Peters, Gentry and Mendelsohn (1989) give even a lower figure and arrive a 30 m³ every 20 years for a sustainable harvest. Some important timber yielding species are meranti *(Shorea ssp)*, teak *(Tectona grandis)*, ramin *(Gonystylus baneanus)* and okoumè, providing poles, sawlogs and veneer for construction, building (houses, ships, etc.), fencing, furniture, mining (pitprops), lumber, joinery, packing, sleepers, plywood, containers, etc.

Socio-economic value

In a recent study, Peters, Gentry and Mendelsohn (1989) calculated that one hectare of Amazonian rain forest in Peru produced 93.8 m^3/ha of merchantable timber. If liquidated in one felling, this sawtimber would generate a net revenue of US$ 1,000 on delivery in the sawmill. Periodic selective cutting would be more compatible with the maintenance of the other functions of the forest, and Peters, Gentry and Mendelsohn (1989) calculated a maximum sustainable harvest of about 30 m^3/ha every 20 years. Multiplying this volume by a weighted average market price of US$ 17.21 per m^3 and deducting harvest and transport costs (transport costs were estimated at 40% of the market value, and a wage rate of US$ 2.50 per man-day was used) giving a net revenue of about US$ 310 at each cutting cycle, or on average a little over 15 US$/ha/year.

(5) Biochemicals (2.3.8)

Wild plants and animals, especially those occurring in tropical moist forests, also provide a wide array of biochemicals or bio-dynamic compounds which can be used by man for many different purposes. An important biochemical product with industrial value is latex or rubber. Most of the world's rubber production today stems from plantations although a small percentage is still taken directly from the natural forest. Peters, Gentry and Mendelsohn (1989) calculated that one hectare of natural Amazonian forest in Peru produced an annual rubber yield of about 50 kg, based on an average production of 2 kg of latex per tree and a natural stand of 24-25 trees per hectare. Raw materials for producing pesticides are another important type of biochemicals obtained from tropical forests.

Socio-economic value

According to Peters, Gentry and Mendelsohn (1989), 1 kg of latex obtained from Shiringa trees *(Hevea quianensis)* in a natural forest in Peru was worth 1.2 US$ in 1987. With a production of 2 kg/tree/year and a total of 24 trees in one hectare of forest, one hectare of natural Amazonian forest in Peru produces a sustainable annual yield of rubber amounting to about US$ 55 at 1987 market prices. Net annual revenues, after deducting the costs asociated with collecting and transport, were US$ 22 (based on 30% transportation costs and US$ 2.50 wage rate per man day). Assuming that 25% of the crop is left in the forest for regeneration, the monetary value of sustainable latex harvests would be somewhat over US$ 16 per hectare/year. In comparison, in 1984 the world consumption of rubber, mostly from plantations, was over 3.8 million metric tons worth ca 2.6 billion US$ (import value) (Oldfield, 1984). This industrialized production is, however, still largely dependent on the regular input of wild genetic resources.

(6) Fuel and energy (2.3.9)

Most people in the developing world still depend on fuelwood for cooking and heating. Because of the humid conditions, rain forests are not very suitable for providing fuelwood (most of the fuelwood harvesting takes place in the dry tropics), and therefore no economic calculations have been made for this resource.

(7) Animal feed and fertilizer (2.3.10)
According to Meyers (1979), 1 hectare of tropical rain forest could provide enough forage on a sustainable basis to produce more meat and leather per year, and do it at lower cost, than 1 ha of grassland through conventional cattle husbandry.

(8) Ornamental resources (2.3.11)
Many plants and animals from tropical moist forests are used and traded for ornamental/decorative purposes, for example orchids, butterflies, birds, skins, and feathers. They are also used as raw material for handicrafts (e.g. ebony for carving) and as objects of worship (i.e. products associated with cultural, tribal and religious ceremonies).

Socio-economic value
The trade in parrots is a well-known example and prices for the rarer species may be very high, up to 25,000 US$ for a pair of Hyacinth Macaws (see chapter 2.3.11). Since demand, and prices, go up when the resource becomes scarce, ornamental resources are especially prone to over-exploitation.

4.1.4 Information functions of tropical moist forests

Tropical moist forests provide a multitude of possibilities for spiritual enrichment, artistic inspiration and cognitive development. In spite of the importance of information functions to human welfare, it is not easy to arrive at a realistic estimation of their socio-economic value; some considerations concerning the economic valuation of information functions can be found at the end of this section (box 4.1.4-1).

(1) Aesthetic information (2.4.1)
In section 2.4.1 it was concluded that, for recreational purposes, most people prefer an open forest where individual plants and animals are easily seen. Yet, the dense rain-forests do have their own special beauty, both when observed from the ground, where the density and height of the vegetation provides impressive scenery to the viewer, and when observed from an aeroplane which shows a vast blanket of green covering the surface until the horizon, only occasionally interrupted by meandering rivers.

(2) Spiritual/religious information (2.4.2)
Apart from providing many material goods and services, tropical moist forests are an important source of spiritual enrichment to many people. Indigenous and tribal people in particular still have a strong spiritual attachment to their natural environment which is expressed in many religious ceremonies and customs in which the 'spirits of the forest' play an

important role. It is also reflected in social customs (taboos) which often have the purpose of ensuring sustainable use of the forest and bring about a responsible attitude towards nature. Many indigenous cultures attribute spiritual or religious values to certain natural phenomena, while certain natural areas or elements are used for religious or spiritual customs and rituals (sacred sites and objects of worship). The heritage value of tropical moist forests is also recognised by modern society which is reflected in numerous organisations and campaigns which strive for the protection of natural rain forests.

(3) Historic information
Tropical moist forests belong to the oldest ecosystems on earth and are therefore an important source of historic information. They are also considered as the 'cradle of evolution' where the development of life continued undisturbed for millions of years. By providing a home to many indigenous people, tropical moist forests are important in safeguarding historic information on how most of mankind used to live thousands of years ago.

(4) Cultural and artistic inspiration
Tropical forests are an important source of inspiration to many types of cultural or artistic expressions, such as painting, sculpture, film-making, television programs, and books. They are also often used as a motive in advertising and industrial design.

(5) Educational and scientific information
Tropical moist forests provide many opportunities for environmental education and research. Yet, relatively little is known as yet about the environmental characteristics and functioning of tropical rain forests. To make better use of tropical moist forests, man needs to improve his understanding of the functions of these complex ecosystems. Compared to the productivity of tropical moist forests, tropical agriculture and animal husbandry are still very inefficient and other (combinations of) uses of the forest are probably more beneficial. Future improvements in agriculture will certainly depend on broadening the range of species upon which man depends. Because competition in tropical moist forest ecosystems between species is very severe, these ecosystems provide unique opportunities for studying the process of evolution, thus improving our knowledge of how continuous selection and crossing of genetic material develops (new) varieties of plants and animals which may be better suited to serve human benefits. More research into the enormous variety of species and subspecies found in topical moist forests will certainly provide information on many novel and improved applications, not only for agriculture but also for many other uses.

Box 4.1.4-1 On the socio-economic value of the information functions of tropical moist forests

Many people enjoy the aesthetic, inspirational and educational information provided by natural ecosystems. Some of the information value of nature is exploited on a commercial basis, through organised tourism, artwork and educational excursions but most information-functions are 'consumed' directly by individual people, often even without them being aware of it. This means that it is rather difficult to arrive at a realistic estimation of the monetary value although the socio-economic importance of the consumptive use value of information functions is surely considerable. Some information functions also provide direct economic benefits, such as the use of natural areas for artistic inspiration (nature films, paintings, etc.) and the use for educational excursions and scientific expeditions. The combined economic value of the information functions of the Galapagos Islands, for example, was calculated at ca 3 million US$/year (De Groot, 1988), or almost US$ 4 ha/year (of which 80% for education and research and 20% for cultural/artistic inspiration). The economic value of the aesthetic, spiritual and historic information provided by tropical moist forests is even more difficult to estimate. For lack of better information, a combined value of 4 US$/ha/year was used in table 4.1.5-1 for the information functions of tropical moist forests.

4.1.5 Total socio-economic value of tropical moist forests

Based on the information provided in the previous four sections, the socio-economic importance of the goods and services provided by tropical moist forests is summarized in Table 4.1.5-1. This table is derived from the overall framework provided in Table 3.0-1.
For a discussion of the various types of values and methods which may be used to arrive at monetary values for environmental functions, the reader is referred to chapters 3.1. and 3.2 respectively.
When determining a total socio-economic value for a given natural ecosystem, care should be taken not to double-count values. It is also important to realize that the data presented in Table 4.1.5-1, are very crude estimations and probably underestimate the true socio-economic value of the natural goods and services in question. They only serve as an illustration of the evaluation method presented in this book and further research is needed to provide more detailed and accurate data.

(1) Conservation value

The conservation value mainly consists of the benefits derived from leaving a given area in its natural state. This type of value is therefore also referred to as non-use value and mainly relates to regulation functions. The importance of undisturbed natural areas to indigenous people and the costs involved in managing the area as a conservation site should be included under this heading, as well as the spiritual or intrinsic value.
Calculation of monetary benefits of the conservation value of regulation functions is quite difficult and this is a research area which deserves much more attention in the future.

Table 4.1.5-1 Socio-economic value of environmental functions provided by tropical moist forest ecosystems (based on maximum sustainable use levels)
(values are expressed qualitatively (++) or in US$/ha/year)

Environmental Functions	1 Conservation value	2 Existence value	3 + 4 Social values[1]	5 Consumptive use value	6 Productive use value	7 Value to employment
	Types of values (based on Table 3.0-1, for explanation, see text)					
Regulation Functions	**>> 11**	**++**	**++**		**++**	
Buffering of CO2	++		+		*	
Climate regulation	++		+		*	
Watershed protection	++				*	
Erosion prevention	++				*	
Storage/rec. human waste	+		+		*	
Bio-energy fixation	(20000)[2]	+			*	
Biological control	11	+	+		*	
Migration habitat	++	++	++		*	
Maintenance of biol. div.	(800)[2]	++	++		*	
Carrier Functions	**>> 2**	**++**	**++**		**> 41.0**	**++**
Habitat for indig. people	++	++	++		*	
Cultivation					15.0	+
Recreation			+		26.0	++
Nature conservation	2	+++	++		*	+
Production Functions			**++**	**++**	**471.0**	**++**
Food/nutrition			++	+	300.0	++
Genetic resources			++		40.0	+
Medicinal resources			++	+	100.0	+
Raw materials for manuf.				+		++
– Rubber/latex					16.0	
– Timber					15.0	
– other					0.3	
Biochemicals					*	+
Fodder and fertilizer				+	*	+
Ornamental resources				+	*	+
Information Functions	**++**		**++**	**++**	**> 4.0**	**+**
Aesth./Spirit./Hist. inf.	++		++	++	*	
Cultural/artistic insp.			+	+	0.8	+
Educ. & scientific inf.				+	3.2	+
Total annual value	**>> 13**	**++**	**++**	**++**	**>> 5160**	

[1] Social values consist of the importance of environmental functions to human health and the option value placed on a safe future.
[2] If a figure is given within brackets it was not used in calculating the total value because the calculation is too speculative.
* These functions do contribute to economic productivity, either directly or indirectly, but no market or shadow price could be determined due to lack of information and/or shortcomings of the market mechanism.

(2) Existence value

Tropical moist forests belong to the oldest and most complex ecosystems on earth which are easily disturbed but very difficult to regenerate. For these and many other reasons, tropical moist forests have a high intrinsic value which is reflected by numerous conservation organisations and individual people who are willing to invest much time, energy and money to ensure their protection and continued existence on earth. In Table 4.1.5-1, the relative importance of this value for a given function has been indicated qualitatively.

(3) Contribution to human health

Many environmental functions provided by tropical moist forests contribute directly or indirectly to the maintenance of human health, such as the maintenance of a certain air-quality (e.g. through buffering of CO_2 and other air pollutants), the regulation of the local and global climate, storage and recycling of human waste, biological (pest) control, providing food and medicinal resources and providing opportunties for recreation and cognitive development.

The conciousness of the importance of these functions to human health is slowly emerging and the economic benefits are partly reflected by some of the calculations made for the productive use values. This value is therefore only indicated in qualitative terms for certain functions in table 4.1.5-1, yet it is an important factor which should be taken into account in the planning and decision-making process on its own merits.

(4) Option value

Tropical moist forests have a large option value because of their complexity and enormous variety of species. Many of these species are not even known to man yet, and the potential for future discoveries of new functions is almost unlimited.

(5) Consumptive use value of tropical moist forest functions

The consumptive use value relates to those goods and services which can be harvested directly from the natural environment, such as production functions. Most information functions should also be mentioned here. The consumptive use value of tropical forests is primarily of importance to the indigenous tribes, although many local 'modern' communities in developing countries also depend directly on the natural forest for food, fodder, wood, fibres, thatch (for construction and handicraft), medicins, etc. Prance et al, (1987), for example, found that four Amazonian Indian groups used between 49 and 79% of the tree species in their habitat, indicating that the rainforest of Amazonia contain an exceptionally large number of species that are useful to local people. De Beer & McDermott (1989) estimate that in Southeast Asia alone, at least 29 million forest dwellers are critically dependent on these resources while the total population deriving benefits from them is substantially greater. Although no real market value can be determined for these resources, since they are 'consumed' directly and do not pass through a market, the socio-economic value of the sustainable use of these 'minor forest products' for domestic use is considerable. By using shadow price techniques, an impression of the monetary value of these forest resources can be obtained.

(6) Productive use value of tropical moist forest functions
This value relates to the direct contribution of environmental functions to the economy. The productive use value mainly relates to production and carrier functions, although also some regulation and information functions also contribute directly or indirectly to the economic production process. Often it is possible to calculate market or shadow prices for these functions and, according to table 4.1.5-1 the total productive use value of tropical moist forest functions amounts to more than 500 US$/ha/year.
As an example, the combined productive use value of the production functions (resources) of tropical moist forests are discussed in some detail below. Marketable tropical forest resources have traditionally been divided into two main groups: timber resources, which include sawlogs and pulpwood, and non-timber or 'minor' forest products (= all other products including medicinal and genetic resources). For many of these resources it is possible to estimate a monetary value, either directly derived from market prices or calculated through shadow pricing techniques. When applied rigorously, such calculations show that, contrary to common belief, timber logging and subsequent cultivation practices, which are often non-sustainable, are less economic than the sustainable harvesting of the so-called 'minor' forest products.
According to Myers (1988), a tropical forest tract of 500 square kilometers could, with effective management, produce a self-renewing crop of wildlife with a potential value of at least US $ 10 million per year, or slightly more than US $ 200 per hectare/year. Peters, Gentry and Mendelsohn (1989) made a detailed study of all the actual and potential benefits of an actual tract of one hectare of tropical forest in Peru and found that of the total number of trees on the site, 72 species (26.2%) and 350 individuals (41.6%) yielded useful products, mainly fruits and latex (rubber) with an actual market value of about US $ 700. After deducting collecting and transport costs, the net annual revenues were US$ 422. Fruits and latex represent more than 60% of the total market value of the forest products, yet they are only but two of many different products provided by the forest. If it were possible to include revenues from other resources, the relative importance of the non-wood products would increase even further. The economic and monetary value of sustainable use of 'minor' forest products is therefore probably much higher than US$ 422/ha/year. At 5% interest rate, this would represent a Net Present Value of US$ 8,440. By contrast, non-sustainable use of tropical moist forest resources has a capitalized value of not more than US $ 4,000 (see box 4.1.5-1). Thus, sustainable use of 'minor' forest products is clearly more economical

than timber-logging, especially since the present timber harvesting practice for commercial logging tends to be an ecologically disruptive procedure, whereas wildlife harvesting can leave forest ecosystems virtually undisturbed (Myers, 1988).

Box 4.1.5-1 Monetary value of logging and intensive cultivation in tropical moist forests

Current use of tropical moist forests for cultivation usually involves clearcut, followed by use of the area for plantations or cattle-breeding, providing the soil in the logged area allows for these types of cultivation. The one-time yield of clearcut timber logging in tropical areas has been estimated to be worth between 150 US$/ha (Meyers, 1988) and about US$ 1,000/ha (Peters, Gentry and Mendelsohn, 1989). Since this is a one-time yield, the Net Present Value, at 5% interest rate, would only be between 10 and 50 US$/ha. Cultivation yields on average US$ 150/ha/year: for example, Sedjo (1989) calculated that the value of timber and pulpwood obtained from 1 ha of Gmelina arborea plantation in Brazilian Amazonia is about US$ 160/ha/year (NPV = US$ 3,184). The gross revenues from fully-stocked cattle pastures in Brazil are reported to be US$ 148/ha/year which amount to a Net Present Value (NPV) of US$ 2,960 (Buschbacher, 1989). Thus, the total return from logging and intensive cultivation amounts to a capitalized value of about US$ 4,000/ha, which will become progressively less as time proceeds.

Another way of measuring the socio-economic value of resources provided by natural tropical forest ecosystems is to estimate their contribution to the national economy, which is often considerable. For example, in India, non-wood forest products in the early 1980's provided 40% of the total net revenues accruing to the Indian government from the forestry sector, and 63% of the forestry exports (Gupta and Guleria, 1982). In 1987, Indonesia, Thailand and Malaysia exported minor forest products (e.g. nuts, fruits, bird-nests and -feathers), with a market value of at least US $ 270 million (de Beer & McDermott, 1989). For Indonesia alone the figure is US $ 238 million; with 90 million ha of tropical moist forest left in Indonesia, the value per hectare would be about US $ 2.6.

(7) Value of (the use of) environmental functions to employment

Another measure for the socio-economic value of environmental functions is their contribution to employment. Ideally, for each function the influence on employment should be assessed and expressed in the number of people (or man-years) which depend on the continued availability and use of the function. Within the scope of this study, such a detailed analysis was not possible. As a general rule, it can be said that sustainable use of environmental functions is usually more labour-intensive than non-sustainable exploitation of environmental goods and services. For example, in 1979 about 150,000 people in Indonesia were employed in the (sustainable) collection of non-timber products. In contrast, the total employment in the logging industry was only 70,000 in 1982 (de Beer & McDermott, 1989).

Recreation and tourism in tropical moist forests in particular could stimulate local employment.

4.1.6 Capital value and some implications for planning and decision-making

(1) Capital or net present value of (sustainable) use of tropical moist forests
In Table 4.1.5-1, estimates have been given of the annual monetary value of some environmental functions provided by tropical moist forests. Since environmental functions provide goods and services indefinitely, when utilized in a sustainable manner, the monetary value of these goods and services must be seen as the interest on the capital stock, i.e. the natural ecosystems that provide these functions. Thus, the future yearly monetary benefits must somehow be included in the present value of the forest. To calculate the net present value (NPV) a simple discounting model can be used: V/r, where V is the annual net revenue of a given function and r is a 5% inflation discount rate (after Peters, Gentry & Mendelsohn, 1989). As discussed in chapter 3.2.3, it would be more appropriate to speak of 'interest-on-capital' in the case of calculating future benefits of natural ecosystems.
It then becomes possible to compare the net present value of sustainable use of tropical moist forests versus non-sustainable use of the conversion of the forest for logging and cultivation.
a. The Net Present Value of 1 ha of tropical moist forest that is converted to timber and pulpwood plantations is estimated at US$ 3,184 (based on 5% interest rate), while that of pastures is estimated at US$ 2.960, excluding the costs of weeding, fencing and animal care. Both estimates are based on the optimistic assumption that plantation forestry and grazing lands are sustainable land use practices in the tropics (Peters, Gentry and Mendelsohn, 1989), which they usually are not.
b. The Net present value of sustainable timber harvests and annual fruit and latex collection of the tree resources growing in one hectare of Amazonian forest was estimated at US $ 6,820 (Peters, Gentry and Mendelsohn (1989). According to Table 4.1.5-1, the annual monetary value of sustainable use of all the functions of the natural tropical moist forests combined is at least US$ 500/ha; at an interest rate of 5% this amounts to an NPV of US$ 10.000. The real value is probably much higher still.

(2) Some implications for planning, management and decision making
Thus far, the use of tropical moist forests has mainly focussed on the short-term exploitation of some production and carrier functions, notably timber exploitation and cultivation. Most financial appraisals of tropical forests have focused exclusively on timber resources and have ignored the market benefits of non-wood products and other long-term benefits of the forest. As a result there has been a strong market incentive for destructive logging and widespread forest clearing. However, compared to the total value of the other functions provided by the forest, which are lost in the logging process, clearcutting for timber in tropical moist forests is not only ecologically disruptive but also economically unsound.

A detailed study of all the present and potential benefits of an actual tract of one hectare of tropical forest in Peru by Peters, Gentry and Mendelsohn (1989) showed that sustainable use of tropical forests presents an economic value which is considerably more than has been previously assumed, and that the actual market benefits of timber are very small compared to those of non-timber resources. Already after two years, income from sustainable use of forest products is greater than that from clear-cut and agricultural profits combined (Peters, Gentry and Mendelsohn, 1989). Moreover, the total net revenues generated by the sustainable exploitation of 'minor' forest products are two to three times higher than those resulting from forest conversion for cultivation (see above).

Thus, tropical moist forests are much more than a timber-mine and a cheap source of land for agriculture. Yet, many governments are apparantly still not aware of the great economic value of natural tropical forests and allow them to be cleared and burned by settlers and cattle ranchers, logged out by timber companies and left bare by miners. These governments are clearly selling a valuable resource cheap (Bolivia, for example, once sold 1 million hectares of virgin forests at a mere US$ 42.-/ha (Myers, 1979).

Before deciding upon the use of a given function in tropical moist forests for productive purposes, a thorough cost-benefit analysis should evaluate all ecological and socio-economic consequences. By making a systematic analysis of all the functions of the forest, the ecological and socio-economic value can be made clearer which may contribute to more balanced planning and decision-making. If all factors are taken into account, it will often show that sustainable use of natural ecosystems, especially tropical moist forests, is not only environmentally safer than short-term (over)exploitation, but also economically more sound.

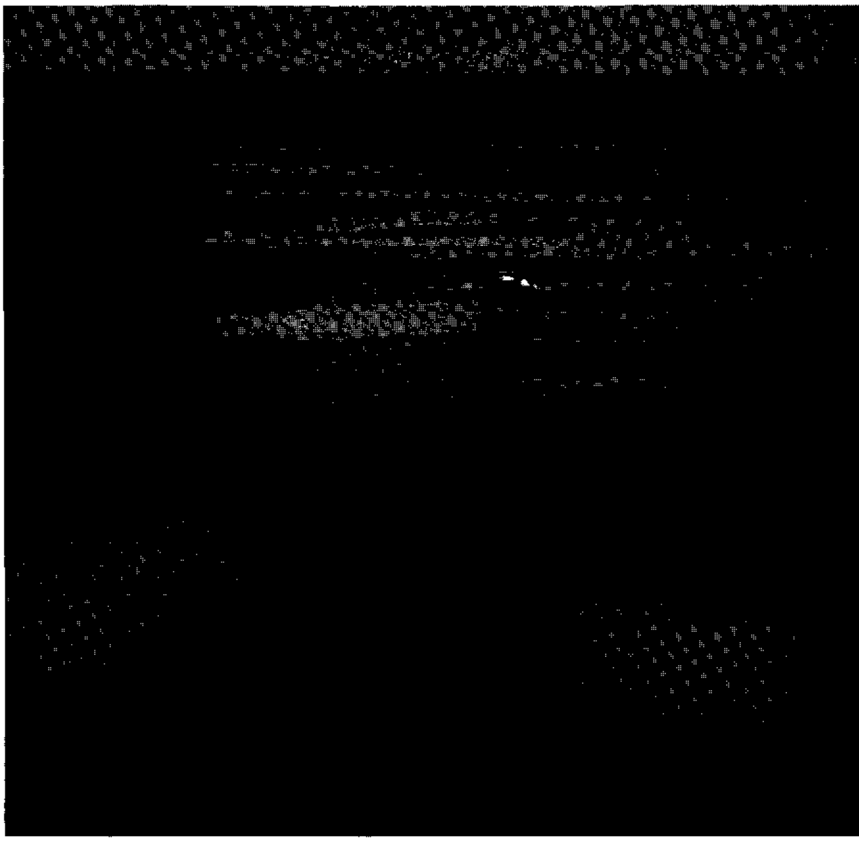
4.2 Functions and values of the Dutch Wadden Sea

Introduction

The Dutch Wadden Sea is an estuarine environment which forms the northern coastline of the Netherlands and has a length of about 195 km, including the Eems-Dollard estuary. The Dutch Wadden Sea is incompletely separated from the North Sea by six barrier islands, with a distance to the mainland varying between 7 and 30 km. In the past, over 100 km^2 has been embanked and in 1932 the IJsselmeer (ca 2,000 km^2) was separated from the Wadden Sea with the closure of the Afsluitdijk. The remaining total surface area of the Dutch Wadden Sea, excluding the islands, is about 2,700 km^2 (De Groot, 1986)
The Dutch Wadden Sea is part of a much larger estuarine area, stretching

further north-east along the coasts of Germany and Denmark. With exclusion of the islands, the international Wadden Sea area covers about 8,000 km^2 and is one of the largest wetlands in the world (Mörzer Bruyns & Wolff, 1983).

Fig. 4.2.0-1 Picture of the Dutch Wadden Sea



'Wetlands' is a collective term to describe those ecosystems which form an interface between land and water. They constitute a very diverse group of ecosystems which have been collectively defined by the Convention on Wetlands of International Importance (the Ramsar Convention, 1975) as 'areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres'. Among the most important wetland ecosystems are: tidal and freshwater marshes, bogs, fens, herbaceous and wooded freshwater and peat swamps, mangroves, coastal lagoons, floodplains, deltas, and estuaries (Dugan, 1990).
The Dutch Wadden Sea belongs to the so-called bar-built estuaries, which are defined as 'a shallow basin, often partly exposed at low tide, enclosed

by a chain of offshore barrier islands, broken at intervals by inlets' (Odum,E.P. 1971). The Dutch Wadden Sea basically consists of three major ecosystem-complexes: permanently submerged areas, tidal flats and salt marshes. Only 3% of the study area consists of more or less permanently dry land: the supra-littoral zone (the area above + 1.3 m MTL (= Mean Tide Level) but still influenced by seaspray). It is usually dry, except during extreme high tide. Coastal ecosystems found in this zone are salt marsh, brackish grasslands, summer polders, reed marshes and dunes. About 47% of the study area belongs to the eulittoral zone (the area between - 1 and + 1 m MTL). This area falls dry twice a day and consists of sandy and muddy tidal flats. The remaining 50% is always submerged (the sub-littoral zone), including shallow areas and deeper gully's and tidal channels with a maximum depth between 10 and 40 m.

Tidal areas, and the wide shallows, marshes and swamps that accompany them perform a multitude of ecological functions many of which have great socio-economic value to man. Because of their location between land and water, wetlands are among the most productive of the world's ecosystems, and play a major role in food production. In addition they provide a wide range of other goods (such as timber and thatch) and services (like flood prevention, shoreline protection, water purification, and possibilities for recreation). Wetlands also have great natural value as breeding, feeding and resting grounds for great numbers of fish, (migratory) birds and other animals. Another important function of estuaries is their role in the continued normal functioning of nutrient cycles. Due to their high mineralisation rate estuaries can recycle large amounts of (organic) human waste without negative side effects.
Coastal marshes, and other shallow water areas such as reefs, export mineral and organic nutrients that support much of the biological production of adjacent estuarine and coastal waters (Gosselink, et al. 1974). These estuaries and coastal waters, in turn, serve as important-nursery grounds for coastal fish and shellfish: about two-thirds of the fish caught throughout the world were hatched in tidal areas (Wagenaar Hummelinck, 1984).
Because of its ecological diveristy, most of these general wetland-functions are also found in the Dutch Wadden Sea (see table 4.2.0-1).

Preferably, these functions should be described for each type of ecosystem (i.e. permanently submerged areas, tidal flats and salt marshes) separately. In order to avoid too lengthy descriptions, however, the functions of the Dutch Wadden Sea are analysed here for the entire study area. When certain functions are performed exclusively by one particular ecosystem, this will be clearly indicated.
For the sake of briefness, only a short description is given of the most important functions and the environmental characteristics (parameters) which determine the function-performance. More information on some

parameters can be found in Appendix I of this book. For reference, the number of the corresponding paragraph in chapter 2, where more general information on a given function can be found, is given between brackets.

Table 4.2.0-1 Functions of the Dutch Wadden Sea

1 Regulation functions	2 Carrier functions
Climate regulation	Cultivation/aquaculture
Flood prevention and coastal protection	Recreation and tourism
Erosion prevention and sediment-control	Nature protection
Bio-energy fixation	
Storage and recycling of organic matter	
Storage and recycling of nutrients	
Storage and recycling of human waste	
Nursery function and migration habitat	
Maintenace of biological diversity	
3 Production functions	**4 Information functions**
Drinking water	Aesthetic information
Food/nutrition	Spiritual/historic information
Raw materials for building/constr.	Cultural/artistic inspiration
Energy resources	Educational & scientific information

Box 4.2.0-1 About the Dutch Wadden Sea case study

The Dutch Wadden Sea was chosen as an example of a temperate, tidal wetland ecosystem. Sometimes additional information on other tidal wetlands is included for explanatory purposes. Most of the information presented in this case study was drawn together from literature research and original inquiries performed by a group of six MSc-students of the Wageningen Agricultural University who worked under the supervision of the author: Herman Bolhuis, Harmke van Dam, Peter Eijsten, Lucas Goldsteen, Hans Kaffener and Carla Upperman (Bolhuis, et al., 1984). Compared to other ecosystems, (tidal) wetlands are relatively well-studied. Yet, much information on the many functions and values of the Dutch Wadden Sea is still lacking, partly because of constraints in time, and financial and human resources which were available for carrying out this case study, and partly because the information simply is not available. One of the benefits of systematic function evaluation is that it reveals in what research disciplines essential information for environmental planning and management is still lacking. This chapter gives a brief summary of the functions and values of the Dutch Wadden Sea, a more detailed description can be found in a separate case study report (De Groot, 1986).

4.2.1 Regulation functions of the Dutch Wadden Sea

(1) Climate regulation (2.1.5)

Large bodies of water, such as the Wadden Sea, have a strong influence on climate conditions such as temperature, precipitation and wind-speed, both in the area itself and in the surrounding areas.

Influence on temperature: The Wadden Sea absorbs more solar radiation than a land mass of comparable size would do. Thus, daily and seasonal temperature differences are buffered, not only in the Wadden Sea area itself, but also on the bordering mainland. Here, winters are milder and

summers cooler than they would be without the presence of the Wadden Sea (which has a positive effect on, for example, agricultural activities).
Influence on precipitation: Above large water masses, evaporation is relatively high, thus increasing precipitation in leeward areas. As a result, the north-eastern provinces belong to the wettest in the Netherlands.
Influence on windspeed: Windspeeds may reach greater values above large bodies of water than above vegetated areas. The average windspeed in the Dutch Wadden Sea area is 6.5 m/s, compared with an average wind-speed for central Holland of 5 m/s. On the other hand, the Dutch Wadden Sea reduces the force of stormwinds and provides a buffer for the adjacent mainland (see also next section).

Socio-economic value
The tempering influence of the Dutch Wadden Sea on the weather conditions in the north-eastern part of the mainland may benefit agricultural production in this part of the country. Also recreational use in and near the study area is influenced by the climate. The Wadden Sea is one of the sunniest parts of the Netherlands, but at the same time relatively cold, wet and windy. It is therefore difficult to determine the exact influence of climate on the number of visitors to the Wadden Sea. The impact of the Dutch Wadden Sea on the climate also influences possibilities to generate energy (from windpower) and to extract (drinking)water from the adjacent dune-systems. In theory, it is possible to calculate a monetary value for this function (which may be either positive or negative) but this has not been attempted for this case study.

(2) Providing flood prevention and coastal protection (2.1.6)
By absorbing energy from waves coming from the open sea, the Dutch Wadden Sea serves as a buffer to the mainland for the impact of storms which mainly come from the north-west. Coasts protected by natural marshes (and barrier islands) suffer comparatively little damage even in fierce hurricanes.

Socio-economic value
This protective function represents a considerable socio-economic value since it prevents economic damage and possible loss of life that would result from flooding of the mainland in the absence of this barrier. An indication of the protective value of a wide band of energy-absorbing marshes and barrier islands is given by the increasing national cost for disaster relief in coastal areas which either lack these natural protective breakwaters or where they have been filled in or bulkheaded for housing or other types of development (Gosselink et al., 1974). Thibodeau & Ostro (1981) calculated a flood-control value for wetlands in Massachussetts (USA) of almost US$ 5,000/ha/year, representing the (prevented) damage that would occur if the wetlands were drained.
Another method would be to calculate the investments that would be needed for coastal protection without the presence of the Dutch Wadden Sea. The difference in actual expenditures on coastal protection and investments that would be needed without the protective function of the Wadden Sea form the so-called 'compensation costs'. Using this appraoch, the U.S. Army Corps of Engineers, calculated that retaining a wetlands complex outside of Boston, Massachusetts realized an annual cost savings of US$ 17 million in flood protection alone - not including other benefits such as sediment reduction (Hair, 1988).
Because of the amount of time needed to gather the necessary information, no shadow price for the flood-prevention function has been calculated for the Dutch Wadden Sea-situation. Yet, as an indication of the monetary value involved, a figure of US$ 500,-/ha/year, being 10% of the value calculated by Thibodeau & Ostro (1981), was used as a minimum estimate.

(3) Prevention of erosion and regulation of sedimentation (2.1.8)
Another function of marsh-estuaries is the protection of beaches on the barrier islands. Gosselinck et al. (1974) state that where the energy and muddy sediments of storm tides can be absorbed by large areas of marsh-estuary the natural erosion of beaches is at least balanced by formation of new beaches. The powerful flow of water in and out of large tidal basins also tends to keep harbours and inlets 'dredged', which is another example of useful 'free work of nature'. According to Coates (1972), all of the harbours in the 19th century on the southeastern coast of England were silted in when the great marshes were reclaimed, and constant dredging and a vast expenditure of national funds became necessary to keep the harbors operational.

Socio-economic value
Similiar to the flood prevention function, the economic value of protective estuaries can be deduced from the amount of money that would be needed to protect beaches from erosion through artificial breakwaters, or restore them after damage has occurred, in the absence of these estuaries. In the case of the Dutch Wadden Sea it is quite difficult to estimate the positive (or negative) influence on the beaches since most are located at the Northsea-side of the barrier islands.

(4) Fixation of solar energy and biomass production (2.1.10)
The conversion of abiotic energy into biomass is an essential pre-condition for all other functions that may be attributed to natural systems and this function may therefore be considered as the overall 'life support value' of a natural ecosystem.
The Gross Primary Production (GPP) of the Dutch Wadden Sea totals on average ca. 1,450 gr. organic matter (dry weight/m^2/year), of which about 700 gr. is detritus which originated in the North Sea, the rest is mainly produced in the salt marshes and muddy tidal flats. The net GPP of the Dutch Wadden Sea (750 gr.) has a caloric value of about 3,200 kcal. The average Gross Primary Productivity for the biosphere (not including the ice caps) is 2,000 kcal/m^2/year or 465 gr. organic matter/m^2/year (Odum,E.P., 1971), thus ranking the Wadden Sea among the most productive ecosystems in the world. The amount of 'useful energy' fixed by an ecosystem is determined by the Net Primary Production (NPP), which is the total amount of organic matter produced by a life community minus loss of organic matter due to respiration, consumption, excretion and other energy-losses at the various trophic levels. On average, NPP equals ca. 50% of GPP (see chapter 2.1.10). The Net Primary Production capacity of the Dutch Wadden Sea is thus about 375 gr/m^2/year. With a total surface area of 2,700 km^2 this amounts to approximately 400,000 ton (dry weight) which equals about 4 million ton freshweight.

Socio-economic value
According to Gosselink et al. (see 2.1.10) the value of the potential 'useful work' of 1 kcal of biomass produced is equal to 1 dollar. For the Dutch Wadden Sea, this would amount to a monetary value of 3,000/ha/year. By using this overall 'life support value', Gosselink et al. (1974) suggest that it is possible to give an indication of the potential value of all functions combined, without having to specify how the available energy is

divided into different uses and functions. This would be an important advantage, since many uses of environmental functions conflict with one another, and it is therefore difficult to integrate or add the monetary values of the separate functions. Consequently, too avoid double counting this value should never be added to monetary values which are calculated for separate functions.

(5) Storage and recycling of organic matter (2.1.11)

Because of the high metabolic activity of wetlands, especially in the salt marshes (see the previous function), and because of the presence of tidal movements, which bring fresh water and decomposers to the areas where sewage systems enter the study area, the Dutch Wadden Sea is able to mineralise large amounts of organic waste. When utilising estuaries for 'secundary treatment' of organic waste, it must be realised that too large amounts of organic matter introduced into natural systems will reduce dissolved oxygen levels, since the mineralisation process requires oxygen. This oxygen demand is expressed in BOD (see appendix I.4.6) and can be used as an indicator of the maximum carrying capacity of aquatic ecosystems for this function. The maximum purification capacity of the Dutch Wadden Sea (270,000 ha) is estimated at 445 person equivalents/ha/day which requires 40 kg BOD5/ha/day for mineralisation (Dankers, 1978). Research in the USA has shown that the BOD in estuaries can vary between 1,650 (Thibodeau & Ostro, 1981) and 8,000 (Gosselink et al.,1974) per hectare/year. Assuming a biological active period of on average 185 days/year, this would amount to an average mineralisation capacity of 26 kg BOD/ha/day. This would imply that the Dutch Wadden Sea has a relatively high capacity to recycle organic waste.

Socio-economic value

The recycling of organic matter and nutrients (see next section) are important services to human society which, if they were not performed and would have to be replaced by artificial methods, would present considerable (compensatory) costs. In addition, the preventive nature of this function saves much money in the sense of non-inflicted damage that would result from polluted air and water, such as lower revenues from, for example, fishery, aquaculture and recreation.

According to Van Beek (1983), artificial (secundary) treatment of organic waste costs Dfl. 17.-/p.e./year (based on exploitation- and investment-costs discounted in 20 years), or Dfl. 0.05/p.e./day. Thus, the potential monetary value of the Dutch Wadden Sea as 'secundary treatment plant' is, 0.05 Dfl x 445 (p.e./ha) x 185 days = Dfl 4,116 or at least US$ 2,000/ha/year.

(6) Storage and recycling of nutrients (2.1.12)

The most important contribution of marshes and estuaries to waste treatment is the removal and recycling of inorganic nutrients, which is a very expensive process if carried out by man artificially (so-called tertiary waste treatment). When nutrient-rich effluents enter a marsh, the nutrients are effectively trapped by the tidal circulation pattern, and assimilated in the productive biological system. Estuarine ecosystems have evolved adaptations to high nutrient levels, and have a large capacity to buffer nutrient changes. As an example, the storage and recycling of nitrogen and phosphate are describe below, whereby it is assumed that tertiary

A problem with many synthetic chemicals (such as oil-products and pesticides) and heavy metals is that they are stored in fatty tissue of living organisms and thus accumulate in the life community through the food chain. In time, regular discharge of even small amounts of these elements can therefore have serious consequences for the survival of certain species.

(8) Nursery function and migration habitat (2.1.15)
Most animals, both resident and migratory, use different habitats within their 'home range' for breeding, feeding and resting. Because of the border-position between land and sea, and their high productivity (see above), estuaries provide important (temporary) habitats to many migratory species (see box 4.2.1-1).

Box 4.2.1-1 Importance of the Dutch Wadden Sea to migratory species

Birds: The Dutch Wadden Sea is a very important area for migrating and wintering birds. About 75% of all bird species found in the Dutch Wadden Sea are migratory. In summer, the average daily number of birds present varies between 200,000 and 400,000, during migration (especially from August - October) and in the winter months the number of birds feeding and resting in the Dutch Wadden Sea may be close to 1 million (Mörzer Bruyns & Wolff, 1983). The actual number of birds depending on the Wadden Sea is still much higher because there is a continuous flow of birds through the area .The tidal flats form important feeding grounds for many species such as teal, wigeon, brent goose and barnacle goose, while salt marshes function as high tide roosts especially for waders, gulls, terns, ducks and geese. A large percentage of the N.W.European population of many bird species is found in the Dutch Wadden Sea during part of the year: godwit (70%), teal (58%), barnacle goose (44%), shellduck (32%), wigeon (16%), avocet and pintail (8%).
Fish: About 70% of all fish-species occuring in the Dutch Wadden Sea are migratory of which 83% depend on the study area for reproduction.
Mammals: Occasionally, specimens of the grey seal, harbor porpoise and bottle-nosed dolphin are seen in the Dutch Wadden Sea.

Some migratory species have commercial value, whereby the adults are harvested outside these breeding (nursery) areas. Most estuaries are important breeding grounds for many commercial species of fish and crustaceans, and the Dutch Wadden Sea forms no exception: species such as plaice (of which 80% of the recruitment depends on the Dutch Wadden Sea), sole (50%), shrimp, dab, herring, whiting and cod all use the Dutch Wadden Sea as nursery area to stock the North Sea populations (Binsbergen, 1983).
North-sea fisheries depend to a large extent on the Wadden Sea as nursery area and in 1981, the nursery function of the Dutch Wadden Sea provided an average of 25% of the North Sea catch of plaice, sole, shrimp, dab and herring. The total 'Wadden Sea-related' North Sea catch in 1981 amounted to almost 18,000 tons (Bolhuis, et al., 1984).

Socio-economic value
In 1981, 18,000 tons of fish and shrimp had a commercial (market) value of almost 65 million guilders (= whole sale price, revenues from further trading and processing not included) (Bolhuis, et al., 1984). For the total Wadden Sea this amounts to an average

value of Dfl. 240/ha/year or about US$ 120/ha/year.
Since this value does not include the importance of this function to the maintenance of healthy populations of all species that use the Wadden Sea as nursery, including those with potential commercial value, a certain option value (shadow price) should be added to the actual market price. As an indication of the potential magnitude of this shadow price, Oldfield (1984) calculated that the value of coastal marshes, which provided primary productivity which in turn supported offshore commercial and recreational fishing industries, was almost US$ 5,000/ha/year. The U.S. National Marine Fisheries Service estimates that the destruction of U.S. coastal estuaries between 1954 and 1978 cost the nation over US$ 200 million annually in revenues lost from commercial and sport fisheries (McNeely, 1988).

(9) Maintenance of biological (and genetic) diversity (2.1.16)

The value of a given area for this function is mainly determined by the diversity of species and subspecies. Especially the number of subspecies is an important indicator of the occurrence of speciation and of the genepool value of the area (i.e. the degree to which natural evolutionary processes continue to produce new genetic material).
At least 4,000 species and subspecies occur in the Dutch Wadden Sea; most of which belong to invertebrate zoobenthos (1,800), micro-fauna (1,450), and micro-flora (655). Other important species groups are birds (100), macro algae (77), vascular plants (53), fish (40) and 4 species of mammals: 2 seals, 1 dolphin and 1 porpoise (De Groot, 1986).
The genepool-value of a given area is further enhanced by the presence of endemic species and subspecies and/or the permanent or temporary presence of at least 1% of the worldpopulation of a certain species or sub-species. To the knowledge of the author, no endemic species or subspecies are found in the Dutch Wadden Sea. However, it is an important area of occurrence of the Harbor Seal *(Phoca vituline)* in the southermost part of its range of distrubution (Reijnders & Wolff, 1982). Also a large percentage of the N.W. European population of many migratory bird species is found in the Dutch Wadden Sea during part of the year (see also the previous function).

Socio-economic value

No monetary value has been calculated for this function, but the genetic diversity in the Dutch Wadden Sea clearly represents a considerable conservation (as well as option and existence) value.

4.2.2 Carrier functions of the Dutch Wadden Sea

This group of functions relates to the capacity of the Dutch Wadden Sea to provide space and a suitable substrate or medium for human activities which require a permanent infrastructure, such as habitation, crop crowing (e.g. aquaculture), industry and engineering (e.g. energy conversion, coastal protection, land reclamation), transportation and communication (shipping and pipelines), militairy training, certain types of recreation, and nature conservation. Because of the constraints with respect to the sustainable use of carrier functions, as discussed in chapter 2, only those carrier functions which mainly depend on the natural biological characteristics of the Dutch Wadden Sea and which can be utilized without serious damage to the conservation values (when managed in a sustainable manner) are included here. Thus, transportation (shipping), military training, land reclamation and gas exploration, which are all important actual uses of the Dutch Wadden Sea are left out of this analysis.

(1) Cultivation/aquaculture (2.2.2)

Because of the aquatic nature of the study area (97% is permanently or periodically under water), only aquaculture deserves mentioning here although in the permanent dry area (3% of the study area) marginal agriculture and animal husbandry (cattle, sheep) occurs on a very small scale. In 1980, 600 plots of mussel cultures, covering over 60 km^2, were rented out by the state, and on average, 26,000 - 70,000 tons of mussels (including the shells) are harvested each year (Bolhuis, et.al., 1984).
Apart from the mussel culture, aquaculture is very little developed in the Dutch Wadden Sea: attempts are underway to influence (natural) cockle productivity by means of transplantation experiments. An attempt to rear rainbow trout *(Salmo gairdnerii)* has failed, but since 1976, pacific oysters *(Crassostrea gigas)* are cultivated in the German part of the Wadden Sea (Binsbergen, 1983).

Socio-economic value

The total revenues from mussel-cultivation, which was practised on 6,000 ha, amounted to Dfl 5.5 million/year in the early 1980's (based on 11.5 cents/kg). The average value per hectare is thus a little over Dfl. 900.-/year (or US$ 450.-/ha/year). Assuming that the maximum sustainable use of the Dutch Wadden Sea for mussel culture would be limited to 10% of the sub-littoral zone, at most 13,500 ha could be used for this purpose. Thus, the average value of the entire Dutch Wadden Sea for this function is 13,500 x 900.- / 270,000 = US$ 22.5/ha/year.

(2) Recreation (2.2.4)

The Dutch Wadden Sea provides space and suitable environmental conditions for many recreational activities. Maintenance of the natural qualities of the area is a prerequisite to safeguard the continued attractiveness for most of these recreational activities.
Boating and windsurfing: In 1981, about 28,000 pleasure boats used the six entry locks to visit the Dutch Wadden Sea. Taking an average of 3-4 persons per boat, this means about 85,000 to 115,000 visitors. About 75% of the pleasure boats are sailing yachts, the rest motor cruisers (de Roos, 1983a). Windsurfing is only practised in a limited number of places.
Angling (sportfishing): The Dutch Wadden Sea offers various possibilities for sportfishing: either from shore and small boats in the viscinity of the coast or from large chartered ships that organise fishing tours. Catches of sport-fish mainly consist of flatfishes like place, flounder and dab. In the summer, the deeper tidal inlets deliver good catches of mackerel and garfish, while in winter smaller cod is caught (Binsbergen, 1983). About 123,000 people make use of the organised fishing tours annually (Bolhuis, et al., 1984) and in total between 260,000 and 300,000 'man-days' (i.e. fishing people) can be counted each year. With a fishing season of 275

days per year, this accounts for approximately 1,000 anglers per day during the season (de Roos, 1983a).
Game (bird) hunting: No good data are available with regard to the amount of birds captured or shot in the Dutch Wadden Sea area for recreational purposes. It is estimated that in total approximately 30,000 ducks (mostly mallard) are caught annually, which is ca. 20% of the average autumn number of birds. In addition, a few hundred geese are caught each year (Augst & Binsbergen, 1983).
Walking across tidal flats: In 1980, approximately 15,000 people walked from the mainland to one of the islands or vice verse during low tide (Bolhuis, et al., 1984).
Shore/beach-recreation: Each year, large numbers of people visit the beaches and salt marshes along the Wadden Sea coast for walking, swimming, sunbathing, etc. Furthermore, over 750,000 people visit the 5 barrier islands and they are at least partly attracted to the islands because of the viscinity of the Wadden Sea which provides possibilities for beach recreation and hiking along the shore.

Socio-economic value
From the above, it is safe to assume that over 1 million people visit the Dutch Wadden Sea area for recreational purposes. If each person spends Dfl 75,-/day, with an average stay of 7 days per year, this would amount to a total value of over Dfl. 500 million per year. Assuming that about 50% of this amount is needed to maintain the necessary infrastructure, net-revenues from recreational activities in the Dutch Wadden Sea amount to about Dfl. 1,000.-/ha/year (= US$ 500/ha/year).

(3) Nature protection (2.2.5)
The total area designated for nature protection in the Dutch Wadden Sea in 1982 was almost 1,200 km^2 which is about 45% of the study area. However, many parts of the Dutch Wadden Sea that are valuable from the viewpoint of nature conservation are still not included in the system of protected areas.
Two important criteria that determine the conservation value of a given area are naturalness and uniqueness. Although the Dutch Wadden Sea is used by man for many different purposes, it is still the largest, relatively undisturbed natural area in the Netherlands. It is part of a large bar-built estuary, stretching approximately 450 km^2 along the north-western coast of The Netherlands, Germany and Denmark. It is a very dynamic area with special geomorphological, hydrographical and ecological development processes. Comparable coastal areas of this size (nearly 10,000 km^2) do not exist in Europe and hardly elsewhere in the world (Dankelman, 1983).
Other relevant features in relation to the conservation value are species richness and diversity. The Dutch Wadden Sea is an area with a rich bottom-living (benthic) fauna, and has a highly varied and specific flora, fauna and vegetation. It is a very valuable breeding, feeding and resting area for many species of coastal birds, migrants as well as moulting and breeding species. It is also an important area of occurrence of the harbour

seal in the southernmost part of its range of distribution.

Socio-economic value

It can be argued that the costs involved in managing protected areas should be seen as productive capital (for a discussion, see chapter 3.3.2). Protected areas provide employment, safeguard opportunities for other uses (such as recreation), and provide many other benefits such as information and regulation functions. In the case of the Wadden Sea, both the Dutch Government and several private organisations invest money in the management of nature reserves and seal-rehabilitation centers.

No information was obtained on the actual amount of money involved in the conservation management of the Dutch Wadden Sea, but Table 4.2.5-1 shows that about 100 people find employment in activities which are directly related to nature protection.

On the benefit side, it could be argued that part of the money donated to organisations that strive to conserve the Dutch Wadden Sea in its natural state may serve as an indication of the socio-economic importance of this function. For example, in the USA the Audubon Society was able to raise US$ 696,000 to preserve 1,085 ha of marsh in Florida (Thibodeau & Ostro, 1981), which amounts to US$ 640/ha. For this case study, it was assumed that Dutch citizens would be willing to spend a similar amount for the conservation of the Dutch Wadden Sea (or about 600 US$/ha). Since this is a one-time donation, this would equal a yearly investment of about 30 US$/ha, based on a 5% interest rate). It was assumed that half of this amount would be spent because people attach spiritual or ethical values to the Dutch Wadden Sea, therefore, 15 US$ are included under the information functions (column 1 in Table 4.2.5-1).

4.2.3 Production functions of the Dutch Wadden Sea

The Dutch Wadden Sea provides various resources which are of actual or potential use.

(1) Food and nutrition (2.3.3)

The average Net Primary Productivity of biomass is 4 million ton freshweight per year (see 4.2.1). According to Odum (1971) no more than 50% of the Net Primary Production should be harvested by man to ensure sustainable use. The present harvest of worms, shrimp, shellfish and fish in the Dutch Wadden Sea amounts to approximately 100,000 ton per year (see below), which is 5% of the maximum sustainable yield (according to the above, very crude calculation). Some species which are harvested, partly for direct human consumption, partly to serve as bait for catching fish.

Worms: On average, 32 million Lugworms (Arenicola marina) are caught in the Dutch Wadden Sea each year, representing approximately 1% of the reproducing stock. Little is known about the scale of Ragworm-digging (Nereis virens) (Binsbergen, 1983).

Crustaceans: In 1981, 1,834 tons of shrimp were caught in the Dutch Wadden Sea (Bolhuis et al., 1984).

Shellfish: The average yearly catch totals approxmately 83,000 tons, of which 35,000 tons of cockle and 48,000 tons of mussel. The mussel catch varies between 26,000 and 70,000 tons/year and is mainly harvested from cultivated plots (see carrier functions, aquaculture).

Fish: In 1981, the total catch was 7,293 tons, mainly consisting of sole, plaice, and eel. In addition, several species of fish and birds are caught for recreational purposes.

Socio-economic value

The monetary value of the landings of lugworms totals Dfl. 3.2 million/year; the value of the fishery in the Dutch Wadden Sea is estimated at Dfl. 54 million/year, shrimp-fishery values about Dfl. 8 million a year, and Cockle-harvesting amounts to about Dfl. 4 million/year (all figures for the period 1978-1981). Thus, direct harvesting of edible plants and animals represents a total monetary 'dockside' value of about Dfl. 70 million/year. The value added in processing is about 75% of the dockside value (Gosselink et al., 1974), thus the total market value is about Dfl. 122 million/year (= Dfl. 450 or US$ 225/ha/year).

The maximum sustainable harvest of biomass in the Dutch Wadden Sea amounts to 2 million tons/year (freshweight, see above). This biomass may be used in many different ways such as food, feed, and energy. Since not all biomass produced is (potentially) useful to man, it is assumed that ca. 10% of the maximum sustainable yield is commercially interesting for food-purposes, this would be 200,000 tons/year. The total actual harvest of edible plants and animals amounts to 100,000 tons/year which, according to the above calculation, is 50% of the maximum sustainable yield. Thus, the potential monetary value of the maximum sustainable yield is 2 x 225 = US$ 450/ha/year.

This is a very crude calculation and more detailed studies are necessary to determine the maximum sustainable yield of the Wadden Sea life communities to calculate the (potential) monetary value of the biomass-production in the study area.

(3) Raw materials for building and construction (2.3.7)

The main resources harvested for this purpose in the Dutch Wadden Sea are shells and sand.

Shells: Clay shells are used for hardening trails and indurating roads; clean shells are used in lime kilns (calcining lime for use as mortar, fertilizer, etc.). The total stock of shells in the Dutch Wadden Sea is estimated at 1,250,000 m^3, while the natural production of shells is estimated at 90,000 m^3/year (Eisma, 1983). Extraction mainly takes place in the channels where large accumulations of shells occur. The total landings of (mainly Cockle-) shells amounts to 100,000-150,000 m^3/year (Eisma, 1983). Thus, each year, the stock is reduced by 35,000 m^3 on average, which would lead to resource depletion within 35 years.

Sand is used for construction of dikes, for building roads and as fill for residential areas. The Wadden Sea soil consists for 80% of sand, of which 90% has a recoverable quality, i.e. a grain-size larger than 6.5 mm (Bolhuis et al., 1984). Since possibilities for sand extraction on land or in freshwater lakes have become rather scarce in the Netherlands, the Wadden Sea became the most important source for sand. There is also a large potential for sand extraction in the southern North Sea, but this requires more effort than in the shallower and storm-protected Wadden Sea (Eisma, 1983). Sand extraction is restricted to the channels to prevent negative ecological effects. Only in exceptional cases sand is extracted from tidal flats or the coast. Sand extraction is limited by legal regulations to approximately 4.5 million m^3 per year. In the early 1980's, on average 2-3 million m^3 (= 4 -6.5 million tons) were extracted each year. Usually, the capacity of natural processes to produce new sand is very limited (i.e. very

The Wadden Sea also offers many opportunities for (environmental) education by means of field excursions. For example, between 1973 and 1976, the Netherlands Institute for Sea Research (NIOZ) organised field courses which on average were attended by 2,014 man-days/year (Bolhuis, et al. 1984).

Socio-economic value

The monetary value of the opportunities provided by the Dutch Wadden Sea for education and research may be deduced from the amount of money spend on educational excursions and scientific studies. On average about 65 scientists are continuously engaged in research in the Dutch Wadden Sea. If we estimate their salaries and costs for equipment and 'overhead' at a conservative Dfl. 100,000 per year on average, this would amount to a total of Dfl. 6.5 million. Assuming an educational value of 1/3 of the research value (or about Dfl. 2 million/year), the total 'cognitive' value of the Dutch Wadden Sea would be about Dfl. 31.50/ha/year (or US$ 16/ha/year).

4.2.5 Total socio-economic value of the Dutch Wadden Sea

As we have seen in chapters 4.2.1 - 4.2.4, the Dutch Wadden Sea fulfills many functions which, directly or indirectly, contribute to human welfare. In order to ensure the incorporation of these functions in planning and decision-making, it is important to qualify and quantify their socio-economic importance and, if possible their monetary value. Table 4.2.5-1 summarises the various types of socio-economic values that can be attributed to the functions of the Dutch Wadden Sea and, where possible, provides and indication of their monetary value. For methods to determine monetary values of environmental functions, the reader is referred to chapter 3.2 of this book. On the following pages, a brief explanation is given of the various types of socio-economic values identified in Table 4.2.5-1.

(1) Conservation value of the Dutch Wadden Sea

The conservation value mainly consists of benefits derived from the services provided by natural regulation processes. Since these processes operate best when left undisturbed this value is also referred to as 'non-use' value. Undisturbed natural areas regulate certain environmental conditions that are essential to the maintenance of a healthy living environment, they often provide the necessary conditions for other uses (e.g. recreation) and safeguard opportunities for future uses. However, for some of these regulation functions, notably flood prevention, bio-energy fixation, and the nursery function, a monetary value can be calculated through shadow-price techniques (see column 1 in table 4.2.5-1)

The costs involved in managing the area as a conservation site should also be mentioned here, as well as the spiritual (ethical) information provided by natural areas which make up an important part of the conservation value.

Table 4.2.5-1 Socio-economic value of environmental functions provided by the Dutch Wadden Sea (based on maximum sustainable use levels)
(values are expressed qualitatively (++) or in US$/ha/year).
Total surface area of the study area: 270,000 ha

	Types of values (based on Table 3.0-1, for explanation, see text)					
	1 Conservation value	2 Existence value	3 + 4 Social values[1]	5 Consumptive use value	6 Productive use value	7[3] Value to employment (# people)
Regulation Functions	**> 5,120**	**++**	**++**		**++**	
Climate regulation	++		+		*	
Flood prevention	500		+		*	*
Erosion prev./sediment.	++				*	
Bio-energy fixation	(3000)[2]	+			*	
Storage/rec. org. matter	2000		+		*	
Storage/rec. nutrients	2500		+			
Nursery f./migration hab.	120	++	++		*	
Maintenance of biol.div.	++	++	++		*	
Carrier Functions	**15**	**++**	**++**		**> 522**	**> 263**
Aquaculture					22	160
Recreation			+		500	>> 10
Nature protection	15	++	++		*	93
Production Functions			**++**	**+**	**> 475**	**> 207**
Food/nutrition			++		450	207
Raw materials for constr. (sand, shells)				+	25	++
Fuel and energy						
Information Functions	**15**		**++**	**++**	**> 16**	**> 65**
Aesthetic information			++	++	+	
Spiritual/hist. inform.	15		++	++	*	
Cultural/artistic insp.			+	+	+	+
Educ. & scientific inf.				+	16	65
TOTAL ANNUAL VALUE	**> 5,150**	**++**	**++**	**++**	**> 1,013**	**(535)**

[1] Social values consist of the importance of environmental functions to human health and the option value placed on a safe future.
[2] If a figure is given between brackets it was not used in calculating the total value because the calculation is too speculative.
[3] Figures in this column refer to # of people, not US$
* These functions do contribute to economic productivity, either directly or indirectly, but no market or shadow price could be determined due to lack of information and/or shortcomings of the market mechanism.

(2) Existence (intrinsic) value of the Dutch Wadden Sea

Many people attach great ethical (intrinsic) value to nature, and are therefore willing to devote time, energy and money to their conservation. In principle it would be possible, through questionnaires or other shadow-pricing techniques to obtain a monetary indication for this value. However, it is difficult to distinguish between money donated to conservation measures for ethical, option or conservation reasons. Also there are

Basin in Massachussets. Another estimate placed the economic value of a hectare of Atlantic Spartina Marsh at over US$ 72,000 per year (Hair, 1988).When utilized in a sustainable manner, the benefits from environmental functions can be enjoyed indefinitely. The income derived from natural goods and services must therefore be seen as the interest of a capital-stock of natural processes and components which provide these functions (see also chapter 3.2.3). At 5% interest, a yearly return of US$ 6,200 would represent a capitalized value of the functions of the Dutch Wadden Sea of about US$ 124,000/ha.

(2) Some implications for planning, management and decision making
In spite of the great socio-economic value of wetlands, many have been drained or filled-in in the past and many are still being threatened (see box 4.2.6-1). Although the Dutch Wadden Sea, compared to other wetlands, is relatively well protected and managed, it too is still threatened by many development plans and ongoing harmful human activites, such as pollution and military training.
The careless way in which tidal areas have been 'developed' (i.e. drained) in the past is partly due to the fact that many natural functions and socio-economic values of these areas are not recognised, or accrue at some distance from the area itself. Today, fortunately, there is a growing awareness that many wetlands are more valuable in their natural, or only slightly modified state, than if radically altered and intensively managed (Dugan, 1988).To ensure the conservation and sustainable utilization of the remaining wetlands (and to stimulate the restoration of lost wetlands), it is necessary to have a clear understanding of the many functions and socio-economic values of wetlands in their natural state. Although present-day market economics do not recognise the monetary value of most environmental functions, such calculations do provide a revealing insight into the great socio-economic importance of natural areas and more awareness of these values may provide an important incentive for their preservation and sustainable utilization.

Box 4.2.6-1 Some threats to wetland ecosystems (caused by undervaluation and overexploitation)

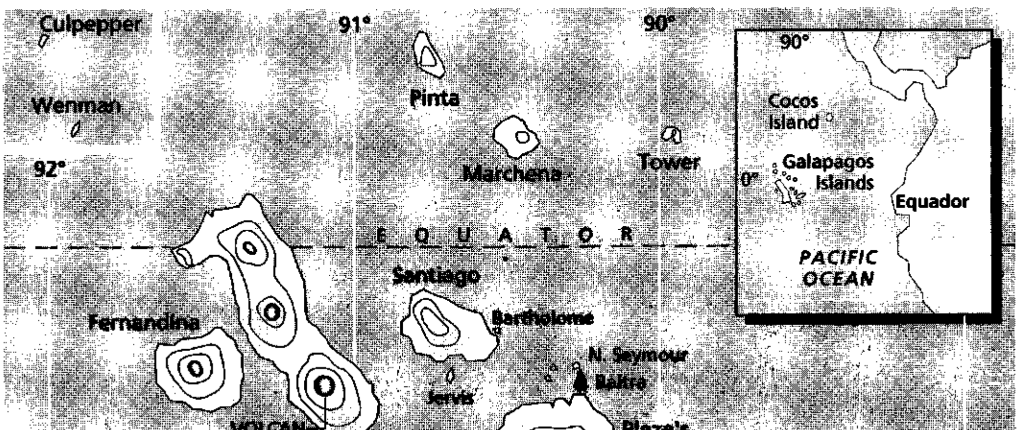
During much of the recent past, many wetland ecosystems have been destroyed or altered as human society sought to extract productive benefits from these natural systems (see Dugan, 1988). Unfortunately, tidal areas are relatively easily disturbed but it is very difficult to restore or re-create them once they are destroyed. The reason for their great productivity also presents the greatest threat: because tidal areas are located at the borderline between land and sea they receive large inputs of energy and nutrients but they are also exposed to strong development pressures due to the fact that coastal areas are often the most densely populated parts of a country. Consequently, many tidal areas have been and still are being reclaimed by man for expansion of agricultural land, urban and industrial areas, etc. In addition, many tidal areas, especially estuaries, are located close to river-mouth's and are thus exposed to pollution from the entire watershed area of these rivers. In Canada, for example, approximately 1.2 million ha of wetland habitat has been converted to agricultural use in the Prairie provinces and of the 1.77 million ha of original wetland in southern Ontario, 70 percent had disappeared by 1970 (Bardecki & Manning, 1987).

4.3 Functions and values of the Galapagos National Park

Introduction

The Galapagos Islands are situated on the equator in the Pacific Ocean, approximately 1,000 km west of Ecuador, of which the archipelago is a province. The archipelago consists of 14 major islands and a larger number of smaller islets and rocks with a total surface area of almost 8,000 km^2 (see Fig.4.3.0-1). Including the territorial waters, the total surface area is approximately 60,000 km^2. In 1959, about 90% of the total land area was set aside as a National Park, and in 1984 about 4,300 km^2 of the marine area was declared a Marine National Park. The evaluation of environmental functions in this chapter is limited to the protected area in the Galapagos Archipelago. The total surface area of the study area is therefore 11,500 km^2 (= 1.15 million ha): 7,200 km^2 terrestrial National Park plus 4,300 km^2 marine National Park (including 41 km^2 of intertidal ecosystems).

Fig. 4.3.0-1 The islands of the Galapagos archipelago



Note: curiously, there is quite some confusion about the total terrestrial surface area of the archipelago. Based on 11 references, figures for the total surface area vary between 7,852 and 8,010 km2, while data for the protected area vary between 86 and 96% of the total surface area (or 6,750 and 7,690 ha respectively) (De Groot, 1988).

The Galapagos islands are of volcanic origin and are considered to be oceanic. Galapagos belongs to the Neotropical Realm and is in a biogeographical province of its own (Udvardy, 1975). The Galapagos natural environment shows a wide variety of habitats, including terrestrial ecosystems (ranging from barren lava fields to dense rainforests), aquatic ecosystems on land (mainly crater lakes), intertidal ecosystems (e.g. cliffs, beaches and lagoons bordered by mangroves), and marine ecosystems (deep sea, shelf sea and some coral reefs). Due to the isolation of the archipelago incomplete life communities have developed with a high degree of endemism: on average endemism within the major taxonomic groups (vascular plants, mammals, birds, reptiles and shore-fish) is 39% while amphibians and freshwater fish are completely lacking.

Galapagos has been permanently inhabited since 1832 and in 1987, the human population was estimated at 8,000 people. With the establishment of the National Park in 1959, the human population was concentrated in the remaining 10% of the land area (about 800 km^2). This so-called colonized zone is divided over parts of five islands: Santa Cruz, San Cristobal, Isabela, Floreana and Baltra (or Seymour South). The most important economic activities are tourism (and related activities such as handicraft), followed by agriculture, animal husbandry and fishery. Also research is an important activity which brings in considerable amounts of foreign exchange.

Due to human activities (expanding infrastructure, cultivation, etc.) and the introduction of many exotic organisms (i.e. ca 250 exotic plants and 10 feral animal species) considerable damage has been inflicted on the natural ecosystems of the five colonized islands (and Santiago which was briefly inhabited in the past). Fortunately, due to conservation efforts by the National Park Service and the Charles Darwin Research Station most of the other islands are still, or again, in a natural state.

Table 4.3.0-1 Functions of the Galapagos National Park

1 Regulation functions	**2 Carrier functions**
Climate regulation	Aquaculture
Coastal protection and flood prevention	Recreation and tourism
Watercatchment and erosion prevention	Nature protection
Bio-energy fixation	
Storage and Recycling of human waste	
Providing biological control	
Migration habitat and nursery function	
Maintenace of biological diversity	
3 Production functions	**4 Information functions**
Food/nutrition (edible plants & animals)	Aesthetic information
Genetic resources	Spiritual/ethical information
Raw materials for building/construction	Historical information
Biochemicals (e.g.Orchilla)	Cultural/artistic inspiration
Energy (fuelwood, solar energy, etc.)	Scientific & educational information
Ornamental resources (e.g.black coral)	

In all, 22 functions can be attributed to the natural ecosystems occurring in Galapagos National Park (see: Table 4.3.0-1)

The Galapagos National Park consists of many different ecosystems and, ideally, the functions listed above should be evaluated for each ecosystem separately. Especially marine and terrestrial ecosystems have a different capacity to provide certain functions. To avoid repetition and too lengthy descriptions, the environmental functions are described in this chapter for the Galapagos NP a whole. When certain functions are performed exclusively by a particular ecosystem, this will be clearly indicated. For the same reason, the environmental characteristics (parameters) that determine the capacity to provide a certain function are only briefly mentioned. To fascilitate cross reference, the number of the corresponding paragraph in chapter 2 is given behind each caption. A more detailed description of the environmental characteristics (parameters) and functions can be found in the original case study report (De Groot, 1988).

Box 4.3.0-1 About the Galapagos case study

The Galapagos islands were chosen as an example of a case study on the functions and values of a specific protected area (national park). One reason for this choice was the fact that I spent almost two years on these islands: between August 1978 and September 1979 as a tourguide, from September 1979 to July 1980 as the principal investigator of a study on the ecology of the only two owl species occurring in the islands. Further information was obtained during a 5-week stay in the spring of 1984. Most of this time was spent interviewing local people and authorities (notably officials from the Galapagos National Park Service and the Charles Darwin Research Station) and collecting information from libraries and archives from both organisations. The detailed results of this investigation were published in a separate manuscript (De Groot, 1988). Most of the information provided in this chapter (4.3) is taken from this document. Many people were most helpful in providing information for this case study for which I thank them all here.

4.3.1 Regulation functions of the Galapagos National Park

(1) Climate regulation (2.1.5)
Galapagos has a rather favourable climate. According to T.Wolff (1892) 'it would be hard to find any place in the world below the equator with a more moderate, healthy and agreeable climate'. In Galapagos, the seawater temperature has a strong influence on climatic conditions such as air temperature, humidity and precipitation. Due to seasonal changes in surface water temperature, an inversion layer is formed in the atmosphere during part of the year, causing much precipitation at the wind-ward side of the higher islands. Houvenaghel (1974) established a direct relation between sea water temperature and precipitation on the south side of Santa Cruz. He calculated that an increase in seawater temperature of 1°C in Academy Bay corresponds with an increase in precipitation of 680 mm (or 60%) at 600 m of altitude. Thus, processes that regulate surface water temperatures (e.g. sea currents, water-discharge, etc.) have a direct

influence on climate, and thereby on climate-dependent human activities such as habitation, cultivation and recreation.

(2) Coastal protection and flood prevention (2.1.6.)
Mangrove forests trap considerable amounts of sediments and organic matter which, after some time build up to form sheltered lagoons and submerged lowlands (Wellington, 1975). They also play a role in the formation and protection of beaches. When these vegetation belts are bordering vulnerable areas and protect human settlements or cultivated lands, this function is of special socio-economic importance. Since this is not the case in Galapagos, and because the hinterland is very stable (consisting of hard volcanic rock), this function is not included in Table 4.3.5-1.

(3) Watercatchment and erosion prevention (2.1.7)
The vegetation cover and soil properties together determine the capacity of a given ecosystem to store water (either at the surface or as groundwater) and prevent runoff and erosion. In Galapagos, the interception of rainwater primarily depends on the density of the vegetation cover. Dense vegetation is mainly found in areas above 200 m. According to Houvenaghel (1974), total precipitation on the south side of Santa Cruz is on average 525 mm/year, of which about 350 mm is evaporated and 175 mm goes into infiltration. Under normal circumstances runoff is negligable because of the dense vegetation and the porosity of the underground. Especially the Scalesia forests are important water catchment areas, both by preventing runoff in times of heavy rainfall and by collecting water during dry periods. This function was eloquently described by Wiggins and Porter, (1971): 'During the dry season, there is an accumulation of thick fog through most of the night and well into the forenoon of the next day. Moisture condenses in appreciable amounts on the leaves and twigs of plants, and drips to the ground from the leaf tips or trickles down the branches and trunks of the trees, lianas, and shrubs. The coatings of mosses, lichens, and liverworths on many of the trees and shrubs also are condensation stations during foggy periods, but much of the water forming on them is absorbed; only a small portion reaches the ground".

Socio-economic value
Watercatchment, groundwater recharge and erosion prevention by the vegetation, especially on sloping land, is a function with considerable socio-economic importance. The monetary value of this function may be deduced from the amount of money that would be needed for artificial irrigation and for measures needed to prevent damage to, for example cultivation and settlements. As a very crude approximation, the monetary value of the intact natural vegetation which provides this function could be put at 10% of the value of the commercial human activities which benefit from this function, notably agriculture and live stock production. This would amount to US$ 90,000/year (based on current production levels) and US$ 220,000/year (= 0.3 US$/ha/year) based on maximum sustainable use levels.

(4) Fixation of solar energy and biomass production (2.1.10)
The rate of primary production can be used as a measure for the energy flow through an ecosystem. In De Groot (1988) it was calculated that the Gross Primary Productivity of the Galapagos ecosystems is on average 260 gr. organic matter/m^2/year (= 1,176 Kcal), varying between 45 gr. for the arid zone to about 4,400 gr. for the wet Scalesia forests and coral reefs. Thus, the total average GPP in Galapagos is about 12 million Kcal/ha/year.

Socio-economic value
According to Gosselink et al. (1974) 10,000 Kcal of energy produced by a natural system represents an amount of (potentially) 'useful work' with a value of 1 US$. This would mean that the energy fixed by 1 ha in Galapagos would represent a monetary value of about 1,200 US$/year. This method, however is quite controversial (see chapter 3.3.1), and this value has therefore not been included in further calculations.

(5) Recycling of human waste (2.1.13)
An important function of natural environments, especially of intertidal ecosystems, is the recycling of organic waste and nutrients. Estuaries, for example, are able to mineralise ca. 60 kg of organic matter/ha/day (see chapter 4.2). Assuming the recycling capacity of the inlets, coral formations and shelf-sea area in Galapagos is only 1% of this amount, the Galapagos shelf-sea environment (ca 6,750 km^2) would still be able to recycle 440 ton organic waste/day without negative ecological effects.
In 1983, 51 tour boats produced an estimated 30,000 tons of organic waste per year which was dumped untreated into the sea. This amounts to about 18.5% of the purification capacity of the shelf sea area. Although this is well below the carrying capacity, the use of the Galapagos marine environment for dumping organic waste should be kept to a minimum to avoid conflicts with other functions.

Socio-economic value
Artificial purification of 1 ton organic matter would cost ca 155 US$/ton (chapter 4.2), thus the use of the Galapagos marine area as a 'free' dump site for organic waste saves the local economy ca. 4.6 million US$/year. According to calculations made above, the maximum carrying capacity for treatment of organic waste by the Galapagos marine ecosystems is ca 440 tons/day, corresponding to a monetary value of ca 25 million US$/year which would have been needed for artificial purification, or 58 US$/ha/year (calculated for the marine area only). If the costs involved in artificial recycling of separate nutrients (so-called tertiary treatment) would be included, the monetary value of this function becomes many times greater since artificial tertiary treatment is very expensive.

(6) Biological control (2.1.14)
Through evolutionary processes, the members of natural life communities have developed many inter-specific relationships (predator-prey and parasite-host relations, symbiosis, etc.) in order to maintain a certain biological balance. Many of these inter-specific relations are (or could be) useful to man, for example for pest control or crop pollination.
Due to the isolation of the Galapagos islands, a relatively pest-free environment has developed which presents advantages to human health and

cultivation (farmers in Galapagos use relatively low amounts of pesticides). On the other hand, due to the relatively low number of insects and absence of other pollinating species, Galapagos may be unsuitable for growing certain crop species. As a consequence of the 'unbalanced' ecosystems, Galapagos is also very vulnerable to the introduction of exotic species because of the absence of potential 'enemies'.

Socio-economic value
No specific benefits (or costs) could be attributed to the biological control functions in Galapagos. Therefore, no monetary value is included in table 4.3.5-1 for this function.

(7) Providing a migration habitat and nursery area (2.1.15)
a. Migration: The importance of Galapagos as a feeding and resting place to migrating birds is rather insignificant. Of the 66 migratory bird species recorded in Galapagos only 29 are regular visitors (in relatively small numbers), most are accidentals and some are obviously lost vagrants. Galapagos is probably more important as a feeding area on the migration routes of marine mammals (whales and dolphins), but no quantative date on this function was obtained.
b. Nursery function: Coastal and intertidal ecosystems, especially inlets bordered by mangrove vegetation, serve as essential reproduction and nursery area's to many marine organisms (e.g sea turtles). To what extent the fishery in Galapagos depends on the nursery function of the many inlets and mangrove lagoons could not be assessed within the scope of this study but is certainly considerable.

Socio-economic value
A case study of the Dutch Wadden Sea revealed that this estuarine area was responsible for 25% of the commercial catch in the adjacent shelf sea area (chapter 4.2.2). Since the relative area of coastal and intertidal ecosystems in Galapagos is much smaller compared to the Dutch Wadden Sea, it is arbitrarily estimated that 10% of the fishery in Galapagos depends on the nursery function of the many inlets and mangrove lagoons. This would correspond with a monetary value of US$ 30,000 per year. If limited to the intertidal area (4,100 ha) this would amount to 7.3 US$/ha/year. For the entire protected marine area the value would be 0.07 US$/ha/year.

(8) Maintenance of biological and genetic diversity (2.1.16)
Three parameters are of special importance to determine the value of a given area for this function: diversity of species and sub-species, presence of rare and/or endemic species, and the naturalness of the ecosystem in question.
Diversity of species and subspecies: The total number of species in Galapagos is relatively low: 625 species of vascular plants, 4 species of mammals, 57 species of breeding birds, 17 species of reptiles, while amphibians and fresh-water fish are completely absent. Yet, there are a large number of varieties and sub-species which is a good indicator for the genepool value and the occurence of speciation (= the formation of new genetic material through natural evolution). Due to the isolated position of the archipelago and the large number of islands in a relatively small

area, speciation in Galapagos proceeds relatively quickly, resulting in the continuous formation of new varieties, subspecies and, eventually, new species.

Rare and/or endemic species: The volcanic origin and isolation are probably the main reasons for the unique flora and fauna in Galapagos: on average, 39% of the major taxonomic groups are endemic: vascular plants (36%), mammals (83%), birds (49%), reptiles (94%), shore-fish (23%) (source: De Groot, 1988, based on various authors). This large number of endemic organisms presents a major contribution to the biological diversity on earth.

Naturalness/integrety: The maintenance of biological diversity depends on the continued operation of evolutionary processes under natural conditions. Integrety of the natural life communities is therefore an important parameter for this function and, fortunately, most ecosystems in Galapagos are still, or again, in a largely natural state (see also chapter 4.3.2: 'nature protection').

Socio-economic value

Although the maintenance of biological diversity is an important pre-condition for many other functions and human activities, thus far it has proved impossible to determine a realistic market value or shadow price. A suggestion for a possible shadow price would be to add 10% to the market value of any activity which, directly or indirectly, depends on this function. The total (actual and potential) market value of the functions in Galapagos which depend on the maintenance of biological diversity is about US$ 56 million (see column 6 in table 4.3.5-1). Thus the shadow price for this function would be US$ 5.6 million (or US$ 4.9/ha/year).

4.3.2 Carrier functions of the Galapagos National Park

The Galapagos natural environment provides space and (more or less) suitable environmental conditions for various human activities such as habitation, cultivation, recreation and nature conservation. Habitation and (most) cultivation activities are limited to the colonized area outside the National Park. Since this case study concentrates on the functions of the National Park, only the (potential) use for aquaculture, recreation and nature conservation are included in the evaluation.

(1) Aquaculture (2.2.2)

Considering the relatively high and stable water temperatures (the average seasonal variation lies between 21° and 26°C) it should be possible to exploit aquacultural productivity on a sustainable commercial basis, without interfering with conservation interests. Until now, no or very little effort is made to utilize this resource potential.

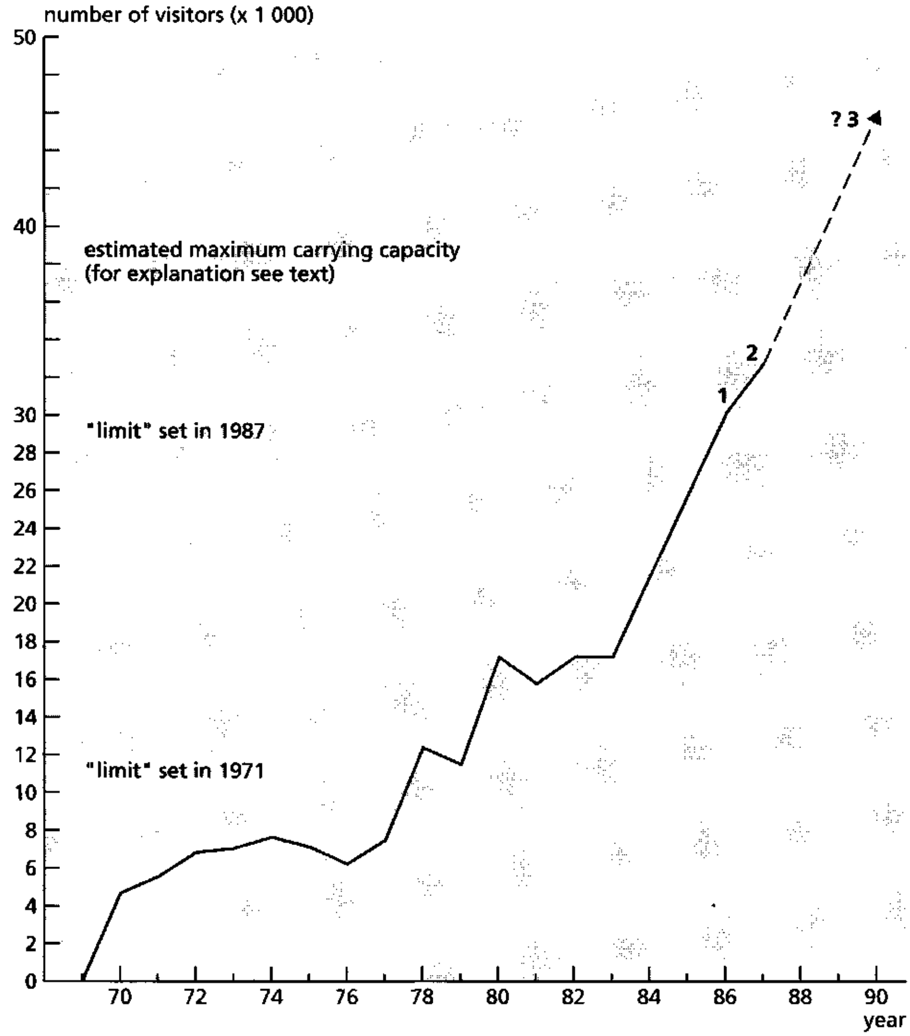
Socio-economic value:

Assuming revenues of 1 US$/m² (De Groot, 1986b), an area of one hectare would yield US$ 10,000/year. Averaged for the entire protected marine area this amounts to 0.02 US$/ha/year.

(2) Recreation and tourism (2.2.4)

The Galapagos Islands are well known for their natural beauty (scenery) and unique wildlife. As on most oceanic islands, the native animals show little or no fear of man. These features, together with a pleasant climate and interesting human history, make the archipelago very attractive for tourism. Since 1970 many people have come to see this 'last paradise' and visitor numbers increase each year (see Fig. 4.3.2-1).

Fig. 4.3.2-1 Annual number of visitors to the Galapagos National Park since 1969



1 Data until 1986 from De Groot (1988)
2 Based on Kenchington (1989)
3 Estimation by the author based on various sources

Considering the fragility of the ecosystens and life communities in Galapagos, care should be taken to limit the number of visitors to the maximum carrying capacity of the islands, based on ecological, socio-economic and management considerations. According to Putney (1983) and calculations by the author (de Groot, 1988), the maximum number of visitors is estimated at 40,000 per year, provided current strict regulations are maintained. If this calculation is correct, this would mean that since 1989 the actual number of visitors is beyond the carrying capacity of the islands.

Socio-economic value
Assuming a maximum carrying capacity of 40,000 visitors per year and total expenditures of 1,300 US$ per visitor (see box 4.3.2-1), the potential monetary benefits from tourism would be 52 million US$/year. For the total protected area (terrestrial and marine) this would amount to an average 45 US$/ha/year.

Box 4.3.2-1 Expenditures on recreation and tourism per visitor to the Galapagos National Park

When calculating monetary benefits of tourism in Galapagos, it must be realised that there are differences between international tourists and local/national visitors. The latter category pays lower entrance and transportation fees and has less money for related expenditures. Expenditures are divided into local expenses and 'off-site' expenses. Prices are calculated for the situation around 1987. For more detailed information on the economic aspects of tourism in Galapagos, see de Groot (1988).
Expenditures in Galapagos (910 US$/pp): The costs of the Galapagos visit include entrance free (40 US$), cruise fare (580 US$), local expenses in the park (50 US$) local expenses outside the park (US$ 160) and the air-fare to and from mainland Ecuador (80 US$).
Expenditures related to the Galapagos visit (390 US$/pp): The total expenses on related costs such as the air-fare from the home-country to Ecuador (on average 470 US$) and expenses on the mainland (310 US$) amount to 780 US$/pp. Only 50% (390 US$) of these related expenses were added to the monetary benefits of tourism in Galapagos because many people come both for a visit to Galapagos and attractions on the mainland.

(3) Nature protection (2.2.5)
The conservation value of a particular area or ecosystem is determined by various parameters; three important parameters are naturalness, uniqueness and diversity (of ecosystems and species), which, not surprisingly, are very similar to the parameters for the function 'maintenance of biological and genetic diversity' (see above). The value of Galapagos for these parameters was the main reason for the establishment of the national park in 1959. In 1978 Galapagos became one of the first World Heritage Site's to be proclaimed by the United Nations (UNESCO).
Diversity of species and ecosystems: The diversity of ecosystems and species in Galapagos is relatively poor, especially on land. On an area of about 8,000 km^2, only 8 types of ecosystems, 21 vegetation types, and a little over 700 species of higher plants and animals occur.
Uniqueness: Most of the terrestrial ecosystems, notably the Scalesia forests, are unique to the Galapagos islands, whereby a large percentage of the members of the life communities occuring in all three major habitats (terrestrial, intertidal and marine) are endemic. On average 39% of the major taxonomic groups are endemic. Because of its unique flora and

fauna, Galapagos was placed in a biogeographical province of its own by Udvardy (1975), among a world-total of 163 terrestrial biogeographical provinces.

Naturalness/integrety/vulnerability: Because most ecosystems in Galapagos are climax communities with long development times, and because of the high degree of endemism, the Galapagos natural environment is extremely vulnerable to human disturbance. In the past, the first visitors (pirates and whalers) killed many native and endemic animals, causing the extinction of four subspecies of the giant Galapagos Toirtoises and reducing the numbers of several other species, notably the fur seals. In the beginning of this century permanent colonists cleared relatively large areas for settlements and cultivation and introduced many exotic plants (ca 250 species) and animals (ca 10 species). Since 1959, when 90% of the archipelago was declared a National Park, attempts have been undertaken to contain the damage and return the protected areas back to their natural state.

Human disturbance within the National Park is now largely related to tourism. Too large concentrations of visitors disturb the flora and fauna and on some islands visitor sites suffer from erosion. The increasing fleet of tourist ships also increases the danger of pollution (De Groot, 1983). Fortunately, regulations in the Galapagos National Park are very strict and, by and large, most of the ecosystems which are included in the National Park are still, or again in a natural state.

Socio-economic value

In 1984, the budget of the Galapagos National Park Service was approximately 320,000 US$. Because most environmental functions, and the associated socio-economic benefits provided by the Galapagos National Park, depend on its conservation, the money invested in conservation management should be seen as productive capital. Putney (1983) suggests that it is necessary to double the budget of the National Park Service in the near future which would amount to an average value of 0.55 US$/ha/year.

4.3.3 Production functions of the Galapagos National Park

The Galapagos natural environment provides many resources which are more or less essential to the local human population, such as food, energy, and building material. Other, potentially important resources are biochemicals and genetic material.

(1) Food/nutrition (edible plants and animals) (2.3.3)

In the past, several species of native Galapagos animals have served as a source of food for the first visitors (pirates and whalers) and settlers, notably the giant tortoises which provided meat and cooking oil. Also many sealions, doves and iguana's were partly killed for their food value. Today, harvesting of wild organisms for food is largely restricted to fishing activities. At least 9 species of fish and several custaceans (notably lobster) are harvested. No native edible plants are collected for food

purposes. The total harvest of fish and lobster in 1983 was ca 350 ton. It is un-known what the maximum sustainable yield of the most important commercial species is, but there are indications that especially for lobster over-fishing is taking place since the quantity and size of the lobster caught are decreasing.
Another natural resource used in the preparation and conservation of food is salt. From approximately 1924 - 1930 and again from 1960 - 1968, salt was extracted from a crater lake near James Bay on Santiago island.

Socio-economic value
The monetary value of the local harvest of fish and crustaceans (i.e. excluding the tuna-catch by commercial ships from mainland Ecuador and abroad), was ca US$ 300,000 in 1983 (or 0.7 US$/ha/year). There are indications for over-fishing which would mean that the maximum sustainable yield is equal to, or lower than the present harvest.

(2) Genetic resources (2.3.4)
Although the wildlife in Galapagos represents a large reservoir of unique genetic material (39% of all species are endemic), thus far little research has been undertaken to study its potential for (commercial) use. Due to the isolation of the archipelago, it's flora and fauna developed unique environmental adaptations which may be useful to man. For example, Galapagos harbours an endemic species of tomato *(Lycopersion cheesmanii)* that is quite different from any other tomato in the world. It has a considerable genetic variation within the species and there are quite distinct local populations, although each population itself is very uniform (Schönitzer, 1974). Since this tomato has evolved under quite extreme climatic conditions in the dry coastal areas in Galapagos, it is well adapted to prolonged periods of drought and high temperatures. It's genes could prove to be useful for crossbreeding programs aiming to develop heat-tolerant and drought-resistant commercial tomato races.
No economic information was obtained on this function.

(3) Raw materials for building and construction (2.3.7)
Several natural resources are used for construction purposes, most of these resources are harvested from 'special use zones' which are usually located at the border between the colonized zone and the national park.
Timber: Several indigenous plant species in Galapagos are able to provide wood for construction. Especially Psidium galapageium and Pisonia floribunda produce trunks of sufficient size and hardness to use them for house-building, ship repairs and local cabinet work. At one time, timber was exported to mainland Ecuador. As a result, the larger trees of these species have been nearly eliminated from areas readily accessible (Wiggins and Porter, 1971).
Volcanic rock: In 1983, 59% of the private houses on Santa Cruz (on a total of 421 houses) were made of volcanic rock, 29% were made of wood and 12% were made of sugar cane sticks (Black, 1983). No data were obtained on the present use of volcanic rock for building and construction.

Sand: In 1983-1984, authorization for the extraction of, on average, 10,000 m^3 sand per year were given. It is unknown over what time period such authorizations have been given in the past (the administrative data were rather fragmentary), but it is a fact that the beaches to the north of Santa Cruz and near the villages on Santa Cruz, Isabela and San Cristobal have disappeared almost completely (Putney, 1983).
Gravel: In 1984, a new grinding machine was installed with a capacity of 600 m3 gravel/day (De Groot, 1988). No information was obtained on the actual amount of gravel extracted per year. The gravel is mainly used for paving roads.

Socio-economic value
The actual annual returns from extraction of natural resources (timber, rocks, sand and gravel) from the Special Use Zones in Galapagos is estimated at US$ 5 million. The potential sustainable harvest is estimated to be only slightly more at US$ 6 million. This would amount to 5.22 US$/ha/year for the terrestrial and coastal area of the Galapagos National Park.

(4) Biochemical resources (2.3.8)
Little or no research has been done on the biochemical properties of the Galapagos flora and fauna. The only known record of the utilization of biochemical resources from native Galapagos organisms is the former existence of a small Orchilla-industry on Floreana and San Cristobal between 1866 and 1904. Orchilla *(Rocella tinctoria)* is a lichen with dye-characteristics.
Especially the marine fauna probably harbours a large array of potentially useful biochemials, many of which may be unique because of the large percentage of endemism in the Galapagos islands.

(5) Energy resources (2.3.9)
As local energy-resources only fuelwood (in small quantities), solar power and geothermal energy are commercially interesting. Tidal differences and wind speeds are too small or too low for commercial energy conversion. In 1982, only 80 m^3 of fuelwood was (officially) harvested, corresponding with 0.5% of the total energy needs in Galapagos; the other 99.5% is covered by fossil fuels which have to be imported from the mainland. It is not known what the maximum sustainable harvest of fuelwood would be, but there are good possibilities in Galapagos for utilizing solar energy. For example, the coastal areas receive at least 1,500,000 Kcal/m^2/year of solar radiation. With 8% efficiency, the solar radiation received on 1 m^2 could be converted into electricity with an equivalent energy-value of 120,000 Kcal. The total energy consumption in Galapagos in 1982 was 26.4 x 109 Kcal. Thus, total energy needs in 1982 could be covered by a solar power plant with a surface area of ca 50 ha.
Commercial exploitation of geothermal energy has not been investigated yet but there is certainly a considerable potential. The Galapagos islands are of volcanic origin and today still contain one of the most active groups

of volcanoes in the Pacific Ocean (McBirney & Williams, 1969).

Socio-economic value
In the near future only utilization of solar-energy seems a realistic option for local energy conversion. It has been calculated that, if 25% of the present energy consuption would be provided by solar-power, this would represent a savings compared to the costs of fossil fuel consumption of about 1.1 million US$/year. Calculated for the terrestrial area alone, this would amount to 1.53 US$/ha/year.

(7) Ornamental resources (2.3.11)

Although the collection of all natural objects is forbidden in the National Park, tourists occasionally collect shells and rocks as souvenir. Since this mostly happens unnoticed, it is impossible to estimate the quantities of shells, rocks, bones, etc. taken from the islands in this manner. Another collectors item is black coral (mainly of the family Anthipathidae). Anthipathidae are believed to have medicinal and magic powers and are therefore popular as amulet. It is estimated that in 1980, ca 220 kg of black coral was harvested and sold as collars, armchains, rings, earrings, etc. In the past, also young giant tortoises were taken from the islands and sold on the international market by animal dealers. Some native trees provide wood for wood-carving, mainly in the form of animal-figures (such as penguins and tortoises).

Socio-economic value
Collecting of most ornamental resources in Galapagos (shells, rocks, tusks, etc.) is forbidden. The economically most important ornamental resource is black coral with an estimated market value of ca 100,000 US$/year. Since black coral is an endangered (group of) species listed in the IUCN Red Data Books and included in CITES, trade in black coral is illegal and the potential economic value of this resource is, or should be, zero. Some handicraft, made from native trees is also sold and, in combination with other ornamental resources which may be harvested on a sustainable basis, the potential value of this function was estimated at 400,000 US$/year (corresponding with 10 US$/per visitor). Per hectare this amounts to 0.35 US$/year.

4.3.4 Information functions of the Galapagos National Park

(1) Aesthetic information (2.4.1)

Appreciation of aesthetic information is rather subjective and difficult to evaluate. The Galapagos scenery seemes to evoke quite contrasting feelings with spectators, ranging from desolation and dejection to awe, excitement and wonder. It is probably safe to presume that many of the visitors are attracted to the Galapagos islands because of their special scenic qualities.
The economic value of this function is largely related to the use of the islands for recreation and tourism. To avoid double counting, no monetary value was calculated here.

(2) Spiritual information (2.4.2)

To some people natural areas provide an important source of spiritual enrichment which is expressed in an ethical attitude towards nature based

Socio-economic value
The money spent on research is estimated at ca 1.25 million US$/year while expenditures on field courses, fellowships, training courses and educative fascilites and materials (books, films, etc.) is estimated at at least US$ 320,000/year. The potential value, based on maximum sustainable use, is at least double this amount which would lead to an average value of 2.73 US$/ha/year.

4.3.5. Total socio-economic value of the functions of the Galapagos NP

In chapters 4.3.1 - 4.3.4 the many functions and values of the Galapagos National park have been listed and described. Table 4.3.5-1 summarises the various types of socio-economic values that can be attributed to these functions and, when possible, gives and indication of their monetary value. For methods to determine monetary values of environmental functions, the reader is referred to chapter 3.2 of this book.

A brief description of the various types of socio-economic values, is given on the following pages.

(1) Conservation value of the Galapagos NP
It can be rightly argued that most functions provided by the Galapagos NP depend on the conservation of the natural ecosystems and biological diversity in the Galapagos islands. Although the importance of the environmental functions which maintain the natural integrity of the national park are usually not reflected in conventional economic accounting procedures, it is possible to assess the indirect economic value of these functions and to calculate a (crude) shadow price (see column 1 in Table 4.3.5-1). The conservation value mainly relates to regulation functions, whereby two functions (climate regulation and coastal protection) have been left out of the analysis since their (economic) importance is neglectible in the study area. Also the conservation value of managing the area as a national park, as well as the spiritual value should be mentioned here.

(2) Existence value of the Galapagos NP
The mere existence of natural areas presents an important factor in the feeling of wellbeing to many people. They attach great ethical (intrinsic) value to nature, and are therefore willing to devote time, energy and money to organisations which strive for their conservation. In principal it would be possible, through questionnaires or other shadow-pricing techniques, to arrive at a monetary indication for this value (see also calculations made for the spiritual or intrinsic value). However, it is difficult to distinguish between money donated to conservation measures for ethical, option or conservation reasons. There are also emotional objections against attempting to quantify the existence value of nature, therefore this value is only included qualitatively in table 4.3.5-1. Considering the many natural qualities and the conservation value of the Galapagos National Park, the existence value is certainly considerable.

Table 4.3.5-1 Socio-economic value of the functions of the Galapagos National Park (based on maximum sustainable use levels)

(values are expressed qualitatively (++) or in US$/ha/year) except column 7
Total surface area of the study area: 1,150,000 ha

Environmental Functions	1 Conser-vation value	2 Existence value	3 + 4 Social values[3]	5 Consump tive use value	6 Productive use value	7 Value to employment (^{3} people)
Regulation Functions	**> 63.00**	**++**	**++**		**++**	
Watercatchm./erosion prev.	0.30		+		*	
Bio-energy fixation	(1,200.00)[4]	+			*	
Storage/rec. human waste	58.00[2]		+		*	
Biological control	++	+	+		*	
Nursery f./migration hab.	7[2]	++	++		*	
Maintenance of biol.div.	4.90	++	++		*	
Carrier Functions	**0.50**	**++**	**+**		**> 45.00**	**> 833**
Aquaculture					0.02[2]	+
Recreation		+	+		45.00	772
Nature protection	0.55	++	++		*	61
Production Functions			**++**	**+**	**> 8.00**	**> 160**
Food/nutrition			++	+	0.70	156
Genetic resources					+	+
Raw materials for constr.					5.20	4
Biochemicals					++	+
Energy resources					1.50[1]	+
Ornamental resources					0.40	+
Information Functions	**0.50**		**++**	**++**	**> 3.00**	**> 67**
Aesthetic information			+	++	+	
Spiritual information	0.52		++	++	*	
Historic information			+	++	*	
Cultural/artistic insp.			+	+	0.20	+
Educ. & scientific inf.				+	2.70	67
TOTAL ANNUAL RETURN	**> 64.00**	**++**	**++**	**++**	**> 56.00**	**(1,060)**

[1] This function applies to the terrestrial area only (720,000 ha).
[2] This function applies to the marine area only (430,000 ha of which 4,100 intertidal zone).
[3] Social values consist of the importance of environmental functions to human health and the option value placed on a safe future.
[4] If a figure is given between brackets it was not used in calculating the total value because the calculation is too speculative.
* These functions do contribute to economic productivity, either directly or indirectly, but no market or shadow price could be determined due to lack of information and/or shortcomings of the market mechanism.

(3) Contribution of the Galapagos NP to human health

Many environmental functions provided by the Galapagos National Park contribute directly or indirectly to the maintenance of human health, such as the regulation of the local and regional climate, storage and recycling of animals provide an important source of spiritual enrichment to many people because of their intrinsic value. Monetary quantification of 'non-use' functions is still more complicated than for functions with a direct productive use and can only be achieved through shadow pricing techniques. For a few functions the conservation value has been calculated (see column 1 in table 4.3.5-1) which add up to about 64 US$/ha/ year. Thus, the total monetary return from environmental functions in Galapagos amounts to about US$ 120 per ha.

Since environmental functions provide goods and services to human society indefinitely, when utilized in a sustainable manner, the monetary value of environmental functions must be seen as the interest of the capital stock of the natural processes and components that provide these functions. At an interest rate of 5%, this amounts to a capitalized value of about 2,400 US$/ha (or almost 2.8 billion US$ for the entire study area). In addition to their great ecological and intrinsic value, the Galapagos islands, in their present largely natural state, thus represent a considerable economic value as well.

(2) Some implications for planning, management and decision-making

The Galapagos islands provide an ideal test case to study the possibilities and obstacles to bringing sustainable development into practice. The archipelago reflects many of the world's problems on a small scale: it has a (rapidly) growing population (Fig. 4.2.6-1) with the people living practically inside the national park. The local population depends to a great extent on the functions of the natural environment for its main economic activities: tourism, fishing and agriculture. All these activities can only continue if the natural processes which provide the necessary environmental conditions are kept intact, which sets a 'natural' limit to the number of people that can live in, and visit the area.

Until recently, Galapagos was one of the most prosperous provinces in Ecuador. Since about 1980 however, the local population is growing rapidly (about 2x the national average, largely due to immigration, see figure 4.3.6-1), and the number of people increase faster than jobs and infrastructure can be provided for, causing increasing socio-economic problems.

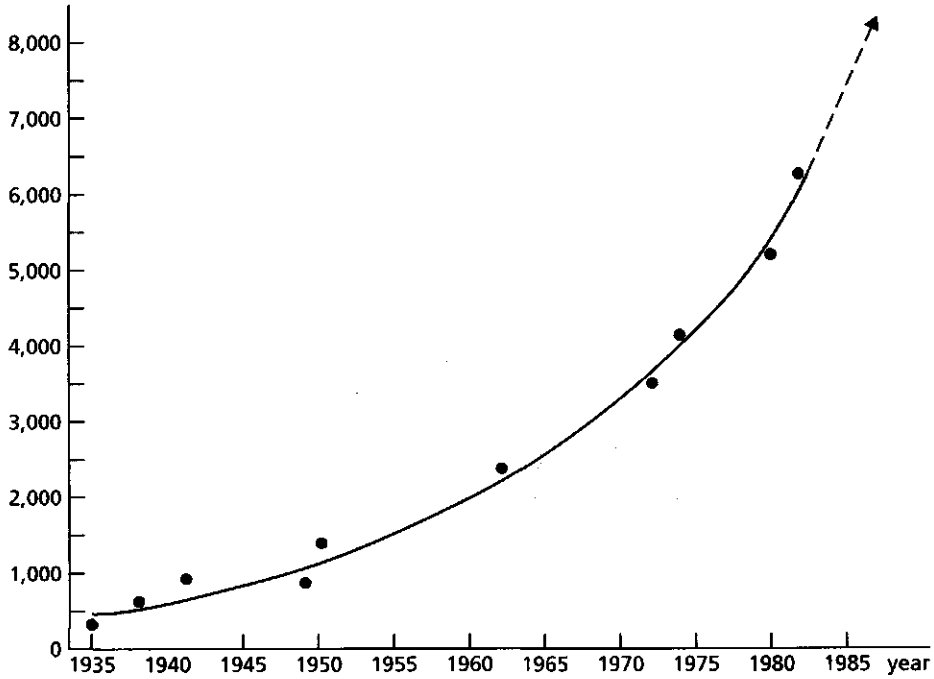
Both the growing local population and the steady increase of tourism increases the pressure on the fragile ecosystems. Clearly there are ecological and physical limits to the capacity of the islands to sustain tourism and local settlements (see box 4.3.6-1).

Box 4.3.6-1 Some considerations concerning the maximum carrying capacity of the Galapagos Islands for habitation

If a human population is to sustain itself, it needs a certain amount of space to satisfy essential survival needs such as food- and fuelwood production. Pimentel et al. (1984) estimate that a person in the tropics requires at least 0.2 ha for food-production and 0.4 ha for fuelwood production). In the Galapagos islands, soils of sufficient depth to permit (moderate) manipulation for cultivation exist only in and above the areas occupied by Scalesia forests. Thus, only about 10% of the land surface in Galapagos is pedologically suitable for cultivation (based on humus -, organic matter - and nutrient contents). About 35% of the arable land is included in the colonized zone; the rest is located in the National Park and utilization is prohibited. Thus the maximum population that could sustain itself in Galapagos would be about 45.000 people, provided other basic needs such as drinking water can be provided for as well.

If the integrity of the natural ecosystems and the biological diversity of the Galapagos islands are to be maintained, steps will have to be taken to reduce the population growth and limit tourism to a certain maximum. Choices will have to be made whether to develop the islands to their maximum economic potential (which will sacrifice much of its natural qualities), or to limit the number of people, both tourists and settlers, to the ecological (and social) carrying capacity of the islands.

Fig. 4.3.6-1 Development of the human population in Galapagos



Source: De Groot (1988)

Since the Galapagos islands have a very high conservation value but, apart from tourism, offer few opportunities for other economic activities at sustainable use levels, the best development strategy would be to concentrate on sustainable development of activities that depend on the conservation value (notably tourism and research) while limiting all other activities to levels where they do not affect the natural integrity of the islands. Systematic function evaluation can help to obtain a clear insight into the choices involved. It shows the ecological and socio-economic importance of the many environmental functions at stake and can provide guidelines for making optimal sustainable use of these functions. Based on literature and the results of this study, it is suggested to limit the local population to ca 45,000 inhabitants (see box 4.3.6-1), assuming the colonized area will not be expanded, and tourism should be limited to ca 40,000 visitors per year (see section 4.3.2). Since both are politically unpopular measures, function evaluation could help planners and decision-makers to demonstrate that giving priority to the conservation of biological diversity in Galapagos is not only of great ecological and scientific importance, but provides considerable economic benefits as well.

Chapter 5

Function-evaluation as a tool in environmental planning, management and decision-making

Introduction

Natural ecosystems such as open oceans, estuaries, wetlands, lakes, rivers, and forests are the basic life-support systems on earth. Through their multititude of functions they are essential to the maintenance of the physical, chemical and biological balance in the biosphere on which most life on earth depends, including human life. Most of the natural ecosystems on earth have already been converted by man for some type of use and, as we have seen in chapter 2.2.5, less than 2% of the remaining ecosystems on land enjoy some form of protection. Considering the losses already sustained, both in terms of habitat destruction and reduction of species diversity, man should take extra care when planning future development projects in these remaining natural and semi-natural areas.
Decisions with respect to the location, scope and management of development projects have far reaching consequences for the few remaining natural ecosystems on earth. Deciding upon the best allocation of possible land use alternatives is the main objective of the environmental planning and decision-making process.Environmental planning and decision-making should therefore be concerned with the question as to which combination of possible uses of the natural environment, such as habitation, agriculture, recreation and nature conservation is best able to satisfy the needs of as many people as possible, now and in the future.

In chapter 5.1 it is argued that the concept of 'sustainability' should be the main guideline for ensuring balanced decision-making, while stressing the importance of systematic application of environmental assessement in the project cycle. The role of function evaluation is especially important in two much used planning instruments, environmental impact assessment (EIA) and cost-benefit analysis (CBA). By providing a systematic checklist of the many functions and socio-economic values of sustainable use of natural ecosystem-complexes, function evaluation could provide an important tool in the planning and decision-making process. Moreover, the book can serve as the basis for a manual with guidelines and terms of reference for evaluating the functions and values of the most important ecosystem-complexes.
The application of the concept of environmental functions for integrating ecological principles in economic theory is the subject of chapter 5.2, while

this last chapter also reflects on some instruments and incentives which are needed to achieve sustainable development, notably resource economics and environmental accounting.

5.1 The role of function evaluation in land use planning and decision-making

Every day, everywhere on this planet, planners, managers and politicians make decisions that determine the use of some part of the biosphere. In spite of the far-reaching consequences of the conversion of natural ecosystems into cultivated land, decisions concerning the location, scope and management of these development projects are often mainly (or only) based on short-term economic feasibility and profitabilty. These, in turn, are most often only determined by comparing the estimated market price of the anticipated goods and services with the direct costs involved in the conversion. For example, in the case of forest clear-cutting, only the market value of the wood and the expected income from agricultural products and cattle breeding on the cleared land (which is often exhausted after a few years) is calculated. Most procedures to estimate the economic costs and benefits of planned development projects take little or no account of the natural capital which is lost in the conversion. In the case of forest clear-cutting this lost capital consists of many non-marketable goods and services of the forest, such as genetic resources, 'minor' forest products, watershed protection, climate regulation, etc. All these functions are considered 'free' and are therefore not or inadequately accounted for in cost-benefit analyses. In addition, the many negative so-called 'external' environmental effects caused by the conversion (such as soil erosion, floods, and drought) are often left out of the calculations.
As a result, natural ecosystems, and the goods and services they provide, are usually undervalued in conventional economic planning and decision-making, leading to over-exploitation and environmental disasters.
Somehow, man must come to terms with the reality of resource limitations and the carrying capacities of the ecosystems that provide these resources, and take into account the needs of future generations. As Polunin et al. (1982) point out, '... it is a simple ecological fact that we cannot go on growing indefinetely on a finite globe. The biosphere has limits in terms of its carrying capacity for human life. Lasting benefits from nature depend upon the maintenance of essential ecological processes and life support systems, and upon the diversity of life forms. The next few decades may well be the most critical in the whole history of our planet. Mankind could leave it in devastation, or could continue to live in and enjoy it with most of the other creatures around him'.
The concept of 'sustainable development' and the role of function evaluation in achieving more sustainable land use planning and decision-making is explained in some detail in the following paragraphs.

5.1.1 Environmental functions and the concept of sustainable development

Although the need for sustainable development is being accepted more and more, maintenance of environmental quality and many important values of natural systems are still not being given adequate consideration in development planning and decision making, both in developed and in developing nations. In spite of the growing knowledge about the importance of natural ecosystems to human welfare, it seems difficult for man to translate this knowledge into concrete actions to stop the ongoing destruction of natural areas and begin to implement the concept of sustainable development in practice. Some of the many reasons for the slow implementation of the integration of conservation and (sustainable) development in everyday planning and decision-making are listed in box 5.1.1-1). An important obstacle is the confusion which still exists regarding the definition of the concept of sustainable development. To reconcile conservation objectives with the aims of economic development, the concept of 'sustainable development' was first introduced in the World Conservation Strategy (IUCN, UNEP and WWF, 1980). The three main objectives of this strategy are: - maintenance of essential ecological processes and life support systems, -preservation of genetic diversity, and - sustainable utilization of species and ecosystems. This strategy attempts to demonstrate that nature conservation (i.e the maintenance of natural systems and biological diversity) is not necessarily incompatible with economic development (i.e. the use of species and ecosystems for economic production), and stresses the need for sustainable development through integration of conservation objectives and economic goals. Recently, the follow-up to the WCS appeared, entitled 'Caring for the Earth' (IUCN, UNEP & WWF, 1991).In 'Caring for the Earth', sustainable development is defined as: 'improving the quality of human life while living within the carrying capacity of supporting ecosystems'.

The most cited definition, however, may be the one given by the World Commission on Environment and Development (WCED) in the so-called Bruntland report: 'Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (WCED, 1987). The Bruntland-report continues by stating that '...in essence, sustainable development is a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development, and institutional change are all in harmony and enhance both current and future potential to meet human needs and aspirations'. Unfortunately, this definition does not explicitly mention the need to conserve the natural resource base and much confusion still exists concerning the practical implementation of the concept of sustainable development.

Because of the far reaching consequences, sustainable development should be defined more specifically in terms of ecological, socio-economic and cultural sustainability. Ecological sustainability could then be defined as the natural limits set by the carrying capacity of a given ecosystem (physically, chemically and biologically), so that human use of the goods and services provided by that system does not irreversibly impair the integrity and proper functioning of its natural processes and components in the future. Sustainable use of nature then means that human activities (economic development) should remain within the limits set by the carrying capacity of the natural ecosystems that support these activities.

Once satisfactory definitions have been found, indicators (ecological, socio-economic and cultural) for measuring progress towards achieving sustainable development should be defined. These indicators, in turn, should provide the basis for formulating common paradigms and concepts to integrate ecology and economics and to develop practical incentives for conservation and sustainable use of nature and natural resources (see 5.2). The function-concept could be useful in this respect since maintenance of environmental functions serves both ecological purposes and economic interests.

In order to maintain environmental functions, the maximum level of sustainable use should be determined for each function separately, as well as for combinations of functions since many functions cannot be utilized simultaneously and may compete with each other. It will then show that sustainable use of combinations of environmental functions is environmentally more safe, socially more acceptable, and economically more sound than the short-term (over)exploitation of only a few resources. Or, as Stortenbeker (1990) put it: 'Not longer the economy should dictate development paths, but ecological constraints should determine the limits for economic activities and social development'.

Although there are still many difficulties and controversies concerning the definition and implementation of the concept of sustainable development in practice, the basic underlying principle (i.e. the need for harmony between man and nature) is clear and should be the main guideline for human actions.

Box 5.1.1-1 Some obstacles to conservation and sustainable development

Reasons for the slow implementation of environmental concerns in economic planning and political decision-making are manyfold:

One of the main obstacles is the difference between political and economic interests, that mainly focus on short-term gains, versus conservation objectives which mainly aim at long-term benefits.

Sustainable development is further hampered by the difficulty to express the effects of economic development on natural systems in terms that are familiar to, and persuasive with decision makers, i.e. financial costs and benefits.

Another important obstacle to the conservation and sustainable utilization of nature and natural resources is the neglect of natural goods and services in economic planning and policy making, in spite of the fact that most economic production processes and human welfare in general, heavily depend on goods and services provided by natural systems in many ways.

The slow implementation of the principles of conservation and sustainable development in economic planning and decision-making may also be caused by a lack of understanding and

communication between those who should work together to implement the concept: ecologists, conservationists, economists, planners and decision-makers. This communication problem may partly be caused by different interpretations of some key-terms or paradigms involved in describing the environment-development interface. For a review, see Cosijn, 1986 or De Groot, 1987).

Other problems, which fall outside the scope of this book, include the still continuing population growth, and the associated increasing demand for space and resources, a continuing economic growth which is still largely based on polluting and wasteful industries, unequal distribution of resources and wealth, political innertness (short-term decision making, not only at the government level but also applying to many decisions taken at corporate and personal levels), institutional obstacles, and cultural barriers. To achieve sustainable development, in the sense of conservation and sustainable use of natural ecosystems, all these obstacles should somehow be removed through changes in, for example, population policies, industrial processes, redistribution of resources and wealth, political time-horizons (and ethics), institutional structures, cultural tolerance and individual human behaviour.

5.1.2 Function evaluation and land use planning (the project cycle)

The principal stages of an 'ideal' planning and decision-making process for development projects (also called the 'project cycle') are: (1) Setting of macro environmental, social and economic goals through, for example, country reviews, environmental profiles and national conservation strategies, (2) Formulation of project idea, (3) Project design and feasibility-assessment, (4) Assessment of ('external') project effects (5) decision making, (6) implementation (after possible adjustments), (7) project evaluation and monitoring.
(partly after: OAS, 1987).
Assessment and evaluation of environmental and ecosystem functions provides information that can be used in various phases of the planning process, notably 1, 4, 5, and 7. A brief description of the role of environmental function evaluation in the main planning phases is given below. A good review of analytical tools for incorporating the environmental dimension in planning and decision-making can be found in, for example, Dorcey, 1984, Knetsch & Freeman, 1979, Stokoe, 1988, and Pearce & Markandya, 1987.

Phase 1: Drafting of environmental profiles (as background information needed to set macro environmental, social and economic goals)
This phase deals with the formulation of development strategies and the identification of regional and sectorial investment goals and projects.Already in this phase it is essential that 'sustainability' is the main underlying concept (see 5.1.1), taking account of environmental, socio-economic and cultural needs, opportunities and constraints. A major input in this phase are data on the state of the socio-economic system (which is usually summarised in the Gross National Product) and on the state of the natural environment. Data on the last aspect is only recently being gathered and presented in a systematic way (e.g. the 'State of the Environment') -Reports of the World Resource Institute (WRI)) and are therefore still not systematically being used in the macro-planning phase.

Another reason for the neglect of environmental data in this planning phase is that many economists and decision-makers simply do not understand the importance and functioning of natural ecosystems. The concept of natural goods and services may help here and should therefore be introduced in environmental education programs for planners and decision-makers to ensure the inclusion of environmental concerns at the very beginning of the planning process.

A recent instrument to guide this phase of the planning process is the National Conservation Strategy (NCS). Other than the word 'conservation' implies, these NCS's are not limited to nature conservation but attempt to provide an objective framework for achieving sustainable development. Important elements of these strategies are environmental, social and economic profiles. Especially for drafting environmental profiles, country reviews and formulating carrying capacity limits, function evaluation can be an important instrument and it has been used for this purpose on various occasions. Case studies on functions and values of specific areas or natural ecosystems may be used to formulate guidelines for sustainable development in these areas. For example, Marchand & Toornstra (1986) used this concept to develop guidelines for river basin development in West Africa. Descriptions of environmental functions and values may also be used to provide more general guidelines for development assistance (e.g. CECOS, 1986) or national government policies. A description of the many functions of tropical forests, for example, was an important element in formulating the Dutch Government Policy concerning Tropical Forests (Min. LNV, 1990)

When proper guidelines for listing and assessing the many functions and values of major ecosystem-complexes are available, formulation of environmental profiles and carrying capacity studies for specific development projects should be possible through desk-studies within a reasonably short period of time. Chapter 4 of this book provides some examples of such case studies which can be used to develop general guidelines for assessing the functions and values of three major habitats: tropical moist forests, wetlands, and volcanic islands. The last mentioned case study (on the Galapagos National park) can also be used as an example of the functions and values of protected areas that are managed as National Parks.

Phases 2 and 3: Formulation of the project idea and design

Based on the environmental, socio-economic and/or cultural needs identified in phase 1, ideas for specific projects and their design can be formulated. In view of the general development aims described in phase 1, and the planned implementation procedure, information should be provided about the scope and relevance of the project.

From the very beginning of the formulation of a project idea, it is essential to obtain information on the possible environmental and socio-economic consequences of the proposed project in order to avoid the evolvement of 'points of no return' beyond which environmental concerns receive less priority because of the amount of time, money and prestige already invested in the project (see phase 4). This preliminary information could be obtained rather quickly through so-called 'initial screening' (ODA, 1989).Depending on the outcome of the effect-analysis (phase 4) and the decision-making process (phase 5), the design of the project could be adjusted accordingly. Therefore, the first presentation of a new project design should have a preliminary character, and several alternatives should be available. Unfortunately, environmental consultants and resource economists are still not sufficiently involved in this early stage of the planning and decision-making process which often leads to unnecessary failures and delays in the project-planning.

Phase 4: Assessment of environmental, socio-economic and cultural effects
Once a first draft of the project design is available, the possible effects should be analysed in more detail. The effect-analysis should involve three disciplines: environmental, socio-economic and cultural, which should all be based on the concept of sustainability (see 5.1.1). For each of these aspects a basic profile should have been drafted in phase 1, which may serve as reference for the effect-analysis. In chapter 5.1.3 the role function evaluation in environmental impact assessment or appraisal is discussed in more detail.

Phase 5: Decision making
The information provided by the previous planning phases should be integrated and presented in such a manner that both the public involved and the authorised decision-makers are able to make a balanced decision concerning the final project design. Too often, short-term economic (or better monetary) gains still dominate the decision-making process which almost by definition leads to the over-exploitation of natural resources. At an early stage in the planning process, information about the ecological implications, in terms of changes in environmental functions and hazards, can help to counterbalance the pre-occupation of decision-makers with economic data (which, by the way, are often of questionable validity). Various methods are available to process and integrate the large amount of data collected in phase 4. Two of the more well-known methods are Cost-Benefit Analaysis (CBA) and Multi Criteria Analysis (MCA). These methods aim to summarize the positive and negative effects of a project in order to be able to make an optimal decision in view of the environmental, socio-economic and cultural costs and benefits of the project.For large projects which involve significant alterations of the environment, the proponent should provide the information necessary to make an assessment of the opportunity costs involved. This means that it should be a requirement to assess the next best site, or next best alternative use for the proposed project and to provide evidence to the review body showing a possible difference in value to the proponent and the community between the various alternatives (after Manning, in lit. 1989).

assess environmental effects, and to transform scientific information into a useful format for integrated development planning, several information systems and sources are available such as computerized mapping systems, remote sensing (areal photography, radar imagery, satellite imagery), geo-based information systems (GIS), rapid appraisal methods and other special models (OAS, 1987, ODA, 1989).

5.1.4 Function-evaluation and Cost-Benefit Analysis (CBA)

Cost-benefit analysis (CBA) attempts to predict and summarize the positive and negative effects of proposed development policies, programs and projects in order to make certain land use decisions. Some general information on possibilities and shortcomings of CBA, which in recent times is often also called benefit-cost analysis (BCA), can be found in Pearce & Markandya (1987), OAS (1987), Stokoe (1988), and De Groot (1991). An important feature of CBA is that it forces decision-makers to list all, or at least most, of the pros and cons of any action. A major shortcoming of (traditonal) cost-benefit analysis is that it is often limited to economic (financial) trade-offs. This last feature is probably one of the main causes of the under-valuation of natural ecosystems and environmental aspects in most economic accounting procedures, since many environmental goods and services are still considered to be 'free' (i.e. they have no economic (market) value), and losses of environmental functions are seen as 'external effects' (see chapter 3.2). Since many functions of natural ecosystems cannot (as yet) be expressed in monetary units, traditional cost-benefit analysis inadequately reflects the true environmental and socio-economic value of natural resources and ecosystems.
Somehow, cost-benefit analysis should be adjusted to better account for the fact that natural ecosystems, besides providing marketable resources also perform many ecological functions with indirect yet important values to economic productivity and human welfare, such as their role in biogeochemical cycles, watershed protection, and maintenance of biological diversity. In addition, 'natural' hazards resulting from disturbance of environmental functions and the related costs should be included in a CBA. Moreover, natural ecosystems, and the wildlife they contain, have an intrinsic value to many people which should also be accounted for in cost-benefit analysis and other decision-making instruments. Other problems involve the differentiation between direct and indirect costs and benefits, the existence of quantifiable and non-quantifiable costs and benefits, and the double accounting problem.

To improve cost-benefit analysis, two approaches should be applied simultaneously: firstly, economic cost-benefit analysis should be modified in order to better account for non-monetary values, both social and environmental. Secondly, methods to determine the economic value of environmental goods and services should be improved. In chapter 3, some

methods to determine the socio-economic value of environmental functions have been discussed. A suggestion for an expanded CBA framework is given below.
The basic problem in achieving sustainable development is making decision-makers aware of, and responsive to, the fact that environmental costs are legitimate costs within their understanding of the term, and therefore have to be taken into account in their decisions. The use of 'opportunity costs' and 'shadow pricing' and other economic concepts can be used to translate environmental costs and benefits into terms which people who make economic decisions can understand. It must be realised, however, that providing sound (or sounder) calculations of economic costs and benefits on a given proposed project does not provide any assurance that a more environmentally sound course of action will be followed. Decision-makers are often prejudiced in favour of the validity of traditional, usually monetary, economic data which mainly relate to man-made goods and services and are not (yet ?) responsive to economic data provided for natural goods and services. Yet, the economic and monetary 'guesstimates' assigned by planners to different projects and activities when they seek to justify an environmentally destructive action are arbitrary enough. For example, the value of time saved by motorists, individually and collectively, by having a new road built, or the value of decreasing congestion by building a new airport terminal or runway (Cartwright, 1987, in lit.).

In an expanded CBA, the monetary factor is less important and should largely be replaced by attaching a relative weight to each attribute which is taken into account in the analysis, rather like the approach followed by Multi Criteria Analysis. It is important that the objectives of the analysis are made clear since this influences the type of data included and the relative weights given to the various attributes. Preferably, the attributes of an expanded CBA should include all of the interests involved in the project such as environmental interests, economic interests, socio-cultural interests, political interests, scientific interests, and technical and financial constraints. The attributes should be listed and specified in further detail in a matrix (which may be divided into various sub-matrices). For each attribute decision-makers may give a relative weight of importance ('coefficients'). When integrating the outcome of the various cells in Table 5.1.4-1 into a final listing of all costs and benefits (the last column in the figure) it is important that those costs and benefits which cannot be expressed in monetary units are clearly represented.

Table 5.1.4-1 Framework for an expanded Cost Benefit Analysis

Effects	Costs (ie: negative effects)	Benefits (ie: positive effects)	Neutral (no effects)	Monetary Effects[2] (sum of costs and benefits)
	Costs and/or benefits of each project-alternative[1]			
Environmental Effects				[3]
(on functions & hazards)				[3]
regulation funct.				[3]
carrier functions				[3]
production funct.				[3]
information funct.				[3]
Socio-Economic Effects				[3]
Land use				[3]
Employment				[3]
Health				[3]
etc.				[3]
Cultural Effects				[3]
Social structure				[3]
Cultural indentity				[3]
etc.				[3]

[1] Effects should be quantified in their 'natural' dimensions as much as possible. If quantification is not possible, at least a qualitative indication of the expected effect should be included in the analysis.
[2] For some changes in availability of environmental functions (and occurrence of natural hazards) and the effects on human welfare (quality of life) it is possible to calculate a monetary value. Some methods to calculate market values and shadow prices for both man-made and natural goods and services are discussed in chapter 3.2.
[3] Sum may be positive, neutral or negative.

A succesful example of an attempt to carry out such an expanded cost-benefits analysis is provided by a study by Thibodeau and Ostro (1981). Thibodeau and Ostro listed the various benefits of the swampy reaches at the mouth of the Charles River near Boston, such as flood prevention, purification of wastes, water supply, and recreation. It was proposed to drain this area for real estate development but Thibodeau and Ostro calculated that the value of the functions which would be lost in the conversion amounted to more than 162,000 US$ per acre, which was much more than the land would have raised as a building site. The timely incorporation of this information in the decision-making process contributed to the decision not to drain the area and to leave it in its orginal state. A similar procedure had success in the decision-making procedure for land reclamation in the Dutch Wadden Sea area (Dankers and Wolff, 1980). This approach could help to make more balanced decisions concerning the choice between conservation and (sustainable) use of other natural ecosystems. For example, before deciding on clear-cutting a tropical moist forest area, a thorough cost-benefit analysis should investigate whether the conversion makes economic sense, based on an assessment of the ecological and economic effects of the, usually irreversable, loss of many species of plants and animals. As chapter 4.1 has shown, it will then often become clear that sustainable use of natural tropical moist forests is, in the long run, more profitable than clear-cutting.

Another important application of function evaluation in cost benefit analysis is its use in justifying the establishment and/or continued conservation of protected areas. Since protected areas have to compete with alternative land uses such as urban development, agriculture, forestry, etc., listing the many functions and benefits (environmental, socio-economic and cultural) of protected areas is essential to justify their establishment and continued protection under increasing land use presssure.

5.2 Environmental functions and (environmental) economics

To structurally implement environmental concerns in planning and decision-making, improvement of environmental assessment methods and planning procedures alone, as discussed in chapter 5.1, is not enough. Most development decisions are mainly based on economic considerations, and therefore principle changes in economic theory are needed. Changes in economic theory, in turn, should lead to basic adjustment of economic assessment and accounting procedures in order to develop practical incentives for conservation and sustainable use of nature and natural resources. To make planning and decision-making more responsive to environmental concerns it is crucial to develop a new kind of environmental economics, which takes account of both economic objectives and ecological constraints.

5.2.1 *Environmental functions as unifying concept for ecology and economics*

If we are to solve the environmental problems of today, the conflict between economic interests (i.e. increasing the economic capital) and conservation goals (i.e. maintaining the natural capital) should somehow be solved.
Much has been written on the need for better integration of ecological principles and environmental considerations in economic assessment and accounting procedures (see for example Dorcey, 1984, Knetsch & Freeman, 1979, and Dixon, 1988, Pearce, Markandya and Barbier, 1989, and Daly, 1991). Without the development of a new kind of 'environmental economics' most efforts to halt environmental degradation and to bring economic development more in harmony with the carrying capacity of nature will fail. The question now is not so much anymore if economics should be 'ecologised', but rather how this can be done.
To reconcile conservation objectives and economic (development) goals, a constructive dialogue between all parties involved in environment and development (decision-makers, economists, ecologists, conservationists

and the general public) is necessary. To achieve the 'internalization' of ecology in economic planning and decision-making common concepts, paradigms and value standards (indicators) should be developed for measuring human welfare. Ecologists, conservationists and economists all have different views on the meaning of such terms as 'conservation', 'sustainable development' and 'natural resources' (for a good review, see Cosijn, 1986). As long as there is no agreement on the definition and interpretation of these key terms, it will be difficult to solve the communication problem, and there is a real danger that the conservation of nature and natural resources (i.e. the maintenance of natural systems and biological diversity) will continue to be sacrificed for the sake of (economic) development.

The compatibility of conservation and development depends to a large extend on the way the natural environment is viewed as a resource. Thus far, economic theory mainly focussed on a limited array of natural resources that satisfy only certain human wants while ignoring needs that are satisfied by many so-called 'free services' of nature such as natural purification processes which contribute to the maintenance of clean air, water and soils. This neglect is one of the main causes for the still continuing process of environmental degradation.

Because nature not only provides many resources to human society but many important services as well, as we have seen in previous chapters, it is therefore suggested to use the term 'environmental functions' (which includes both goods (resources) and services) instead of the more narrow concept of 'natural resources'. This is all the more relevant since these services are in particular increasingly being threatened by current economic production processes (e.g. ozone-depletion, climate change, acid rain, etc.).

Both maintenance of environmental quality and quality of life (i.e. satisfaction of human needs) depend on the availability of environmental functions. The use of the concept of environmental functions may therefore provide a useful tool for integrating ecological and economic indicators and paradigms, since conservation and sustainable use of environmental functions serves both ecological interests (i.e. conservation of natural resources and maintenance of environmental health) and economic goals (i.e. maintenance and enhancement of human welfare). Thus, the use of environmental functions as a common indicator for measuring environmental quality and quality of life, broadens the subject matter of economics to all environmental goods and services that are relevant to human welfare.

Another advantage of the use of the function-concept as a common paradigm in ecology and economics, instead of the narrower concept of natural resources, is its potential as an indicator for measuring both environmental quality and the quality of life. By definition, environmental functions satisfy human needs. The satisfaction of human needs is also an important

element of economic theory. Thus, the maintainance of environmental functions serves both ecological interests (i.e. environmental health) and economic goals (i.e. human welfare).
The thought of environmental functions as a unifying concept for ecology and economics is worked out in some more detail in de Groot (1987)

5.2.2 Resource economics and ecological pricing

The market price of many products, both man-made and natural, does not adequately reflect their increasing scarcity, their true socio-economic value, and the (environmental) costs involved in the production and/or extraction of these resources, which are usually referred to as 'external effects'. Also, the contribution of many natural goods and services to the economic production process is not, or insufficiently accounted for in the pricing mechanism because the market is not able to provide realistic 'environmental' prices for nature's works, many of which are entirely neglected because they are labelled 'free goods and services'. As a result, natural ecosystems, and the goods and services they provide, are usually undervalued in conventional economic accounting procedures leading to over-exploitation, non-sustainable development and environmental disasters (see box 5.2.2-1).

Box 5.2.2-1 On the pricing mechanism for tropical timber

An illustrative example of the under-valuation of natural goods is the market value of tropical timber.The market value of tropical timber today is little more than the cost (including margins and profits) of bringing that timber from the forest to the market (Burns, 1986). Thus, only the product is valued, not the capital (i.e. the forest) which provides the product. In addition, most financial appraisals of tropical forests have focused exclusively on timber resources and have ignored the market benefits of non-wood products. As a result there has been a strong market incentive for destructive logging and widespread forest clearing. However, it has been proven in several cases that the financial benefits generated by sustainable use of tropical forests tend to exceed those that result from forest destruction and conversion (see chapter 4.1). Already after two years, income from sustainable use of non-wood forest products is greater than that from clear-cut and agricultural profits combined (Peters et al., 1989). Therefore, large scale tropical deforestation makes no financial sense other than raising short-term profits of the logging companies, concession holders and a few others involved in the tropical timber industry. If industry (i.e. the consumer) would pay the real costs of timber exploitation by including the value of lost benefits from other goods and services provided by the forest, and the cost of the environmental damage and mitigation measures, consumption rates would probably drop and the search for alternatives would most likely be intensified. As early as in 1983, Dr. Marius Jacobs, suggested that governments owing forests rich in genetic resources, should charge money for the maintenance and harvesting of such wild materials. Assessments like the method presented in this book can help to increase awareness about the many functions and great socio-economic value of intact tropical moist forests and provide governments with plausible arguments to increase the price of timber and timber concessions.

It is essential to internalise ecological costs and benefits into the pricing mechanism, not only for timber (see box), but also for other natural products. An important instrument is the application of environmental pricing and taxing, based on realistic shadow prices which reflect the full costs and benefits of the use (and non-use) of both man-made and natural goods and services.Even if these shadow prices cannot be included in the market prices immediately, the listing of these 'soft' monetary values in cost-benefit analysis can provide an important economic incentive for their conservation and sustainable utilization. Some references for further reading on this subject include Kneese (1984) and Johansson (1987).

Another application of function evaluation in environmental economics is the role in restructuring debts of developing countries in exchange for the conservation of natural ecosystems. Most development projects in the 'third world', where still much of the remaining natural heritage is found, are financed by large international banking institutions which therefore have considerable influence on the design of development projects in these countries. To ensure more sustainable use of natural ecosystems, adjustment of the financing policies of these institutions would be an important instrument.
The concept of environmental functions can help to better represent the full value of the natural ecosystems under consideration for development projects. By calculating the 'full value' of these natural ecosystems, the sell-out of natural resources (at the expense of most other goods and services) could be reduced or even halted. For example, Bolivia once sold licences for logging in tropical forests for a mere 48 $/ha. Also in the recently developed instrument of 'debt swapping' it is important that the full value of the natural ecosystems be taken into account.
Application of ecological pricing would provide more realistic prices for the natural goods and services of the ecosystems involved, and in international financing and debt-issues it could provide a powerful economic incentive for sustainable development in these countries.

5.2.3 Adjustment of economic accounting procedures (e.g. GNP), and the need for better indicators for measuring environmental quality and quality of life

Because the current pricing system of the market economy is based on incomplete cost-benefit analyses, economic accounting procedures must be reconsidered in order to better account for the benefits of natural goods and services and the costs of the loss of these goods and services (i.e. loss of environmental quality) due to non-sustainable production activities.
In traditional National Accounting Systems (SNA's), such as the Gross National Product, (GNP), human welfare is still crudely measured by means of a limited number of economic indicators. Much emphasis is placed on measuring the total amount of marketable, man-made goods and services, while the availability of nature and natural goods and services is usually not accounted for. As a result, an increase in traditional welfare indicators such as GNP often goes at the expense of natural goods

and services. It is therefore quite curious to note that costs involved in efforts to maintain and/or restore natural goods and services (e.g. through water purification plants) are added to GNP (!). This strange accounting procedure implies that it is economically sound to pollute as much as possible since more pollution means more treatment plants and more labour and capital invested.

Box 5.2.3-1 On some shortcomings of the concept of Gross National product (GNP)

'Gross National Product (GNP) is probably the most important economic indicator used by ministries of finance worldwide. It is the total of all incomes (wages, salaries, profits) generated in the production of goods and services in a given year. While widely interpreted as a measure of welfare, GNP is actually quite a narrow concept, the measure of total economic activity in the accounting period. As such, GNP has been subject to a great deal of criticism from environmental analysts and theorists, notably that it measures the 'goods' but not the 'bads' associated with production and that there is no way to determine from the accounts whether an economy is evolving sustainably' (Hamilton, 1990). Hamilton further states that the environment should be brought into the national accounts through deductions from GNP for various aspects of environmental degradation, including costs of pollution and abatement control, environmental damage and the depletion of natural resources. To this end, resource stock and flow accounts should be constructed for both living and non-living resources, in physical quantities and values. There is no international consensus on how to deal with these issues, and both the United Nations and the World Bank are doing research on environmental and national accounting.

The integration of environmental concerns in economic planning and policy- making clearly needs new, and more appropriate instruments. Since the notion of Gross National Product (GNP) plays a predominant role in overall sectoral planning, this indicator should be extended in order to reflect the quality of the environment as an important factor to human welfare.

In present national accounts, man-made assets are valued as productive capital, while natural resources and other environmental functions are not. To correct this, international agencies including the UN Statistical Office, UNEP, and the World Bank are attempting to broaden the system of national accounts (Ahmad, Serafy and Luts (1989), see also Friend (1988), and Hueting (1990) on adjusment of national accounting systems (SNA's) through so-called National Resource Accounting (NRA)).

The welfare of a country should not only be measured by the monetary value of the marketable goods and services it produces, but also by other factors that contribute to human welfare and the quality of life, notably those natural goods and services which are not traded on the market place and therefore have no monetary value in conventional economic accounting procedures (see Table 5.2.3.-1). Thus, the 'wealth' of a nation is not only determined by its economic capital, i.e. the stock of man-made factories, equipment, knowledge, etc. (the upper-half of the table) but also by the natural capital, i.e. the 'stock' of natural and semi-natural ecosystems (the lower-half of the table). An example is the 'Environmental Quality Index' published by the National Wildlife Federation in Washington, describing a variety of changes in the environment each year, chiefly related to the availability of wildlife, forests, water, energy, soil and (clean) air. From these indices, it has been concluded that the overall quality of life in the USA in 1989 was lower than in 1985 (Pierce, 1990)

Table 5.2.3-1. Indicators for human welfare and national 'wealth'

	Availability	Monetary value[1]
Man-made goods and services (provided by the economic capital/infrastructure)		
Human constructions		
Agricultural products		
Energy production		
Industrial products		
Health care		
Education/research		
etc.		
Natural goods and services (provided by the natural capital/ecosystems)		
Regulation functions		
Production functions		
Carrier functions		
Information functions		
Total National Welfare/Wealth		

[1]Methods to calculate monetary values for both natural and hand-made goods and services have been discussed in chapter 3.2.

By including both the goods and services provided by the economic capital (i.e. the man-made infrastructure) and the natural capital (i.e. natural ecosystems) as separate entries into national accounting systems, it becomes clear that an increase of the economic capital, especially in the market sector, often goes at the expense of the natural capital. The net-effect of many so-called development activities on human welfare is thereby greatly reduced, and may sometimes even be negative. For example, the 'mining' of tropical forests for hardwood converts the natural capital into economic capital which quickly evaporates into paying off national debts. What remains are devastated landscapes which havew lost their productive potential and the many other functions they provided, bringing much hardship to the local communities. Natural ecosystems are more than just a cheap source of resources and land to be used at will for short-term economic gains. They should be seen as a productive natural capital which could provide many goods and services indefinitely if conserved and used in a sustainable manner.

Thus, so-called environmental accounting procedures should be developed which include the benefits of natural goods and services and the costs of the loss of these goods and services due to non-sustainable production activities. Here too, the function-concept can be useful as an indicator for both environmental quality and human welfare (quality of life) by providing an instrument for measuring the availability and the 'full value' of environmental functions to human society.
Only when ecological principles become an integral part of economic planning and political decision-making is there a chance of achieving sustainable development based on a new kind of environmental economics which integrates conservation objectives and economic interests into one common goal: i.e. the maintenance and sustainable utilization of the functions (goods and services) provided by nature and natural ecosystems.

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Table I.0-1 Checklist of environmental characteristics (parameters) which influence the capacity of a given ecosystem or natural area to provide certain functions*

1. Bedrock characteristics and geological processes
1.1 Bedrock properties and lithology
1.2 Occurrence of distinct geological formations
1.3 Volcanoes and areas of volcanic activity
1.4 Geotectonics and geophysical features

2. Atmospheric properties and climatological processes
2.1 Chemical composition of the atmosphere
2.2 Concentration of atmospheric dust
2.3 Concentration of water vapour/air humidity
2.4 Precipitation/drought
2.5 Clouds
2.6 Solar radiation input
2.7 Temperature
2.8 Winds
2.9 Occurrence of lightning/fire

3. Geomorphological processes and properties
3.1 Topography (slope/relief/atitude)
3.2 Presence of distinct landform units
3.3 Type and structure of surface (see also 6.4)
3.4 Albedo
3.5 Weathering/erosion
3.6 Sedimentation and fossilization

4. Hydrological processes and properties (at the surface)
4.1 Water reservoirs/availability (volume, area, depth)
4.2 Interactions with atmosphere
4.3 Runoff and river discharge
4.4 Tides and ocean currents
4.5 Groundwater table
4.6 Water quality/BOD5

5. Soil processes and properties
5.1 Soil depth
5.2 Texture/structure (physical characteristics)
5.3 Organic matter (humus content and litter)
5.4 Mineral content (fertility)
5.5 Soil moisture/humidity/drainage
5.6 Chemical characteristics/chelation
5.7 Biological characteristics (see also 8.6)

6. Vegetation characteristics
6.1 Height, structure, density and roughness
6.2 Succession stage/age/maturity
6.3 Standing biomass/chlorophyll (see also 8.1)
6.4 Surface covering/leaf area index (LAI)
6.5 (Evapo)transpiration/water use efficiency
6.6 Litter-production
6.7 Root system and nutrient uptake/recycling

7. Characteristics of flora and fauna (species properties)
7.1 Species composition and diversity
7.2 Population size (rarity) and distribution (endemism)
7.3 Population viability/vulnerability (genetic diversity)
7.4 Population dynamics (increase, decrease, etc.)
7.5 Dispersal and migration
7.6 Special functional properties
- edibility/nutritious value
- useful genetic and biochemical properties
- role in biogeochemical cycles
- indicator value
- other (e.g. aesthetic value)

8. Life-community properties and food chain interactions
8.1 Biomass production/photosynthesis (see also 6.3)
8.2 Consumption and respiration
8.3 Decomposition
8.4 Food-chain interactions
8.5 Deposition of calcareous material
8.6 Bioturbation/activity of soil communities (see also 5.7)

9. Ecosystem parameters
9.1 Naturalness/integrity/heritage value
9.2 Uniqueness/distinctiveness
9.3 Diversity/richness
9.4 Minimum critical ecosystem size
9.5 Ecological fragility (carrying capacity)
9.6 Replacability/renewability
9.7 Information value
- amenity value/aesthetic qualities
- historic/cultural value
- inspirational/spiritual value
- scientific and educational value

*In figures I.0.1-4 the relation between specific functions and these parameters is given in four separate matrices, one for each main function category.

Fig. I.0-1 Environmental parameters related to regulation functions (see chapter 2.1)

FUNCTIONS*:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
PARAMETERS **																
1. Bedrock/geology																
1.1 Lithology							•		•							
1.3 Volcanic activity			•	•	•							•				
1.4 Geotectonics				•												
2. Atmosphere and climate																
2.1 Chemical composition	•	•			•											
2.2 Atmospheric dust	•	•			•				•							
2.3 Water vapour/humidity		•			•											
2.4 Precipitation/drought			•	•		•	•	•			•	•				
2.5 Clouds	•	•			•											
2.6 Solar radiation		•			•					•						
2.7 Temperature									•	•						
2.8 Winds		•	•					•					•		•	
2.9 Lightning/fire			•								•					
3. Geomorphology																
3.1 Topography					•	•	•	•								
3.3 Surface type/structure					•	•	•	•	•				•			
3.4 Albedo		•			•											
3.5 Weath./erosion			•	•					•			•				
3.6 Sedimentation/fossilization			•	•					•			•				
4. Hydrology (surface)																
4.2 Interact. with atmosphere		•	•	•	•											
4.3 Runoff and river discharge				•				•								
4.4 Tides and ocean currents		•			•							•	•		•	
5. Soil																
5.1 Soil depth						•	•									
5.2 Texture/structure						•	•	•								
5.3 Organic matter/humus						•	•	•	•	(•)	•					
5.5 Soil moisture								•								
5.6 Chemical properties													•			
5.7 Biological properties											•	•	•			
6. Vegetation characteristics																
6.1 Height, structure, roughness		•			•	•	•	•					•			
6.2 Succession stage/age										•						
6.3 Standing biomass						•		•		(•)	•					
6.4 Surface covering (LAI)								•	•	•						
6.5 Evapotranspiration					•											
6.6 Litter-production						•	•	•	•				•			
6.7 Root system & nutrient uptake						•	•	•				•				
7. Flora and fauna																
7.1 Species composition & div.															•	•
7.2 Population size/distribution																•
7.4 Population dynamics														•		•
7.5 Dispersal & migration				•											(•)	
7.8 Role in biogeochemical cycles				•	•											
8. Life-community																
8.1 Biomass prod./photosynth.		•	•							•	•	•			•	
8.2 Consumption & respir.			•								•			•		
8.3 Decomposition			•						•		•	•	•	•		
8.4 Food-chain interactions			•	•							•	•	•	•		
8.5 Deposition of calcareous mat.				•												
8.6 Bioturbation									•	•						
9. Ecosystem parameters																
9.1 Naturalness/integrety														•	•	•
9.2 Uniqueness/endemicity																•
9.3 Diversity/richness													•		•	
9.4 Minimum critical size															•	•

* For explanation of numbers, see Table 2.0-1

** The numbering is based on Table I.0-1, but may be interrupted because not all parameters apply to this function-category.

( ) This parameter does not influence a given function but may be used as an indicator for measuring the capacity of the ecosystem to perform a certain function

Figure I.0-2 Environmental parameters related to carrier functions (see chapter 2.2)

FUNCTIONS:	1 habit.	2.1 crop.grow	2.2 anim.hust.	2.3 aquac.	3 energy	4 recreation	5 nature cons.
PARAMETERS *							
2. Atmosphere and climate							
2.1 Chemical composition	•	•	•			•	•
2.3 Humidity		•	•				
2.4 Precipitation/drought	•	•	•		•	•	
2.6 Solar radiation		•	•	•	•	•	
2.7 Temperature	•	•	•	•			
2.8 Winds		•			•	•	
3. Geomorphology							
3.1 Topography	•	•	•			•	
3.2 Distinct land forms						•	
3.3 Surface type/structure						•	
4. Hydrology							
4.1 Water availability		•	•	•		•	
4.3 Runoff & river discharge		•		•	•	•	
4.4 Tides/ocean currents				•			
4.5 Groundwater table		•	•				
4.6 Water quality				•		•	•
5. Soil		•	•				
6. Vegetation						•	•
7. Flora and fauna							
7.6 Edibility/animal feed			•				
8. Life-community							
8.4 Food-chain interactions				•			
9. Ecosystem parameters							
9.1 Naturalness/integrety						•	•
9.2 Uniqueness/distinct.						•	•
9.3 Diversity/richness						•	•
9.4 Minimum critical size						•	•
9.5 Ecological fragil./cc	•	•	•	•	•	•	•
9.6 Replaceability	•	•	•	•	•	•	•
9.7 Amenity value/aesthetics						•	

* The numbering is based on Table I.0-1, but may be interrupted because not all parameters apply to this function-category.

Fig. I.0-3 Environmental parameters related to production functions (chapter 2.3)

FUNCTIONS:	1 Oxyg.	2 Water	3 Food	4 Genet.	5 Medic.	6 Fabrics	7 Indus.	8 Biochem	9 Ener.	10 Fodder	11 Ornamen
PARAMETERS*											
1. Bedrock/geology											
1.1 Lithology								•		•	
2. Atmosphere and climate											
2.4 Precipitation/drought		•									
4. Hydrology											
4.1 Water reservoir		•									
4.3 Runoff			•								
4.5 Groundwater table		•									
4.6 Water quality	•										
5. Soil											
5.3 Organic matter/litter										•	
6. Vegetation & habitat											
6.3 Standing biomass			•			•	•		•		
6.6 Litter-production									•	•	
7. Flora and fauna											
7.1 Species compos./div.				•							
7.2 Population size/distr.				•							•
7.3 Population viability			•	•	•	•	•	•	•	•	•
7.4 Population dynamics			•	•	•	•	•	•	•	•	•
7.6 Special properties											
- Edibility/nutr.value			•								
- Genetic properties				•							
- Biochemical properties					•			•	•	•	
- Amenity/aesthtic value						•	•				•
8. Life-community											
8.1 Biomass prod/photosynt.	•		•	•	•	•	•	•	•	•	•
9. Ecosystem parameters											
9.5 Fragility/carr.capacity		•	•	•	•	•	•	•	•	•	•
9.6 Replaceability		•	•	•	•	•	•	•	•	•	•

* *The numbering is based on Table I.0-1, but may be interrupted because not all parameters apply to this function-category.*

Fig. I.0-4 Environmental parameters related to information functions (see chapter 2.4)

FUNCTIONS: PARAMETERS*	1 Aesthetic	2 Spiritual	3 Historic	4 Cult./art	5 Scient/educ.
1. Bedrock/geology					•
1.2 Geological form.			•		•
1.3 Volcanic activity	•	•		•	•
2. Atmosphere and climate					•
2.8 Winds		•		•	•
2.9 Lightning/fire		•		•	•
3. Geomorphology					•
3.1 Topography	•			•	•
3.2 Landform units			•	•	•
3.3 Surface type/structure	•				•
4. Hydrology					•
5. Soil		•			•
6. Vegetation					•
6.1 Vegetation structure	•			•	•
7. Flora and fauna					•
7.1 Species comp./div.		•		•	
7.5 Dispersal & migration		•		•	
7.9 Indicator value					•
7.6 Aesthetic qualities	•			•	
7.6 Special relig. value		•			
7.6 Historic value (old trees)			•		
8. Life-community					•
9. Ecosystem parameters					•
9.1 Naturalness/integrety	•	•	•	•	
9.7 Information value	•	•	•	•	•

* The numbering is based on Table I.0-1, but may be interrupted because not all parameters apply to this function-category.

I.1. Bedrock characteristics and geological processes

Many processes and components below the surface of the earth influence the functioning of the biosphere.

I.1.1 Bedrock properties and lithology
The occurrence of rocks, minerals and other chemical elements is an important parameter to many functions. They can be used as raw materials for the manufacture and synthesis of products (see chapter 2.3.7) and energy (2.3.9). Bedrock characteristics are also important for watercatchment and groundwater recharge (2.1.7) and the formation of topsoil (2.1.9). Also most carrier functions depend on a stable substrate.

I.1.2 Occurrence of distinct geological formations
The presence of distinct geological formations, especially the occurrence of fossils, is important to several information functions, notably historic (2.4.3) and scientific information (2.4.5).

I.1.3 Volcanoes and volcanic activity
Volcanic activity influences the chemical composition of the atmosphere (2.1.3), and thereby also the climate (2.1.5). Fallout also influences the chemical composition of the oceans (2.1.4) and plays an important role in the recycling of certain nutrients (2.1.12). Also most carrier functions are influenced by the presence of volcanoes and they have special aesthetic (2.4.1) and other information values. For example in spiritual and religious ceremonies (2.4.2), as a source of cultural and artistic inspiration (2.4.4) and for research purposes (2.4.5).

I.1.4 Geotectonics and geophysical features
The occurrence of geological movement (such as uplifting, subsidence, earthquakes, sea floor spreading, plate formation and displacement) influences various functions, including the regulation of the chemical composition of the oceans (2.1.4). Geological movements have considerable scientific interest but negatively influence the suitability of the substrate for most carrier functions.

I.2. Atmospheric properties and climatological processes

The atmosphere and climate have a crucial influence on the functioning of the entire biosphere.

I.2.1 Chemical composition of the atmosphere
Table I.2-1 gives the average composition of 'clean dry air'and the role of each gas in the functioning of the biosphere.
The chemical composition of the atmosphere plays an important role in many functions, as tables I.0-1 - I.0-4 show. For example, certain gases

intercept harmful cosmic radiation and the total mass of gas-molecules in the air provides a protective shield against cosmic particles (2.1.1.). Certain so-called greenhouse gases regulate the global energy balance (2.1.2), and thereby influence the global climate (2.1.5). Also most carrier functions are influenced by the air quality, notably habitation (2.2.1), cultivation (2.2.2), recreation (2.2.4) and nature protection (2.2.5).

Table I.2.-1 Average composition of natural dry air [1])
Based on: Ehrlich et al., 1977, Lovelock, 1987, Usher, 1988

Element	Symbol	Fraction of air Molecular [2] Volume %	ppm	Total mass (10^6 tonnes)	Function (see legend)
Nitrogen	N_2	78.09	780,900	3,850,000,000	1,2,3,6
Oxygen	O_2	20.94	209,400	1,180,000,000	4,6
Argon	Ar	00.93 [3]	9,300	65,000,000	[4]
Carbon dioxide	CO_2	00.03 [3]	345	2,500,000	5,6
Neon	Ne		18	64,000	[4]
Helium	He		5.2	3,700	[4]
Methane	CH_4		1.3-2.9	3,700	6,7,8
Krypton	Kr		1.0-1.1	15,000	[4]
Nitrous Oxide	N_2O		0.25-0.5	1,900	7,9
Hydrogen	H_2		0.5	180	6
Carbon monoxide	CO		0.1	500	?
Ozone (25-30 km)	O_3		0.01-0.02	200	6,10
Ammonia	NH_3		0.01	30	6,11
Nitrogen dioxide	NO_2		0.001		8 ?
Sulfur dioxide	SO_2		0.0002		2,12

Functions:
1. Pressure builder, 2. Fire extinguisher, 3. Alternative to nitrate,
4. Energy reference gas, 5. Photosynthesis, 6. Climate control/energy balance,
7. Oxygen regulation, 8. Ventilation of the anaerobic zone, 9. Ozone regulation
10. UV-filter, 11. pH-control, 12. Transport of sulfur

[1] Concentrations are based on measurements in the period between approx. 1975 and 1985
[2] A mole of any substance is 6.02×10^{23} molecules, and the mass of a mole is equal to the molecular weight of the substance in grams.
[3] In a hypothetical equilibrium world, without life interfering with chemical reactions, this would be 99 % CO_2 (and 1% Argon).
[4] Most of the elements in the table play important roles in atmospheric chemistry and physics. By contrast, argon, helium, krypton, and neon, are chemically inert, monotomic gases, whose presence in the atmosphere is of interest only as resources for certain applications in technology (function 2.3.6)

I.2.2 Concentration of atmospheric dust

Atmospheric dust is brought into the air by various natural processes (among others: volcanic eruptions and wind erosion) and by human industrial processes, agricultural activities and traffic. The concentration of atmospheric dust influences various functions, such as protection against harmful cosmic radiation and particles (2.1.1), regulation of the energy balance (2.1.2) and the global climate (2.1.5). Deposition of atmospheric dust may enhance the formation of topsoil and soil fertility in certain areas (2.1.9).

I.2.3 Concentration of water vapour/air humidity

The concentration of water vapour (H2O) in the atmosphere is influenced by many factors (precipitation, evaporation, temperature). By trapping long-wave radiation which is reflected and emitted from the earth`s surface, water vapour plays an important role in the regulation of the local and global energy balance (2.1.2). The concentration of water vapour thus also influences the climate (2.1.5) which, in turn, is important for the vegetation, both natural and man-managed (e.g. agricultural systems, see function 2.2.2).

I.2.4 Precipitation/drought

Most biological processes require water, and the constant recycling of water through the atmosphere may be one of the most important environmental features which make life on earth possible (see chapter 2.1.5). Precipitation (e.g rain and snow) is an essential part of the hydrological cycle and is an important parameter to many functions: it influences the chemical composition of the atmosphere (2.1.3) and oceans (2.1.4), it influences runoff (2.1.6), watercatchment (2.1.7) and erosion (2.1.8), which in turn influences many biogeochemical recycling mechanisms (2.1.11 and 2.1.12). Also many carrier functions depend on (sufficient) precipitation of some kind, notably for cultivation (2.2.2), energy conversion (2.2.3), and certain types of recreation (2.2.4). Also the supply of water, for drinking, irrigation, etc. (2.3.2) is very much dependent on the precipitation.

I.2.5 Clouds

Clouds consist of condensed water-vapour which evaporates from surfaces, mainly large water-bodies and vegetation. The occurrence of clouds influences, among others, the protective function of the atmosphere against harmful cosmic radiation (2.1.1), the global energy balance (2.1.2) and climate (2.1.5).

I.2.6 Solar radiation input

The energy-output from the sun reaches the earth in many types of electromagnetic radiation which are distinguished by their different wavelengths. The entire range of wavelengths that have been observed, from tiny fractions of a micron to tens of kilometers, is called the electromagnetic spectrum. Some types of electromagnetic radiation occupying different parts of the spectrum are indicated in the table below.

Table I.2-2 Type of radiation and corresponding wavelengths

Type of radiation	Wavelength range
Radio	1 - 10 m
Radar (microwaves)	1 - 30 cm
Infrared	0.71 - 100 μ
Visible	0.40 - 0.71 μ
Ultraviolet	0.10 - 0.40 μ
X-rays	10^2 - 10^2 μ

Source: after Ehrlich et al., 1977

Solar radiation is essential to the maintenance of life on earth by providing heat and kinetic energy which maintain the global energy balance (2.1.2). About 30% of the incoming solar energy is directly reflected back into space by the atmosphere, 23% is used for the circulation-processes in the atmosphere and hydrosphere. About 2 x 1015 kWh are absorbed daily by the earth's surface. After taking part in various ecological processes, most of the energy is radiated back into space as heat-(long-wave) radiation (see chapter 2.1.2).
The amount of energy received from the sun has been relatively constant since the beginning of life, 3.5 billion years ago, but small fluctuations do occur due to the activity of the sun's surface. For example, between 1980 and 1985, solar radiation decreased by 0,1 % . Since 1985 the activity of the sun has increased again to reach it's maximum in 1990. It is believed that these small fluctations may influence the climate (see also chapter 2.1.5).
Solar radiation also serves as the most important source of energy for photosynthesis (2.1.13) which stands at the base of most food-chains. Also most types of cultivation (2.2.2) directly or indirectly depend on the energy provided by the sun, while new technologies enable man to convert solar radiation into other forms of useful energy (e.g. for heating and generation of electricity, see chapter 2.2.3). Also various types of recreation depend on the availability of sunshine (2.2.4).

I.2.7 Temperature

Air-temperature, together with precipitation and solar radiation, belong to the most important parameters which characterise the local, regional and global climate. Air temperature influences various functions, notably soil formation (2.1.9), biomass production (2.1.10) and several carrier functions such as human habitation (2.2.1) and cultivation (2.2.2).

I.2.8 Winds

Winds are generated by differences in air pressure and are influenced by the presence or absence of the vegetation and other landscape forms.

Wind speeds vary between 0 and more than 120 km/hr. Depending on the force of the wind, air turbulance has many different functions, it is instrumental in transporting heat (2.1.2), it diffuses chemical substances in the atmosphere (2.1.3) and thereby helps reduce the (local) impact of human waste disposal (2.1.13). It influences soil erosion and sediment control by transporting dust through the atmosphere (2.1.8) and it acts as a means of transport for plant-seeds, insects and migratory birds (2.1.15). By stimulating evapotranspiration (moderate) wind speeds are beneficial to plant growth (2.2.2) and may be used by man for energy conversion (2.2.3). Also many recreational activities depend on (moderate) wind speeds (2.2.4). Winds also have various information values, including spiritual information (2.4.2), artistic inspiration (2.4.4) and scientific information (2.4.5).

I.2.9 Occurrence of lightning/fire

Lightning influences the chemical composition of the atmosphere (2.1.3) and is an important cause for the occurrence of fires which, in turn, influence the recycling of organic matter (2.1.11). To some cultures, lightning at (still) a part of spiritual and religious customs (2.4.2) and is also used in cultural and artistic expressions (2.4.4).

I.3. Geomorphological processes and properties

This group of parameters relates to landscape features and processes which operate at or near the surface of the earth.

I.3.1 Topography

The topography of a given landscape is mainly determined by differences in altitude and the relief. Special methods and scales have been developed to describe the topography of a landscape. Relief and altitude both influence climatic conditions (2.1.5). With increasing altitude temperatures drop (on average ca 0,5° C/100 m), and mountains influence the occurrence and distribution of rainfall over large areas. In areas with steep hillslopes, runoff (2.1.6) is much greater than in areas with less relief. Also watercatchment (2.1.7) and soil erosion (2.1.8) are influenced by the topography. Relief is also important for most carrier functions (2.2 and several information functions, notably aesthetic information (2.4.1) and cultural and artistic inspiration (2.4.4).

I.3.2 Presence of distinct landform units

Some geomorphological formations can be clearly identified in the field and can therefore be depicted on (geomorphological) maps. Distinct landform units often provide information about the history of the landscape (2.4.3) and sometimes they are a source of cultural and artistic inspiration (2.4.4). They may also have recreational (2.2.4) and scientific value (2.4.5)

I.3.3 Type and structure of surface covering

The surface of the earth consists of a large variety of landscapes, ranging from open sea, ice- and sand-deserts to dense rain forests. Different types of surface-covering (which together with the topography are the main determinants of landscapes and ecosystems) have a different influence on local, regional and global climatic conditions, notably on the temperature, precipitation and air turbulance (see chapter 2.1.5). For example, cyclones and hurricanes only originate above large open areas (oceans, deserts), vegetated areas on the other hand reduce wind speeds (windbreak function). Generally speaking, vegetated areas and oceans have a buffering influence on climate conditions while unvegetated land areas induce more extreme climate conditions (see also appendix I.6.1 and I.6.4). Other important functions which are influenced by the structure and type of surface covering are regulation of runoff, watershed protection and flood-prevention (2.1.6), watercatchment and groundwater recharge (2.1.7), prevention of soil erosion and sediment control (2.1.8), soil formation (2.1.9) and filtering of (polluted) air (2.1.13). The structure of the surface covering, notably the openness, also has important recreational (2.2.6) and aesthetic (2.4.1) functions.

I.3.4 Albedo

The reflective property of a surface or substance is called its albedo (on formula the albedo equals reflected energy divided by incoming energy). The albedo depends on the structure of the surface area, as well as the colour. If a surface is completely white, it will reflect all sunlight to space causing a cooling-effect, if it is completely black, all sunlight will be absorbed causing a warming effect. Table I.3.-1 gives a few examples for various types of surfaces. It has been suggested that the earth's surface in earlier times was darker in colour than today and therefore absorbed more of the sun's heat. With the evolution of the atmosphere and changes in the land-cover, the albedo of the earth changed. It is now of an intermediate colour and half covered with clouds, reflecting about 45 per cent of the incoming sunlight (Lovelock, 1987).

Table I.3-1 Albedo of various surfaces

Surface	Albedo
Snow	0.50 - 0.90
Clouds	0.25 - 0.90
Water	0.03 - 0.80
Sand	0.20 - 0.30
Grass	0.20 - 0.25
Soil	0.15 - 0.25
Forest	0.05 - 0.25

Source: Ehrlich et al., 1977

The albedo has an important regulating influence on the global energy balance (2.1.2) and climate (2.1.5).

I.3.5. Weathering and erosion
Weathering is the process whereby rock and stone are disintegrated to smaller particles under the influence of solar radiation and weather conditions (rain, temperature changes, etc.). Through wind and water erosion the smallest particles are transported through the biosphere. Weathering and erosion thus influence the chemical composition of the atmosphere (2.1.3) and oceans (2.1.4), and play and important role in the storage and recycling of nutrients (2.1.12), and influence the formation of topsoil (2.1.9).

1.3.6 Sedimentation and fossilization
Most of the material which is eroded (see I.3.5) is eventually deposited in river banks or on land. In combination with weathering and erosion, sedimentation plays an important role in the storage and recycling of nutrients (2.1.12), in the formation of topsoil (2.1.9) and the regulation of the chemical composition of the oceans (2.1.4). When sediments contain high concentrations of organic material part of this material may escape the biological recycling process when it is burried under special circumstances which make fossilization possible. It has therefore been suggested that sedimentation of weathered material may be involved in the regulation of the oxygen concentration in the atmosphere (2.1.3), since fossilization binds atmospheric oxygen in the sediments.

I.4. Hydrological processes and properties (at the surface)

The set of processes that maintain the flow of water through the biosphere is called the hydrological cycle (see Fig. 2.1.5.-3). Some important hydrological parameters which influence many functions are briefly described below.

I.4.1 Water reservoirs/availability (volume, area, depth)
The total amount of water on earth is almost 1.4 billion km^3. A review of the different reservoirs is given in table 2.1.7-1. Water, as a resource, is a physiological necessity to most living organisms (2.3.2) and is essential to most cultivation practises (2.2.2). As a medium, water has various functions, including its (potential) use for aquaculture (2.2.2) and recreation (2.2.4).

I.4.2 Interactions with the atmosphere
Through absorption, dissolution, evaporation and sublimation there is a continuous interaction between water-surfaces and the atmosphere. Large bodies of water are able to absorb considerable amounts of heat and chemical substances from the air. Also the transformation of liquid water

to water-vapour (evaporation) and the sublimation of ice and snow are important ecological processes which are part of the hydrological cycle, and thereby influence many functions of the biosphere: notably regulation of the global energy balance (2.1.2), regulation of the chemical composition of the atmosphere (2.1.3) and oceans (2.1.4), and climate regulation (2.1.5). Especially the dissolution of CO_2 is important in relation to the 'greenhouse effect'; it has been estimated that the oceans absorb about 50% of the carbon dioxide brought into the atmosphere by human activities (chapter 2.1.5).

I.4.3 Runoff and river discharge

The difference between precipitation and evaporation is the amount of water available at the surface. Part of this water sinks into the soil and may feed groundwater reservoirs. The rest goes into surface-runoff and river discharge. Depending on the slope and structure of the surface, the flow of water at the surface is more or less strong. Surface runoff is a major determinant of the configuration of the physical environment by influencing erosion and sedimentation processes (2.1.8). Through runoff, sediment is transported from the continent to the sea, which also influences the chemical composition of the oceans (2.1.4). The amount of river discharge is important to various carrier functions, notably cultivation (2.2.2) to generate hydro-electricity (2.2.3). Also the availability of drinking water (2.3.2) and several recreational activities (2.2.4) depend on the presence of running water.

I.4.4 Tides and ocean currents

Tidal movements and ocean currents have several functions, including the transportation of heat (2.1.2) which has considerable influence on local, regional and global climates (2.1.5). Ocean currents are instrumental in dispersal of nutrients (2.1.12) human waste (2.1.13) and also serve as an important means of transportation for migratory organisms (2.1.15). They also influence possibilities for marine aquaculture (2.2.2) and may be used for energy generation (2.2.3).

I.4.5 Groundwater table

The groundwater table marks the surface of the body of groundwater that saturates the soil or rock in which it is found. Below the groundwater table, all pores and spaces in the soil or rock are filled completely. The groundwater extends downward until it is limited by an impermeable layer of rock. In some circumstances, there are successive layers of groundwater (aquifers) separated by impermeable layers of rock. the absolute lowest limit of groundwater is probably about 16 kilometers from the surface, where the pressure is so great that all pores are closed and any rock becomes impermeable (Ehrlich et al., 1977). Groundwater is important to cultivation (2.2.2) and as reservoir from which water may be extracted for drinking, irrigation, etc. (2.3.2).

I.4.6 Water quality/BOD

The water quality is determined by many factors, including chemical substances, sediment load, and biological criteria (e.g. occurrence of pathogens). In aquatic ecosystems, oxygen forms an important limiting factor to aquatic life. Monitoring oxygen concentrations is therefore a convenient way of assessing the general quality of the aquatic ecosystem, and measurement of the Biological Oxygen Demand (BOD) is therefore a standard method of pollution assay (see box I.4-1). The pH is another important water-quality indicator. The pH measures the acidity of aquatic systems which in most natural water bodies varies between 6.5 and 8.5. Highly acidified waters have values in the range of 4.5 - 5.5. The acidification of fresh waters, as a consequence of acid precipitation, has immidiate impact on aquatic life, and it increases corrosion in water collection and distribution systems. Low pH values in water also lead to increases in the dissolved concentrations of heavy metals including lead and cadmium (WRI, 1990, p. 334). A certain minimum water quality is important to many functions (see tables I.0-1 - I.0-4).

Box I.4-1 BOD (= Biological or Biochemical Oxygen Demand)

BOD stands for the biodegradability of the total organic matter dissolved or suspended in water. BOD5 is the amount of oxygen, expressed in mg/l, that is necessary to reduce the amount of organic matter suspended in one liter of water at 20°C during a period of 5 days. In aquatic ecosystems oxygen-measurement gives an indication of the total or gross photosynthesis (biomass production) since the oxygen produced is proportional to dry matter produced: 1 gr. organic matter (dry weight) = 4.7 Kcal = ...gr. Oxygen (After: Odum, 1971), Ehrlich et al., 1977). Pollution of aquatic ecosystems with organic matter increases the O_2 consumption (respiration) which is needed for the breakdown of the organic matter, resulting in oxygen depletion and (should the imbalance continue) eventually may lead to anaerobic conditions. Along with dissolved oxygen, BOD is therefore the most commonly used water quality indicator. Rivers can be said to be seriously polluted if they have a BOD of 6.5 mg/l or more, that is: if more than 6.5 mg of oxygen would be required to oxidize the organic matter in a liter of water (WRI, 1990). Due to pollution, the oxygen-concentration in many rivers and lakes has fallen below critical levels to sustain higher life forms such as fish.

I.5. Soil processes/properties

Soils can be classified by means of soil-profiles and colour. At the top is a dark, humus-rich layer called the ‘A’-horizon, which is rich in roots and organic matter and contains most of the living creatures: worms, ants, moles, mites, springtails, nematodes, bacteria, etc. Below this layer is the lighter ‘B’-horizon which is stripped of most of its minerals and clay as water percolates through it. Because it has less air and water than the topsoil, it has less microscopic life. The ‘C’-horizon lies just above the bedrock and this is where many of the percolating minerals come to rest (National Wildlife Federation, 1985).

the presence of green plants which together make up the vegetation. The vegetation is such a characteristic feature that land communities are usually classified by it, rather than on the basis of the physical environment as is often convenient in aquatic systems.

I.6.1 Height, structure, densitiy and roughness of the vegetation

Important parameters which determine the nature of a given habitat or ecosystem are the height, structure and density of the vegetation. Depending on the type of vegetation, the height may vary from several centimeters in grassland-habitats to 50 m or more in forests. The structure of the vegetation is determined by the amount of life-forms present (e.g. trees, shrubs, grasses, herbs, mosses). The density of the vegetation can be measured by the leaf area index (LAI, see I.6.4).

The height, structure and density of the vegetation together determine the 'roughness' of the vegetation which has various consequences for the local and regional climate (2.1.5), influencing, among others, surface temperature, rainfall, evapotranspiration (air-moisture), air turbulance (wind-break-function), and the radiation balance (2.1.2). Also runoff (2.1.6), watercatchment (2.1.7), and soil erosion (2.1.8) are all influenced by the structure and density of the vegetation. The aerodynamic roughness also influences the capacity of the ecosystem to intercept atmospheric dust particles and the noise abatement function of the vegetation (2.1.13). The structure of the vegetation is also important as a source of aesthetic information (2.4.1) and artistic inspiration (2.4.4).

I.6.2 Succession stage/age/maturity of the vegetation

Most ecosystems are characterized by a certain combination of species (see appendix I.7.1). The species composition of natural ecosystems, especially of the vegetation, is strongly influenced by environmental conditions such as climate and soil. Soil, in turn, is derived from the underlying rock types and formed under influence of climate, vegetation and the soil flora and fauna. Because of the many interactions between vegetation, soil and living organisms, there is a strong correlation between the abiotic environment, especially the type of soil (and bedrock) and the species composition of the vegetation. For example, rocks of volcanic origin, limestones, ultrabasic and nutrient poor white sands and granites al support different types of vegetation. Because of the interplay between species and the abiotic environment, changes in the abiotic environment will lead to changes in the species composition and vice versa. As a result, a gradual succession of species can be observed along environmental gradients, both in time and space, usually leading from relatively species-poor pionier communities to species-rich climax communities. Sometimes species are exclusively or chiefly found in certain ecosystems or succession stages and the presence or absence of such so-called key-species provides important information about the succession stage and integrety of the ecosystem in question.

Sometimes, characteristic floral types provide information about the underlying rock types, including the minerals they contain, e.g. ironwood, mangrove, pine and moss forests (UNDP & FAO, 1982). Knowledge about the succession stage is therefore an important source of scientific information (2.4.5). The gradual succession of habitats and life communities is an important regulating factor in the formation of topsoil (2.1.9), while the maturity or age of an ecosystem is an important parameter to determine its conservation value (2.2.5)

I.6.3 Standing biomass/chlorophyll

In terrestrial ecosystems, the standing biomass is expressed in gr organic matter/ surface area. The total biomass on earth is estimated at 1,841 billion ton, of which 99.8% is found on the continents (mostly in forests). On average, the amount of biomass on earth is 3.6 kg/m^2, varying from 0.0003 kg/m^2 in open oceans to 45 kg/m^2 in tropical rain forests (see table I.6-1)

Another measure used to approximate the standing biomass in terrestrial ecosystems is the leaf area index (LAI, see I.6.4). In aquatic systems, measuring total biomass is a difficult procedure. Here the amount of chlorophyll is often used as a measure for the amount of (plant)biomass and photosynthetic activity (Odum, 1971), which can even be monitored from satellites (see also I.8.1).

Total biomass is an important parameter for many functions. First of all, of course, as an indicator for the total amount of organic matter stored (2.1.11), but also for other functions such as regulation of runoff (2.1.6), prevention of erosion (2.1.8), and the capacity to transform solar radiation into biomass (2.1.10). Also for some production functions, notably food (2.3.3), raw materials (2.3.6, building and construction materials (2.3.7), and bio-energy (2.3.9), standing biomass can be used as an indication for the capacity of the ecosystem to provide these resources.

I.6.4 Surface covering/leaf area index (LAI)

The degree of surface covering of the vegetation can be measured with the leaf area index (LAI = ratio between leaf area of the vegetation and the ground surface). The LAI can also be used as a measure for the photosynthetic capacity of an ecosystem (see 2.1.10). The amount of vegetation cover is also an important parameter for assessing the role of an ecosystem in producing and maintaining a fertile layer of top soil (2.1.9). The vegetation cover also plays an important role in the prevention of soil degradation and erosion (2.1.8) since the plants and associated litter layer protect the soil from the impact of heavy rainfall and the roots keep the topsoil in its place.

I.6.5 (Evapo)transpiration/water use efficiency

As a measure for the transpiration capacity of a given type of vegetation the leaf area index (LAI, see I.6.4) may be used. By transpiring water

Table I.6-1. Estimated Net Primary Production (NPP) and amount of biomass for some major ecosystem types

	Net Primary Production g/m²/year (dry matter)		Biomass (dry matter) kg/m²	
Ecosystem type	Mean	(range)	Mean	(range)
Tropical rain forest	2,200	(1,000-3,500)	45	(6-80)
Tropical seasonal forest	1,600	(1,000-2,500)	35	(6-60)
Temp. evergreen forest	1,300	(600-2,500)	35	(6-200)
Temp. deciduous forest	1,200	(600-2,500)	30	(6-60)
Boreal forest	800	(400-2,000)	20	(6-40)
Woodland and shrubland	700	(250-1,200)	6	(2-20)
Savanna	900	(200-2,000)	4	(0.2-15)
Temperate grassland	600	(200-1,500)	1.6	(0.2-5)
Tundra and alpine grassland	140	(10-400)	0.6	(0.1-3)
Desert and semi-desert scrub	90	(10-250)	0.7	(0.1-4)
Extreme desert (rock/sand/ice)	3	(0-10)	0.02	(0-0.2)
Cultivated land	650	(100-4,000)	1	(0.4-12)
Swamp and marsh	3,000	(800-6,000)	15	(3-50)
Lake and stream	400	(100-1,500)	0.02	(0-0.1)
Open ocean	125	(2-400)	0.003	(0-0.005)
Upwelling zones	500	(400-1,000)	0.02	(0.005-0.1)
Continental shelf	360	(200-600)	0.001	(0.001-0.04)
Algal beds and reefs	2,500	(500-4,000)	2	(0.04-4)
Estuaries (excl. marsh)	1,500	(200-4,000)	1	(0.01-4)

Source: Whittaker and Likens, 1975, in: Simmons, 1981.

from the surface of the leaves, vegetated areas contribute to the maintenance of water vapour in the air (2.1.5), whereby the amounts of water transpired are different for different types of vegetation.

I.6.6 Litter-production

Different ecosystems produce different types and amounts of litter (see table I.6-2)

Litter influences various functions, notably watershed protection (2.1.6), watercatchment (2.1.7) and prevention of soil erosion (2.1.8). It also contributes to the maintenance of soil fertility (2.1.9) and even influences the noise abatement function (2.1.13). Litter may also be gathered as a source of fodder and fertilizer (2.3.10), and energy (2.3.9).

I.6.7 Root-system and nutrient recycling

The root-system of the vegetation influences various functions, notably watershed protection (2.1.6), watercatchment (2.1.7) and prevention of soil erosion (2.1.8). Through the root system, the vegetation takes-up many nutrients from the environment which are (temporarily) stored in the biomass. The root system is therefore an important factor in the storage and recycling of nutrients (2.1.12).

Table I.6.2 Rate of litter production in various ecosystems

Type of community	Location	Age (years)	Litter fall ($g/m^2/year$)
Tropical rain forest	Thailand	Mature	2,322
Tropical rain forest	Costa Rica	Interm.	547
Oak forest	Russia, steppe	?	350
Beech forest	Germany	?	450
Pine forest	Virginia	17	490
Fir forest	Russia, N.taiga	?	150
Perennial herbs	Japan	?	1,484
Tallgrass prairie	Missouri	?	520
Mesic alpine tundra	Wyoming	?	162

Source: Russwurm & Sommerville, 1974

I.7. Flora and fauna (species properties)

When assessing the characteristics of a given ecosystem or (natural) area the presence of plants and animals should be one of the most important factors. Ultimately, the living part of an ecosystem consists of individual species and, ultimately these species are, or should be, the main concern in planning and management. In this section, a few of the most important characteristics of species, in relation to assessing their functions, values and opportunities for (sustainable) use, are briefly presented.

I.7.1 Species composition and diversity

Ideally, the species composition in a given area or ecosystem should be documented by a complete list of occurring species of plants, animals and other organisms. It is estimated that there are between 5 and 30 million species on earth, and a much greater number of sub-species and varietes. Thus far, about 1,5 million have been named, while of the insects only about 10% has been identified (Ehrlich, 1985, May, 1988). It will therefore be impossible to make a complete list of all occurring species in a given area or ecosystem. Usually only the most characteristic species are documented.

The species composition is an important piece of information which is necessary for the determination of many other parameters, notably species diversity and genetic diversity (I.7.3). Over the years, various methods have been developed to determine the species diversity of a particular area or natural ecosystem, see for example Figure I.7-1

Fig. I.7-1 Indices of species diversity

(1) Three species richness or variety indices (d) *

$$d_1 = \frac{S-1}{\log N} \qquad d_2 = \frac{S}{\sqrt{N}} \qquad d_3 = S \text{ per 1000 ind.}$$

where S = number of species
N = number of individuals, etc.

(2) Eveness index (e) **

$$e = \frac{\bar{H}}{\log S}$$

where $\bar{H}$ = Shannon index (see legend)
S = number of species

(2) Shannon index of general diversity ($\bar{H}$) ***

$$\bar{H} = -\Sigma \left(\frac{ni}{N}\right) \log \left(\frac{ni}{N}\right) \quad \text{or:} \; -\Sigma P_i \log P_i$$

where ni = importance value for each species
N = total of importance values
P_i = importance probability for each species = ni / N

Legend

*
d_1 see Margalef (1958).
d_2 see Menhinick (1964).
d_3 see H.T. Odum, Cantlon and Kornicker (1960)

**
See Pielou (1966); for another type of 'equitability' index, see Lloyd and Ghelardi (1964).

***
See Shannon and Weaver (1949); Margalef (1968).

Note: in d_1, e and $\bar{H}$ natural logarithms ($\log_e$) are usually employed, but $\log_2$ is often used to calculate $\bar{H}$ so as to obtain 'bits per individual'.

Source: Odum, 1971, p. 144

The species composition is also needed as a checklist for describing the functional properties of the flora and fauna in a particular area or ecosystem (see Figures I.0-1 - I.0-4).

I.7.2 Population size (rarity) and distribution (endemism)

Not only a list of occurring species is important (see I.7.1), but also the (relative) abundance of the different species and subspecies. Many species only occur in certain biogeographical ranges, and within this range usually distinct populations can be distinguished with differing numbers of individuals. Often populations of the same species are geographically isolated and may eventually evolve into separate varieties or subspecies.

Rarity thus relates to the total number of individuals in a given population, which may relate to widespread species which are locally rare, or to species which have a narrow distribution range. Basically, three types of rarity can be distinguished: (a) species with a wide separation of small populations so that interbreeding between populations or sub-populations is seriously reduced or eliminated, e.g. alpine plants which occur in small numbers in a few areas throughout their geographical range, (b) species which are restricted to a single population with relatively few individuals, or (c) species which occur in large numbers but are restricted to a small number of locations (modified after Drury, 1974, in: Spellerberg, 1981.

Endemism occurs when the total world population is restricted to a distinct geographically limited area. Usually, endemic species are also rare but rare species are not necessarily endemic.

The population size (i.e rarity or endemism) of a given species or subspecies provides information about the viability of the population (see I.7.3) which in turn is an important parameter for the maintenance of biological and genetic diversity (2.1.16). The population size also determines the suitability of the species or subspecies for harvesting by man, for example for food (2.3.3) and most other production functions. In general, (commercial) use of rare or endemic species should be avoided or strictly regulated.

I.7.3 Population viability (genetic diversity)

The viability of a given population depends on the number of interbreeding individuals. When the population becomes too small, too few individuals remain for succesful reproduction which eventually leads to the extinction of the population. The minimum viable population size differs for each species. As a general 'rule of thumb' a number of 5,000 individuals has been suggested, although also recoveries are known from populations which had decreased to less than 10 individuals. However, under these circumstances the genetic diversity in the population probably decreased to such a level that certain characteristics of the original species must have been lost. Subsequent interbreeding between the remaining individuals then leeds to the development of a new variety which is more or less different from the original species.

The population viability and genetic diversity of a given species are important for the maintenance of biological and genetic diversity (2.1.16). Especially the total number of sub-species gives a good indication of the genetic variation and speciation (evolution) processes operating in a certain area or ecosystem. Most biological production functions, either provided by wild, domesticated or cultivated plant and animal species, depend on the natural genetic diversity, and they will only be available to mankind as long as their natural stocks are maintained, with an adequate genetic diversity, in an environment in which they can thrive.

I.7.4 Population dynamics

Trends in the increase or decrease of populations is important to determine their vulnerability to extinction (2.1.16) or their potential to develop into a pest (2.1.14).

I.7.5 Dispersal and migration

Many plant and animal species are able to disperse over large distances. For conservation measures to be succesful it is therefore essential to include all functional areas (i.e. feeding, breeding and resting) in a network of protected areas. Besides ensuring a higher survival-rate of the species involved, migration has several other important purposes. Migration of seabirds, for example, is important in relation to the phosphor-cycle in the oceans (2.1.4).

I.7.6 Special functional properties

When drawing up a list of species occurring in the area under investigation, data on their functioning in the ecosystem, as well as their actual and potential uses to man should be collected too. Some important characteristics include: edibility/nutritious value, biochemical and genetic characteristics, (potential) usefulness as raw material, aesthetic and recreational value, and their role in the food chain. Also the influence of certain species or species groups on biogeochemical cycles and thereby on the regulation of the chemical composition of the atmosphere (2.1.3) and oceans (2.1.4) should be mentioned here. For example, biological methylation by algae and the production of methane by certain bacteria. Finally, many species have a special indicator value which provides information about certain environmental conditions (e.g. pollution or presence of certain minerals).

I.8. Life-community properties and food chain dynamics

The community concept is one of the most important principles in ecological thought and practice because it emphasizes the fact that diverse organisms usually live together in an orderly manner, not just haphazardly strewn over the earth as independent beings (Odum, 1971). In appendix I.7, some characteristics of individual species have been described. The concerted activities of individual species living together in life communities have special functional properties, some of which are briefly described below.

I.8.1 Biomass production/photosynthesis

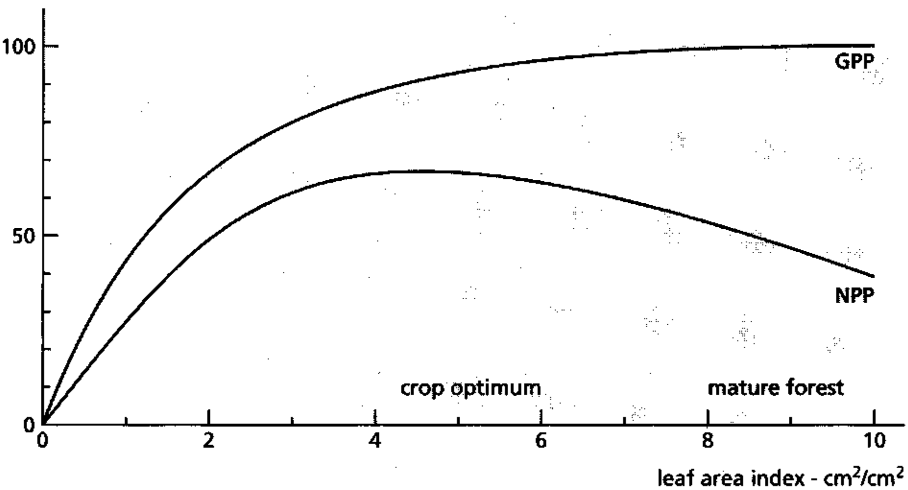
Photosynthesis is the process in which carbon-dioxide plus water plus light energy, in presence of enzyme systems associated with chlorophyll, results in glucose plus oxygen (see formula below). During photosynthesis, part of the sunlight energy is stored as potential or 'bound' energy (ATP). Photosynthesis involves an oxidation-reduction reaction, and a general equation can be written as follows (after Ehrlich et al., 1977)

$$6\ CO_2 + 12\ H_2O + \text{solar energy} \rightarrow 6\ O_2 + C_6H_{12}O_6\ \text{(glucose)} + 6\ H_2O$$

The capacity of a given ecosystem or life community for bio-energy fixation is probably best measured by means of the Gross Primary Productivity which may be as much as three times the Net Primary Productivity, as is the case in mature rainforests (see table 2.1.10-1). Some conservative estimates of the Net Primary Production of major ecosystem types have been given in Appendix I.6.3. Estimated mean values for large areas show that production varies from 3 gr. organic matter/m^2/year in 'extreme' deserts to 2,200 g/m^2/year in tropical rain forests and 3,000 g/m^2 per year in swamps and marshes. The total Net Primary Production in the world, which is in the order of 10^{18} Kcal per

year, amounts to 160-180 billion ton organic matter (dry weight) per year (Whittaker, 1975).
Another measure for the capacity of an ecosystem to convert solar (or other forms of abiotic energy) into organic matter and biomass is the total weight of the living organisms (or 'standing crop') in an ecosystem, which is the result of the Net Primary Production.
In terrestrial ecosystems, also the leaf area index (LAI, see I.6.4) can be considered as a measure of photosynthetic biomass. Maximum net production is obtained when the leaf area index is about 4 (which means that the leaf surface exposed to light is 4 times the ground surface), but maximum gross production is reached when the leaf area index reaches 8 to 10, which is the level found in mature forests (see Fig. I.8-1).

Fig. I.8-1 Relationship between gross primary productivity (GPP), net primary productivity (NPP) and leaf area index (LAI)



Odum, 1971

Another measure for the biomass production is the amount of chlorophyll (I.6.3) present in the ecosystem. Especially in aquatic ecosystems this is a good measure of photosynthetic activity. With the help of satelite images it is possible to measure the amount of chlorophyll present in ecosystems on a global scale.

The production of biomass influences several functions, such as the regulation of the oxygen/carbon dioxide balance in the atmosphere (2.1.3), storage and recycling of organic matter (2.1.11) and nutrients (2.1.12), and transformation of solar energy (2.1.10). The capacity to produce biomass is also an important indicator for the nursery function (2.1.15) and for most production functions (2.3).

I.8.2 Consumption and respiration

The biomass produced by green plants is consumed ('burnt') both by the plants themselves and by plant-eating animals through respiration, a process which uses atmospheric oxygen and returns CO_2 to the atmosphere. The chemical reaction of respiration is basically the reverse of the photosynthetic reaction (I.8.1).

An amount of organic matter which is approximately equivalent to the amount produced by photosynthesis is oxidised back to CO_2 and H_2O as a result of the respiratory activity of living organisms through mineralisation in food chains (formula after Ehrlich et al., 1977):

$6\ O_2 + C_6H_{12}O_6 \text{->} 6\ CO_2 + 6\ H_2O + \text{heat}$.

In nature, there are several types of respiration which play different roles in the ecology of natural ecoystems (see box I.8.-1).

Box I.8-1: Types of respiration:

1. Aerobic respiration is the process through which organic matter is broken down in carbon dioxide and water whereby gaseous (molecular) oxygen is the hydrogen acceptor (oxidant). Aerobic respiration, is the reverse of the 'regular' photosynthesis as discussed above (I.8.1). It is the means by which all of the higher plants and animals, obtain their energy for maintenance and for the formation of cell material. Complete respiration yields CO_2, H_2O and cell material, but the process may be incomplete, leaving organic compounds that still contain energy which may be used later by other organisms.
2. In anaerobic respiration no gaseous oxygen is involved but an inorganic compound other than oxygen is the electron acceptor (oxidant). Anaerobic respiration is largely restricted to the saprophages (bacteria, yeasts, molds, protozoa), although it also occurs as a dependent process within certain tissues of higher animals. For example, methane bacteria are involved in the breakdown of forage within the rumen of cattle and other ruminates.
3. Fermentation is also an anaerobic respiration process, but an organic compound is the electron acceptor (oxidant). Yeasts are well-kown examples of fermentors. They are not only commercially important to man but are abundant in soils where they play a key role in the decomposition of plant residues (Odum, 1971).

Some idea of the amount of consumption/respiration can be obtained by measuring the O_2/CO_2 balance in the ecosystem, notably in the soil (see also Odum, 1971). In aquatic ecosystems, the Biological Oxygen Demand (BOD, see I.4.6)) may be used as an indicator to measure the amount of organic matter consumed (respired).

Apart from the importance of respiration as an oxidizing process which breaks down organic matter (2.1.11) while returning carbon dioxide to the atmosphere (i.e. as part of the carbon dioxide cycle, see chapter 2.1.3), the consumption of organic matter through various trophic levels of the food chain has an important biological control function at the species and population level (see chapter 2.1.14).

I.8.3 Decomposition

Decomposition is a process whereby dead organic matter is broken down in smaller particles (basically carbon dioxide, water, ammonia and minerals). Three stages of decomposition can be distinguished: (1) the

formation of detritus from litter and dead animal bodies by physical and biological action, (2) humification, which involves the relatively rapid production of humus and release of soluble organics by saprotrophs (= organisms living on dead or decaying matter), and (3) mineralization, a relatively slow process which involves the release of nutrients from humus and detritus by microbial activity or by phagotrophic organisms (= organisms living on bacteria).
1. Formation of detritus: The soil fauna plays a major role in the physical conversion of organic debris through bioturbation. Studies are now showing that the phagotrophs, especially small animals (protozoa, soil mites, nematodes, ostracods, snails, and so on) play a more important role in decomposition than was previously suspected. When microarthropods (i.e. microscopic mites and collembolans) are removed from forest litter by an insecticide treatment that has little or no effect on bacteria and fungi, breakdown of the dead leaves and twigs is greatly slowed (Odum, 1971).
2. Production of humus (humification): In terrestrial ecosystems, the more resistant products of decomposition end up as humus (or humic substances). The quantity of humus (see I.5.3) on an area or volume basis may therefore be used as an indicator for the rate of decomposition in terrestrial ecosystems. (Odum, 1971).
3. Mineralization of humus: The heterotrophic micro-organisms or plants and animals, although it is not known for certain if humus is ultimately broken down to minerals by special organisms with special enzymes, or by abiotic chemical processes. Finally, bacteria and fungi in the soil break down the complex molecules of dead organic matter, and the cellulose and lignin of wood and leaves, into molecules which plants can use for food. Mineralisation of humus is an absolutely vital function because, if it did not occur, all the nutrients would soon be tied up in dead bodies, and no new life could be produced (Odum, 1971).

The capacity of a given terrestrial ecosystem for decomposition may be measured by the amount of humus (I.5.3) or the concentration of micro-organisms in the soil. In aquatic ecosystems, the biological oxygen demand (BOD, see I.4.6) can be used as an indication of the (aerobic) decomposition process. Under anaerobic conditions, the production of methane gives an indication of the breakdown-activity of micro-organisms.

Some functions that can be attributed to the decomposition process are: regulation of the chemical composition of the atmosphere (2.1.3), modification of the abiotic materials of the surface of the earth, which is an important step in the processes that form soil (2.1.9), storage and recycling of dead organic matter (2.1.11) and nutrients (2.1.12), including organic human waste (2.1.13). Also the efficiency of sewage disposal systems depends on the activity of micro-organisms. The decomposition process performs many other important functions that maintain the biological balance in natural ecosystems (2.1.14), for example the production of food for a whole range of organisms in the detritus food chain, and production of environmental hormones (which regulate population dynamics in the ecosystem). Decomposing organisms also provide a special habitat for a variety of organisms, such as a fallen log in a forest which supports a well-developed subcommunity that changes with the state of the decay.

I.8.4 Food-chain interactions

Although the great diversity in species and subspecies on earth leads to an almost unlimited number of interactions in very complex foodweb-systems, the simple autotroph-phagotroph-saprotroph classification provides a good working arrangement for describing the ecological structure of a biotic community (Odum, 1971). Between these three trophic-categories many interactions exist, such as animal-foodplant relations, predator-prey relations, parasitism, symbiosis, etc. Ideally, the role of the most important species in the food-chain of a particular area or ecosystem should be described and, if possible, depicted in a food-web diagram (see for example Fig. 2.1.14-1)
The most important function of food-chain interactions is the maintenanace of biological control mechanisms (2.1.14), notably the control of (potential) pests. Through their role in biogeochemical cycles (see I.9) the combined activity of individual organisms contributes to the regulation of the chemical composition of the atmosphere (2.1.3) and oceans (2.1.4), and plays an important role in the recycling of organic matter (2.1.11), nutrients (2.1.12), and human waste (2.1.13). Food chain interactions are also important to cultivation, notably aquaculture (2.2.2).

I.8.5 Deposition of calcareous material

By their concerted action, life communities can have a significant role in changing the abiotic environment. Reef-building coral communities, for example, create entire new habitats for many plant and animal species. By closing in bodies of water between the reef and nearby land (islands), it has also been suggested that the building of coral reefs contributes to the regulation of the chemical composition of the oceans, as does the continuous rain of skeletons and debris from marine life communities (2.1.4).

I.8.6 Bioturbation/activity of soil communities

Soil communities play an essential role in the decomposition process (see I.8.3) and thereby on the many functions related to this process, notably the formation of topsoil and maintenance of soil fertility (2.1.9), and the storage and recycling of organic matter (2.1.10). See also appendix I.5.7.

I.9. Ecosystem parameters

The combination of a life community and its physical environment is called an ecosystem. Some integrative characteristics of ecosystems which are relevant to assessing their functions and benefits to man, are briefly described here. For more information on the relation between ecosystem parameters and specific functions, see figures I.0-1 - I.0-4.

I.9.1 Naturalness/integrety/heritage value

The naturalness or integrety of a given area or ecosystem depends on the degree of human presence, either in terms of physical, chemical or biological disturbance (see box I.9-1). The degree of naturalness can be described by documenting human impact, e.g. percentage surface area converted or pollution level. When human disturbance is less obvious, naturalness can also be measured by comparing the present succession stage to the climax or virgin condition which would occur without human interference. A practical reference point may be the presettlement landscape. Another parameter for measuring the integrety of a given natural area or ecosystem is the representativeness or community representation which relates to localized or relict situations and geographic variants of a specific type of community (Gehlbach, 1975). Many life communities are characterised by certain 'key species'; determining the difference in presence or absence of key species, compared to similar, intact ecosystems, also provides a measure for the naturalness or integrety of the area.

Box I.9-1 Some thoughts on defining the concept of 'naturalness'

When discussing man's place in the natural environment, the question is raised whether man and all his activities should be considered as a part of nature or as an unnatural phenomenon. If we believe in an evolutionary development of *Homo sapiens*, originally all human actions where part of the natural system. Only after man's influence on his environment tresspassed a certain level of impact (in quantity and/or in quality), the question of man's '(un)natural' behaviour was raised. If and where this line must be drawn is a question still unanswered and subject to much discussion. Yet, if not in practice, at least emotionally man did become more and more separated from nature and as a result he increasingly made a distinction between the natural and cultural environment. The use of the term 'natural environment' actually implies that a strict separation between man and nature is possible since the 'environment' is by definition everything outside the object of study. In practice, the transition between cultural and natural landscapes and ecosystems is often gradual and is characterised by the degree of human influence. Strictly speaking, only ecosystems that are totally free of human influences can be considered natural. However, slowly it has become virtually impossible to find a purely 'natural' ecosystem on earth. Even on the icecaps in the polar regions traces of human waste have been found. The separation between natural and cultural ecosystems has thus become a rather academic question, involving both scientific and emotional arguments. It is therefore probably more convenient to make a distinction between man-dominated ('cultural') systems and 'nature-dominated' systems, where man's influence is very limited or largely absent.

I.9.2 Uniqueness/distinctiveness

This parameter is based on a combination of the occurrence of rare and/or endemic species (see I.7.2) and the 'rarity' of the area or ecosystem as a whole. Usually, ecosystem-uniqueness is taken as the mean of the endemism for various taxonomic groups, for example plants, birds and mammals. For various reasons, different weight can be attached to endemism in different taxonomic groups. A study by UNDP & FAO (1982) in Indonesia, for example, used the average of the faunal endemism (based on birds and mammals only) and plant endemism to determine the regional endemism for Java (7%) and Borneo (23%). When calculating 'total' endemism the number of species per taxonomic group should be taken into account: the larger the number of species in a taxonomic group, the more weight the endemism-figure would receive in calculating the average endemism-percentage for the total area or ecosystem.

There are other ways of approaching the problem of determining ecosystem uniqueness. For example, UNDP & FAO (1982) used a formula for scoring rarity, as an approximation of the increasing probability of habitat extinction, namely 1/Log 0 , where log 0 is the original area of the habitat type.

I.9.3 Diversity/richness

Ecosystem diversity may be determined for various factors, such as species diversity (see I.7.1), diversity of abiotic factors (e.g. soil types, geomorfology, etc.), diversity of vegetation structure, etc. Various methods exist to arrive at a given diversity-index, some examples are given in table I.7.1-1.

I.9.4 Minimum Critical Ecosystem Size

The concept of minimum critical ecosystem size is partly based on the island biogeographic theory which relates the size of a given area to the number of species that can be maintained in equilibrium. From several classic studies of the biogeography of islands (Diamond, 1975, Simberloff, 1974) it is known that small islands are unable to support as many species as large islands of similar habitat and that isolated islands support fewer species than islands of similar size close to the mainland. For a given island or reserve there is a limited number of species that can be maintained and this equilibrium is restored even after artificial attempts to enrich or depauperate the island by adding or removing species. Each habitat type can thus be related to the number of species of a certain taxonomic group to be expected at a given size.

In order to be able to determine the minimum critical ecosystem size, it should be investigated what the minimum viable size is of all plant and animal species belonging to that ecosystem. There are two ways of estimating the minimum viable population size: (a) Genetical and mathematical estimates of the numbers of breeding individuals needed to maintain natural levels of genetic diversity. Estimates for this parameter vary widely but are usually numbered in the thousands with 5,000 as a medium figure. (b) The second approach involves looking at populations on small islands to see what are numerically the smallest stable surviving isolated populations. Again figures in the order of 5,000 are suggested.

I.9.5 Ecological fragility (carrying capacity)

The ecological fragility or vulnerability relates to the sensitivity of a given ecosystem for human disturbance. Fragility is often related to specific abiotic or biotic factors, such as sensitivity for erosion or the presence of rare and endangered species. Ecological fragility can also be seen in relation to the capacity of the system to restore the original situation after disturbance (i.e. the resiliance of the ecosystem).

The ecological fragility also depends on the degree of isolation. Isolated habitats that are dependent upon other habitats for important biotic or physical resources, such as small reserves in a cultivated landscape, are highly vulnerable. For example, the interactions between mangrove forests and the surrounding marine and inland habitats is an intricate system which is easily disturbed.

Ecological fragility is closely related to the concept of 'carrying capacity' which is defined very broadly by Ehrlich (1985) as 'the capacity of environmental systems to support human beings". Defining the carrying capacity is especially relevant with respect to determining sustainable use levels of carrier functions and the harvesting natural resources (production functions).

I.9.6 Replacability/renewability

The renewability and/or replacability of entire ecosystems after disturbance depends very much on the complexity of the ecosystem which, in turn, is strongly correlated with the succession stage. Climax communities are usually very rich in species with complex food-web relations between the members of the life community; pionier communities are therefore less difficult to replace or renew after disturbance, either in the same location or elsewhere, than climax communities.

I.9.7 Information value

Natural ecosystems have many characteristics which provide various forms of information, such as aesthetic qualities and amenity value, the presence of historic features or elements with cultural and inspirational value. They also provide numerous opportunities for education and research. The number and diversity of natural elements with information value is so large that is is impossible to give a specific listing here. This aspect should, however, be incorporated in the evaluation procedure and is therefore included here under a general heading which should be investigated for each case study situation separately.

Appendix II

Ecosystem classification

A habitat can be defined as 'the natural home of wild plants and animals'. Together with the occurring plants and animals, habitats form ecosystems which are geographically limited, more or less uniform configurations of habitats and the life communities they contain. Because of the enormous variety of abiotic environmental circumstances, and the even greater number of plant and animal species and subspecies on earth, it is practically impossible to reduce the complexity of the natural world to a limited number of declared ecosystems.

Yet, for all practical purposes it is necessary to somehow come to grips with this complexity and a rough division of habitats and ecosystems is given below. The division into habitats and ecosystems is mainly based on the characteristics of the vegetation. In absence of vegetation, other physical characteristics of the landscape are used to distinguish between different habitats and ecosystems.

Table II-1 List of major ecosystems of the world and their surface covering (situation roughly for the period 1970 - 1990)

Ecosystem/land cover type	Area (x 1.000.000 ha)
a. TERRESTRIAL ECOSYSTEMS	**14,400 - 14,796***
Evergreen forests	*2,704*
Tropical evergreen rainforest	1,214
Tropical/subtrop. evergr. seas. broadleaved forest	331
Subtropical evergreen rainforest	19
Temperate/subpolar evergreen forest	38
Temp. everg. seas. broadleaved forest (summer rain)	81
Evergreen broadl. sclerophyll. forest (winter rain)	43
Tropical/subtrop. evergr. needle-leaved forest	49
Temperate/subpolar evergr. needle-leaved forest	929
Deciduous forests	*1,213*
Tropical/subtropical drought deciduous forest	290
Cold deciduous forest with evergreens	520
Cold deciduous forest without evergreens	403
Evergreen woodland	*687*
Xeromorphic forest/woodland	269
Evergreen broadleaved sclerophyllous woodland	165
Evergreen needleleaved woodland	253
Deciduous woodland	*624*
Tropical/subtrop. drought deciduous woodland	370
Cold deciduous woodland	254
Shrubland/thicket (chaparral, maquis, brush)	*1,207*
Evergreen broadleaved shrubland/thicket	127
Evergreen needleleaved shrubland/thicket	66
Drought deciduous shrubland/thicket	84
Cold deciduous subalpine/subpolar shrubland	46
Xeromorphic shrubland/dwarf shrubland	884
Grassland	*2,691*
Grassland (10-40% woody tree cover)	640
Grassland (< 10% woody tree or plant cover)	354
Grassland with shrub cover	930
Tall grassland	81
Medium grassland	79
Short grassland	607
Arctic/alpine tundra	*743*
Desert	*1,555*
Ice/glaciers	*1,640*
Cultivated land (agriculture/pastures)	*1,400*
Human occupied area (settlements, infrastructure)	*332*
b. AQUATIC ECOSYSTEMS (fresh & brackish)	**530**
Wetlands (bogs, swamp and marsh)	330
Lakes and streams	200
c. MARINE ECOSYSTEMS	**36,100 - 36,236***
Estuaries (excl. marsh)	1,400
Algal beds and reefs	600
Continental shelf	2,660
Upwelling zones	40
Open ocean 33,200	
TOTAL SURFACE AREA EARTH	**51,000**

* some sources give different surface aereas.
Compiled mainly after: Matthews (1983), with additional information from: Deevey (1970), Ehrlich et al. (1977), Ryther (1969), UNEP & WMO (1990), and Whittaker and Likens, 1975

can be defined as the capacity to provide space, resources and suitable environmental conditions in a sustainable manner. IUCN, UNEP and WWF (1991) define it as the 'capacity of an ecosystem to support healthy organisms while maintaining its productivity, adaptability, and capability of renewal'.

Chelation - Chelation is a natural neutralisation-mechanism of metal-ions in the soil (fr. chele = claw, referring to `grasping'). Certain chemical elements form a complex formation with metal ions that keeps the element in solution and nontoxic (Odum, 1971).

Chemosynthesis (see also: photosynthesis) - As photosynthesis but with use of chemical energy instead of sunlight.

Community - A biotic community is any assemblage of populations of plants and animals inhabiting a common area and affecting one another. A combination of such a biotic community with the physical environment that supports it is called an ecosystem (after: Odum, 1976, and Dasmann, 1976). A short definition may read 'the living part of an ecosystem'.

Conservation - Conservation means literaly `protection against undesirable changes'. In IUCN, UNEP and WWF (1991), conservation is defined as 'the management of human use of organisms or ecosystems to ensure such use is sustainable'. The word conservation is used in a variety of ways, for example in relation to energy conservation, resource conservation or the conservation (maintenance) of the production level of a given commodity. In the sense of 'nature conservation", it means the protection of the natural environment against undesirable changes. Thus, as with the term 'environment', it must always be made clear what type of conservation is meant to avoid confusion, which is especially important when using the term conservation in combination with the term sustainable development (see further).A good definition in relation to resource-use is given by Oldfield (1984): 'The wise use of natural resources [should involve] the planned management of ...the resource to deter or prevent overexploitation, irreversable destruction, or neglect'.

Criterion - Principle or standard that a thing is judged by. See also under 'parameter'.

Development (see also: sustainable development) - The word 'development' refers both to a process (the gradual unfolding of a potential) and to a steady state (the more elaborate form of a product) (Sykes, 1982). In the conservation versus development debate, usually the process-interpretation is used. For example, OAS (1987) defines development as 'the use, improvement and/or conservation of system goods and services and the mitigation of hazardous events'. IUCN, UNEP and WWF (1991) define development as 'increasing the capacity [of the environment] to meet human needs and improve the quality of human life'.

Discount rate - The rate that determines the present monetary value of future benefits that will accrue from an investment, or a measure of revenue or income that will be lost through receipt of monetary returns in the future rather than now; high discount rates tend to inhibit conservation and facilitate development [conversion] of natural environments (Oldfield, 1984).

Ecological processes - 'A continuous action or series of actions that is governed or strongly influenced by one or more ecosystems' (IUCN, UNEP and WWF, 1991).

Ecology - The word ecology is derived from the greek oikos, meaning 'house' or 'place to live'. Literally, ecology is the study of organisms 'at home'. Usually, ecology is defined as the study of the relation of organisms or groups of organisms to their environment, or the science of the interrelations between living organisms (plants, animals and microorganisms) and their non-living environment. Another definition of ecology reads 'the study of the structure and functioning of nature, it being understood that mankind is a part of nature' (after: Odum, 1971, Dasmann, 1976, Ehrlich et al., 1977). Ecology is not a new science. The word was first used by

Ernst Haeckel in 1869, but ecological studies have been carried out since antiquity.
Economics - Oldfield (1984) defines economics as 'The study of how men or their society choose various methods of using scarce, productive resources and of allocating them among competing uses or applications over generations of humanity (i.e., inter-generationally)'. According to Hueting (1980), the subject matter of economics is concerned with 'making choices among scarce, alternatively applicable means that satisfy classifiable human wants'. From this definition, it follows that **all** scarce means (goods and services) that satisfy human wants are part of the subject matter of economic theory, including (scarce) environmental goods and services.
Ecosystem - An ecosystem is any unit limited in space that is made up of a biotic community interacting with the physical environment so that a flow of energy leads to a clearly defined trophic structure (food chain) and material cycles within the system. The interaction between living organisms and material cycles within an ecosystem has, to a certain degree, the power of self regulation (after Tansley, 1935, Odum, 1971, Muller, 1974, and Odum, 1989. Ecosystems may be small and simple, such as a small isolated pond, or large and complex, such as a specific tropical rain forest or a coral reef in tropical seas.
Environment (human) - The term 'environment' cannot stand on its own and should always be used in combination with a given object, region, or condition. The point of reference in this book is the human environment which can be defined as a set of natural, social, cultural values which exist in a given place and point in time that influences the material and psychological life of man (OAS, 1987). Thus, 'environment' clearly means much more than nature and/or natural resources (see further) while the natural world is but one aspect of the total human environment. When using the term 'natural environment' the point of reference should therefore always be made clear; i.e humans require quite different (natural) environmental conditions than a bird, or a fish or a tree.
Environmental assessment and ecological evaluation - The word '**assessment**' is used in a generalised way for the estimation of the magnitude or quality of the natural environment (air, water, soil) or to investigate the way in which one function or activity affects another function or activity. The term '**evaluation**' is used when determining the value (numerical expression) of something, for example the value of environmental functions provided by natural ecosystems to human society.
Environmental conservation - Is defined by Dasmann (1976) as 'the rational use of the environment to provide the highest sustainable quality of living for humanity'.
Environmental function - In this book, environmental functions are defined as the capacity of natural processes and components to provide goods and services that directly or indirectly contribute to human welfare.
Environmental impact (in the negative meaning; see also Environmental management) - Negative environmental impacts are the result of any activity of development (or the result of any hazardous event) which prohibits the use of, deteriorates, or destroys goods and services which could be used or are being used to improve the quality of human life' (OAS, 1987).
Environmental management (positive environmental impact) - Environmental management is the planning and implementation of actions geared to improve the quality of the human environment (partly after OAS, 1987)
Environmental quality and quality of life - The quality of an environment is measured in terms of its capacity to offer goods and services that satisfy the needs of the individuals and groups which belong to that environment (OAS, 1987). As explained above, these individuals or groups may either be human or non-human, depending on who's environment is meant. In the case of man, the quality of life depends on the degree to which both physiological and psychological human needs

are met, which, in turn, depends on the goods and services provided by the natural environment.
Evaluation - Means the determination of the value (numerical expression) of something, e.g. the (socio- economic) value of environmental functions to human society.
Evolution - A change in the genetic make up (allele frequencies) of a population over time (Oldfield, 1984). See also: genetic diversity.
Gene pool - The sum total of all the genetic information encoded within all the genes of a breeding population (Oldfield, 1984).
Genetic diversity - The heritable variation within and among populations which serves as the source of genetic resources, and which is created, enhanced, or maintained by evolutionary forces (mutation, selection, genetic drift) or gene reshuffeling processes (recombination). (Oldfield, 1984).
Habitat - The specific place where a plant or animal usually lives, often designated by some physical characteristic or by a dominant plant type (Oldfield, 1984)
Heterotrophic - Heterotrophic organisms derive their nourishment from outside (not **autotrophic**). They are chiefly animals, which ingest other organisms or organic matter. (after: Odum, 1971 and Sykes, 1982).
Humification - Is the process whereby the dead bodies of plants and animals are reduced to finely divided organic material in the soil (after Odum, 1971)
Life support system - 'An ecological process that sustains the productivity, adaptability and capacity for renewal of lands, water, and/or the biosphere as a whole' (IUCN, UNEP and WWF, 1991).
Natural resource (see also: resource) - Natural resources are all those objects and processes in the natural environment which have some benefit or use to man. The term natural resource is rather vague. At one time it referred to the things, or sources of energy, in the environment used by humanity - coal, iron, timber, rivers for hydropower, and the like. As our knowledge of the environment and our use of the planet expanded, virtually everything on earth along with the sunlight impinging on it has come to be considered as a natural resource. Some resources, such as the Antarctic ice cap are only potential resources, since we are not using them (Dasmann, 1976). For distinction between renewable and non-renewable resources, see 'resources'.
Natural ecosystem - According to IUCN, UNEP and WWF (1991), a natural ecosystem is an ecosystem where since the industrial revolution (about 1750) human impact (a) has been no greater than that of any other native species, and (b) has not affected the ecosystem's structure.
Nature/natural environment - The term nature is used in this book for all those processes and components in our environment which are spontaneously formed and not, or minimally, influenced by man. The natural world consists of both biotic (living) and abiotic (non-living) components and all the interactions between these components. Since mankind has become the dominating factor on this planet, it tends to see itself as separated from the natural order, which is reflected by the increased use of term 'natural environment', to emphasise that the remaining natural processes and components are only one aspect of man's total environment (see also under 'environment'). Interestingly, the term 'nature', is usually used when referring to the living part of the biosphere while 'environment' is usally associated with the abiotic aspects (e.g. the quality of air, water and soil).
Non-Governmental Organisation (NGO) - Any organisation that is not a part of federal, provincial, territorial, or municipal government. Unless otherwise indicated, NGO's include private voluntary organisations, corporations, educational institutions, and labour unions. (IUCN, UNEP and WWF, 1991).
Organic matter (see also: biomass)- Matter containing carbon in its molecule (e.g. carbohydrates or glucose); the main constituent of living organisms.

Organism - 'A living being or form of life that is a cell or is composed of cells. Any member of the kingdoms of Prokaryotae (bacteria), Protoctista, Fungi, Animalia, or Plantae' (IUCN, UNEP and WWF, 1991).
Overexploitation (overharvesting) - The use or extraction of a resource to the point of depletion (or extinction). Biologically, it usually refers to overharvesting of a resource population to alevel below the maximum needed for a sustainable yield (= the level at which a population can, theoretically, continue to be optimally harvested over the long-run) (Oldfield, 1984).
Parameter and criterion - For both assessment and evaluation (see elsewhere in this glossary) the use of some kind of 'value-standard' or measuring unit is necessary: in the case of assessments, the word '**parameter**' may be most appropriate since it is defined as 'a quantity constant in the case considered, but varying in different cases' (another definition reads: 'measurable or quantifiable characteristic or feature"). The word '**criterion**' may fit better to the evaluation-concept since it is defined as a 'principle or standard that a thing is judged by'. Although it is attempted to use the combinations assessment - parameter and evaluation - criterion as defined above consistently throughout the book, the use of these terms in literature is quite confusing and sometimes the distinction is quite difficult to make, especially when the assessment and evaluation make use of the same measuring unit.
Peat - Peat is partially decomposed organic matter that is the precursor of coal.
Person equivalent - 1 person equivalent (p.e.) is the amount of organic waste per person/24 hours. 1 p.e. equals 110 gr. organic matter with a BOD 5 (= Biological Oxygen Demand, see appendix I..) of 54 gr 02 in 5 days. For complete mineralisation 91 gr oxygen is required (Dankers, 1978).
Pest - A 'pest' may be defined as an uncontrolled increase in numbers of one* species in an otherwise balanced ecosystem. Oldfield (1984), defines pest as 'an organism that competes with, preys upon, parasitizes, or otherwise interferes with man or his domesticated (cultivated or husbanded) biota'.
Phagotrophic - Organisms which are able to consume or absorb bacteria.
Pheromones - Pheromones are volatile secretions which control the behaviour of insects and other organisms (Odum, 1971)
Photosynthesis - Photosynthesis is the process in which carbon-dioxide plus water plus light energy, in presence of enzyme systems associated with chlorophyll, results in glucose plus oxygen (see App. I.8.1 for further details).
Preservation - keeping something in its present state (IUCN, UNEP and WWF, 1991)
Protected area - An area dedicated primarily to protection and enjoyment of natural or cultural heritage, to maintenance of biodiversity, and/or to maintenance of life-support systems (IUCN, UNEP and WWF, 1991).
Protection - Securing something for a particular purpose (IUCN, UNEP and WWF, 1991).
Rehabilitation (see also: restoration) - To return a degraded ecosystem or population to an undegraded condition, which may be different from its original condition (IUCN, UNEP and WWF, 1991).
Resin - Adhesive inflammable substance insoluble in water secreted by most plants and exuding naturally or upon incision, for example from fir and pine. A synthetic resin is a solid or liquid organic compound made by polymerization or other process and used especially as, or in plastics (Sykes, 1982).
Resource - The term resource relates to any means of supplying what is needed, and usually refers to a stock that can be drawn on. Resources are used to maintain the human metabolism (e.g. water and food), to provide shelter or satisfy other material needs (e.g. wood, metals, stone, energy, etc.), or to satisfy recreational and aesthetic needs (e.g. water for swimming, the scenic value of the landscape).

To determine the (sustainable) use level, it is important to make a distinction between renewable and non-renewable resources.
- A renewable resource can be regenerated at a constant level, either because it recycles quite rapidly (water), or because it is alive and has the capacity for reproduction and growth (organisms and ecosystems). As long as the rate of use is less than their rate of regeneration, and as long as their environments are kept suitable, they will go on replacing themselves.
- Non-renewable resources are not regenerated or reformed in nature at rates equivalent to the rate at which we use them (such as oil). A special category of non-renewable resources are resources which are not lost or worn out by the way we use them, and can be reprocessed (recycled) to be used again and again (such as many metals).
- A special category of resources are 'inexhaustible' resources such as sunlight. Also those resources for which our foreseeable rate of use is relatively minute in relation to the supply (such as table salt from the oceans) could be mentioned here. (partly after Dasmann, 1976 and IUCN, UNEP and WWF, 1991)
Respiration - The respiratory activity of living organisms oxidizes organic matter (carbohydrates) back to CO_2 and H_2O (i.e. the reverse of photosynthesis). There are three types of respiration, which roughly parallel the various types of photosynthesis: (1) Aerobic respiration - gaseous (molecular) oxygen is the hydrogen acceptor (oxidant), (2) Anaerobic respiration - gaseous oxygen not involved. An inorganic compound other than oxygen is the electron acceptor (oxidant). (3) Fermentation - also anaerobic but an organic compound is the electron acceptor (oxidant). (partly after Odum, 1971).
Restoration (see also: rehabilitation) - To return a degraded ecosystem or population to its original condition (IUCN, UNEP and WWF, 1991).
Saprobic/saprophages - Organisms living on dead or decaying matter
Succession - Biotic succession is defined by Dasmann (1976) as 'the sequence of bioric communities which tend to succeed and replace one another in a given area over a period of time'. Each community in the sequence changes the environment in such a way as to favor those species which will next take over. The starting point is alwys the pioneer community, able to colonize and inhabit bare surface. The end product in any succesion is known as a climax community. This is a relatively stable community, able to maintain itself over longer periods of time and to regenerate and replace itself without marked further change.
Sustainability - A characteristic of a process or state that can be maintained indefinitely (IUCN,UNEP and WWF, 1991).
Sustainable development - The concept of 'sustainable development' was introduced in the early 1980's (in particular through the publication of the World Conservation Strategy by IUCN, UNEP and WWF, 1980), in order to reconcile conservation and development objectives. Since then, it has evoked much discussion. The word sustainable means to keep going continuously, which is difficult to combine with the steady-state or conservative meaning of the word development. The dualistic use of the concept of sustainable development is reflected in the many attempts to draft a satisfactory definition for this concept.
(1) The most cited definition is that given by the World Commission on Environment and Development (WCED) in the so-caled Bruntland report: 'Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (WCED, 1987). The report further states that 'in essence, sustainable development is a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development, and institutional change are all in harmony and enhance both current and future potential to meet human needs and aspirations'. Unfortunately, this definition does not explicitly

mention the need to conserve the natural resource base.
(2) In 'Caring for the Earth', the successor to the World Conservation Strategy, IUCN, UNEP, and WWF (1991)p211) give a very brief definition: 'Improving the quality of human life while living within the carrying capacity of supporting ecosystems'.
(3) A definition given by the Overseas Development Natural Resources Institute (ODNRI, 1987) reads: 'Sustainable development is about meeting the needs of the present generation without prejudicing the future productivity of the natural resource base'.
(4) According to OAS (1987) the concept of sustained development has not been defined satisfactorily yet and probably cannot be defined. OAS suggests the use of the phrase 'sustained flow of a system good or service'. This definition, however, also has its limitations, because it does not exclude the danger that the sustained flow of a given good or service goes at the expense of other, or future goods and services provided by the same or other (eco)systems. To avoid confusion, it might therefore be better to speak of sustainable **use** rather than development.
Sustainable use - Use of an organism, ecosystem or other renewable resource at a rate within its capacity for renewal (IUCN,UNEP,WWF, 1991)

List of tables

Acronyms/abbreviations

CEARC	= Canadian Environmental Assessment Research Council
FAO	= Food and Agricultural Organisation
GEMS	= Global Environmental Monitoring System (UNEP)
ICSU	= International Council of Scientific Unions
IIASA	= International Institute for Applied Systems Analysis
IIED	= International Institute for Environment and Development
IPCC	= Intergovernmental Panel on Climate Change (UNEP/WMO)
IUCN	= The World Conservation Union (formerly the International Union for Conservation of Nature and Natural Resources
NASA	= National Aeronautics and Space Administration (USA)
OAS	= Organisation of American States
OECD	= Organisation for Economic Co-operation and Development
ODNRI	= Overseas Development Natural Resources Institute (UK).
SCOPE	= Scientific Committee on Problems of the Environment (ICSU)
UN	= United Nations
UNEP	= United Nations Environmental Programme
UNESCO	= United Nations Educational, Scientific and Cultural Organisation
UNDP	= United Nations Development Programme
US-AID	= United States Agency for International Development
US-EPA	= United States Environmental Protection Agency
WCED	= World Commission on Environment and Development
WCMC	= World Conservation Monitoring Centre
WHO	= World Health Organisation
WMO	= World Meteorological Organisation
WRI	= World Resources Institute
WWF	= World Wide Fund for Nature (formerly World Wildlife Fund)