R.S. de Groot

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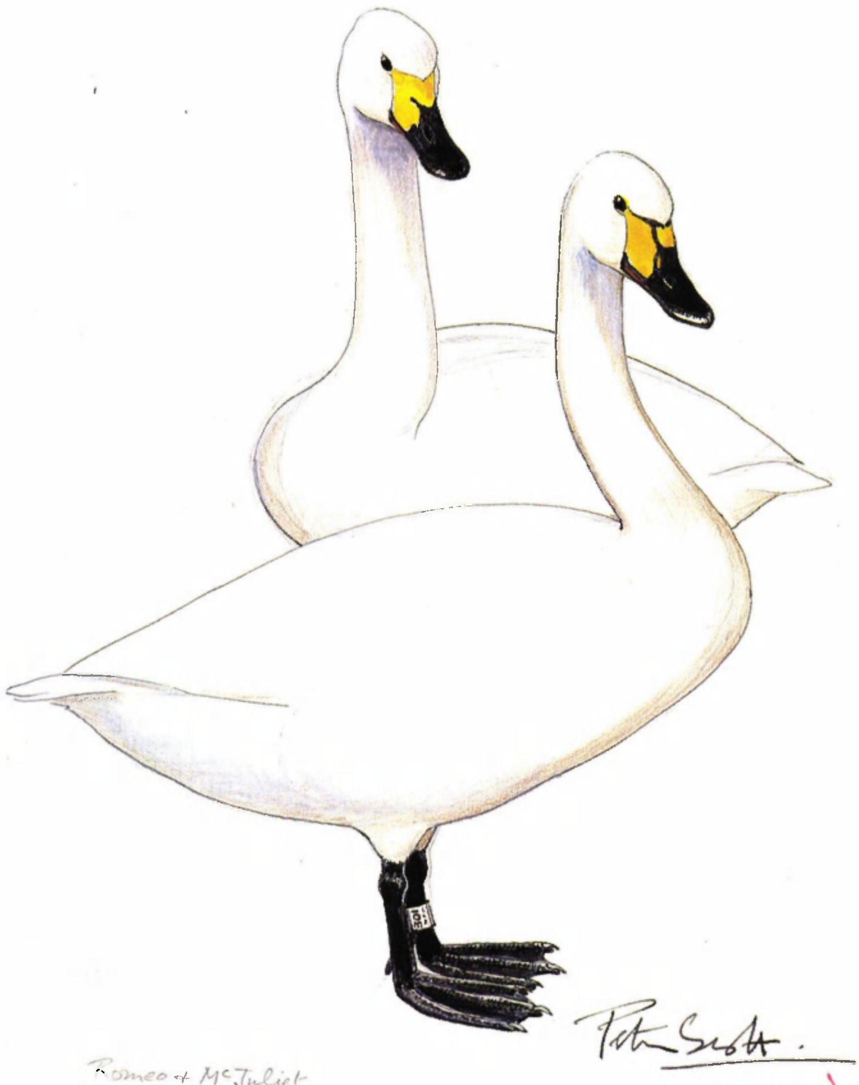
as a tool in environmental planning and decision making



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A FUNCTIONAL ECOSYSTEM EVALUATION METHOD AS A TOOL IN ENVIRONMENTAL PLANNING AND DECISION MAKING

R.S. de Groot

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Nature Conservation Department
Agricultural University
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Cover Story

Another report with a complicated title, full of diagrams and tables ... And what on earth are those birds doing on the cover?

This report is concerned with nature-conservation: preventing the extermination of species. In practice, this means the protection of their habitats, and this, in turn, is more and more a matter of environmental planning.

Environmental planning - or the lack of it - is dependant on human decisions. Every day, everywhere on this planet, planners, managers and politicians make decisions which determine the use of some part of the biosphere in the most profitable, so-called "economic" way. This "economic" use is most often determined by comparing the estimated market value of several combinations of human activities. If this is done well, the effects on Nature and the environment are taken into account and the desirability of non-intervention (non-intrusion) is also considered. But if relevant data are not available, decisions are taken nevertheless - with disregard of the ecological consequences.

The author of this report attempts to measure the value of Nature by analysing the various goods and services which it provides for mankind and classifying these as what he terms "functions". Such analysis must be as detailed as possible, for it is only when all the functions of an area are taken into consideration that the full consequences of a proposed development-plan become apparent. And only then can steps be taken to prevent Nature's being sacrificed or exploited in a non-sustainable manner.

Many people object to placing a monetary value on something so priceless as Nature. But this should be seen as a realistic response to the thought patterns of decision-makers rather than as a betrayal of our own principles. It is not a capitulation to dollar-economics, but on the contrary, a new instrument to reveal the weaknesses and inadequacies of present-day decision-making. The incorporation into cost-benefit analyses of the estimated cash value of certain environmental functions - and this is often quite feasible - does not in any way imply that they have no other values. Indeed, this system provides a more complete approach, and has more predictive value than economic calculations that are based on expected profits and returns or do not take account of so-called external factors.

We are grateful to Sir Peter Scott for permission to use his drawing of the Bewick swans Romeo and MacJuliet. Swans at the Slimbridge Wildfowl Trust are identified and named by their black and yellow bill markings. Romeo was a regular visitor. Once, when he returned from his annual visit to the tundras of Siberia, he brought with him a girlfriend, who, of course, ought to be named Juliet; however, because of a particular bill-pattern she was obliged to bear the prefix Mac.

One may think of the tundras as a rather valueless type of ecosystem. But each year Romeo and MacJuliet manage to find their way over 2600 miles to bring the message that even such little-esteemed ecosystems can have important functions for the maintenance of natural balance and of biological diversity and serve as an inspiration for science and the arts, in short, the quality of life on earth.
So why shouldn't they be on this cover?

M.G.W. Hummelinck

CONTENTS

Preface

"The world moves into the future as a result of decisions, not of plans" (Kenneth Boulding in: Lang & Armour, 1980).
This brief statement indicates one of the main obstacles to the conservation and sustainable utilization of nature and natural resources: how can it be ensured that the economic and political decision-making process takes due account of preferably all environmental factors that influence human welfare?
Maintenance of essential ecological processes and life support systems, preservation of genetic diversity, and sustainable utilization of species and ecosystems are the main goals of the World Conservation Strategy (WCS). This document, published by the IUCN in 1980, contains several Priority Issues on how to achieve conservation and sustainable utilization of species and ecosystems. Priority Issue 10 deals with Environmental Planning and Rational Use Allocation as the main instrument to implement the principles of the WCS. An important aspect of this Priority Issue is ecosystem evaluation. During a conference on the implementation of the World Conservation Strategy ('Conservation and Development', organised by IUCN, UNEP en WWF in Ottowa, Canada, 31 May - 5 June 1986), the need for more functional information on 'goods and services' provided by ecosystems was expressed by planners and other participants.

The evaluationsystem presented in this paper is such a functional ecosystem evaluation method which aims to analyse possibly all functional interrelations between man and the natural environment in a complete and systematic manner.
The theoretical concept of ecosystem (environmental) functions was primarily developed in the Netherlands. One of the first authors to use the function-concept 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 and since then wrote many publications on the (potential) use of environmental functions in economic theory (e.g. 1980 and 1984). Another pioneer in the field of environmental function analysis is Ir. M.G. Wagenaar Hummelinck, ex-chairman of the World Wildlife Fund, Netherlands. Ir. Wagenaar Hummelinck initiated a working group who formulated 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 "Natuur is Duur" (1977); in 1979 an english version appeared: "Nature's Price, the economics of Mother Nature", followed by a spanish edition in 1981. An attempt to incorporate function-evaluation in (Dutch) physical planning by Van der Maarel and Dauvellier (1978) provided additional views on the possible classification and evaluation of environmental functions.
Outside the Netherlands, the function-concept is less well-known and most authors use terms as 'environmental or wildlife values' when referring to goods and services provided by (natural) ecosystems, e.g. Odum & Odum (1972), Pimentel (1980, 1984), Thibodeau & Ostro (1981) and Kellert (1983).

Although much has been written on environmental functions, the value of nature to human society is still not fully recognised in economic planning and political decision-making.
This research, therefore, attempts to combine existing, mainly theoretical literature with original research into a functional ecosystem evaluation method as a tool in environmental planning and (economic and political) decision making. Based on existing literature, consultations and original ideas, a so-called function-evaluation system was developed which includes all functions that can possibly be attributed to natural and semi-natural ecosystems.
In order to design a practical evaluation method, which should enable the user to collect and process the necessary data to evaluate the ecological and socio-economic value of the functions of a given ecosystem in a relatively short period of time (3-6 months), this function-evaluation system was further elaborated and tested by means of a number of case studies, including the Galapagos Islands (Ecuador), the Darien Rainforest (Panama), the Dutch Wadden Sea and the National Park "De Hoge Veluwe" (The Netherlands).
Eventually, it is planned to produce a manual for function-evaluation, based on these case studies, with a check-list of functions and practical guidelines on how to use the various evalution matrices as a tool for environmental planning and management in these, and other areas.

The research, of which this paper presents some preliminary results, is in progress since January 1982, and during most of this time-period, the Nature Conservation Department of the Agricultural University of Wageningen, The Netherlands, has kindly provided office space and many "goods and services", which is greatly appreciated.
The continuous support and the many helpful suggestions throughout the

entire research period by Prof.dr. C.W.Stortenbeker (head of the Department) and Ir. M.G.Wagenaar Hummelinck is gratefully acknowledged. Furthermore, I thank Dr. Roefie Hueting, Drs. S.W.F. van der Ploeg and Dr. Norbert Dankers for their useful comments on earlier drafts of this, and other manuscripts produced in the course of this research.

I also wish to mention Herman Bolhuis, Harmke van Dam, Theo van Drunen, Peter Eijsten, Lucas Goldsteen, Hans Kaffener, Olga de Lange, Carla Upperman and Ronald Zollinger, all students of the Wageningen Agricultural University who participated in two case studies in the Netherlands. Their case study reports (Bolhuis, et al., 1984 and Van Drunen, et al., 1986) were welcome contributions to the design of a practical function-evaluation system.

During visits to the various case study sites in The Netherlands, Ecuador and Panama, many people were most helpful in various ways. Their contribution to this research is acknowledged more personally in separate case study reports.

Finally, I thank the members of the secretariate of the Nature Conservation Department for their assistance and the cheerful way in which they coped with my irregular presence at the department. Special thanks go to Gerda Bruinsma and Marijke Kuipers for typing and retyping this manuscript. Financially, this study has been made possible by grants from World Wildlife Fund-Netherlands, Prince Bernhard Foundation, Dutch Ministry of Education and Science, Netherlands Foundation for International Nature Protection (the Van Tienhoven Foundation), K.F. Hein Foundation, Metropolitan Touring (Ecuador), and private donations.

An earlier version of this manuscript was presented to a Workshop on Environmental Management Methods during the conference on Conservation and Development in Ottawa, Canada, 31 May - 5 June, 1986 (De Groot, 1986b). Financial support for my participation in this conference by the Netherlands National IUCN Committee is gratefully acknowledged.

Summary

Man depends on the natural environment for physical and mental wellbeing in many ways: natural processes regulate essential environmental conditions (e.g. climate, soil-condition, etc.), nature provides space and a suitable substrate for many human activities (e.g. agriculture), natural ecosystems provide many biotic and abiotic resources and many people enjoy nature for spiritual enrichment and recreational experience. Yet, in spite of man's dependence on these environmental goods and services (i.e. functions), degradation and depletion of nature and natural resources continues on a large scale.
To make the environmental planning and political decision-making process more aware of the many functions of natural environments, this paper presents a method for evaluating the ecological and socio-economic value of environmental functions to human welfare in a systematic manner. This so-called function-evaluationsystem basically consists of three evaluation steps:

1) Ecological Function Analysis: this evaluation step translates environmental characteristics into functions (goods and services) of natural ecosystems, e.g. watershed protection, genetic resources, opportunities for recreation, etc.
2) Socio-economic Function Evaluation: this evaluation step analysis the contribution of environmental functions to human welfare. For some functions it is possible to translate the socio-economic value into a monetary value. For example, the monetary value of only some functions of the Dutch Wadden Sea was estimated at Dfl. 226 million/year (De Groot, 1986a).
3) Environmental Impact Assesment: this evaluation step determines the impact of human activities on environmental characteristics.

Chapter 4 (Interaction Analysis) integrates these three evaluation steps in order to determine the sustainability and (in)compatibility of man's use of environmental functions.
To illustrate the practical application possibilities of function evaluation and interacion analysis, several case studies were performed, including the Dutch Wadden Sea, the National Park "De Hoge Veluwe" (The Netherlands), the Galapagos Islands (Ecuador) and the Darien National Park (Panama).
Finally the place of function evaluation in the environmental planning and decision-making process is discussed in chapter 5.
The paper concludes that, if conservation and sustainable use of natural species and ecosystems is to be realised, environmental and economic planning and decision-making must take due account of possibly all functional interactions between man and the natural environment. By demonstrating the ecological and socio-economic importance of

environmental functions to human welfare it is hoped that man's use of environmental goods and services will become more sustainable and take better account of the many values of natural ecosystems to human society.

1. INTRODUCTION

In spite of the increased awareness about many environmental problems, thus far man has been unable to establish a sustainable relationship with the natural environment.

The need for conservation and sustainable use of nature and natural resources should need no further explanation; man is an integral part of the biosphere which constitutes our only life support system in the universe (as far as we know it today). However, "the escalating needs of soaring numbers have often driven people to take a short-sighted approach when exploiting natural resources. The toll of this approach has now become glaringly apparant and may be illustrated with a long list of hazards and disasters, including soil erosion, desertification, loss of cropland, pollution, deforestation, ecosystem degradation and destruction and extinction of species and varieties" (IUCN, 1980).

Yet, actions to prevent further deterioration are "pathetically below the scale on which problems are spreading and remain reactive rather than preventive in intent" (Polunin, et al., 1982).

The global interrelatedness and future implications of environmental deterioration gives rise to the need for global strategies for conservation and sustainable use of nature and natural resources. One such a global strategy is the World Conservation Strategy of the IUCN, UNEP and WWF (IUCN, 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.

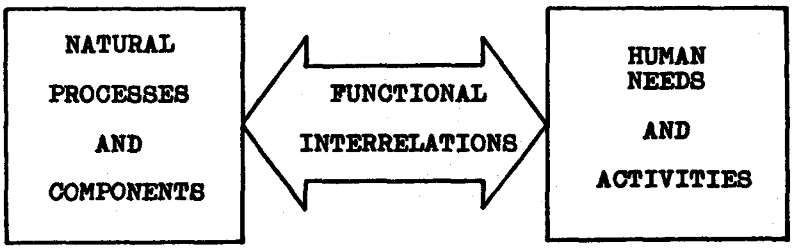
Priority Issue no. 10 of the World Conservation Strategy proposes the integration (in so far this is possible) of conservation and development through environmental planning and rational use allocation, specifically through ecosystem evaluation, environmental assessment and a procedure for allocating uses on the basis of such evaluations and assessments.

Apart from political and economic motives (i.e. the preference for short-term gains over long-term benefits), one of the obstacles to the implementation of the principles of conservation and sustainable development in economic planning and decision-making may be the problem of conveying ecological data to economic and political planners and decision-makers (De Groot, in preparation).

The ecosystem-evaluation method presented in this paper, therefore, aims to provide more functional information on goods and services provided by the natural environment.

If conservation and sustainable use of nature and natural resources is to be achieved, it will be necessary to have a clear insight in possibly all functional interrelations between man and the natural environment (see fig.1).

Fig. 1: Simplifyed man-environment model



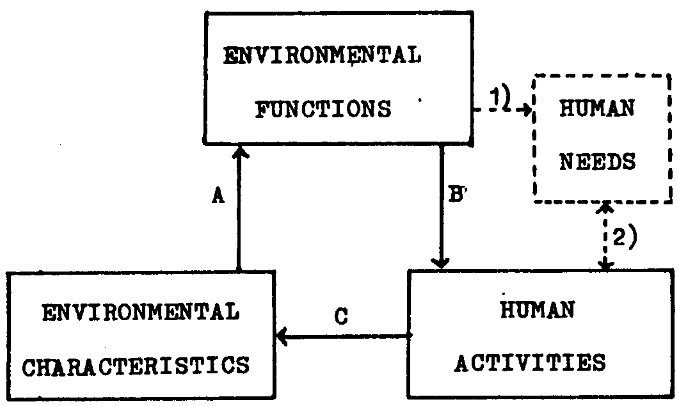
An important element in this 'man-environment model' is the function-concept: i.e. the capacity of the natural environment to provide goods and services that satisfy human needs (directly and/or indirectly).
Human needs may be divided into three main categories:

- Physiological needs: the need for oxygen, water, food, physical health, etc. (i.e. a healthy living environment)
- Psychological needs: i.e. the need for mental wellbeing through cognitive development, re-creation, social contacts and status, etc.
- Future needs: i.e. the need for a safe future and future prospects for both present and future generations.

The satisfaction of many of these needs depends on certain environmental conditions. Defining these environmental conditions in terms of functions of the natural environment that satisfy human needs is the main purpose of this research.

To this end, a so-called function-evaluation system was designed which basically consists of three evaluation steps: (see fig. 2 A-C).

Fig. 2: Main elements of a function-evaluationsystem of the natural environment



A = Ecological Function Analysis
B = Socio-economic Function Evaluation
C = Environmental Impact Assessment
1) Some environmental functions directly satisfy human needs (e.g. aesthetic enjoyment)
2) Some environmental functions satisfy human needs through economic activities (e.g. agriculture).

The first evaluation step (A) translates environmental characteristics (i.e. natural processes and components) into functions (goods and services) of the natural environment (see chapter 2). The second evaluation step (B) analyses the contribution of environmental functions to human welfare (see chapter 3). The third evaluation step (C) analyses the impact of human activities on environmental characteristics (see chapter 4.1).
By applying all three evaluation steps simultaneously, this function-evaluation system offers the opportunity to determine the degree of (in)compatibility of human activities and environmental functions: changes in environmental characteristics caused by human activities cause changes in the function fulfilment of a given area (ecosystem) resulting in a change in the capacity (qualitative and/or quantitative) of the area to sustain certain types of land (i.e. ecosystem) use (see chapter 4.2).
Thus, this function-evaluation system provides a basis for systematic and complete ecosystem evaluation as a tool in environmental planning and decision-making for conservation and sustainable use of the natural environment.

2. ECOLOGICAL EVALUATION OF ENVIRONMENTAL FUNCTIONS

Natural (and semi-natural) ecosystems fulfil many important functions to human society. This study defines environmental functions as the capacity of natural processes and components to provide goods and services that satisfy human needs, directly or indirectly.
Based on literature (a.o. Braat et al., 1979 and Van der Maarel & Dauvellier, 1978) and several case-studies, the following four function-categories are distinguished:

1) Regulation functions: the capacity of natural ecosystems to regulate and maintain essential ecological processes and life support systems.
2) Carrier functions: the capacity of the natural environment to provide space and a suitable substrate/medium for human activities.
3) Production functions: the capacity of the natural environment to provide raw materials and energy,
4) Information functions: the capacity of the natural environment to provide opportunities for cognitive development and 're-creation'.

The capacity of a given natural or semi-natural ecosystem to perform certain functions depends on the environmental characteristics (natural processes and components). Thus, a matrix should be developed showing the relation between environmental characteristics as evaluation parameters for environmental functions (see fig. 3).

Fig. 3: <u>Ecological</u> <u>Function-evaluation</u> <u>Matrix</u>

	Environmental Functions
Environmental Characteristics	ECOLOGICAL FUNCTION PERFORMANCE

Braat, et al. (1979), points out that: "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, one function for a short time. However, 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 one function is often related to other functions".

Another problem in finding the most suitable combination of environmental functions and evaluation parameters is the fact that many functions are determined by more than one parameter and that many parameters influence more than one function.

2.1. Ecosystem evaluation parameters

Selecting the appropriate parameters for evaluating the function-performance of a given ecosystem is essential to the practical application possibilities of the function-evaluationsystem. To this end, several case-studies were carried out on various ecosystem complexes, i.e. the Dutch part of the Wadden Sea (estuarine environment), the National Park "De Hoge Veluwe" (semi-natural mixture of temperate, mixed forest, heather, grassland and sand-dunes), the Galapagos Islands (Ecuador) (volcanic island ecosystems) and the Darien National Park (Panama) (subtropical pre-montane rainforest).
Based on these case studies, a preliminary and incomplete list of environmental characteristics that are of importance as evaluation parameters for analysing the capacity of a given ecosystem to perform certain functions, is given here:

a Atmosphere (climate, air quality, etc.),
b Lithosphere
  - geology (volcanism, petrology, etc.),
  - geomorphology (inclination, sedimentation/erosion, etc.),
  - soil (fertility, carrying capacity, etc.),
c Hydrosphere (watershed, runoff, water quality, etc.),
d Biosphere
  - vegetation (surface covering, structure, etc.),
  - life community (species diversity, productivity, etc.)
  - other ecosystem characteristics (often a combination of previous parameters such as naturalness, uniqueness, openness, etc.).

For the purpose of this paper, it would be impractical to discuss all these parameters here in any detail. The most relevant parameters will be further elaborated during the description of the environmental function performance (2.2).

2.2. Functions of the natural environment

Natural (and semi-natural) ecosystems provide many important functions (i.e. good and services) to human society.

2.2.1. Regulation functions

This group of functions deals with the capacity of natural ecosystems to regulate and maintain essential ecological processes and life support systems. Some important ecological processes are energy transfer, biogeochemical cycles, mineralisation of organic matter, and

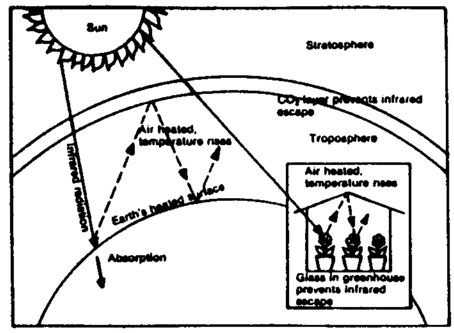
storage and transfer of energy and minerals in biomass (food chains). The many functions that are performed by these processes often do not directly satisfy human needs but provide the necessary conditions for other functions to be fulfilled.
Usually, regulation functions are best performed by natural ecosystems and in order for man to benefit from these functions, he only needs to ensure the continued existance and integrety of these natural ecosystems and processes.
However, due to man's still increasing numbers and non-sustainable activities, regulation functions are increasingly overstressed and threatened by physical, chemical and biological disturbance of the basic ecological processes that provide these functions.
Some examples of regulation functions include:

Protection against harmful cosmic influences
The atmosphere not only provides a reservoir for such vital elements as oxygen, but also forms a shield between us and the hostile cosmic environment. Most solid cosmic particles desintegrate in the atmosphere before reaching the earth's surface and the atmosphere, especially the ozone-layer, intercepts about 75% of the UV-radiation (Odum, E.P., 1971).
This 'cosmic shield'-function of the atmosphere is increasingly being endangered by the exhaust of propellants (e.g. chloro-fluorocarbons) from airplanes, spray-cans, etc. As a result, the ozone concentration is declining and a 'hole' in the ozone-layer has recently been discovered over the Antartics, 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 increase the occurrence of skin-cancer.

Regulation of certain climatic conditions
Different types of surface-covering (i.e. ecosystems) have a different influence on micro- and macro-climatic conditions. For example, a sand desert and a rainforest not only show great differences in micro- and local climate but also have a different impact on the temperature, precipitation and air turbulance in surrounding areas. Generally, vegetated areas have a buffering influence on climatic conditions while unvegetated areas induce more extreme climatic conditions.

Another important function of natural systems is the maintenance of the earth's heat balance. Due to human activities, the amounts of some trace gases in the troposphere, notably carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), ozone (O_3) and chlorofluorocarbons (CFC) are increasing. These gases are essentially transparant to incoming short-wave solar radiation but they absorb and emit long-wave radiation and are thus able to influence the earth's climate (see figure 4).

fig.4 The Greenhouse Effect



(Lang & Armour, 1980)

As a result of the increasing concentrations of these so-called greenhouse gases, it is now believed that in the first half of the next century a rise of global mean temperature could occur which is greater than any in man's history. The estimated increase in global mean temperature during the last hundred years of between 0.3 and 0.7 ^{o}C is consistent with the projected temperature increase attributed to the observed increase in CO_2 and other greenhouse gases. If present trends continue, the combined concentrations of atmospheric CO_2 and other greenhouse gases would be radiatively equivalent to a doubling of CO_2 from pre-industrial levels possibly as early as the 2030s, leading to increasing of the global mean equilibrium surface temperature of between 1.56 and 4.5 ^{o}C. It is estimated on the basis of observed changes since the beginning of this century, that global warming of 1.5 to 4.5 ^{o}C would lead to a sea-level rise of 20-140 cm (UNEP, WMO & ICSU, 1985).

The role of the vegetation and oceans in buffering 'greenhouse gases' is discussed under the function "strage and recycling of human waste".

Watershed protection and watercatchment
This function relates to the capacity of certain ecosystems to prevent water-runoff and store water, either at the surface or as groundwater. A regular distribution of water along the surface, especially on sloping land, enables the vegetation to take in sufficient amounts of water during longer periods of time. Vegetation also prevents soil-erosion due to water runoff and has a buffering effect on extreme water levels, both high (flooding) and low (droughts) further downhill

in the watershed area. For example, water runoff on bare slopes is 10 to 25 times as great as that on vegetation-covered slopes (Pimentel, et al., 1980). Many agricultural systems in valleys depend for their water supply on this natural irrigation system.

Maintenance of the top soil
Together with the activity of soil organisms (bio-turbation) the vegetation cover plays an important role in producing and maintaining a fertile layer of top soil. By preventing soil degradation and erosion, the vegetation cover reduces the danger of land slides in mountaineous areas and helps in halting the process of desertification. For example, soil erosion on 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. Runoff water from agricultural and other land with minimal vegetation cover carries away an estimated 3.6 billion tonnes of topsoil annually in the USA (in addition, 1 billion tonnes is eroded by wind), so that about 1/3 of the original topsoil of agricultural land in the USA has been lost to erosion (Pimentel, et al., 1980).

Storage and recycling of organic matter
Natural systems contribute in various ways to the storage and recycling of organic matter, including organic waste produced by man. Basically, three processes can be distinguished: mineralisation (food chains), humification and fossilisation. Only the first two are of relevance as recycling mechanisms for human organic waste. For example, aquatic ecosystems, especially estuaria are able to recycle large amounts of organic matter and the average quantity of organic matter degraded per hectare in terrestrial ecosystems is about 4.000 kg dry matter per year, basically broken down into carbon dioxide, water and ammonia (Pimentel, et al., 1980). This process is extremely important for, for example, the maintenance of the fertility of agricultural soils.

Storage and recycling of nutrients
Life on earth depends on the continuous recycling of certain nutrients such as phosphor and nitrogen. Biogeochemical (re)cycling mechanisms ensure the continues availability of these nutrients and allows man to discard certain amounts of nutrients into the environment without negative side-effects. For example, wetlands remove nutrients (and organic waste) from sewage wastes which have already received secundary treatment. The 'tertiary treatment capacity' of tidal marshes for nitrogen, for example, has been estimated between 365 (Thidodeau & Ostro, 1981) and 2.715 (Gosselink et al., 1974) kg nitrogen/ha/year.

On land, for example, each year an estimated 140 million tonnes of nitrogen is removed from the soil in crop production world wide. More than 90 million tonnes of this deficit is made up by biological nitrogen fixation (Pimentel, et al., 1980).

Storage and recycling of inorganic human waste (other than organic matter or nutrients

Clean 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 inorganic human waste. Some examples are briefly discussed here.

- certain bacteria are able to metabolise chemical pollutants: e.g. soaps, detergents, phenols and oils;
- the oceans assimilate approximately 50%, and the vegetation cover on earth removes about 15% of the total amount of carbon dioxide produced by the combustion of fossil fuels, thus reducing the danger of the 'greenhouse effect' (Pimentel, et al., 1980) (see also text with figure 4);
- the peats at the wetland surface absorb heavy metals and organic pesticides, significant amounts of lead and copper and possibly also mercury, magnesium, cadmium and zinc. However, little is known about the long term effect or permanence of these substances in wetlands (Thibodeau & Ostro, 1981);
- dust particles: forests, for example trap 30-70 tonnes of dust particles/ha/year (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)

Bio-energy fixation (i.e. storage and recycling of energy)

Autotrophic organisms, such as green plants and certain bacteria, are able to convert abiotic energy (i.e. solar radiation and chemical energy) into organic matter and ATP. The biomass thus formed provides the structural basis for the build-up of ecosystems and may be used by other organisms (including man) for food, building material, fuel, etc. As long as mankind is unable to copy this proces of bio-energy fixation, this function of nature is essential to the maintenance of human life on earth.

Maintenance of biological diversity

By providing a permanent habitat to wild organisms, natural ecosystems contribute to the maintenance of the biological diversity on earth. In addition, natural ecosystems allow the continuous changing of genetic material by means of evolutionary processes which produce new organisms (i.e. genetic material) that can have many (potential) benefits to human society: medicinal use, crop improvement, pestcontrol, etc. The importance of a given ecosysem for this function may be deducted from the species diversity and the number of endemic species and subspecies.

Providing a nursery habitat
Many animal species have separate feeding and breeding areas, both in time and/or space. Disturbance and destruction of ecosystems that are important breeding (=nursery) areas for migrating species will have serious consequences for the functioning of other, sometimes remote ecosystems. Many marine organisms, for example, depend to a large extent on estuaria for reproduction: species as Plaice (80%), Sole (50%), Shrimp, Dab, Herring, Whiting and Cod use the Wadden Sea as nursery area to stock the North Sea populations (De Groot, 1986a).

Providing a feeding and resting habitat to migrating organisms
Many ecosystems provide food and shelter to organisms that spend only part of their life cycle in that ecosystem. For example, the average daily number of birds present in the Dutch Wadden Sea varies between 200.000 and 400.000 in the summer, during the winter months the number of birds feeding and resting in the Dutch Wadden Sea may be close to 1 million (Mőrzer Bruyns & Wolff, 1983).

2.2.2. Carrier functions
Every living being on earth needs a certain amount of space in accordance with its particular environmental requirements (i.e. an ecological niche). The natural suitability of a given ecosystem to support human activities depends on the carrying capacity for a particular type of use and the available surface area. Ecological parameters for measuring the capacity of a given ecosystem for providing space and a suitable substrate/medium for human activities are, however, difficult to provide since human technology enables man to convert virtually every type of substrate or medium into space that can suit his needs, for example habitation, agriculture and animal husbandry, industry, waste disposal, transportation and recreation. The suitability may therefore better be deducted from the amount of resources, energy and money needed to utilize the natural environment for a particular type of use. The use of a given ecosystem for a certain carrier function will usually be exclusive, i.e. space allocated for industrial use cannot simultaneously be used for agriculture, recreation, etc. Also, the carrying capacity of natural ecosystems for human activities will usually be very limited since most human activities that require permanent space alter the original (natural) state. Two examples of

carrier functions will briefly be discussed here.

Providing space and a suitable substrate/medium for agriculture
Depending on the type of crop, certain climatic and soil-requirements will determine the suitability of a given ecosystem to provide arable land (e.g. temperature, precipitation, soil fertility, inclination, etc.). At present, the total area under cultivation on earth amounts to 1.5 billion hectares. This amount will have to expand with 200 million hectares by the year 2000 to help meet increased food needs (Pimentel, et al., 1984).

Providing space and a suitable substrate/medium for nature conservation
Some criteria that determine the suitability of a given area (ecosystem) for nature conservation include: naturalness, uniqueness, number of rare and or endemic species, etc. Depending on the management objectives, the natural environment in a conservation area will be more or less strictly protected. Management types may range from National Parks, allowing certain other types of use that do not interfere with the conservation objectives (e.g. recreation), to strict Nature Reserves, prohibiting all other types of use. Around 1980, over 400 million hectares of both aquatic and terrestrial ecosystems enjoyed some form of protection (IUCN, 1982).

2.2.3. Production functions
The natural environment provides many resources that are essential to man's physical existance on earth, such as oxygen, water, food, energy, etc. If utilized in a sustainable manner, nature could provide many of these resources in perpetuity. However, the consumptive nature of the use of these functions and the short-term interests of the market economy make these resources vulnerable to over-exploitation. In addition, many of nature's resources are considered 'free goods' and as such are not taken into account in economic policy making (see also chapter 3). Consequently, many natural resources are being exploited until it becomes too expensive to obtain the resource and transport it to the market place. The exploitation-level at which a natural resource becomes 'un-economical' thus often exceeds the sustained yield level (carrying capacity) of the ecosystem involved. Apart from resource depletion, overexploitation of a resource often causes other negative side effects such as desertification, pollution, etc. It should therefore be stressed here that utilisation of the production functions of natural ecosystems should take due account of the 'external' effects and be limited to sustainable yield levels as much as possible.

Production functions may be sub-divided as follows:

Providing oxygen
This function of nature (together with providing clean air) is a good example of a natural resource which is considered a 'free good'. Consequently, in spite of the vital importance of oxygen (and clean air) to human life, the role of natural ecosystems in providing this resource is not considered in economic planning and decision-making. Only when oxygen (and clean air) become scarce, for example in large cities, some action is taken to reduce air pollution and supply additional oxygen.

Providing water
Man needs water in many ways: for drinking, household needs, irrigation, industry (cooling, flushing, processing), etc. Water is provided by the natural environment in the form of rainwater, surface water and ground water. The water-quality determines the suitability of the resource for a certain type of use. In many parts of the world both the quality and quantitiy of especially drinking-water is far below required standards and near heavily populated areas it becomes increasingly necessary to apply cost- and energy-inefficient purification procedures.

Providing mineral resources
I.e.: inorganic substances which can be obtained by mining, for example sand, clay, oil, metals, precious stones, etc.

Providing energy
Nature provides an almost limitless array of energy (re)sources which may be used by man:
-) Abiotic energy: solar radiation, wind-energy, hydro-power, geo-thermal energy, fossil fuels (oil, coal, gas), nuclear energy.
-) Biotic energy: fuelwood, litter, dung, etc.

Providing litter
Dead plant material and animal excrements may be used as fodder (animal feed), compost (fertilizer) or even as a source of energy.

Providing woody biomass and plant fibers
Woody biomass may be used for construction purposes, handicraft, energy conversion (fuelwood) etc.

Providing wild plants and animals (and their products)
Wild plants and animals can be used in many different ways and for many different purposes:

a) Food and animal feed

I.e. the use of wild plants and animals (fish, game, etc.) and their products as food and/or animal feed. For example, in the U.S.A. alone, yearly more than 4.3 million metric tonnes of wild plants and animals are harvested with a food-value of 2.3×10^{12} kcal (or 335 million kg of protein) (Pimentel, et al. 1980).

b) Genetic material

"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" (Ehrlich, 1973 in: Van Dieren & Hummelinck, 1979).

Apart from the use of wild genes for agriculture, germplasm of wild plants and animals is used in biotechnology, pharmaceutical industry, medicine, etc. For example, the genetic share in the increased productivity of United States agriculture can be put at 1 percent of the annual farm-gate value of crops or some US$ 1 billion a year. Agricultural experts hope they are within a few years of introducing a nitrogen-fixing capacity into several major crop plants, thus reducing the need for chemical nitrogen fertilizer that now costs the world's farmers US$ 15 billion a year. As for medicine, genetic improvements in the production of penicillin, for instance, have led to a 55-fold increase in production processes (Meyers, 1983).

c) Biochemicals

Many biodynamic compounds (e.g. alkaloids) can be used by man for many different purposes, especially medicine: the value of drugs and pharmaceuticals, that are derived in some form or other from plants has now reached US$ 20 billion a year in the United States. Industry too benefits from plants of diverse sorts. American chemical enterprises import plant materials such as oils, fats and waxes worth many millions of dollars a year, using them to manufacture a vast array of endproducts whose ultimate economic value is many times greater than the cost of the raw materials. Thanks to a number of hydrocarbon-bearing plants, we may soon be able to establish "petroleum plantations" and grow our own gasoline (Meyers, 1983).

d) Ornamental plants and animals

Many plants and animals (and their products) are used and traded for ornamental purposes: for example orchids, butterflies, aquarium fish, birds, skins, ivory, etc.

e) Test-animals

Medicine and the pharmaceutical industry heavily depend on certain animal species for testing purposes. Although many test-animals are now specially raised for this purpose, wild animals are sometimes still used. Also, certain plant and animal species can be used as indicators for certain environmental conditions, for example for testing water quality.

f) Other wildlife functions

- Providing biological pest control: natural predators and parasites play an important role in the prevention of pests. Many insect pests can be controlled by other insects, such as wasps, that attack crop plant eaters. In California alone, during the period of 1928-1979, seven leading biological control projects have reduced the need for chemical pesticides to an extent of savings worth US$ 987 million (Meyers, 1983).
- Providing cross-pollination of commercial crops: a total of 90 US-crops, valued at nearly US$ 4 billion, are dependent upon insect pollination, and 9 additional crops, valued at US $ 4.5 billion are significantly benefited by insect pollination (Pimentel, et al., 1980).

2.2.4. Information functions

"...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" (Forster, 1973).

Providing opportunities for re-creation

Recreation is experienced by many people as a reward for professional labour and as a necessary compensation for daily routines. As such, recreational activities are essential to man's mental and physical wellbeing. Through its aesthetic qualities and almost limitless variety of landscapes, the natural environment provides many opportunities for recreational activities, such as walking/hiking, camping, fishing, swimming, nature study, etc. "The advantages of this recreation in nature's surroundings are not only that many people (and countries) derive an income from it but also that those who recreate benefit directly, e.g. through improved health and a relief of tension" (Van Dieren & Hummelinck, 1979).

Providing spiritual/religious information

Many people feel a need to experience a certain continuity in their environment and to understand their place in the universe. To some, natural areas (and nature in general) are an important source of spiritual information by providing a certain measure for orientation in time and space. All life on earth is part of the same evolutionary process (or subject to the same 'creative force') and without all these 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. This feeling of one-ness (unity) with nature presents to some an important spiritual enrichment and is expressed by a general reverence (respect) for nature and other living beings on earth. This respect may be translated into an ethical, or religious attitude towards nature; some societies even approach running water with considerable reverence, for them it is 'alive'.

Providing cultural inspiration

Without nature, life would be very dull indeed. Nature is a source of inspiration for painting, films, television programmes, architecture, advertising, fashion, industrial design, dancing, folklore, popular art, etc. There is hardly any province of culture to which nature does not give shape or inspiration (Van Dieren & Hummelinck, 1979)

Providing educational and scientific information

Awareness and understanding of the functioning of natural processes and components in our environment can contribute much to a more responsible attitude of people towards their environment and fellow-creatures. Natural areas provide many opportunities for (environmental) education and research. The value of a given nature area to this function may be deducted from the number of educational excursions, scientific studies and the number of publications, samples, etc. derived from it.

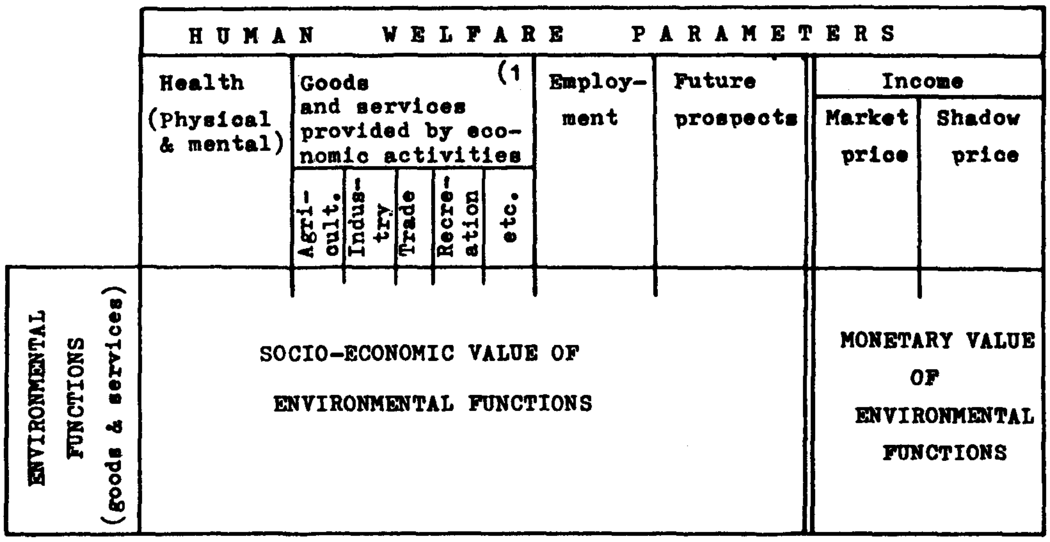
Providing a reservoir of potential information

Man has only just begun with exploring the many functions of the natural environment and most natural areas still contain a vast reservoir of as of yet unknown functions with possible future benefits to human society. The present rapid destruction of natural habitats and the exterminations of wild species greatly reduces the opportunity to explore and use this reservoir of potential information and endangers the survival of present and future human generations.

3. ENVIRONMENTAL FUNCTIONS AND HUMAN WELFARE

The contribution of environmental functions to human welfare is determined by the degree to which these functions satisfy human needs.
Fig. 5 shows the most important welfare parameters, including physical and mental health, goods and services provided by economic production, employment (i.e. a meaningful place in society) and future prospects (i.e. a safe future).

Fig. 5. Socio-economic and monetary value of environmental functions



1) The amount of goods and services provided by economic activities is usually measured by the Gross National Product (GNP).

The satisfaction of many of these human needs, or welfare parameters, depends directly or indirectly on the availability of environmental goods and services which thus have socio-economic value to human society (see chapter 3.1).
In addition, for some environmental functions it is possible to translate the socio-economic value into a monetary value based on 'real' market price or calculated by means of so-called 'shadow-prices' (see chapter 3.2).

3.1. Socio-economic value of environmental functions
According to Hueting (1984), the subject-matter of economics is defined as "making choises among scarce means that satisfy human wants". Although Hueting includes (natural) environmental goods and services as 'means that satisfy human wants', many economists still assume that the production of material goods and services provided by human acti-

vities is the only concern of economics, thus excluding environmental concerns from economic planning and decision-making.

NB: Another reason why environmental goods and services are neglected in 'traditional' economic theory is the misconception that they are not scarce and thus can be considered as 'free' goods. Since it is good economic practice to provide goods and services as cheaply as possible, in order to be competitive on the market place, the natural environment, as a 'free good' has been (and still is being) over-exploited, degraded and polluted. Because environmental functions are seen as 'free' goods and services, the impacts of the economic production process on the natural environment are labelled 'external effects' and thus excluded from economic accounting. Slowly it is becoming clear, however, that these so-called external effects are not as external as we would like them to be and the external effects of the past are costing us billions of dollars today in repairing, replacing and/or neutralising the loss of environmental goods and services such as clean air, water and soil (in so far this is possible).

That environmental functions do (or should) belong to the subject matter of economics, as defined by Hueting, follows from the fact that they satisfy human wants (see fig. 5) and, unfortunately, are becoming increasingly scarce.
Yet, even today, environmental functions are still neglected in economic planning and decision-making because most countries still use the Gross National Product (GNP = the amount of goods and services produced by 'economic' activities) as the main indicator of human welfare, disregarding other welfare parameters such as health, employment and future prospects (see fig.5).
This (wrong) identification of the GNP as the only, or most important measure of collective happiness causes many social and environmental problems because the continuous attempts to increase the GNP (by increasing production-processes that aim to satisfy consumptive wants), leads to a decrease in the satisfaction of non-consumptive needs; e.g. pollution and resource-depletion endanger human health and reduce future opportunities.

NB: There are more objections to the use of the GNP as a measure for collective welfare; a good discussion of this topic can be found in Hueting (1980).

Since the concept of environmental functions links 'environmental quality' with 'quality of life' (i.e. <u>all</u> human welfare parameters), it could provide a unifying concept for the development of a new kind of 'environmental economics' based on conservaton and sustainable utilisation of environmental goods and services (De Groot, in preparation). Thus, any information on environmental functions is economic information and loss of environmental functions formerly disregarded as 'external effects', form economic costs.

3.1.1. Contribution of environmental functions to human health
Many functions of the natural environment contribute to the maintenance of a healthy living environment by providing clean air, water and soil and by regulating essential ecological processes and life support systems (e.g. regulation functions, see chapter 2.2.1).
Many wild plants and animals provide biochemicals and genetic material that helps, and sometimes are essential to modern medicine.
In additional, natural environments contribute to the maintenance of mental health by providing opportunities for reflection, spiritual enrichment, congnitive development and recreational experiences (i.e. information functions, see chaper 2.2.4).

3.1.2. Contribution of environmental functions to economic production
The contribution of environmental functions to economic production (i.e. human activities that are included in the GNP) is determined by the degree to which these activities depend on environmental functions. Human activities that depend on environmental functions in one way or another include: habitation, harvesting of biotic resources (hunting, agriculture, etc.), extraction of abiotic resources (i.e. mining) many types of industry, waste disposal, commerce/trade, transportation/communication, health care, military training, recreation and tourism, cultural activities, religion, education, research and nature conservation. Ideally, the dependence of all these activities on environmental functions should be expressed in a percentage scale ranging from 1 to 100%. This is very difficult, however, partly because little research has been done on this subject, partly because the interactions between human activities and the natural environment are so complex.
Some examples of the dependence of human activities on environmental functions are briefly discussed here.

Harvesting biotic resources
This group of human activities includes gathering (e.g. forest products, also logging can be included here), hunting (e.g. fishery), crop growing (agriculture, horticulture, forestry, etc.) and animal husbandry (aquaculture, game farming, ranching, etc.). Clearly, all these activities depend to a greater or lesser extent on environmental functions; without natural production processes, such as bio-energy fixation and food chains, gathering and hunting would be impossible and also crop growing and animal husbandry depend partly on environmental functions, such as the regulation of environmental conditions (e.g. climate, watershed-protection, recycling of nutrients, etc.),

providing a suitable substrate (i.e. arable land), providing genetic material for crop-improvement, providing possibilities for biological pest control and pollination mechanisms (see also chapter 2.2.).

Industry
The chemical industry, for example, depends in many ways on environmental functions, many raw materials are derived from natural resources and even clean air is indispensible, e.g. for the manufacture of photographic emulsions (Hueting, 1980).

Recreation and tourism
Tourism in many countries depends to a large extent on the presence of National Parks and other relatively undisturbed natural areas.

3.1.3. Contribution of environmental functions to employment
Besides health and material goods, most human beings need a meaningful place in society in order to function properly. This meaningful place (or social status) is, among others, determined by employment. Many employment opportunities depend directly or indirectly on environmental functions. Good examples are people that are employed in the management of nature areas and recreational activities in nature. Also jobs held by fishermen, farmers and many industrial employees depend in one way or another on environmental functions.
NB: Employment opportunities would probably greatly increase if the production process would take better account of environmental constraints and would be more sustainable.

3.1.4. Contribution of environmental functions to a safe future
"Man derives part of the meaning of existance from the company of others. These others include in any case 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" (Hueting, 1984). Thus, maintenance of the regulation functions of nature, conservation of representative samples of (possibly all) types of natural habitats and sustainable utilization of species and ecosystems is essential to human welfare.

3.2. Monetary value of environmental functions
Clearly, translating the socio-economic value of environmental functions into a monetary value (see fig. 4) is quite complicated, and sometimes even impossible: "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 "all'mighty" dollar. One wonders how to place a quantitative or monetary value on what Aldo Leopold (1968) described as the sound of cranes signifying the "trumpet in the orchestra of evolution ... underlying and conditioning the daily affairs of birds and man" (in: Kellert, 1983).
In spite of the many, often emotional, objections raised against placing a monetary (or other quantitative) value on environmental functions, it must be realised that most economic and political decisions of today do not take these "priceless experiences" into account either and are still mainly based on 'dollar-economics'. This in spite of the fact that many economists agree upon the relativity of placing monetary values even on man-made goods and services and question the way the GNP and National Income are used as the main yardstick for measuring human welfare (see also the beginning of this chapter).
As Kellert (1983) suggests, it would be better, instead, to develop "a universal value unit additive across varying evaluative criteria providing, thus, a relative basis for diverse land-use decisions". Thus, also non-monetary values must be taken into account when evaluating land use alternatives and ecologists and economists somehow must find a common measuring standard. The function-concept presented in this paper may provide such a common standard since it links environmental quality with quality of life.

NB: Even if it proves impossible to achieve a common measuring standard for both environmental and man-made goods and services, it is still worth-while to discuss the subject since often it is 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 approach towards solving the environmental problems of today. A change in attitude of economic and political decision-makers in favor of long-term sustainability is probably more important than construing an artificial yardstick for measuring 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, or most of the values of the natural environment in the socio-economic planning and decision-making process.

Thus, as long as it is clearly indicated how the monetary value of environmental functions was obtained and the relativity of these values is clearly explained, placing dollar-values on environmental functions can only increase our awareness of the enourmous contribution of natural systems to human welfare and make the decision-making process more responsive to environmental values.
For example, the monetary value of only some of the functions of the Dutch Wadden Sea was estimated at Dfl. 226 million/year (De Groot, 1986a), thus providing an important incentive to conserve this area in its natural state.

Basically, there are two possibilities for determining the monetary value of environmental functions:

3.2.1. Determining the market price of environmental functions
For some environmental functions it is possible to calculate the 'real' market price since some goods and services that are provided by nature are directly 'traded' on the market place. For example, in the USA alone, yearly more than 4.3 million metric tonnes of wild plants and animals are harvested, including fish (3.5 million m.t.), game animals, maple sirup, tree nuts, blueberries and algae/plankton, with a commercial value of US$ 2.8 billion (Pimentel, et al., 1980). Besides production functions of nature also part of the recreational value of natural areas can be expressed in 'real' market prices: entrance fees to National Parks and other protected areas open to the public present a considerable addition to the national income, especially in developing countries. For example, direct revenues from tourism in the Galapagos NP (Ecuador) may be close to 500.000 US$ (entrance fees, licences, etc., see De Groot, 1983) in addition, most tourists spend hundreds of dollars during their stay in the country.

3.2.2. Determining the shadow price of environmental functions
Contrary to the examples mentioned above, most environmental functions are not considered in modern market economics (and are thus 'free of charge'), because many economists and politicians consider environmental goods and services not to be scarce enough, or because they are not aware of these functions or purposely ignore them to protect the production process from additional expenditures (however, ignoring environmental functions usually means postponing the expenditures into the future).
Yet, many environmental functions do contribute substantially to human welfare and/or to the possibility to produce certain marketable goods and services.
Some methods for calculating shadow prices will briefly be discussed here.

Determining the 'opportunity' costs (or value)
This method calculates the amount of money that would be 'lost' (or not gained) when environmental goods and services were not available. For example, agricultural productivity not only depends on artificial inputs (e.g. fertilizer, irrigation, etc.), but to a large extent also depends on natural processes and environmental conditions. Without certain environmental functions, it would be impossible to grow many crops, or only at much higher costs. For example, biological pest control, provided by the natural enemies of the Bollworm and Budworm

caterpillars, a menace to cotton crops, prevent a calculated 8% annual loss, worth about US$ 191 million in the USA alone (Pimentel, et al., 1980). Cross pollination is essential to reproduction in many plants and a total of 90 US-crops, valued at nearly US$ 4 billion, are dependent on insect pollination. An additional 9 crops, valued at US$ 4.5 billion, are significantly benefited by insect pollination (Pimentel, et al., 1980). In the Third World, genetic improvement of certain types of wheat have boosted output by an amount estimated at US$ 2 billion a year by the mid-1970s, and genetically superior strains of rice in Asia have helped expand output by US$ 1.5 billion a year (Meyers, 1983). As for medicine, the value of drugs and pharmaceuticals that are derived in some form or other from biochemicals found in wild plants has now reached US$ 20 billion a year in the United States alone. The rosy periwinkle, to cite a notable instance, supplies alkaloidal materials for two potent anticancer drugs that now generate worldwide sales of more than US$ 100 million a year (Meyers, 1983). Also other economic activities besides agriculture, depend on environmental functions, for example fishery: 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, amounting to almost 25 million US$. (De Groot, 1986a).
Also, the capacity of natural systems to remove or neutralise pollutants from the environment presents a considerable economic value since it prevents damage to, for example, fishery and human health.

Determining restoration costs
This method uses the costs of restoring the loss of environmental functions in sofar this is possible, as a measure for the monetary value of these functions. For example, the costs involved in cleaning poisoned soil or reforestation projects are an expression of the amount of money man is willing to spend to maintain the original condition (i.e. clean soil and intact forest).

Determining compensation costs
This method calculates the monetary value of environmental functions by determining the costs involved when environmental goods and services were not available and would have to be replaced, if possible, by artificial goods and services. For example, natural purification processes that neutralise certain types of human waste perform a service to human society which otherwise would have to be performed by artificial and often costly methods such as water-purification plants. Thus, this purification-function of the natural environment saves man a certain amount of effort and money that should be accounted for in economic analyses. Thibodeau & Ostro (1981) calculated that one acre

of marsh, by removing nutrients substitutes for plant-construction costs of 85 US$ and annual operation and maintenance costs of 1.475 US$. The total of the plant-cost and capitalized annual costs is 24.668 US$ per acre (at an interest rate of 6%).

Determining eliminination costs

Another method for calculating the economic value of environmental functions is to determine by means of interviews, the willingness to pay for the continued availability of certain environmental goods and services that are now provided free of charge or threaten to disappear because too few funds are presently allocated to ensure their maintenance. For example, the willingness to pay for (or the actual costs of) measures that remove a polluting agent at the source, and/or investments in 'clean' technologies to prevent the loss of clean air, water and soil or the expenditures made to conserve threatened ecosystems and species.

NB : See Hueting (1980, 1984) for a discussion on the application possibilities of 'shadow-prices' in economic theory.

4. INTERACTION ANALYSIS

As we have seen in the previous chapters, human society depends in many ways on environmental functions. Yet, many of man's activities negatively affect the environmental characteristics on which these functions depend, thus affecting man's opportunities to use these functions. In order to be able to decide upon the optimal sustainable use of natural and semi-natural ecosystems, it is necessary to have a clear insight in the (in)compatibility of human activities and environmental functions.
To fascilitate the incorporation of environmental function evaluation in environmental planning and decision-making, a so-called interaction matrix has been developed which combines environmental impact assessment with an analysis of the possible changes in function fulfillment that may be expected from the ewnvironmental impact, and an evaluation of the (potential) socio-economic effects (see fig. 7).

4.1. Environmental Impact Assessment

The third step in the function-evaluationsystem presented in this paper (see Fig. 2C), deals with an analysis of the effects of human activities on environmental characteristics. Ideally, an Environmental Impact Matrix should be developed, showing both the type of effect and the scale of the environmental impact for each type of human activity separately (see fig. 6).

Fig. 6: Environmental Impact Matrix

	Environmental characteristics
Human Activities	ENVIRONMENTAL IMPACT ASSESSMENT (1

(1 Each cell in the matrix should show the type of effect (i.e. chemical, physical or biological) and the impact on the environment.

The following types of environmental impacts caused by human activities can be distinguished:

Pollution

Pollution (i.e. chemical disturbance) of air, water and soil disturbs the proper functioning of many natural processes and components. Large quantities of about 50.000 chemical compounds are produced annually, such as pesticides, soaps and detergents, ammonia, alkalies, acids, phenols, oil, etc. Most of these chemicals eventually find their way into the environment; each year billions of tonnes of SO_2, CO, NO_2 and

CO_2 are brought into the air through combustion of fossils fuels, causing the so-called 'acid rain' which disturbs the soil chemistry and affects the growth and health of the vegetation cover.

Physical disturbance

Examples of physical disturbance include, climatic changes caused by deforestation, for example, as many as 80 countries, accounting for nearly 40% of the world population, now experience serious droughts (Pimentel, et al., 1984), depletion of natural resources (oil, metal ore, etc.), removal of the vegetation cover (deforestation), causing erosion and floods which may eventually lead to desertification: each year, 6 million hectares of arable land is lost due to soil degradation and erosion (Pimentel, et al., 1984) and 1/3 of the land surface on earth is already desert or subject to desertification (IUCN, 1980).

Biological disturbance

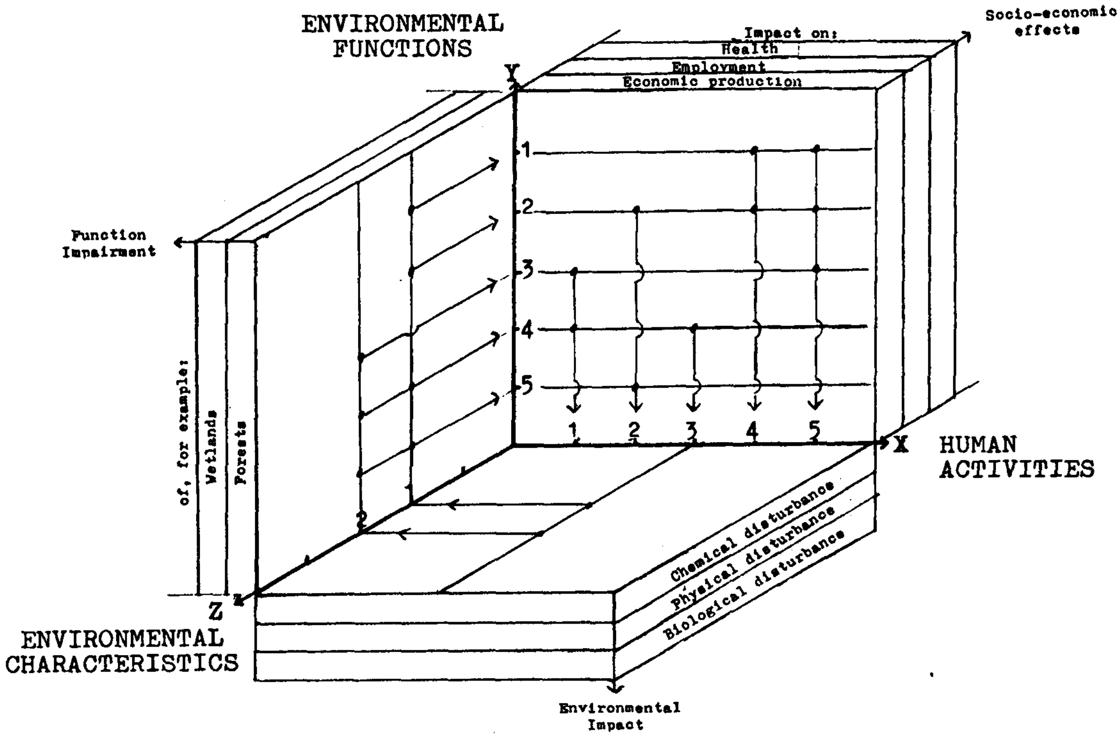
Pollution, physical disturbance and other effects of human activities may disturb the 'biological balance' through changes in natural habitats and species compositions. For example, outbreaks of pests and diseases caused by introduction of foreign organisms or counter-productive use of pesticides: according to Van Dieren & Hummelinck (1979), 240 species of insects, including mites and ticks, are increasing at an alarming rate due to resistance to chemical pesticides. Habitat destruction and over-exploitation of wild plants and animals causes extinction of many species, and the rate at which species have become extinct during the last 300 years has increased dramatically. It is now estimated that, for example, 60.000 species of plants (on a total of 250.000) will become extinct or seriously endangered during the next 30-40 years (Mayo, 1986).

4.2. Assessment of (in)compatibility of ecosystem use and environmental functions

For environmental planning and management it is not only important to know what the effects are of certain (planned) activities on the environment, but even more so to know what this means in terms of sustainability and (in)compatibility of various (combinations of) land use options.

Fig. 7. Interaction matrix

Determination of land use (in)compatibility based on analysis of the interactions between human activities (X), environmental characteristics (Z) and environmental functions (Y)



X = HUMAN ACTIVITIES	Y = ENVIRONMENTAL FUNCTIONS	Z = ENVIRONMENTAL CHARACTERISTICS
for example:	for example:	for example:
1 = Gathering/hunting	1 = Watershed protection	1 = Vegetation cover
2 = Recreation	2 = Maintenance of top soil	2 = Species diversity
3 = Logging*	3 = Genetic resources	
4 = Habitation	4 = Forest products	
5 = Agriculture	5 = Recreation opportunities	

*(underlined is the activity (X_3) for which an Interaction Analysis is described in the text)

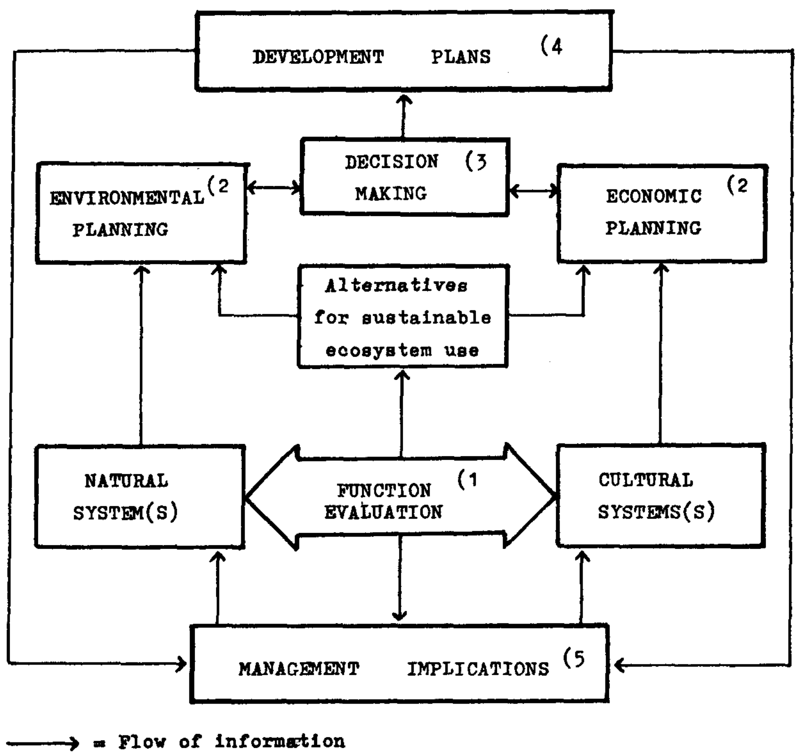
For example, logging-activities (i.e. deforestation)(=X3, see fig.7) lead to complete removal of the vegetation cover (Z1); on hillslopes removal of the vegetation cover causes the loss of such functions as watershed protection (Y1) and maintenance of the topsoil-layer (Y2) resulting in flooding and erosion which seriously endangers other human activities such as habitation (X2) and agriculture (X5) further downhill. Also, with the loss of the vegetation cover (and the animals that lived there (Z2)) other functions are lost, such as climate regulation, genetic resources (Y3), forest products (Y4), recreation opportunities (Y5), etc.
N.B.: a more detailed elaboration of the interaction matrix is given in the various case study reports (e.g. De Groot, 1986a).
In order to achieve conservation and sustainable use of species and

ecosystems, it is essential for environmental planners and decision makers to have a clear understanding of possibly all functional inter-relations between man and the natural environment.
Systematic Function Evaluation, in combination with Environment Impact Assessment and Interaction Analysis can identify (actual and potential) conflicts between present ecosystem use and ecosystem functions and can formulate alternatives to make optimal and sustainable use of environmental functions, taking account of both socio-economic needs and environmental constraints.

5. ENVIRONMENTAL PLANNING AND DECISION MAKING

Environmental planning should 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. Deciding upon the best allocation of possible land use alternatives is the main objective of the environmental planning and decision-making process. In order to reach a balanced (i.e. sustainable) decision, the decision-making process should take account of possibly all environmental and socio-economic factors involved. Figure 8 presents such an integrative planning and decision-making procedure of which function evaluation forms an essential part.

Fig. 8: The place of function evaluation in environmental planning and decision making.



1) Function evaluation provides information on environmental goods, services and hazards and on the ecological and socio-economic (in)compatibility of human activities and environmental functions. This information can be used for development planning and environmental management.
2) Environmental and economic planners can use the information provided by function evaluation to design development plans which make

optimal use of ecosystem functions whithin the framework of development objectives formulated by the decision making process and in accordance with human needs and environmental constraints. 3) Decision makers can use the information provided by environmental and economic planners to formulate development plans which are based on sustainable use of environmental functions.

N.B.: In this procedure, it is essential that planners and decision makers work closely together in order to ensure that decisions are in accordance with socio-economic needs and environmental constraints. Unfortunately, it still occurs too often that environmental planners are not (sufficiently) consulted and/or that pressure of industry or public interest groups has too much influence on decision making, thus leading to non-sustainable use of environmental functions with often both negative ecological and socio-economic effects (see also point 4).

4) Through cooperation between planners and decision makers, development plans can be formulated which optimise socio-economic benefits while remaining within the limitations of environmental constraints. To ensure sustainable development, cost-benefit analyses must be made which include socio-economic as well as environmental effects, both in the short- and long term future.

   N.B.: often the decision making process only or mainly takes account of the short term economic (read: monetary) effects, disregarding the impact on the (natural) environment as 'external effects'. However, these so-called external effects are not as external as some decision makers would like to believe, and non-sustainable development plans of the past are costing billions of dollars today in repairing, neutralising or limiting the environmental damage, in so far this is possible.

5) Once a decision on the type of ecosystem use has been reached, and development plans have been formulated, measurements must be taken in order to realise the plan-objectives. These management measures may include organisational measures, legislative measures, infrastructural/technological measures and informative measures, i.e. providing adequate information about plan objectives and management implications to those who are directly affected by the planning decision: "Unless major efforts are made to explain the value of protected areas and to associate the local people with their management, all conservation measures will be bound to collapse sooner or later" (W. Lusigi in: Batisse, 1982).

6. CONCLUSIONS

It may be concluded that, if methods for environmental planning and management are to be successful in achieving sustainable use of nature and natural resources, they must take due account of possibly all environmental, socio-economic and cultural values involved. Considering the political and economic consequences of such an integrative approach, persuasive arguments will have to be presented to change the present short-term decision-making process into a land use policy that is based on long term sustainability. The function-evaluation system presented in this paper can be instrumental in such an integrative environmental planning and decision-making process.

By demonstrating the ecological and socio-economic importance of environmental functions to human welfare, more awareness can be created among politicians, economists and the general public for the (urgent) need for, and economic sense of conservation and sustainable use of environmental goods and services. By translating environmental characteristics into goods and services provided by natural environments, this evaluation system can provide environmental planners and decision-makers with more functional information on the interactions between man and the natural environment. To improve the availability of information on environmental functions, a data-bank should be developed which could (quickly) provide important information on ecosystem functions to environmental planners, land managers and other people involved in conservation and (sustainable) development.

Of course, the actual use of any integrative planning procedure for conservation and sustainable development ultimately depends on the willingness of decision-makers to implement the outcome of such planning and evaluation procedures, preferrably before (environmental) disasters demonstrate the danger of non-sustainable and/or uncontrollable use of nature and natural resources (pollution (e.g. acid rain, radioactive fallout), soil-erosion, extinction of species and varieties, etc.).

To ensure the implementation of ecosystem evaluation in development planning, ecologists, environmental planners and managers should become much more involved in the decision-making process; many development decisions are still made without proper environmental impact assessments, leading to negative environmental (and, consequently, socio-economic) effects that could have been avoided.

Only when ecological principles become an integral part of economic and political planning and decision-making is there a chance of achieving conservation and sustainable use of nature and natural resources.

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