Evaluation of environmental functions as a tool in planning, management and decision-making

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EVALUATION OF ENVIRONMENTAL FUNCTIONS AS A TOOL IN PLANNING, MANAGEMENT AND DECISION-MAKING

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Stellingen

Stellingen behorende bij het proefschrift van Rudolf S. de Groot:
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1. Bij de afweging van de vele belangen die een rol spelen bij de besluitvorming rond economische ontwikkeling en ruimtelijke ordening wordt het (economisch) belang van natuurlijke ecosystemen nog steeds onderschat.

2. Verandering in een bepaalde milieu-eigenschap (bijv. luchtkwaliteit) heeft vaak ingrijpende, en deels nog onbegrepen, consequenties voor het functioneren van hele ecosystemen. Voor het inzichtelijk maken van de vele terugkoppelingsmechanismen in de natuur is functie-analyse een nuttig hulpmiddel en onderstreept het belang van systeem-ecologisch onderzoek.

3. De jaarlijkse baten (monetair en anderszins) van de functies van een ecosysteem of natuurgebied zouden gezien moeten worden als de "rente" op dit "natuurlijk kapitaal"; kennis over de ecologische én economisch waarde van het natuurlijk kapitaal kan derhalve een nieuwe invulling geven aan het begrip "goed rentmeesterschap".

4. 'Natuurbehoud is zelfbehoud' is geen originele, maar wel een juiste stelling.

5. De "externe" kosten van bijv. bespoten groeten en fruit, verbranding van fossiele brandstoffen en kernenergie, worden nu uit algemene belastingmiddelen betaald. Dit is een verkapte subsidie op verspilling van natuurlijke hulpbronnen en aantasting van een gezond leefmilieu die zo snel mogelijk moet worden afgeschaft.

6. "Pas als het zo wordt, dat de kippigheid echt toeslaat en het belang van de dingen wordt gezien als een functie van hun nabijheid, gaat het echt de verkeerde kant op.." [H. Mullisch, 1992]
Deze uitspraak verwoord op treffende wijze de kern van vele milieuproblemen.

7. Indien het "vervuiler-betaalt-principe" consequent wordt doorgevoerd, in combinatie met een verschuiving van de belastingdruk van arbeid naar gebruik van milieufuncties, zal milieu-onvriendelijk handelen zich vanzelf "uit de markt" prijzen.

8. Het steeds luider wordende geweeklaag van de industrie (en sommige politici) dat de "milieukosten" te hoog zouden worden is volstrekt onterecht: we zijn slechts bezig een bescheiden begin te maken met de aflossing van de reeds ontstane milieu-schuld, voor zover dit nog mogelijk is.

9. Door de hardnekkigheid waarmee veel mensen volharden in voor henzelf vermijdbaar schadelijk gedrag (zoals roken en gevaarlijk auto rijden), mag betwijfeld worden of voorlichting en regelgeving alléén ooit voldoende zal zijn om de negatieve gevolgen van irrationeel handelen, ook t.a.v. het milieu, tot een aanvaardbaar nivo terug te dringen. Het consequent doorberekenen van alle milieu, sociale en economische kosten in het prijs- en belastingstelsel is derhalve een essentiële aanvulling.

10. Om vast te stellen of een economie zich duurzaam ontwikkelt moeten milieukosten (en -baten) veel nadrukkelijker in het BNP opgenomen worden. Dan zal blijken dat het netto-effect van traditionele economische groei op de welvaart sterk overschat wordt, en soms zelfs negatief is.

11. Als alle kosten en baten meegerekend worden zal blijken dat de meeste guldens die in milieubeleid en natuurbehoud geinvesteerd worden minstens een daalder waard zijn.

12. In N. Amerika is geconstateerd dat de huidige generatie studenten merkbaar minder goed in staat is zich te concentreren dan 20 jaar geleden; de invloed van de media (vooral TV) wordt daar voor een groot deel schuldig aan geacht. Studenten zouden erover kunnen denken schadevergoeding te verlangen voor de hierdoor veroorzaakte slechtere studie resultaten.

13. Het getuigt van onverantwoord optimisme om te veronderstellen dat de jaarlijkse uitstoot van enorme hoeveelheden chemische stoffen in het milieu waarschijnlijk geen invloed zal hebben op het klimaat.
[reactie op diverse uitspraken in de pers van Prof. C. Böttcher]

14. Beter 10 zwaluwen in de lucht dan 1 in de hand.

"We hebben de aarde niet geërfd van onze ouders
maar geleend van onze kinderen"
[naar een oud-chinees gezegde]

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ABSTRACT

Although there is a growing awareness about the many benefits of natural ecosystems, concrete information on their full economic value is still scarce. This thesis provides a comprehensive method whereby all functions and values of natural and semi-natural ecosystems can be assessed and evaluated in a systematic manner. A checklist of 37 environmental functions is given with examples of the functions and socio-economics value of three major types of ecosystems: tropical moist forests (based on a case study of the Darien National Park, a pre-montane rainforest on the border between Panama and Colombia), wetlands (based on a case study of the Dutch Wadden Sea) and an oceanic, volcanic island ecosystem: the Galapagos National Park (Ecuador).
In order to achieve the conservation and sustainable utilization of nature and natural resources, better information on the (economic) importance of natural areas alone, however, is not enough. Unless ecological information is structurally integrated in economic planning and decision-making, solving environmental problems will prove difficult, if not impossible. In the last section of this thesis, the use of the function-concept as a tool in planning, management and decision-making is therefore discussed in detail, including the application in project-evaluation, in environmental (or ecological) economics, in environmental law, and in environmental education.

Key words: environmental functions, nature valuation, conservation evaluation, ecological economics, assessment, planning and management

CONTENTS

Part L EVALUATION OF ENVIRONMENTAL FUNCTIONS: A CRITICAL DISCUSSION

Attachment: *Book* ***"FUNCTIONS OF NATURE"*** (315 pp)

PREFACE

One of the main reasons for the still continuing degradation and loss of natural ecosystems is the fact that the importance of nature and a healthy natural environment to human welfare is still not fully reflected in economic planning and decision-making. This undervaluation of nature leads to over-exploitation of resources and excessive use of the natural environment as a receptor of human waste. Gradually it is becoming clear, however, that the so-called "external effects" of the economic production process are not as external as we would like them to be and the effects of non-sustainable development in the past are costing us billions of dollars today in repairing, neutralising or limiting the damage to the environment and human health, in so far as this is possible. The global scale of these environmental problems is now threatening the integrity and functioning of the entire biosphere: the thin layer of soil, water and air surrounding the earth in which life exists naturally.
To steer the economic development process into a more sustainable direction, environmental considerations should be integrated more structurally in planning and decision-making. By providing a method for assessing the many functions and socio-economic values of the natural environment in a systematic and objective manner, it is hoped that this thesis can contribute to this difficult task.

The idea for the research underlying this thesis was inspired by a two-year stay in the Galapagos Islands, Ecuador (from 1978-1980), where I was confronted with the practical problems involved in trying to bring economic use of nature in harmony with environmental constraints. The carrying capacity of these islands for habitation, agriculture and tourism in combination with the maintenance of their important conservation value is limited. Although this is generally recognised and, compared to many other places, Galapagos is still in a rather pristine state, there is a "natural" tendency to let development take its own course which usually leads to over-exploitation of nature and natural resources. The problem is to convince local (and national) decision-makers to limit human activities to the natural carrying capacity of these islands. That usually means that they will have to forego the short-term profits that could be made with maximising the use of a few functions (notably tourism and fishery) for the sake of safeguarding the future benefits of *all* functions of these islands. To give nature more "weight" in the decision-making process, not only in Galapagos but also elsewhere, I felt it would help if it could be demonstrated that conservation and sustainable use of nature and natural resources is not only ecologically important but also economically sound.

After my return to the Netherlands in 1980, I came across the work of the Institute for Environmental Studies (IvM) of the Free University Amsterdam on "ecological and economic analysis of nature", carried out by van der Ploeg, an ecologist, and Bouma, an economist, between 1971 and 1975. The initiative for this research project came from Ir. Maas Wagenaar Hummelinck, then chairman of the Dutch World Wildlife Fund, who established a working group "Evaluation of Nature" in 1969 consisting of biologists, economists and conservationists. The final report of this study (Braat et al., 1979) was transformed into a more

popular publication by W. van Dieren & M.G.W. Hummelinck entitled "Nature's Price, the economics of Mother Earth" (1979).
Besides "Nature's Price" and the IvM-reports, two other publications were a particular source of inspiration for my own work namely the "General Ecological Model" of Van der Maarel & Dauvellier (1978) and the thesis by Dr. Roefie Hueting ("New Scarcety and Economic Growth", 1980).
During my research I became acquainted with the work of many other people working on the interface between ecology and economics, and more detailed acknowledgements of other sources and personal contacts are given in the preface of part A of this thesis (see further).

Based on these personal contacts, literature research and original ideas, I approached Prof. Claus Stortenbeker in 1981 (then Head of the Nature Conservation Dept. of the Agricultural University Wageningen) with the idea to develop a so-called 'function-evaluation system' for assessing the functions and values of National parks and other protected areas. During our ensuing discussions, it was decided to attempt to develop an evaluation system which should be able to assess all functions and values that can possibly be attributed to the natural environment in a comprehensive and systematic manner.
The practical application of this function-evaluation system was tested on various case studies including the Dutch part of the Wadden Sea, the National Park "De Hoge Veluwe" (the Netherlands), the Darien National Park, a pre-montane tropical moist forest between Panama and Colombia, and the Galapagos Islands, Ecuador.
The results of these case studies, and an extensive description of the evaluation method, were published in book-form in 1992 ("Functions of Nature", de Groot, 1992). Since the publication of this book, many reactions were received on the proposed function evaluation method. Partly based on these reactions, and partly based on new publications and ideas, the need was felt to discuss some methodological aspects and application-possibilities of the evaluation method in further detail.
This thesis therefore consists of two parts: the book "Functions of Nature" (part A) and a critical discussion (part B).

An important element in this thesis is the linking of ecological concepts with economic theories and evaluation methods. Since my scientific background is in (landscape)ecology, this thesis should not be interpreted as an attempt to give a "state of the art" of economic and monetary evaluation procedures of the natural environment. The main purpose is to provide the ecological basis for a much needed dialogue between ecologists and economists in order to structurally integrate environmental constraints in economic evaluation and accounting procedures.
To become familiar with economic theory and evaluation methods, I spent much time reading economic literature and personal discussions with economists (notably Dr. Henk Folmer, Dr. Roefie Hueting, Dr. David Pearce, and Dr. Peter Stokoe), and I should like to thank them all here for their help with reviewing the economic sections in this thesis. Of course, if any errors did remain in the text this is my sole responsibility.

During the last stages of finalising this thesis, this dialogue was deepened further in the discussions with my promotors Claus Stortenbeker (emeritus Professor in Nature Conservation) and Henk Folmer (Professor in economics). Although they were not always easy, I enjoyed these "sessions" very much and hope our talks may serve as an example of the constructive dialogue between economists and ecologists referred to above.
I also hope my thesis can help to stimulate the general debate on how to structurally incorporate ecological information in planning, management and decision-making in order to achieve a more sustainable relationship between human society and the natural environment.

Acknowledgments

This thesis presents and discusses the results of research carried out over a period of about 10 years (1982-1992), and there are many people I would like to thank for their help and support in many different ways. Since a separate acknowledgment section is included in part A of this thesis (which is reprinted below), I do not mention them all here again, with the exception of my wife and children who, after the publication of the book had to endure another 2 years with periods in which I was more or less occupied with finalising this thesis.
Finally, a word of thanks and appreciation to the various organisations who provided financial support for the realisation of this thesis. The grants received for the research for part A are acknowledged in the preface to that section. Since the publication of the book "Functions of Nature" in 1992, additional subsidies were received from the Ministry of Agriculture, Nature management and Fishery (LNV), the Ministry of Housing, Physical Planning and Environment (VROM), and WWF-Netherlands, which I herewith gratefully acknowledge.

Acknowledgments (reprinted from de Groot, 1992)

I am greatly indebted to HRH Prince Bernhard of the Netherlands for writing the foreword to this book, and to Lady Philippa Scott for giving her permission to use the drawing of her late husband on the cover.

This book is largely based on a research project which started early in 1982 when I approached Prof.dr. Claus Stortenbeker (then Head of the Nature Conservation Department of the Agricultural University Wageningen) with the idea of developing a methodology for assessing the full value of nature to man. Now, almost 10 years later, I am very pleased to be able to thank him for endorsing my idea in the early stages of the project, and for his continuous support and many helpful suggestions throughout the entire research period.
During my research, the Nature Conservation Department kindly provided office space and many "goods and services", and the hospitality of the members of the Department is greatly appreciated. In particular, I wish to thank the (former) members of the secretariat (Mrs. Gerda Bruinsma, Marijke Kuipers and Arja v.d. Voorde) for their assistance and the cheerful way in which they coped with my irregular presence.

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Being an ecologist with only limited knowledge of the complexity of economic theories, I am very grateful to Dr. Henk Folmer (Dept. of General Economics, Agricultural University Wageningen), Dr. Roefie Hueting (Central Bureau of Statistics, the Netherlands), Dr. David Pearce (Dept. of Economics, Univ. College London, U.K.), and Dr. Peter Stokoe (School for Resource and Environment Studies, Dalhousie Univ., Canada) for their help with the economics, in particular chapters 3 and 5. I owe special thanks to Dr. Hueting who invested much time and energy in reviewing sections of the book. My ignorance in his field of expertise may at times have driven him to despair. Yet, I hope that our discussions on the links between ecology and economics have been useful to him and the others too, and that they may serve as a model of a constructive dialogue between ecologists and economists, the need for which is emphasised in several chapters of this book. If, in spite of our mutual efforts, some errors do remain in the final tekst, this is my sole responsibility.

I am also grateful to a great number of people who shared their ideas and took the time to comment on earlier drafts of (parts of) this book, and other manuscripts produced in the course of the research carried out for this book. I thank them all and should like to mention a few people who made a special effort and whose comments in one way or another contributed directly to the final contents of this book: Prof. John Cartwright (Canada), Mr. Nick Coppin (UK), Dr. Raymond Cote (Canada), Dr. Norbert Dankers (Netherlands), Dr. J. van Donselaar (Netherlands), Mr. Christopher Elliott (Switzerland), Dr. Carl Folke (Sweden), Dr. Barry Goldsmith (UK), Prof. Anil K. Gupta (India), Prof. Brian Hackett (UK), Ms Jill Hanna (UK), Prof. Charles Howe (USA), Dr. Ileana Ionescu-Sisesti (Rumania), Dr. Sophie Jakowska (Dominican Republic), Mr. Greame Kelleher (Australia), Prof.dr. D.J. Kuenen (Netherlands), Mr. Ad Littel (Netherlands), Dr. Edward W. Manning (Canada), Dr. Stephen McGaughy (USA), Dr. Charles Munn (Canada), Dr. Marjory Oldfield (USA), Prof.dr. J.B.Opschoor (Netherlands), Dr. Armando Perez (USA), Prof. David Pimentel (USA), Dr. Floris van der Ploeg (Netherlands), Dr. Jack Ruitenbeek (UK), Dr. P.H. Selman (UK), Mr. David Simmons (Barbados), Dr. Ronald A. Stanley (USA), Dr. M.S. Swaminathan (Philippines), Dr. John Terborgh (USA), Mr. A.D. Vas Nunes (Netherlands), Prof.Dr. K.H. Voous (Netherlands), and Mr. Bradley Walters (USA).

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In the course of the research and preparations for this book, various presentations on certain aspects of the function-evaluation system were made. The most important ones are included in the references (De Groot, 1986, 1988a, 1998b, 1988d, 1990). I thank the organisations who made my participation in these meetings possible, and I gratefully acknowledge the financial support for my participation which was provided by IUCN-International, the Netherlands National IUCN Committee, the Netherlands Foundation for International Nature Protection, the WWF Indonesia Advisory Committee, the United Nations University (Japan), and several organizing parties.
In addition, the Dutch Ministry for Agriculture, Nature Protection and Fishery, the K.F. Hein Foundation, the Foundation for Sustainable Development, Koninklijke Wessanen N.V., and Mr. F.W. Sijthoff provided funds for the publication and dissemination of the final results. All these donations are greatly appreciated and gratefully acknowledged.

The original idea for this book was conceived during my two-year stay in the Galapagos Islands, Ecuador (August 1978 - July 1980) where I was in the fortunate position to be able to observe the natural wonders of these islands, while at the same time becoming exposed to the problem of how to limit man's presence to the carrying capacity of the natural environment of this unique place. I am indebted to the people who helped me realize this experience and I especially thank Prof.dr. M.F. Mörzer Bruyns, Prof.dr. G.P. Baerends, and Prof.dr. A.M.Vôute for their moral, practical and financial support.

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Finally, there is a large group of people who supported and inspired me in various ways during the past 10 years and thereby, knowingly or unknowingly contributed to the completion of this book. I thank them all, in particular, of course, my parents, my wife (Sonja) and my children (Kira and Arjan) for their patience and understanding during this long time period.

INTRODUCTION

Problem statement and aims of this thesis

In spite of the growing awareness of the many environmental problems that we face today, degradation and pollution of the natural environment by human activities still continues on a large scale. The negative impact of the combined effects of many small- and large-scale land use decisions on the natural environment has become clearly visible and may be illustrated with a long list of environmental hazards and disasters, including desertification, soil erosion, loss of cropland, pollution of air, water and soil, deforestation, habitat destruction and extinction of species and varieties. In order to achieve the conservation and sustainable utilization of nature and natural resources, the "full value" of natural ecosystems, and the wildlife within them, should be better represented in land use planning and decision-making instruments. 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 planners and decision-makers to decide on the best alternative use of "environmental space"[1], including natural areas and the option to conserve these in their natural state.

Current application of evaluation methods in decision-making, such as environmental impact assessment, cost-benefit and cost-effectiveness analysis, inadequately reflect the true environmental and socio-economic value of natural ecosystems and the goods and services they provide. 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 (in the narrow economic sense, such as cultivation, real estate development, etc.). These decisions were often based on incomplete information, and one of the main objectives of this thesis 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.

Structure and outline of this thesis

This thesis consists of two main parts: The basis of this thesis is formed by the book "Functions of Nature" (Part A) which gives a detailed description of the function-evaluation method developed in this thesis, including a checklist and description of 37 environmental functions, a description of socio-economic valuation methods, and a summary of the results of three case studies which

[1] See for example Siebert (1981) and Opschoor (1987) for the definition and use of the concept of "environmental space".

were carried out to test the method in practice. Part B of this thesis deals with a critical discussion of the proposed function-evaluationsystem.[2]

The discussion consists of two methodological chapters on issues related to ecological assessment of environmental functions (chapter B-2) and their socio-economic valuation (B-3). Opportunites and obstacles related to the practical application of the proposed function-evaluation system are discussed in chapter B-4. The various steps in the evaluation-procedure proposed by this thesis can be visualised as follows (a more detailed description of the function-evaluationmethod is given in chapter B-1):

Natural environment -(1)-> environmental functions -(2)-> socio-economic values -(3)-> human needs.

In this "flow diagram", the complexity of the subject matter or study object is subsequently reduced: the almost limitless ecological complexity of natural[3] processes and components (e.g. species and abiotic elements) is reduced to 37 environmental functions (chapter B-2). The importance of these functions to human welfare can roughly be divided into 6 main types of socio-economic values (chapter B-3). These values, in turn, relate to the satisfaction of human needs whereby the preference for the availability of environmental functions is expressed in planning and decision-making procedures (chapter B-4). The various steps in the evaluation procedure, and their relation to the chapters in this thesis, are briefly summarised below.

(1) Translation of natural properties into functions

The ecological assessment (chapters B-2/A-2) is entirely based on the concept of environmental functions which is defined as 'the capacity of natural processes and components to provide goods and services that contribute to human welfare, directly and indirectly' (de Groot, 1987). From this definition, it is clear that this thesis is written from an antropocentric perspective: only those functions are taken into account that contribute to satisfying human needs. However, since man is seen in this thesis as being an integral part of the biosphere, maintenance of environmental quality is considered to be an essential human need. Environmental quality, in turn, is interpreted to include not only "clean" air, water and soil but also maintenance and enhancement of the integrity of natural ecosystems and biodiversity on earth.

In chapter B-1, a checklist of 37 environmental functions, divided into 4 function-groups, is given. With this checklist, it should be possible to describe all benefits of the natural environment to human society in a comprehensive manner. Although the emphasis in this thesis is on those functions which are provided by natural ecosystems (i.e. wild plants and animals), the approach can

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2 To avoid confusion when referring to a given chapter in this thesis, chapter-numbers are preceded by an A (for the book) or B (the discussion)

3 The term nature (or natural environment) is used in this thesis 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.

also be applied to assess and evaluate the environmental functions of semi-natural or cultivated landscapes.

Several issues concerning ecological assessment of environmental functions are discussed in chapter B-2, including the relation between functions and environmental characteristics, the problem of scale and classification of environmental functions, the ranking order and completeness of the function list, and the problem of determining sustainable use levels of environmental functions and competition between function use.

(2) Socio-economic valuation of environmental functions

Once environmental functions have been identified and their (sustainable) use level have been estimated, the next step is to assess their importance to human society (chapters B-3/A-3). The importance (or use) of any good or service, either man-made or natural, can be derived from a large number of values attached to them by man. These values not only relate to the direct use of natural resources to the economic production process, but also to less tangible values such as the preference for a safe future (bequest value) and intrinsic values that many people attach to nature and wildlife. In chapter B-3.1, a brief discussion is devoted to these values and their relation to the various function-categories.

A further step in the evaluation procedure is represented by attempts to measure human preferences for a given function by quantifying these values in monetary terms (B-3.2). For some functions and types of values this is relatively simple and can be directly related to market prices. For other functions, more or less complicated shadow-pricing techniques are necessary to arrive at a monetary value. Since monetary valuation of environmental functions is a difficult and somewhat controversial procedure, an important part of the discussion in this section is devoted to two questions: (a) *should* nature be quantified in economic/monetary terms (on benefits, drawbacks and ethical considerations) and (b) *can* nature be quantified in monetary terms. Chapter B-3 closes with a discussion of two more technical problems namely the issues of double-counting (B-3.3) and discounting (B-3.4).

(3) Application of function-evaluation in planning and decision-making

The last part of this thesis (B-4) is devoted to a discussion of the more general application possibilities of function-evaluation as a tool in environmental planning, management and decision-making. Some main issues thereby are:

- the use of function evaluation in planning instruments such as carrying capacity studies and environmental impact assessment. Economic and monetary information on environmental functions provides important information which gives nature a more correct "weight" in decision-making instruments and project evaluation techniques such as cost-benefit analysis and multi-criteria analysis (section B-4.1);
- the use of environmental functions as a unifying concept for ecology and economics (section B-4.2). It is argued that the function-concept can provide a "bridge" between ecology and economics since environmental functions (goods and services) by definition contribute to satisfying human needs based on

maintenance of the natural resource base. It can therefore be of use to various aspects in the developing field of "ecological or environmental economics", including ecological pricing and taxes, and adjustment of national accounting procedures.
- information on environmental functions can also prove useful for the development of legal instruments to implement the "polluter-pays-principle" (section B-4.3) and general environmental education purposes (B-4.4).
- the last section (B-4.5) discusses possibilities to use the function-concept for measuring progress towards achieving "sustainable development". The availability of environmental functions could serve as common indicator for measuring the compatibility between human activities and environmental constraints.

Part B

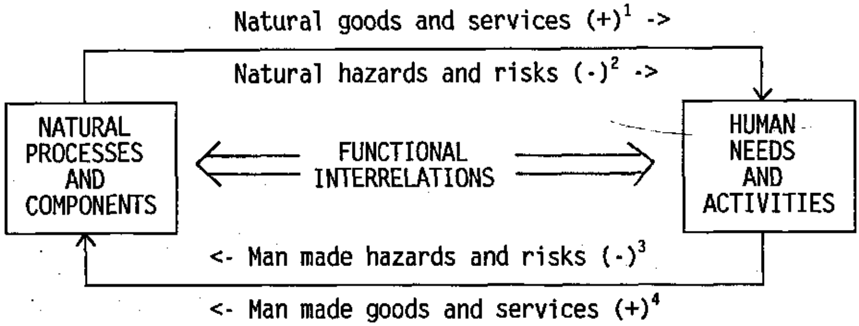
EVALUATION OF ENVIRONMENTAL FUNCTIONS:

A CRITICAL DISCUSSION

B-1 FUNCTION-EVALUATION: THE METHOD AND CONCEPTS USED IN THIS THESIS (summary)

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 was used (see Figure B1-1).

Figure B1-1. Functional interactions between man and nature



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).

The most relevant functional interrelations between man and the natural environment (the central arrow in figure B1-1) 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* makes an analysis 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.).
This thesis only deals with an elaboration 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 (chapter B-4). Environmental Risk Assessment is not explicitly dealt with, although over- or non-sustainable use of environmental functions often leads to environmental hazards and risks. When appropriate, reference is made to this potential extension of the function-approach.

In this thesis, 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)"* (de Groot, 1987).
Several terms in this definition need further explanation:
- *"natural processes and components"* refer to the biotic and abiotic characteristics of the natural environment, which can be divided into several elements or sub-systems like bedrock, atmosphere and climate, relief, water, soil, vegetation, flora and fauna, and the many interactions within and between these sub-systems, such as biogeochemical cycles and life community interactions (e.g. food-chains). Natural processes and components can be grouped into spatial units such as ecosystems or landscapes, which form the main subject-matter of this thesis (see chapter B-2.1. for further discussion);
- the use of the terms *"goods and services"* indicates that the concept of environmental functions includes not only the harvestable goods (i.e. natural resources in the traditional, more narrow sense) but also refers to other benefits of natural processes (i.e. the services), such as the capacity to recycle certain types of human waste;
- the *"capacity"* of natural ecosystems to provide goods and services depends on the degree to which these functions can be utilised by man in a sustainable manner. The level of sustainable use should be determined for each function individually (e.g. the maximum sustainable harvest of biological resources) as well as for combinations of function use (see chapter B-2.7 for further discussion);
- *"human needs"*, finally, should be defined in the broadest sense possible, i.e. not limited to material prosperity provided by marketable goods and services, but also including physical and mental health and the prospect of a safe future.

To develop a complete checklist of environmental functions, and to investigate which environmental characteristics can be used as parameters to assess the capacity of natural ecosystems to provide environmental functions, several case-studies were carried out on various ecosystem complexes. A summary of the results of three case studies, and a description of 65 environmental parameters, is given in part A of this thesis, 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, including 4.300 km2 of coastal and marine protected area.

In total, 37 separate functions are distinguished in this thesis (Fig. B1-2) which are grouped into four main function categories: (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. Other categories and ranking-orders are possible, and a discussion is devoted to this issue in chapters B-2.4 and B-2.5.

Fig. B1-2 **FUNCTIONS OF THE NATURAL ENVIRONMENT**

1) **REGULATION FUNCTIONS** *(maintenance of essential ecological processes)*

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

2) **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

3) **PRODUCTION FUNCTIONS** *(providing natural resources)*

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

4) **INFORMATION FUNCTIONS** *(providing opportunites for cognitive development)*

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

Some methodological aspects of assessing and evaluating the capacity of nature to provide environmental functions are discussed in further detail in chapters B-2 and B-3. The terms "assessment" and "evaluation" are often used and interpreted differently, depending on the subject and aim of the assessment or evaluation. To avoid confusion, a brief description of these terms is given here:

- *assessments* are usually restricted to making an inventory of the ecological characteristics of a certain ecosystem or natural area in a (relatively) objective manner. Such assessments may be carried out under different names such as resource-mapping and landscape ecological studies or inventarisations. A well-known extension is represented by the term "environmental impact assessment", which aims to describe the possible effects of human activities on environmental characteristics;
- *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.

The term "assessment" is used in the title of chapter B-2 because this first part of the proposed function-evaluation method aims to give an objective checklist of environmental functions based on environmental parameters that describe the capacity of a given area or ecosystem to provide these functions. It is only in the second phase of the evaluation procedure (chapter B-3) that value judgements are made with respect to the importance of these functions to human society.
For both assessments and evaluations the use of some kind of "value-standard" or measuring unit is necessary. In this thesis, the word "*parameter*" is used for assessments 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")[4]. The word "*criterion*" is used in combination with evaluations since it is defined as a "principle or standard that a thing is judged by".

Finally, a word about the use of the terms "ecology" and "environment":
- 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 inter-relations 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".

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[4] A more extensive glossary, with references to sources of certain definitions, is included in part A of this thesis.

- the term "*environment*" cannot stand on its own and should always be used in combination with a given object (e.g. human environment), or condition (e.g. natural versus cultural environment). The point of reference in this book is the human environment which can be defined as a set of "natural, social and cultural values which exist in a given place and point in time that influences the material and psychological life of man". 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.

B-2. ECOLOGICAL ASSESSMENT OF ENVIRONMENTAL FUNCTIONS

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, 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, (re)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 order to better incorporate the importance of natural ecosystems in the planning and decision-making process, information about their many functions and benefits is essential and in part A of this thesis (chapter A-2), 37 environmental functions, and many more sub-functions, have been described and tested on a number of case studies (chapter A-4).
In the following sections (B2.1 - B2.7) several methodological aspects related to the ecological assessment of environmental functions are discussed in more detail.

B-2.1 Subject matter: applicability to natural and semi-natural ecosystems

As was explained in the introduction, the emphasis of this thesis is on the evaluation of functions of natural and semi-natural ecosystems. This raises the question as to what is understood by "natural ecosystems". A very short definition is given by IUCN, UNEP and WWF (1991) who state that "a natural ecosystem is an ecosystem where since the industrial revolution (about 1750) human impact has been no greater than that of any other native species, and has not affected the ecosystem's structure". Considering man's still increasing influence on this planet, it can be questioned wether true natural ecosystems in the sense of this definition still exist. At least in W.Europe the landscape is dominated by managed ecosystems, and air pollution and groundwater manipulation have a strong impact on the species composition of most of the remaining natural ecosystems and landscapes in this part of the world. The term

"semi-natural" is therefore used to indicate that the evaluation-system can also be used to assess the functions of those ecosystems and landscapes which are subject to relatively strong human management activities, such as many forests and heather-fields, but where maintenance (or enhancement) of biological diversity are important management objectives.
In fact, the checklist of environmental functions can, in theory, also be applied to assess the ecological and socio-economic importance of more man-dominated systems such as cultivated areas or even cities. Only in that case the list of functions will become shorter since some functions are used to their maximum potential (and sometimes over-used) at the expense of most other functions. Thus, the function performance not only depends on the ecological characteristics of a given area, but also on the management status and objectives of the area. For example, the main purpose of scientific or strict nature reserves is the safeguarding of the natural processes and biodiversity which will leave little or no room for the use of other functions (such as recreation and harvesting of resources). National Parks, on the other hand, were created with as main objective to provide opportunites for recreative experiences in "natural" surroundings. This also leaves more room for other activities such as harvesting, even hunting, small-scale cultivation like (nomadic) pasturing or aquaculture, etc. In more man-dominated systems, like cultivated areas the productivity of one crop-species is maximised at the expense of most other functions the area could provide under a different management regime.
In physical planning, choices will have to be made concerning the most desirable combination of land use alternatives. For example, wether management should aim at extensive cultivation in order to maintain some conservation values and recreational opportunities or wether it is better to make a strict spatial separation between protected areas and (intensive) cultivation. For balanced decision-making, which takes account of both nature conservation objectives and cultivation needs, it is therefore important to be aware of all the actual and potential functions of the planning area in question and of the relation between various management regimes and the function performance.
These last remarks touch upon the need to distinguish between actual and potential function-fulfillment and the problem of competition between function use (see sections B-2.6 and B-2.7 for further discussion).

B-2.2 Relation between environmental characteristics and functions

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). 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, in this thesis it has been attempted to develop a general checklist of parameters that may be used to assess the contribution of a given ecosystem to certain environmental functions. Appendix 1 (of part A) lists 65 environmental parameters, which is still a strong simplification of the true complexity of the natural processes and components on earth. For each of the four main function categories Appendix A-1 gives a separate matrix, based on the format shown in Fig. B2-1, to show the relation between environmental functions and parameters.

A 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. For example, the structure of the vegetation (height, roughness) influences not only many regulation functions such as the (local) climate and energy balance, prevention of runoff and erosion, the watercatchment function and groundwater recharge, but also the aesthetic quality of the landscape and thereby the attractiveness for recreation.

On the other hand, one function is usually influenced by more than one parameter. For example, the watercatchment and groundwater recharge function not only depends on vegetation characteristics (such as structure and litter-production), but also on the root-system of the plant communities, the texture and depth of the soil and the contents of organic matter in the soil as well as the topography and bedrock characteristics.

Fig. B2-1 Relation between environmental characteristics and functions
(schematised version)*

Environmental characteristics (parameters)#	Environmental functions			
	Regulation functions	Carrier functions	Production functions	Information functions
- Bedrock properties				
- Air quality				
- Relief				
- Water quality				
- Soil condition				
- Vegetation prop.				
- Standing biomass				
- Species composition				
- Food-chain interact.				
- Uniqueness/rarity				
- etc.				

*) In Appendix A-1, the relation between the 37 functions and these environmental characteristics is described in in detail in four separate matrices.
#) Appendix 1 (of part A) lists 65 environmental parameters.

This interrelatedness of functions and parameters clearly illustrates why changes in a given environmental factor (like vegetation structure or air quality) usually affect several functions which, in turn, may cause changes in other environmental characteristics leading to a chain of reactions and sometimes the degradation of the entire system. This underlines the importance of a "holistic" approach to understanding the functioning of ecosystems and the need to increase research efforts in the field of systems ecology and other related disciplines.

Apart from the scientific difficulty to identify the most important relations between environmental characteristics and functions, there is also a time-constraint. Planners and decision-makers often do not have the time to wait for the results of ecological studies which may require much time, depending on the complexity of the situation, and data to quantify the most essential variables should be collected within a reasonable time-period. A choice must therefore be made, and selecting the appropriate parameters and criteria for assessing and evaluating the function-performance of a given ecosystem or (natural) area is essential to the practical application of the proposed function-evaluation system.
From the case studies presented in part A, and various authors who used the function-approach in actual planning situations (see section B4.1), it proved to be possible to collect qualitative and quantitative information on the most important functions and environmental variables within a reasonable time period (3-6 months). Even in cases where complete quantification of functions and values was not possible the checklist of functions and associated hazards (in case of over-use) gives a comprehensive overview of the many trade-offs involved. A first attempt to link environmental functions with environmental parameters (characteristics) is presented in this thesis but this is one of the topics where further research is needed.

B-2.3 Environmental functions and the problems of scale

Another important problem 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 or ecosystem to such a function. This is especially the case for certain regulation functions which operate on a biospheric scale. Coastal wetlands, for example influence major biogeochemical cycles which regulate the chemical composition of the atmosphere which, in turn, may influence the energy-balance and associated climate processes in large areas.
The role of marine algae in the sulphur-cycle is a good example. 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 organic matter. Here one finds certain algal seaweeds wich are extremely efficient in extracting sulphur from sulphate ions and converting it to dimethyl-sulphide. 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. In addition, dimethyl-sulphide is also one of the natural greenhouse-gases and even has a direct influence on local rainfall in coastal areas (see part A chapters 2.1.4 and 2.1.5).
For such "diffuse" or "global" functions, it is difficult to determine the contribution of individual ecosystems and, even if quantification is possible, the relative importance of a given site is often so small that it is considered

insignificant in the decision-making process. However, the combined results of many small-scale land use changes (like draining parts of wetlands, cutting patches of forests, the "regulation" of rivers and paving over of land) has a significant effect on the capacity of the natural environment to provide these functions. The neglect of these functions has led to environmental hazards such as acid rain, the decline of the ozone-layer and the enhanced greenhouse effect.

Early recognition of these global processes and functions, and the role natural ecosystems play in maintaining these functions, is essential for ensuring the long-term integrity of the biosphere. The existence of these "unquantifiable" regulation functions should therefore always be kept in mind in land use planning and decision-making, not only on a national but also on a regional and even local scale.

Another, more space-dependent problem is the fact that certain environmental functions are not only important for maintaining environmental health "outside" the ecosystem but are also essential to the maintenance of the ecological integrity of the area itself. This is best illustrated with the difference between regulation and production functions. Most of the production functions are resources, such as wood or food, which are harvested and extracted from the ecosystem. As long as the use-level remains within the capacity of the system to regenerate the extracted resource, the ecosystem can provide these resources indefinitely. On the other hand, many regulation functions not only contribute to the maintenance of environmental quality outside the area (like the prevention of soil erosion by forests on hillslopes) but are also essential to maintain the integrity of the ecosystem itself, such as regulation of biological control mechanisms, the nursery function and maintenance of biological (and genetic) diversity. When assessing the functions of a given ecosystem or natural area, this difference between "internal" and "external" function-fulfillment must be taken into account when assessing the level of the carrying capacity which is to be determined for each function separately, as well as for the system as a whole (see section B-2.6 for a further discussion on sustainable use of environmental functions).

B-2.4 Classification and ranking-order of environmental functions

In this thesis, four main categories of environmental functions are distinguished (see fig. B1-2). In part A of this thesis, a review is given of other classifications used in literature and as an example, Fig. B2-2, gives three classifications from different perspectives (economic, ecological and from a planning perspective), whereby the presentation in table-form is from the author. After extensive literature research and several pilot-studies in case study situations, it was decided to use the four function-categories listed under the "planning perspective" as the basis for the function-classification in this thesis, whereby some functions were placed in another category (notably the agricultural production and waste absorption functions), and some function categories are worked out in greater detail (especially the production and regulation functions).

The number of function-categories found in literature varies roughly between 4 and 7, whereby it is interesting to note that ecologists tend to distinguish more function-categories while people involved in policy-making tend to reduce them to fewer categories. Bouwhuis (1993), for example (who used the function approach for a cost-benefit analysis of three development projects), suggests to combine the carrier and production functions into one group of "user-functions" which are also called "economic functions", as opposed to the regulation or "ecological" functions. On the other hand, Bouma (1972) suggests to distinguish the reserve-function and "Natur-an-sich" function as separate categories. From figure B2-2 it is also interesting to note that the ranking order of the various listings used in literature all start with production functions. This may be a coincidence but there may also be an implicit value-judgement involved, which is discussed in more detail later in this section. It would lead too far to present all arguments in favour and against the various ways in which environmental functions can be "categorised", also because this is an ongoing debate which may never come to a final conclusion. From the case studies carried out for this thesis the division of 37 functions over 4 main categories was found to be most comprehensive and consistant and is therefore used here.

Fig. B2-2. Classification of environmental functions, some examples

Siebert, 1987 ["economic perspective"]	Bouma, 1972 ["ecological perspective"]	vd.Maarel & Dauvelier, 1978 ["planning perspective"]
Public Cosumption goods - air to breathe - amenity of landscape - recreation	**Production functions** - food - raw materials - hydro-power - new elements	**Production functions** - abiotic (cosmic energy, (water, minerals, etc) - biotic (biomass) - agricult. production
Supplier of resources - water - sun - mineral - oxygen - etc.	**Wellbeing-functions** - education - health - recreation - aesthetic pleasure - art	**Carrier functions** - urban/industr. activity - rural act. (incl. water-(control & military act.) - absorption of waste - recreational facilities
Receptor of wastes - CO2 - SO2 - etc.	**Scientific function** (geology, biology, medicine, psychology, physical geogr., etc)	**Information functions** - orientation - research - education - indicator (signal) - reservoir
Location of space - industry - residential loc. - agricultural land - infrastructure	**Ecological functions** - provider of genes - producer of oxygen - recycl. of org. mat. - etc. **Reserve-functions** (unknown ecol.relat.) **"Natur-an-sich" function**	**Regulation functions** - purification (e.g. dust, biol. matter) - stabilization (e.g. climate regulation, water retention)

In addition to deciding on the division of environmental functions in several main categories, a choice must be made concerning the order in which they are placed. When contemplating where to place each function-category, one is faced with the conscious or sub-conscious expression of value-judgements. Although the ranking-order should not be taken too strict, as is explained at the end of this section, there is a certain logic in the order used in this thesis which is based on an "environmental perspective". From this perspective, those functions which are important for the maintenance of essential ecological processes and environmental quality (= regulation functions) are placed first: without these regulation functions, there would be no biosphere and thus no place for man, and other living beings, to live. In many ways, these regulation functions provide the necessary pre-conditions for all other functions.
With the next category (carrier functions), the environmental requirements are narrowed down further to those functions that relate to the physical requirements of the ecological niche within the biosphere. These differ for specific species groups, but include in any case the physical carrying capacity of the substrate for certain activities, and the spatial needs (minimum critical ecosystem size) of the natural ecosystems which provide them.
The third category (production functions) narrows the environmental requirements down still further to the harvestable goods needed for survival and wellbeing. Production functions depend on the previous two: without biospheric regulation processes, and without the ecosystems which provide them, there are no resources for man (or other species) to harvest.
Finally, the use of information functions only becomes relevant when all other functions (or needs) are fulfilled.

The ranking-order used in this thesis can also be explained by considering the relative importance of each category for (human) survival: without clean air and a protective atmosphere life cannot exist. One can do without shelter and food a little longer although both are quite essential requirements for life too. The last category of information functions is the least directly life-threatening when absent, although quite important for the non-materialistic quality of life.
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 reason for the order used in this thesis is the fact that regulation functions are performed by nature regardless of man's presence and also benefit other species. Clean air, water and soil are necessary preconditons for any living organism, possibly even more so for non-human species since they cannot compensate effects of environmental pollution with medicinal treatment.
Carrier and production functions relate to more species-specific environmental requirements like the physical characteristics of the habitat (ecological niche) and the type of food and other resources needed to survive. While, finally, most information functions are only (or primarily) relevant to the human species because of man's cognitive capacities.
Since human life seems quite impossible in the absence of any one of these function groups, the hierarchy should not be interpreted too strictly. Other

ranking orders and (sub-) divisions are of course possible and, considering the complexity of the subject (the 37 functions listed in figure 1-2 encompass at least 60 separate sub-functions, see section A-2), a completely satisfactory listing and division of functions may never be found.

B-2.5 Completeness of the function-list

To make the proposed evaluation procedure applicable to any planning or decision-making situation where environmental quality is at stake, the list of functions should be as complete as possible. Fig. B1-2 is a first attempt to provide such a complete check-list of functions of the natural environment which may be adjusted once more experience has been acquired with its use in practical planning and decision-making situations. From the reactions received thus far, no indications of incompleteness were received.
A more difficult problem is to decide on the degree of detail needed for each main function. The function "Watershed-protection" (regulation function # 6), for example, can be specified into at least 3 separate "sub-functions": prevention of surface-runoff, regulation of river discharge, and flood-prevention. In part A, the 16 regulation functions alone are divided into at least 45 sub-functions.
In addition, it must be realised that there are probably many sub-functions which are not yet recognised, but which may have considerable (potential) benefits to human society. The production-function "medicinal resources" for example, is still poorly investigated. Only a fraction of potentially useful biochemical substances present in wild plants and animals has been studied while natural selection and evolutionary processes continuously lead to the development of new combinations of genetic material and biochemicals.
Research on the many functions of the natural environment has only just begun and most of the few remaining natural areas on earth contain a vast reservoir of still unknown applications of environmental functions provided by wild plants and animals, with possible future benefits to human society. The present rapid destruction of natural habitats (e.g. primary tropical rain forests and coral reefs), and the extermination of wild species and indigenous people, which depend directly on these natural habitats for their survival, greatly reduces the opportunity to explore and use this reservoir of potential information. This not only deprives present and future generations of potentially beneficial applications of environmental functions but may eventually have serious consequences for the survival and wellbeing of the human species on earth.

B-2.6 Sustainable use-level of environmental functions

An important factor to take into account is that the benefits from environmental functions should be determined for *sustainable use levels*.
When assessing the sustainable use level of environmental functions it is convenient to make a distinction between biotic versus abiotic and renewable versus non-renewable functions (see Fig. B2-3). For renewable functions it is in

principle always possible to determine sustainable use levels, for non-renewable functions this is more difficult. Some considerations concerning the renewability of environmental functions, and how to determine sustainable use levels, are briefly discussed below.

Fig. B2-3 Renewability of environmental goods and services

	Biotic goods and services	Abiotic goods and services
Renewable	Most resources from wild plants and animals (e.g. fish)	Many regulation functions (e.g. recycling of nutrients) and certain energy sources (such as wind and tidal energy)
Non renewable	E.g. genetic material, certain types of tropical timber, fertile topsoil (*	E.g. fossil fuels and minerals and certain carrier functions such as the use of land for permanent human constructions

*) In principle, most biotic goods and services are renewable. However with the extinction of species or even sub-species and varieties, unique genetic material is lost forever. Also certain types of tropical hardwoods grow so slow that renewability is not possible within a reasonable period of time.

(1) *Renewable biotic goods and services*

When assessing the capacity of a natural ecosystem to provide renewable biotic resources, food for example, this should be based on the amount of plants or animals (e.g. fish) that can be harvested without reducing the natural stock below the point where natural reproduction is threatened and/or vital balances in the ecosystem are disturbed. As a general "rule of thumb" a sustainable harvest of biotic resources should remain below 50% of the natural Net Primary Productivity (NPP)[5] of the species or ecosystem involved (Odum, 1989, see also chapter A-2.1.10 for further explanation). Extrapolated to the world-scale this would mean that human use of the natural productivity (in the form of harvesting wild fish, fuelwood, etc.) should not exceed half the global net primary productivity which amounts to about 170 billion ton organic matter (dry weight) per year.[5] This means that, generally speaking, pioneer-ecosystems or those ecosystems with a large external nutrient-input like coastal wetlands or grasslands are able to provide relatively large amounts of biomass (fish, algae, grass) which can be harvested without threatening the integrity of the ecosystem. On the other hand, climax communities like tropical rainforests, provide very little "extra" biomass and sustainable use of the biotic resources from these ecosystems (like wood) can therefore only take place at very small scales.

The carrying capacity for function-use is also reflected by the sensitivity of the

[5] The Net Primary Productivity is the total amount of energy fixed in living organisms, mainly green plants, minus energy loss due to metabolic activities and heat loss over a certain period of time. It is estimated that human use of natural biomass on a global scale already appropriates 40 percent of terrestrial Net Primary Production (Vitousek et al., 1986). Even if this appropriation increased at a constant growth rate of merely 1.7 % per year (= current world population growth), humankind would be using all the products of natural photosynthesis within 54 years.

system for external disturbance. Due to their ecological complexity and many internal regulation mechanisms, climax communities have a relatively high resistance against small-scale disturbances from outside but once they are degraded beyond a certain point (due to over-exploitation of a given function) the regeneration rate is very slow. Pioneer-communities on the other hand have a large natural throughput of energy and nutrients and are therefore more resilient to external disturbances such as extraction of resources and their use as a receptor of human waste.

(2) *Renewable abiotic goods and services*

The carrying capacity for renewable abiotic functions, such as the purification capacity of wetlands for organic waste and nutrients is more difficult to calculate and depends, among others on the degree to which the use leads to (ir)reversible changes to the life communities. Standards should therefore be set concerning the physical, chemical and biological minimum requirements to maintain a healthy ecosystem. For certain ecosystems it may be possible to monitor the health of the ecosystem by means of the presence (or absence) of certain key-(indicator) species.

(3) *Non-renewable goods and services*

Roughly three types of non-renewable resources may be distinguished:

a) Space: for carrier functions, which are defined as the capacity of nature to provide a suitable substrate or medium for certain human activities such as cultivation, recreational parks, protected areas, and infrastructure (roads, etc.), the main limiting factor is space. Since space, depending on the type of use (function) can only be occupied by one of these activities at the same time, and is usually allocated for that purpose for long time-periods, space should be considered a non-renewable resource and certain minimum-standards will have to be set for the division of space for the various uses. In the case of natural ecosystems, there are certain physical limits the minimum size of the area which is needed to maintain the integrity of a given ecosystem (i.e the "minimum critical ecosystem size", see appendix A-I.9.4). On a world scale it has been argued that at least 10% but preferably 30% of the total surface area should remain in a (more or less) natural state.

b) Fossil fuels and minerals. The regeneration of these abiotic resources, in so far they "regenerate" at all, is so slow that they are, for all practical purposes, non-renewable. Since part of the rationale behind the concept of sustainable use relates to the responsibility we feel towards future generations, the question with these non-renewable resources is how much of the stock should be left over for future generations. As with the restriction placed on natural space (see a), one could consider to reserve, for example, between 10 and 30% of the total (original) world stock of each resource as a type of safety-deposit for future generations. The problem is, of course, that there will be many more future generations to come while this minimum reserve-level will be reached for most non-renewable resources sometime in the next century. This would imply that once the stock has been reduced to, say, 20% there would be a total ban on its use.

Another approach could be to set a limit on the use-level in relation to the remaining stock, e.g. each year not more than, for example, 5% of the remaining stock may be utilised. This would automatically lead to declining use levels and would, in theory, always leave some reserve for the next year (an next generation). Decisions on use or non-use also depend on many other considerations such as the environmental and societal consequences of use as well as non-use, what the possibilities are for substitutes, time preferences, etc. (see also chapter B3.4 for a discussion of this last issue).

c) Non-renewable biotic resources. Although biotic resources are, in principle, always renewable, certain biotic resources like genetic material, certain types of tropical hardwood and fertile topsoil, regenerate so slow that they should be considered non-renewable. Human use of these resources should be done with great care and it is therefore quite astonishing that especially these fragile resources are utilised by man with very crude methods leading to the loss of millions of square kilometers of (tropical) forest and topsoil each year, and the disappearance of thousands of species and sub-species (and thereby the loss of unique genetic material).

From the above, it follows that sustainable use levels are different for each ecosystem and for each type of function or combination of function-use (see also B-2.7 on competition between function use).
When determining sustainable use levels it should also be realised that the current use of the environmental functions may not be equal to the potential use. Certain environmental functions are not utilised at all or below their maximum sustainable use level, either because of lack of infrastucture (such as the recreation-function for eco-tourism in some areas), or because the functions are not recognised. Only some functions of tropical forests, for example, are (consiously) used, such as extraction of wood and some forest products. Their role in many regulation functions is still poorly understood and many other functions, such as their use for providing genetic material and medicinal resources have only recently become subject of more detailed investigation.
To safeguard the availability of these potential function uses, the diversity of the remaining ecosystems and species on earth should (at least) be maintained and preferably enhanced. To remain on the safe side, ecologist (like Odum, 1989) suggest that *one third* of the original surface area of the remaining natural ecosystems should be kept in a natural state to maintain essential life-support services.

B-2.7 Interdependency of environmental functions

When assessing the sustainable use level for environmental functions of a particular area or ecosystem, as was discussed in section B-2.6, it must be realized that many environmental functions are interlinked, which is also reflected by the fact that most environmental functions are influenced by many environmental characteristics, and vice verse (see chapter B-2.2 and Appendix A-I). Each function is the result of the interactions between the dynamic and evolving processes and components 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 integrity of the entire ecosystem which provides them, based on the concept of "minimum critical ecosystems size" (see Appendix A-I.9.4).

When the maximum sustainable use level of separate functions in a geographically limited area is to be determined, the interdependency of environmental functions and thereby the (potential) competition between function-use is an important aspect which should be given due consideration in the assessment procedure. A choice will have to be made to what extent the use of environmental functions can be combined or wether it is better to separate the function-use in time and/or space. A well-known example is the discussion on the (in)compatibility of agriculture, nature conservation and recreation. When cultivation is carried out on a limited ("extensive") scale, these agricultural landscapes may also have recreational and conservation value. On the other hand, the output of agricultual products is much lower than the productivity on intensively cultivated areas and therefore much more space is needed which may cause the loss of important conservation values.

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 continued integrity of the full range of functions of the area in question. When all functions and values are taken into account properly, it will often become clear that sustainable use of a combination of functions provides more economic benefits, especially in the long run, than non-sustainable use of only a few functions. For example, 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 (see chapter A-4.1 for further discussion).

B-3. SOCIO-ECONOMIC VALUATION OF ENVIRONMENTAL FUNCTIONS

Introduction

Although the general awareness of the many benefits of natural ecosystems and ecological processes is increasing, concrete information about their full economic value is still scarce. Consequently, natural goods and services are systematically undervalued in economic planning and decision making, which is an important cause for many environmental problems[6] To better integrate environmental considerations in planning and decision-making, information on the socio-economic importance and monetary value of environmental functions (goods and services) is therefore essential.
In part A of this thesis, an overview is given of the various methods available to assign socio-economic values to environmental functions, illustrated with examples from three case studies. For some environmental functions an attempt was undertaken to translate their socio-economic importance into monetary values.

It is not the intention to provide an extensive "state-of-the-art" on economic valuation-methods in this thesis, partly because of the scientific background of the author (which is in ecology), partly because this research area is still very much in development. This thesis mainly aims to provide the ecological basis needed for the incorporation of environmental information in economic planning and decision-making. It is the task of economists to find ways to assess the economic value of these functions and to design methods to structurally integrate this information in economic planning and accounting procedures.
On the following pages, a discussion is devoted to various aspects of economic valuation of environmental functions, including the types of socio-economic values which can be attributed to nature (B-3.1), some objections against, and benefits of monetary valuation (B-3.2), the issue of Total Economic Value and the problem of double counting (B-3.3), and the capitalisation of the economic value of natural ecosystems, including the issue of discounting (B-3.4)

B-3.1 Types of socio-economic values attributed to nature

Over the years, a variety of methods have been developed for assigning values to nature and natural resources and there are many titles on this subject. A brief discussion of the various types of socio-economic values which can be attributed to environmental functions is given below. A more detailed description, including a more complete listing of references, is given in chapter A-2.1).

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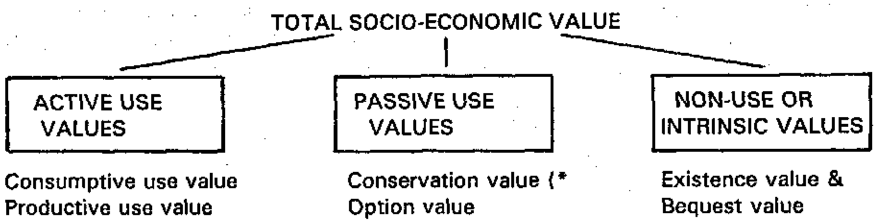
[6] Siebert (1987) explains the undervaluation of the [natural] environment with ownership-problems. In the past (and to some extent still today) the environment is regarded as a common property, both with respect to its (free) use as a receptor of human pollutants and the free use of natural resources such as water and fish. The consequence of a zero price of environmental use is that the prices of goods which are produced with a high pollution intensity are too low. This, in turn, leads to overproduction of ecologically harmful products and overuse of natural resources. The consequence is environmental degradation.

Basically, three types of values can be distinguished: (a) actual or direct use values, (b) potential or indirect use values, and (c) non-use or intrinsic values (see Fig. B3.1).

Fig. B3-1 Total socio-economic value of environmental functions



*) The conservation value is often placed under the category "non-use values" which is not done here. For explanation, see text on this and following pages.

As with the classification of environmental functions (see chapter B-2.4), the division of values given in figure B3-1, should not be interpreted too strictly. Especially the distinction between "use" and "non-use" values, as proposed by, among others, Munasinghe (1992), is somewhat misleading because the so-called "non-use" or intrinsic value of nature also provides a certain feeling of satisfaction to the person attaching this value to nature. Also, the conservation value is often placed under the category "non-use values" which is even more misleading since the conservation value is mainly related to regulation functions (e.g. maintenance of biodiversity and a healthy environment) which have very concrete benefits (use) to man.
Since the various types of values that can be attached to nature are, to some extent, interpreted and classified differently by different authors, they are briefly discussed below to describe how they are used in this thesis.

Consumptive use value
The consumptive use value of environmental functions relates to the use of natural products which are harvested directly from the natural ecosystem. This value therefore mainly relates to natural resources in the narrow sense, which are included in the category of production functions. Especially in "less developed" countries, many natural products are consumed directly without passing through a market and therefore these consumptive use values seldom appear in their national income accounts although their economic value is often considerable. In Sarawak (Malaysia), for example, 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). Somehow, the economic value of natural goods and services that are not (yet) tradable at a "real" market should be included in national income accounts (in section B-4.2.2 a more detailed discussion is devoted to the need for adjusting national accounting procedures).

Productive use value
The most important part of the traditional economic value of a given good or service is probably still its contribution to the (economic) production process which consists of many different sectors, such as agriculture, energy conversion, transportation, and industry. 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 these activities (the carrier functions). Yet, also many regulation and information functions contribute to the economic production process but this is usually not recognized. Ideally, the dependence of a given production process or economic sector on environmental functions should be calculated. The (market) value of the end-product (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.

Conservation value
Many environmental functions do not provide direct economic benefits (in the traditional sense) but are nevertheless quite essential to human welfare. The conservation value, as it is used in this thesis, applies to the importance of natural (and semi-natural) ecosystems to maintaining environmental 'health'. This value is therefore mainly related to the services (as opposed to the goods) provided by nature such as the protective function of forests on hillslopes, maintenance of clean air and many other regulation functions.
The functions which together determine the conservation 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 straightforward, while measuring the value of the maintenance of the global carbon cycle would be much more difficult. Yet, it is essential to somehow quantify the economic benefits of these non-marketable goods and services because they will otherwise continue to be undervalued in the planning and decision-making process.

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 or serendipity value (Pearsall, 1984, Myers, 1984). Since bequest value is mainly related to the responsibility we feel towards future generations it is discussed together with the existence value (see further).
Sometimes also the term "quasi-option value" is used to indicate that nature may still hold unknown benefits and should therefore be conserved until more

information is available (Pearce & Markandya, 1989; Johansson, 1990). 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.

Existence and bequest value
The existence value relates to the intangible, intrinsic and ethical values attributed to nature, 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": even if we do not benefit ourselves directly, we do have a responsibility to our children and grand-children to conserve natural ecosystems and enhance the evolution of biological diversity as much as possible (related to quasi-option value, see above).

Once concensus is reached on what type of socio-economic values can be attributed to nature, ways must be found to measure the importance of environmental functions and values to human society. The way this importance is measured will be different for the main types of functions and values. For example, the conservation value of regulation functions (e.g. watershed protection) is described and quantified in different ways than the consumptive and productive use value of natural resources (fish, medicins) or the intrinsic value attached to wild plants and animals.
The multiplicity of ways and means for measuring 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 can hardly be compared to the value of the forest to the local inhabitants as a provider of their daily living-needs, while the value of the forest for tourism or watershed protection is measured in yet another way.
In order to find a generally applicable yardstick for measuring human preferences for the availability of environmental functions, economists suggest to use money as a common indicator. For most of the values listed in figure B3-1. it is indeed possible to arrive at a monetary indication of their (relative) importance to man. The various methods for monetary valuation of environmental functions are presented in chapter A-3.2, while arguments in favour and against monetary valuation are discussed in more detail in chapter B-3.2.

B-3.2 Monetary valuation of environmental functions and values

For several types of functions and values, notably those which are of direct economic importance, it is possible to calculate monetary values. Figure B3-2 shows some of the methods available to calculate monetary values for environmental goods and services which broadly fall into two categories: market pricing and shadow pricing (or direct and indirect valuation methods). A description of these methods, and a review of relevant literature is given in chapter A-3.

Fig. B3-2 shows that for all types of environmental values it is, in principle, possible to arrive at a monetary indication of human preferences for the (continued) availability and maintenance of the related environmental functions. Since assessing monetary values of environmental functions is a rather complicated, and somewhat controversial procedure, some objections against monetary valuation, as well as the benefits and some practical problems are discussed in more detail in the following two sub-sections.

Fig. B3-2. Monetary valuation of environmental values: types and methods

Types of socio-economic values	Monetary valuation methods (1					
	Market Price (2				Shadow Price (3	
	Direct	Indirect			CVM	Hedonic Pricing
	tradable goods & services	Costs of environmental damage (4			(= Contingent Valuation Methods)	e.g. - Property pr. - Travel cost
		Cost of function loss	Mitigation costs	Substitution costs		
Consumptive use value	(x)5	x		x	x	x
Productive use value	x	x	x	x	x	x
Conservation value		x	x	x	x	x
Option value					x	
Existence value					(x)6	

1) The crosses in the boxes are a rough indication of the methods that can be used to measure the monetary expression of the preference for (importance of) a certain environmental value.
2) The distinction between market and shadow pricing, and direct and indirect valuation methods is still subject to much debate (e.g. Navrud, 1992). In this thesis, indirect market values relate to the costs (actual or potential) of environmental damage, which can be assessed by measuring the costs of function loss (e.g. erosion due to deforestation), the costs incurred by repair-measures or the cost of substitutes. Direct market values relate to goods and services that are tradable at the ("conventional") market place.
3) Shadow pricing methods measure a certain part of the willingness to pay (WTP) for the maintenance of a given environmenal function, or the willingness to accept (WTA) compensation for the loss of a given function. Hedonic pricing methods measure only user values, Contingent Valuation Methods measure both user and non-user values.
4) Or the benefits of prevented damage.
5) Environmental goods and services which are directly "consumed" usually do not have a formal market price (this is especially the case in less-developed countries). Yet, their value can be made visible through surrogate market-pricing or other techniques.
6) The existence value could be quantified by CVM techniques, but it is argued that especially for this type of value it may be better not to attempt to assign monetary values (see B-3.2.1 for further discussion)

B-3.2.1 *Some objections against, and problems involved in monetary valuation of natural goods and services*

There are several dillema's involved 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. 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. As Aldo Leopold 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 "all'mighty" dollar" (Leopold, 1949).

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 "price-less" 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.
Figure B3-2 also shows that it is possible to arrive at a monetary indication of human preferences for all of these values. The problem is that the outcomes of the various valuation methods produce monetary values which are more or less "hard". For example, measurement of the monetary value of natural resources (like tropical hardwood) on the market place is relatively straightforeward, although incomplete (see box B3-1), but measuring the costs of environmental damage caused by deforestation is already more difficult while assessing the loss of wild species or living space for indigenous people in monetary terms is a daunting exercise.

Box B3-1. Incompleteness of the market price for natural goods

The market prices which exist for most products provided by nature are incomplete. Tropical hardwoods, for example, 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 (e.g. pollination). 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 scarcity would soon raise prices to astronomic levels because the factories would fall apart and production would stop. If we find it normal that the maintenance costs for human factories is included in the price of the goods provided, 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 relatively 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.

With the help of shadow pricing techniques it is in theory possible to arrive at a monetary value for a tree or forest. For example, through contingent valuation one could determine what the willingness to pay would be for the maintenance of a historic tree by a local community (or the willingness to accept compensation for the loss of this tree)[7]. If the tree has no other (economic) value, like providing fruits or as motive for artistic inspiration, one could use this value as the monetary indication of the preference of the local community for

[7] However, it is argued that the end-value found cannot capture all aspects of human preferences, and it is illustrative in this respect that the monetary value of the "willingness to pay" is systematically lower than the value found for the "willingness to accept" the loss of a given environmental good or service (e.g. Knetch & Sinden, 1984).

this tree. In case the tree is cut and the local community is compensated for its loss with the aforementioned amount of money, they should, according to economic theory, be "just as well off"[8] as they were before the tree was cut, provided they are able to make an objective, well-informed choice. This last assumption may be one of the main issues in the debate between ecologists and economists concerning the use of money as universal yardstick for measuring human preferences. At the time the decision was taken, most members of the community may feel to be better off because the space where the tree was, can be used for a new road or new houses. In the long run, however, history has shown us that many decisions that seemed rational and economic at that time (like the "rationalisation" of river-courses and the "cleaning-up" of hedgerows along cultivated fields) turned out not to leave the community just as well off as before and much money is now spend again to re-create the original situation. One could argue that such mistakes are caused by lack of information but usually local action groups did draw attention to these problems but for whatever reason decision-makers were not able or willing to take this information into account, even when monetary data on the environmental consequences was provided. This information problem gives reason to doubt wether it is principally possible to order all human preferences that influence decision-making based on money as the main yardstick, and wether monetary values can ever be a reliable reflection of individual preferences for any good or service, natural or man-made.

Yet, decisions will have to be made and a certain "ordering system" for measuring human preferences is *essential and unavoidable*. Consciously or subconsciously, preferences are ordered in any decision-making situation and it is therefore better to provide as much information as possible on the costs and benefits of the various planning alternatives, including monetary information, than to take decisions based on incomplete information on the economic importance of nature, as is now often the case.

B-3.2.2 Reasons for, and benefits of monetary valuation

Bearing in mind the words of caution expressed in section B-3.2.1, there are several reasons for, and benefits of monetary valuation of environmental functions. Every day thousands of decisions are made that affect the (natural) environment in one way or another. In all these decision-making situations, private as well as corporate and political, the value of the natural environment has to compete with many other interests. These "other interests" (e.g. a new car, a new car-factory or a new road) often have a more or less clear price-tag or profit-expectation attached to them. Consciously or subconsciously decision-makers weigh this price or the expected profit against what they think the environment is worth. This "worth" is most likely based on incomplete knowledge of the ecological and socio-economic importance of the

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[8]The use of this term may be somewhat misleading to non-economists (Folmer, pers.comm.) but is used by some economists (e.g. Madisson, in lit., 1993) and quoted here to indicate the dilemma decision-maker's face when comparing the situation before and after a planned intervention

environmental function(s) involved. To better represent the "full value" of natural goods and services, and the ecosystems which provide them, in economic planning and decision making, there is a clear need to express the socio-economic value of natural goods and services in monetary terms as much as possible. Economic, and especially monetary information on environmental functions provides important information which gives nature more "weight" in economic planning and decision-making instruments (such as CBA) and makes the consequences of environmental trade-offs more explicit (see section B-4.1. for further discussion).

The most important reason for monetary valuation of environmental functions might be that this information can be used to internalise the costs of the "external effects" in economic accounting procedures. As long as environmental "friendly" (or less harmful) products are more expensive than their more damaging alternatives, degradation and pollution of the natural environment will continue. The need for "ecological pricing" is discussed in more detail in chapter B-4.2, which would be an important step forward since the market mechanism would then "automatically" favour sustainable use of environmental functions.
Once all externalities and different types of values that can be attached to environmental functions are incorporated in the (market) price of *all* goods and services, both environmental and man-made, money could become a relatively objective yardstick for measuring human preferences for the availability of environmental functions. This, however, is still a long way to go (due to lack of information and other, more institutional obstacles) and, considering the difficulties discussed in section B-3.2.1, it is questionable wether the monetary price of any good or service can ever capture its entire socio-economic value. There should therefore always be room in the decision-making process for non-monetary values and ethical considerations. 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 monetary benefits of environmental functions.

B-3.3 Total socio-economic value and the problem of double counting

From figures B1-2 and B3-2 it can be concluded that natural ecosystems and protected areas fulfil a multitude of functions with many different values to human society. Most natural areas provide various functions simultaneously, and the total socio-economic value of a given ecosystem or natural area consists of the sum-total of the monetary and non-monetary benefits of the individual functions. When trying to calculate a total monetary value for a given area, ecosystem or function, care should be taken not to double-count values. For each of the case studies carried out for this thesis, a standardised matrix was used to assess the functions and associated values in a systematic and comparable way. As an example the matrix for the functions and values of Tropical Moist Forests has been included here (fig. B3-3). It must be stressed here that figure B3-3. represents a first attempt for a comprehensive assessment of the functions and values of a particular natural ecosystem or protected area, in this case a tropical Moist Forest ecosystem. So far, emphasis has been on developing the methodology and consequently the figures are mainly indicative and give a rough indication of the types and magnitudes of monetary returns and economic benefits to be considered. Much more research is needed to obtain more complete and accurate data for each individual function (which should not be taken as an excuse not to use the information already available for more balanced planning and decision-making, see chapter B-4).

Figure B3-3. clearly illustrates some problems related to double counting when attempting to determine the total annual benefits of the functions provided by natural ecosystems:

(i) The total value of a specific function (the horizontal axis in figure B3-3) may consist of various types of values. For example, the importance of Tropical Moist Forests (TMF) to maintaining the biological and genetic diversity on earth represent an important conservation value. The plants and animals "providing" this diversity may also have consumptive and productive use value when they are harvested. In addition, the importance of this function to future use (e.g. not-yet discovered medicinal biochemicals) represents an important option-value which may be measured by contingent valuation methods. Although each one of these values reflect a more or less independent aspect of one function, there is danger of *overlap when adding all these values*, especially for "integrative" functions such as bio-energy fixation and maintenance of biodiversity. On the other hand, since only some values of environmental functions can (realistically) be expressed in monetary terms, the monetary value is usually a minimum estimate, and represents only a part of the true socio-economic importance of the function in question.

(ii) Another double-counting effect may occur when the benefits of all functions within one value-category (the vertical axis in figure B3-3), are added to arrive at a sum-total for the conservation or productive use value of a particular ecosystem or natural area. The problem here is that the value found for one function may include (part of) the monetary value of other functions in case they are interlinked, for example bio-energy fixation and maintenance of biodiversity (see chapter B2.7)

(iii) The opposite of the problem described under ii may occur when the use of one function negatively influences the use of other functions. The value found for one function may then go at the expense of the availability, and monetary returns, of other functions (for example resource-extraction versus recreation). Monetary estimations of the benefits of environmental functions should therefore be based on sustainable use levels: i.e. just below the maximum carrying capacity of the area for a given function like harvesting of natural resources or recreational use. When more functions are used simultaneously the sustainable use level of each function is most likely to be lower then when only one function is used. Thus, the total potential demand for the combined use of environmental functions should be taken into account when calculating sustainable use levels for individual functions.

From the above (i-iii) it is clear that it will usually be difficult to determine one total "end value" for a given ecosystem or natural area, unless functions and values are entirely mutually exclusive, which will rarely be the case, especially for complex ecosystems like tropical rain-forests. According to figure B3-3, the total annual monetary benefits of tropical moist forest ecosystems is at least 500 US$/ha. Figure B3-3 also shows that there are still many functions for which no monetary value was calculated so the real monetary value will surely be much higher.

Fig B3-3 Total socio-economic value of environmental functions provided by tropical moist forest ecosystems (based on maximum sustainable use levels)

Environmental Functions	Types of values (a					Total
	Consumptive use value	Productive use value	Option value	Conservation value	Existence value	
Regulation Functions		++	++	>> 11	++	11 ++
Buffering of CO2		*	+	++		++
Climate regulation		*	+	++		++
Watershed protection		*		++		++
Erosion prevention		*		++		++
Air-purification		*	+	+		++
Bio-energy fixation		*		(20,000)b	+	(20.000)b
Biological control		*	+	11	+	11 +
Migration habitat		*	++	++	++	++
Maintenance of biol. div.		*	++	(800)b	++	(800)b
Carrier Functions		>> 41	++	>> 2	++	43 ++
Habitat for indig. people		*	++	++	++	++
Cultivation		15				15
Recreation		26	+			26 +
Nature conservation		*	++	2	++	2 ++
Production Functions	++	471	++			471 ++
Food/nutrition	++	300	++			300 ++
Genetic resources		40	++			40 ++
Medicinal resources	++	100	++			100 ++
- Rubber/latex	+	16				16 +
- Timber	+	15				15 +
- other raw materials	++	0.3				0.3+
Biochemicals	+	*	++			++
Fodder and fertilizer	++	*				++
Ornamental resources	+	*				+
Information Functions	++	> 4	++	++		4 ++
Aesth./Spirit./Hist. inf.	++	*	++	++		++
Cultural/artistic insp.	+	0.8	+			0.8+
Educ. & scientific inf.	+	3.2				3.2+
TOTAL ANNUAL VALUE	++	>> 516	++	>> 13	++	529 ++

a) Values are expressed qualitatively (+ +) or in US$/ha/year. For explanation of figures, see chapter A-4.1
b) 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.

Further research will probably make it possible to obtain more quantitative (and monetary) information on the benefits of natural ecosystems, but it is doubtful wether it will be possible to replace all qualitative data by monetary values (see also chapter B3.2 for further discussion). Data on environmental functions and values should therefore be brought into the decision-making process as presented in figure B3-3, including both qualitative and quantitative data. If a further integration or reduction is deemed necessary, section B-4.1. in this thesis gives a suggestion how figure B3-3 can be simplified further without loss of the most essential information (i.e. figure B4-3).

B-3.4 The capital value of natural ecosystems and the discounting issue

When interpreting the total monetary value of a given function, natural area or ecosystem, it must be realised that this value only represents the discounted 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 economic "net-present value"[9] of the area or ecosystem concerned.

In order to estimate the present worth of future benefits (and costs) a practice applied in economics is *discounting*. An important aspect is the choice of discount rate to be used which depends, among others, on the time horizon applied (or the rate of time preference). Usually the time-horizon is rather limited: 50 years or less, resulting in (market) discount rates of 10% or more. Discount rates for future benefits of development projects, including conservation projects, found in literature range between 5 and 15% (Bojo, et al., 1990, see also chapter A3.2 for a review). However, using discount rates for calculating the depreciation of the monetary return of the benefits derived from environmental functions, and thereby of the natural ecosystems which provide them, has some problems. 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. The benefits of the "works of nature", however, will last in perpetuity when used in a sustainable manner.

Since natural environments could provide goods and services indefinitely, when utilised in a sustainable manner, it would seem more appropriate 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. When calculating the present worth of future benefits of environmental functions, the interest (or discount) rate 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 (as a measure for the "renewability" of the ecosystem). Succession times differ strongly between various types of ecosystems and may range from a few years for pioneer communities (such as many salt-marsh and grassland communities) to a thousand years or longer for climax communities like tropical moist forests and even over 10,000 years for a bog ecosystem. For practical purposes, it is proposed here to apply a range of interest rates between 1 and 6 % for environmental functions provided by natural ecosystems, whereby the higher figure applies to pioneer communities and the lower figure to climax communities. Assuming an average interest rate of 5%, the capital value of the conservation and sustainable utilization of all functions of the three case study areas presented in part A (chapter 4) of this

[9] The concept of "Net Present Value" relates to the fact that the present availability of goods and services is valued higher than the availability of these same goods and services in the future. According to Heijman (1991), based on a literature-review, this time preference has three reasons: "first, the difference between need and satisfaction of goods in the present and in the future; second, the systematic underestimation of future needs; third, the productivity of capital".

thesis 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. When interpreting these figures, it must be realised that they are only based on the (estimated) annual return of those functions for which a "real" or derived market value could be calculated. The values given here must therefore be considered a minimum estimate since for many functions no monetary value could be calculated although their (potential) contribution to the economy is considerable.

Although much has been written on the subject of discounting (see also chapter A-3.2), a satisfactory solution with regard to estimating the present worth of future benefits of environmental functions is not in sight yet. In general, it would therefore be better to only use the annual benefits of environmental functions as an indication of their (monetary) value. However, in certain planning and decision-making situations, it may be necessary to estimate a capital or net present value for the functions provided by natural ecosystems.
Information about the capital value of natural ecosystems is important, for example, when decisions have to be made about the conversion of entire ecosystems or natural areas for other purposes.
An interesting calculation can be made for the difference between non-sustainable and sustainable use of tropical moist forests, i.e. between (a) logging and cultivation, and (b) the conservation and sustainable use of all its functions:

(a) *Monetary value of non-sustainable use of tropical moist forests*
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) (Sedjo, 1989), while that of pastures is estimated at US$ 2,960, excluding the costs of weeding, fencing and animal care (Peters, Gentry and Mendelsohn, 1989). Both estimates are based on the optimistic assumption that plantation forestry and grazing lands are sustainable land use practices in the tropics, which they usually are not. The total capital value of the conversion of tropical forest to cultivated land is thus, at best, a little over 6,000 US$/ha.

(b) *Monetary value of sustainable use of tropical moist forests*
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). The annual monetary value of sustainable use of *all* the functions of the natural tropical moist forests combined is at least US$ 500/ha (Figure B3-3); at an interest rate of 5% this amounts to an NPV of at least US$ 10,000.

Thus, the net present value of sustainable use of tropical moist forests is much higher than the non-sustainable use of the conversion of the forest for timber-logging and cultivation: a difference of almost 4.000 US$/ha [10] (see chapter A-4.1 for a more detailed account of the above calculations).

Not only for tropical moist forests, but also for most other natural ecosystems, it can be stated that their conservation and sustainable utilization is usually more beneficial, also in economic terms, than non-sustainable use of only one or two functions. Incorporating information on the capital value of natural ecosystems could help to prevent further destruction and, instead, stimulate investments in maintaining and enhancing this natural capital.

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10 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. 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, Gentry and Mendelssohn, 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 (and thereby the consumers) 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.

B-4 FUNCTION EVALUATION AS A TOOL IN PLANNING, MANAGEMENT AND DECISION MAKING

Introduction

Although it is now realised that many natural ecosystems are not only ecologically important but also provide many important goods and services to human society, the structural incorporation of ecological information in environmental planning and decision-making still needs improvement. When a choice must be made between various development options (ranging from local road-constructions to large development-aid projects), too often the environmentally "unfriendly" alternative is chosen, partly due to incomplete information on the true socio-economic consequences of the environmental effects.
The function-approach, as described and discussed in this thesis, can make environmental trade-offs and the associated socio-economic effects of development projects and human activities more explicit in terms of gains and losses in the availability of environmental functions. Thus, it is hoped that function evaluation can help to improve the assessment and presentation of the environmental costs and benefits of development options, and thereby can contribute to more balanced decision-making.

To obtain insight in the practical applicability of the function-evaluation method developed in this thesis, the book (part A) was sent to representatives of many potential "user-groups" such as environmental planning-organisations (governmental and non-governmental as well as private consultancy firms), conservation-organisations and organisations involved in environmental education and awareness, and researchers interested in the interface between ecology and economics. Many people responded, and their reactions and examples of the use of the function approach are incorporated in the following paragraphs where appropriate.
Five application-fields are discussed in this last chapter, including the use of the function evaluation approach in environmental planning and project evaluation (B-4.1), in environmental or ecological economics (B-4.2), in environmental law (B-4.3), in environmental education and awareness (B-4.4), and for the operationalisation of the concept of "sustainable development" (B-4.5).

B-4.1 Environmental planning and project evaluation

Assessment and evaluation of environmental functions provides information that can be used in various phases of the planning process. A brief description of the main phases involved in environmental planning is given in chapter A-5.1, including a literature review of analytical tools for incorporating environmental aspects in the planning and decision-making process.
In the following paragraphs, the role of function-evaluation in three important planning-phases is discussed in more detail, namely drafting of environmental

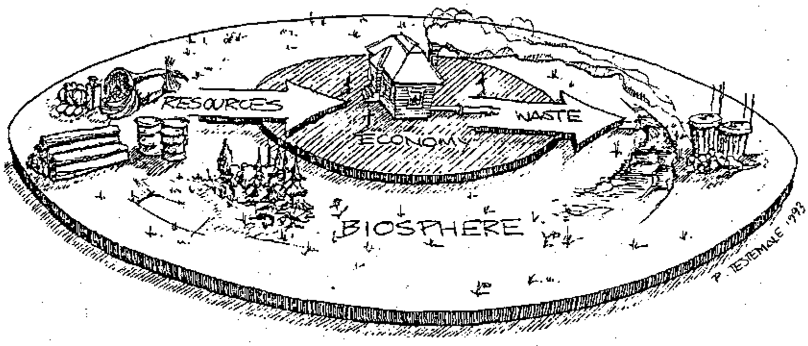
profiles which describe the environmental situation and ecological carrying capacity (B-4.1.1), evaluation of the potential environmental effects (B-4.1.2) and the use in analyzing the trade-offs (costs and benefits) of development projects (B-4.1.3)

B-4.1.1 *Environmental profiles and carrying capacity studies*

For drafting environmental profiles, country reviews and formulation of carrying capacity limits, function evaluation can be an important instrument. Carrying capacity can be defined in many ways. A recent definition reads: the "maximal population size of a given species that an area can support without reducing its ability to support the same species in the future" (Daily and Ehrlich, 1992).
An interesting example of the use of the function concept for defining carrying capacity is the work of Drs. Rees and Wackernagel from the University of British Columbia (Canada). They incorporated the function-concept in what they call the "ecological footprint": i.e. how much land is necessary to sustain an average person's lifestyle and what is the "appropriate carrying capacity" of the environment ? To determine wether the land and resources available to the economy have sufficient carrying capacity to supply present and anticipated future demand indefinitely, Rees and Wackernagel (1993) developed an ecological accounting concept that uses land-area as its biophysical measurement unit. They reason that every major category of consumption of waste discharge requires the productive or absorptive capacity of a finite area of land or water (ecosystems). They measure resource productivity and human demand in biophysical units such as square meters, kilograms and energy. The energy consumption of an average Canadian, for example, adds up to over 850,000 kj/day, of which only 12,000 kj is needed for food (Wackernagel et al, 1993). Adding up the land requirement of all these categories gives an aggregate or total area which they call "ecological footprint" of the economy on Earth. The total land demand for Canadian's is calculated at 4.8 ha per capita. Following a similar approach, van Brakel et al. (1993) calculated that the Netherlands use over 17 times more land for food production, forestry products and energy-use than there is within the country.
To determine the adequacy of a resource stock it should be investigated if the amount and quality of the stock suffices to produce a continuous flow of the biophysical "goods and services" that this economy consumes to sustain itself. I.e. can the stock provide for present demand without compromising future production ? To investigate this question, Wackernagel et al. (1993) compared the calculated ecological footprint with nature's carrying capacity to provide the necessary good and services (functions) in a sustainable manner. On a global scale the available land for ecologically sustainable production of the necessary goods and services is 1.6 ha per person (World Resources Inst., 1992); thus, if everybody on Earth lived like today's Canadians, it would require three Earths to provide all the resources needed. By including the requirement that human use should not exceed the sustainable flow of goods and services provided by the biosphere, the ecological footprint can be translated into an Appropriate Carrying Capacity (ACC) which Wackernagel et al. (1993) define as "the aggregate land (and water) area in various categories required by the people in a

region to provide continuously all the resources they presently consume, and to absorb continuously all the waste they presently discharge".
Rees and Wackernagel suggest that the concept of Appropriate Carrying Capacity (ACC), based on the availability of environmental functions, can be used as a sustainability indicator to facilitate the comparison of policy choices society must face to provide everybody with essential resources while maintaining ecological stability.

Fig. B4-1 The Human Economy as Part of the Biosphere
(from: Wackernagel et al., 1993)



Each economy appropriates land areas from all over the globe to provide its resources and to absorb the corresponding waste. This land area is that economy's ecological footprint or its appropriated carrying capacity. It demonstrates the biological or ecological dependency of that economy.

The function-concept also proved useful to the developing discipline of ecosystem-health studies. It has been adopted, for example, in a project on "Ecosystem Recovery of the St.Lawrence River" (Crabbe, 1992)[11]. The major goal of the project is to identify and propose courses of action needed to rehabilitate the Cornwall basin of the St.Lawrence River and to design a strategy for sustainable re-development of the community in the region. The function-concept is used as a framework to identify the most important functional interactions between the human community and the river, as well as for the ecological assessment of the "health" of the river. The project also studies the public perception of the value placed on the ecological functions of the river to assess the communities perception of the impact of degradation of the St.Lawrence River on their quality of life.
From the above it follows that function evaluation provides a useful basis in various phases of the planning process. A critical point, however, is the fact that much information that is needed to describe the relevant functions is still fragmentary or not available at all. Possibly the amount of information needed could be condensed further once proper indicators are found to describe the

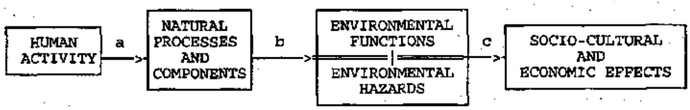
[11] The project started in 1993 and will last 4 years. It is carried out by a large multi-disciplinary team of researchers advised by an international Scientific Advisory Committee of which the author of this thesis is a member.

availability and maximum sustainable use level of the various functions. Once 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.

B-4.1.2 *Function evaluation and Environmental Impact Assessment (EIA)*

At an early stage in the planning process, information about the ecological implications of the possible trespassing of the carrying capacity, due to changes in environmental functions and hazards, should be included in order to obtain a clear insight into the environmental trade-offs involved in alternative development projects. An instrument that is becoming increasingly accepted in this phase of the planning process is Environmental Impact Assessment (EIA) which aims to assess as far as possible all environmental effects resulting from a given development project.
Environmental impact assessment studies should assess both the direct environmental effects of certain human activities or interventions in a given area, and the influence of changes in environmental properties on the environmental functions and associated hazards affected by the activity. Unfortunately, conventional EIA's are usually restricted to an assessment of the direct effects of a given project on the environmental characteristics of the area, without a proper analysis of the secondary effects on changes in environmental functions and hazards. Deforestation, for example, not "only" means the loss of the vegetation-cover and associated plant and animal species but causes the loss of many environmental functions (e.g. maintenance of genetic variability, protection against erosion, and climate regulation) which, in turn leads to environmental hazards such as soil erosion and drought with serious socio-economic consequences affecting the lives of many people (both locally and globally) often for decades and generations to come.
Environmental impact assessment should therefore be an integrative process involving both the evaluation of the direct environmental impact of human activities as well as the changes in environmental functions and hazards.
A suggestion for a more complete (expanded) EIA-procedure is given in figure B4-2, consisting of three steps: (a) an assessment of the direct effects (physical, chemical and/or biological) of a given (planned) activity or intervention on the natural environment, (b) an evaluation of the (indirect) effects of human activities on environmental functions and associated hazards (through changes function-fulfillment), and (c) An analysis of the socio-cultural and economic effects caused by changes in environmental functions and hazards. By applying these evaluation steps consecutively in one integrated environmental assessment procedure, it is possible to obtain a complete overview of the potential environmental and socio-economic effects of a planned intervention.
The checklist of functions provided in this thesis can serve as a reference for a comprehensive environmental impact *and* risk assessment to determine the suitability (or un-suitability) of the natural environment for certain uses. A good example of the use of the function-concept for this purpose is the case study carried out by van Pelt (1993) which is discussed in the next section.

Fig. B4-2 A suggested framework for an expanded Environmental Impact Assessment procedure



Changes in environmental characteristics caused by human activities (step a), cause changes in the environmental functions and/or risks provided by a given natural or semi-natural area or ecosystem (step b), leading to certain socio-cultural and economic effects (step c). For further explanation, see text.

B-4.1.3 *Function-evaluation and Cost-Benefit Analysis (CBA)*

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. Various methods are available to process and integrate the large amount of environmental and socio-economic data. Two of the more well-known methods are Cost-Benefit Analysis (CBA)[12] 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. A major shortcoming of (traditional) cost-benefit analysis is that it is usually limited to economic (financial) trade-offs. As a result, environmental aspects are still very much neglected in CBA's because of quantification and valuation difficulties. A problem with MCA's is that they are often viewed as impractical because of the large amount of data needed and the difficulty to compare the various attributes which are often measured in different dimensions.
Since the function-concept combines ecological and socio-economic data into a limited number of functions, many of which can be expressed in monetary value units, it can help to overcome some of these problems. In figure 4-3, a framework is given for an expanded ("functional") CBA, whereby the monetary factor should always be complemented by a brief indication of the "physical dimensions" of each attribute which is taken into account in the analysis (see Fig. B4-3).

Once a clear overview has been obtained of all, or most, functions and values that are at stake in a given planning situation, it must be decided wether the project can go ahead as proposed, wether adjustments are needed or if the project must be cancelled. For larger development projects, decisions are usually based on the Internal Rate of Return (IRR) which is the expected net-profit as percentage of project-investments. The IRR, in turn, is based on the Benefit-Cost Ratio of the project as calculated by figure B4-3.
If only the difference between costs and benefits in direct market values is

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[12] Instead of CBA also the reverse terminology (Benefit-Cost Analysis) is used, as well as the concept of Benefit/Cost or Cost/Benefit Ratio. For Cost-effectiveness Analysis, see for example Boumol and Oates (1988).

taken into account (column a), the project has a clear positive benefit/cost ratio (+ 4,500 $) and would go ahead without hesitation; when also the indirect market values (in this case mainly the waste recycling capacity) is also taken into account (column b), the net-positive effect is only 500 $/ha/year. When, finally, also the "soft" shadow prices calculated for the loss of rare species and some information functions is considered (column c) the benefit/cost ratio becomes negative (i.e. - 100 $).

Fig. B4-3 Fictive example of an expanded "functional" Cost-Benefit Analysis for draining a coastal wetland for cultivation

"ATTRIBUTES" (Socio-economic consequences of the planned intervention and environmental effects)	COSTS (-) and BENEFITS (+)			
		Monetary values (in $/ha/year)		
	Physical & natural dimensions (*	Direct market values	Indirect market values	Shadow price (#
I. INTERVENTION		+ 5,500	+ 200	?
Draining wetland	e.g. 5,000 ha	+ 200 (1		
Cultivation	e.g. maize, potatoes	+ 5,000		
Miscell. (2		+ 300	+ 200	
II ENVIRONM. EFFECTS (e.g. loss of:)		- 1,000	- 4,200	- 600
Regulation funct.				
- Waste recycling	x m3 org.matter+nutr.		- 4,200	
- Nursery	x % commercial catch	- 150		
- Biol.diversity	e.g. rare species			- 300
Carrier functions				
- Aquaculture	mussel cultivation	- 50		
- Recreation	sailing, etc.	- 400		
Production funct.				
- Food-biomass	e.g. fish, shellfish	- 350		
- Building mat.	sand, shells	- 20		
Information funct.				
- Aesthetic inf.	visual disturbance			- 100
- Historic inf.	cultural interest			- 200
- Artistic insp.	e.g. films, paintings	- 10		
- Scient/educ. inf	e.g. research activ.	- 20		
BENEFIT/COST RATIO (a-b-c) = -100 US$ (3		+ 4,500 (a	- 4,000 (b	- 600 (c

#) See figure B3-2 for explanation of types of values, and distinction between market and shadow pricing, and direct and indirect valuation techniques.
*) 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.
1) The capital value of the land (e.g. 4,000 $/ha) translated into an annual value based on 5% interest
2) E.g. the "added value" of the processing of cultivated products, employment benefits, etc.
3) For explanation and discussion, see text.

Bouwhuis (1993) applied the function approach in three case study situations to analyse the costs and benefits of water-use for sustainable agriculture in developing countries (Egypt, India, Senegal). The report aims to contribute to the discussion on water-scarcity in these countries in relation to balancing the conflicting interests between agriculture and nature conservation. Bouwhuis used the function-approach to assess the "value of water" in the river basins of the Nile in Egypt, the Narmada-river in India and the Senegal river (Senegal). By applying the "expanded CBA-method", Bouwhuis found several important differences with conventional cost-benefit analysis.
One of his first conclusions was the omission of regulation and information functions in conventional CBA, with the exception of the importance of the study sites to biodiversity and nursery functions. The expanded analysis of

environmental functions and values was very helpful, he found, because it includes both the measurable production-functions as well as the more difficult to measure regulation and information functions. It also showed the apparent undervaluation of the many functions of water. For his Senegal case study, for example, the application of the function-value analysis, as he calls it, led him to include two important aspects into the CBA that would "normally" have been left out of the analysis: (1) he included the monetary value of the avoided degradation by traditional (sustainable) grazing in the surrounding area during the dry season as benefits of the present situation, and (2) he calculated the optional value of the conservation and sustainable use of the forest in the watershed area. Another difference, he found, was that the expanded analysis made it possible to include the indirect and optional values for the production and carrier functions.

Another interesting observation by Bouwhuis was that the expanded CBA-matrix makes it easier to distinguish between the "users" or beneficiaries of the projects and the "non-users" or even people who are harmed by the project. The identification of these "user" and "non-user" groups makes it possible to allocate more fairly the financial and economic costs and benefits.

This approach makes it also possible to divide responsibility for function-use and maintenance between the government and the private sector. According to Bouwhuis, the (sustainable) exploitation of production and carrier functions should be (co-)financed by the direct or indirect beneficiaries. Maintenance of regulation functions should be a mixed responsibility of private and government organisations while the information functions should primarily be a government responsibility.

In his study, Bouwhuis was also confronted with the need to adjust economic incentives. He found that the prices charged for the various uses of water are far below the costs incurred to provide the water. For example, many irrigation schemes cannot cover the operational costs. In India 90% of the costs are covered by government subsidies or international development aid. Because the prices are not related to the costs they do not provide an incentive to conserve water, leading to wasteful use, social injustice and environmental degradation. He therefore recommends that the true value of environmental functions must be incorporated in the prices of the goods and services provided by nature.

Bouwhuis concludes that the function-approach, in combination with environmental valuation methods, proved to be very useful for a more balanced analysis of the costs and benefits of development projects[13]. His only critical

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13 From his three case studies of development projects in Egypt, India and Senegal, Bouwhuis (1993) observed several reasons why decision-making of development projects is often unbalanced (translation from Dutch by the author): "..in spite of the many, both positive and negative effects of development projects, politicians, planners and financing institutions are mainly interested in the direct effects and costs. The 'indirect' effects are often neglected although they often strongly influence the overall net-impact of the project. A problem with these indirect effects is that it is often difficult to quantify them which provides planners with an excuse to ignore them. Undoubtably, also political pressure from national politicians and international financing institutions forced hasty decision-making, while matters of prestige prevented thorough environmental impact studies. The focus on short-term success and the impossibility to hold politicians and financiers responsable for their decisions stimulates hasty and unbalanced decision-making with regard to development projects, often leading to serious problems that could have been prevented with an expanded impact assessment of environmental functions and values".

remarks relate to the fact that not all values are quantifiable and the large amount of data needed which are usually not available in developing countries. Bouwhuis also mentioned the danger of misuse of information on the economic value of environmental functions although he did not elaborate if or how this danger related to the three case study situations.
His general conclusion was that "Such an [function-] analysis may be regarded as an elaboration of an environmental impact assessment and a preamble to economic analysis. External effects are made more visible and can thus be better internalized in a cost-benefit analysis. Some practical examples show that, in principle, a function-value analysis is possible" .

Van Pelt (1993) used the function-concept for his thesis on "sustainability - oriented project appraisal for developing countries". He developed a framework for project appraisal based on two case studies in Colombia and Egypt. In Egypt, the presently brackish Lake Burullus, or a major part of it, would be converted into an artificial lake for storage of fresh Nile water. By saving Nile water, which otherwise would spill into the sea, additional irrigation water for agriculture would become available. For his analysis of the present ecological conditions and impacts in the Lake Burullus case study van Pelt distinguished 22 ecological functions (based on figure B1-2, ranging from water purification via maintenance of biodiversity to its scientific value. Although van Pelt did not attempt to monetize the (full) ecological value of the Lake Burullus ecosystem, his study showed how much net benefits in the field of water conservation (and hence agriculture) the government of Egypt should be willing to give up in order to preserve the lake.
One of his conclusions was that "..to allow for a proper assessment of environmental impacts of a project, it is necessary to develop qualitative and quantitative models for ecological-economic interaction in the project setting". As these interactions and linkages are complex and wide-ranging, van Pelt states that there is a need for a comprehensive approach for which the function-concept is a useful starting point. "Interaction models may be based on De Groot's classification, and elaborate on the functions that are particularly important in the project setting". With regard to environmental impact assessment, he suggests that conditions for sustainability could be specified for each function, but adds that this approach is time-consuming and would apply to large projects only.

One of the first examples of the application of an expanded cost-benefits analysis based on an evaluation of environmental functions 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 capital 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 original state.

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 pressure. As has been shown, it will then become clear that sustainable use of natural ecosystems is, in the long run, often more profitable than over-exploitation for short-term monetary gains.

B-4.2 Environmental or ecological economics

Much has been written on the need for better integration of ecological principles and environmental considerations in economic assessment and accounting procedures. Already in 1920, Pigou remarked that "over-hasty exploitation of stored gifts of nature ... make it harder for future generations to obtain supplies of important commodities" (in: Bojo, et al., 1990). The earliest attempts to structurally incorporate ecological information in economics date back already to 1928 (Folmer, pers.comm.) and since then many publications appeared on this topic (for a review, see part A, chapter 3.1 of this thesis). Thus, there is widespread concensus for the need to develop theories and methods for "environmental or ecological economics" in order to halt environmental degradation and to bring economic development more in harmony with the carrying capacity of nature. Considering the many difficulties involved in this process, a constructive dialogue between economist and ecologists is essential.
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. The use of the concept of environmental functions provides 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). The thought of environmental functions as a unifying concept for ecology and economics is worked out in some more detail in de Groot (1987).
Important areas within the developing discipline of environmental or ecological economics where function-evaluation can be of use are ecological pricing and adjustment of national accounting systems.

B-4.2.1 *Function evaluation and ecological pricing*

The current market price of many products does not adequately reflect the true environmental costs involved in the production and distribution of these products. 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. All too often environmental damage caused by the extraction of natural resources needed for the production and the

environmental pollution caused by the production and distribution are labeled as "external effects" which are not accounted for in the price of the product. That these "external effects" do have a price-tag is, however, clear from the enormous amounts of (tax)money used to mitigate the environmental and socio-economic consequences of air, soil and water pollution, erosion, etc.
For example, the environmental effects of the construction of ski-areas in alpine regions costs billions of dollars each year due to damage caused by erosion, land slides and flooding, and for building artificial fences to replace the protective function of the forest which was cut. The costs for these environmental restoration measures is now payed from general taxes but should actually be included in the cost-benefit analysis of the project in the planning phase. If construction of these ski-areas is then still considered economical (or necessary) the costs of these "external effects" should be included in the price of the ski-tickets.
Another reason why the contribution of many natural goods and services to the economic production process is not, or insufficiently, accounted for in the pricing mechanism is 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". An illustrative example of the under-valuation of natural goods is the market value of tropical timber. The current market price of tropical timber is little more than the cost of bringing that timber from the forest to the market (increased with margins and profits) while ignoring the loss of the other functions of the forest such as genetic resources, "minor" forest products (fruits, latex, etc.), watershed protection, climate regulation, etc. All these functions are considered "free" and are therefore not or inadequately accounted for in the cost-benefit analyses of the logging project. Thus, only the end-product is valued, not the depreciation of the (natural) capital, in this case the forest, which provides the product. The consequence of not accounting for the costs of environmental effects in current prices is that these costs, both in monetary terms and in reduced health or other wellbeing factors, are deferred to others, either in time (i.e. to future generations) and/or in space (e.g. transnational pollution of air and water).

Fortunately, this omission in the market pricing mechanism is slowly being acknowledged and efforts are now undertaken to make these "external effects" and the "free" use of natural goods and services more visible through input-output analysis, material-balances, environmental auditing and other assessment techniques. The outcome of these assessments should be used to develop "ecological prices" based on a realistic estimation of the full costs and benefits of the use (and non-use or conservation) of environmental functions. For example, the Worldwatch Institute recently calculated that one Hamburger should cost about 200 US$ (!) if all environmental costs associated with the production, distribution, marketing and sale of one Hamburger were properly calculated and accounted for. Over 110 US$ of this amount is related to the environmental damage caused by the fact that most of the meat for Hamburgers comes from cattle that is kept on pastures in deforested tropical rain forest areas. The checklist of functions given in this thesis can help to provide the necessary ecological information to make such calculations.

Eventually additional economic incentives should be developed to stimulate sustainable use of nature and natural resources (see chapter B-4.2.2).[14] Application of ecological pricing would also provide more realistic values for the natural goods and services of the ecosystems involved in international financing (aid and development projects), in debt-issues and in international negotiations involving the natural environment (see box B4-1). Higher compensation for both conservation of natural ecosystems (e.g. in debt-swapping negotiations) or sustainable utilization of their natural resources (hardwood, genetic and medicinal material) could provide a powerful economic incentive for sustainable development in the countries which still have the richest ecological heritage but are (therefore?) usually poor in the economic sense (see also the next section).

Box B4-1. International financing and "debt-for-nature" swaps

Another application field of function evaluation in environmental economics is the role in restructuring debts of developing countries in exchange for the conservation of natural ecosystems (also referred to as "debt-for-nature" swaps). 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.

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 many natural resources could be reduced or even halted. For example, Bolivia once sold licences for logging in 1 million ha of tropical forests for a mere 48 $/ha. According to the case study described in chapter A-4.1 of this thesis, the capital value of one ha of tropical rainforest is at least 10.000 US$ (based on a net-annual return of 500 US$/ha). Another recent example of the application of information on the economic value of wild plants and animals in international financing is the Biodiversity Convention drafted at the UNCED Conference in Rio de Janeiro (1992). Especially the USA was reluctant to sign because this would mean that chemical and pharmaceutical companies would have to begin to pay for the biochemicals which they thus far collected for free (or at marginal costs) in the tropical rainforests. In the mean time most countries, including the USA, signed this treaty which is another hopeful sign that some fundamental changes are taking place.

B-4.2.2 *Adjustment of economic and national accounting procedures*

National income accounts, such as Gross National Product (GNP), were designed in the 1940s to give information on "the balance between total supply and total demand, on savings and investment in reproducible capital, and on international relations" (Mäler, 1991). The Gross National Product summarises the total of all incomes (wages, salaries, profits) generated in the production of goods and services in a given year. Although GNP was primarily designed to obtain insight in the general state of the economy, over time it became increasingly used as a measure for human welfare. Especially the use of GNP as a welfare measure receives much criticism. Hamilton (1990) notes that GNP measures the "goods" but not the "bads" that are associated with production and that there is "no way to determine from the accounts whether an economy is evolving sustainably". Hamilton further states that the environment should be

[14] As long as environmental friendly products (like biologically grown agricultural products) are more expensive in the store than their chemically treated counterparts, their market share will most likely remain marginal. Environmental pollution and degradation can only be stopped with proper economic incentives through the application of environmental pricing and taxing. A shift in taxes on labour to the use of natural resources and environmental space would be an important step in the right direction.

brought into the national accounts through deductions from GNP for various aspects of environmental degradation, including costs of pollution and abatement control[15], 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.

According to Mäler (1991), GNP is a gross concept which should be replaced by net national product (NPP). Mäler adds, however, that "even if depreciation [of environmental costs] is deducted from GNP, the NPP measure may still be a bad measure of welfare, in particular in connection with natural and environmental resources". Mäler (1991) therefore concludes that .."we will have to continue relying on physical and other special indicators to a large extent in order to judge the performance of the economy with respect to the use of environmental resources".

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 so-called "grey capital") but also by the natural (or "green") capital, i.e. the 'stock' of natural and semi-natural ecosystems which determine the availability of wildlife, forests, water, energy, soil and (clean) air. By including both the goods and services provided by the economic ("grey") capital and the natural ("green") capital as separate entries into national accounting systems, it will become clear that an increase of the grey capital, especially in the market sector, often goes at the expense of the green 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 hardwood from forests (through clear-cut of both tropical as well as temperate forests) converts green capital into grey capital. What (usually) remains are devastated landscapes which have lost their productive potential and the many other functions they provided, bringing much hardship to the local communities. The returns of this conversion mostly do not weigh-up against the environmental and social costs, and are often used for purposes which do not bring structural improvements to the communities most affected.

This discrepancy between allocation of costs and benefits of projects whereby green capital is converted into grey commodities also occurs on a macro-economic scale. It is no coincidence that most of the remaining natural wealth on earth is found in the less-developed ("poor") countries and that in most of the (economically) rich countries the grey capital has been built up at the expense of the green capital. If the economic (monetary) value of the green capital would be included in National Welfare Measures (instead of using GNP as a comparative yardstick) could stimulate the willingness to find more sustainable ways of utilizing the goods and services of the green capital, and could contribute to a more balanced relationship between developed and less-developed countries.

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15 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.

B-4.3 Environmental law

Another interesting field of application is the use of the function-concept in estimating the ecological and socio-economic costs of environmental damage caused by industry (e.g. steady pollution from factories or sudden local effects from oil-pollution caused by ship-accidents). Increasingly, the "polluter-pays principle" is applied to these cases whereby law-suits in most countries were thus far mainly limited to the estimated costs for clean-up activities only (with the USA as notable exception). These clean-up activities are, inevitably, of a "cosmetic" nature: in a few months man cannot repair the longer-term disturbance of ecological processes nor the loss of plant- and animal-life. There is also an emotional cost involved in the damage inflicted upon the few remaining wilderness areas, which are still decreasing in number and quality.
With the function-approach, it is possible to make a systematic review of the consequences of environmental damage for all, or at least most, of the functions and values of the area in question. In addition to the repair- or clean-up costs, a certain sum should be calculated for the loss of these functions and values which could be seen as a type of compensation cost. This compensation-sum could be used to finance longer-term conservation activities in the area in question or pay for the (re)creation of substitute areas. Support for the idea to deposit payments for irreparable damages to the environment in a type of "environmental damage fund (or 'Ecofund') seems to be increasing (e.g. Bastmeijer, 1992). A recent example of an expanded cost-calculation for environmental damage, is the case of the oil spill caused by an oil-tanker (the 'Exxon Valdez') in Alaska in 1989; the clean-up costs amounted to about 2 billion US dollar but the responsible oil-company was charged with a "penalty" of an additional 1.2 billion dollar as compensation for the lost "bequest value". This additional amount was placed in a special fund to pay for long-term rehabilitation measures and to compensate local inhabitants for lost income (Folmer, pers.comm.).

B-4.4 Environmental education and awareness

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 of natural ecosystems to human society, and thereby for measures needed to reduce and prevent further environmental deterioration. 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 that we are also destroying many essential services with serious socio-economic consequences (e.g. local and possibly even global changes in climate caused by large scale deforestation). Knowledge about the socio-economic value of natural goods and services may help to adjust planning and decision making in favour of the conservation and sustainable utilization of natural ecosystems. 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 disturbance and loss of functions previously taken for granted (such as the protective function of the ozone layer against UV-radiation and climate-regulating processes). It is a sad fact that most environmental decisions are still taken based on the "management by disaster" approach rather than the "precautionary principle"[16]. The function-concept may be of help to explain the many feedback-mechanisms and links in nature, and can contribute to raising general awareness of the socio-economic importance of natural ecosystems, and thereby increase understanding and support for measures aimed at their conservation and sustainable utilisation.

B-4.5 Environmental functions as indicators for "sustainable development"

Although the concept of "sustainable development" was introduced by IUCN, UNEP and WWF in 1980, the most cited definition 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 definition and practical implementation of the concept of sustainable development. One problem relates to the interpretation of the word "development" and it may be more correct to speak of sustainable <u>use</u> rather than development since the natural resource base cannot be "developed" but, at best, used in a sustainable manner.
Because of the far reaching consequences, the concept of 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 the natural environment (physically, chemically and biologically), so that human use does not irreversibly impair the integrity and proper functioning of its natural processes and components' (this thesis).

Once satisfactory definitions have been found, indicators (ecological, socio-economic and cultural) for measuring progress towards achieving sustainable development should be defined (see box B4-2). These indicators, in turn, should provide the basis for formulating common paradigms and concepts to integrate

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16 The most recent example is the call for stricter safety regulations on the North Sea after the loss of ten-thousands of small packages containing a dangerous pesticide.

ecology and economics and to develop practical incentives for the conservation and sustainable use of nature and natural resources. The function-concept could be useful in this respect since maintenance of environmental functions serves both ecological purposes (i.e. ecosystem health) and socio-economic interests (i.e a sustained flow of goods and services). Thus, the availability of environmental functions could be used as an indicator for measuring both environmental quality and quality of life. For each function, standards should be set for the minimum availability based on selected environmental indicators (e.g. air quality, species diversity). 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 function-use since many functions cannot be utilized simultaneously and may compete with each other.

Box 4-2 On environmental sustainability

A recent publication by Ekins (in press) illustrates the complexity involved in defining "sustainability" with a matrix which shows the interactions between the three types of sustainability: environmental, economic and social. With reference to part A of this thesis, Ekins defines environmental sustainability as "..the ability of the environment to sustain human life which, in turn, depends on the maintenance of environmental functions". Which functions are important for which ways of life, and the level at which they should be sustained, will vary to some extent by culture and society, although there are obviously basic biophysical criteria. According to Ekins, such considerations provide the context for the setting of standards for sustainability. Ekins sees chronic competition between functions as the main cause for unsustainability. He suggests that the different forms of competition will need to be addressed by different kinds of standards: qualitative (effect, concentration and emissions), quantitative (minimum reserve, minimum life expectancy, capital fund), and spatial (e.g. waste dumping and species extinction)

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. 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". 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 (environmental) economic accounting procedures which integrate 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.

From the examples provided in this chapter, and other publications (e.g. Vellinga, de Groot and Klein, 1994) it can be concluded that the function-approach proves to be a useful tool to structurally integrate environmental concerns in planning and decision-making. In the next, and last chapter, some general conclusions are drawn concerning some methodological aspects and the practical applicability of the function-evaluation method described and discussed in this thesis.

B-5 SUMMARY AND CONCLUSIONS

In spite of the growing awareness of the many environmental problems that we face today, degradation and pollution of the natural environment by human activities still continues on a large scale. One of the main reasons for the still continueing degradation and loss of natural ecosystems is the fact that the importance of nature and a healthy natural environment to human welfare is still not fully reflected in economic planning and decision-making. This undervaluation of nature leads to over-exploitation of resources and excessive use of the natural environment as a receptor of human waste. Gradually it is becoming clear, however, that the so-called "external effects" of the economic production process are not as external as we would like them to be and the effects of non-sustainable development in the past are costing us billions of dollars today in repairing, neutralising or limiting the damage to the environment and human health, in so far as this is possible.
To curb the economic development process into a more sustainable direction, environmental considerations should be integrated more structurally in planning and decision-making. 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. The application of current methods of evaluation in decision-making, such as environmental impact assessment and cost-benefit analysis, inadequately reflect the true environmental and socio-economic value of natural ecosystems and the goods and services they provide. One of the main objectives of this thesis 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.

Ecological assessment of environmental functions
In order to better incorporate ecological information into the planning and decision-making process, it is essential to increase our knowledge of the many benefits provided by nature. For this purpose, the concept of environmental functions is very useful, which is defined in this thesis as 'the capacity of natural processes and components to provide goods and services that contribute to human welfare, directly and indirectly'. In total, 37 separate functions are distinguished in this thesis which are grouped into four main function categories: (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.
By means of the function-evaluationsystem described in this thesis, it is possible

to translate, and reduce, the ecological complexity of natural processes and components into a relatively small number of specific environmental functions, including the goods (i.e. resources) as well as the services (e.g. maintenance of essential life-support processes).
With the checklist of 37 environmental functions given in this thesis it is, in principle, possible to describe all benefits of the natural environment to human society in a systematic and comprehensive manner.
Although the emphasis in this thesis is on those functions which are provided by natural ecosystems, the approach can also be applied to assess and evaluate the environmental functions of semi-natural or even cultivated landscapes.
Several case studies were carried out to test the proposed function-evaluation in practice on different ecosystems including the Dutch part of the Wadden Sea, the Darien NP, a tropical rainforest along the border between Panama and Colombia, and the Galapagos NP, a volcanic oceanic island ecosystem. The results of these case studies, and a general description of the methodology, were published in 1992 ("Functions of Nature", part A of this thesis).
From these case studies, and comments received since the publication of the book, it can be concluded that the general approach proved to be very useful. To discuss some methodological aspects and the most important application possibilities of the proposed function-evaluationsystem in further detail an additional chapter was written which forms part B) of this thesis.

Environmental characteristics and parameters
An important issue concerning the ecological assessment of environmental functions is the relation between functions and environmental characteristics. The capacity of a given ecosystem to provide certain goods and services depends on its environmental characteristics (natural processes and components). 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, in this thesis it has been attempted to develop a general checklist of parameters (derived from environmental characteristics) that may be used to assess the contribution of a given ecosystem to certain environmental functions, and Appendix 1 (of part A) lists 65 environmental parameters.
A problem in finding the most suitable combination of environmental functions and assessment parameters is the fact that many functions are influenced by more than one parameter and that one parameter may influence more than one function. This interrelatedness of functions and parameters clearly illustrates why changes in a given environmental factor (like vegetation structure or air quality) usually affect several functions which, in turn, may cause changes in other environmental characteristics leading to a chain of reactions and sometimes the degradation of the entire system. This underlines the importance of a "holistic" approach to understanding the functioning of ecosystems and the need to increase research efforts in the field of systems ecology and other related disciplines.
Apart from the scientific difficulty to identify the most important rèlations between environmental characteristics and functions, there is also a time-constraint. The data needed to quantify the most essential variables should be

collected within a reasonable time-period. A choice must therefore be made, and selecting the appropriate parameters and criteria for assessing and evaluating the function-performance of a given ecosystem or (natural) area is essential to the practical application of the proposed function-evaluation system. A first attempt has been made in this thesis but this is one of the topics where further research is needed. Eventually, separate handbooks should be written with guidelines to assess the functions and benefits of the major types of ecosystems and landscapes in a comprehensive and systematic manner.

Sustainable use of environmental functions
Another important factor to take into account is that the benefits from environmental functions should be determined for sustainable use levels. For certain functions, like resources provided by wild plants and animals, it is in principle always possible to determine sustainable use levels. The carrying capacity for regulation functions, such as the purification capacity of wetlands for organic waste and nutrients, is more difficult to calculate and depends, among others on the degree to which the use leads to (ir)reversible changes to the life communities. Standards should therefore be set concerning the physical, chemical and biological minimum requirements to maintain these functions, and thereby a healthy ecosystem.
A special problem is presented by non-renewable goods and services, such as the use of space (for carrier functions) and the extraction of minerals and fossil fuels. For these type of functions, physical limits will have to be set to find a balance between the present function use and the interests of future generations, both in terms of space (i.e. the competition for land between agriculture and nature conservation) and time (i.e. maximum extraction rates for certain minerals to maintain a reserve for future generations).
In chapter B-2, the problem of actual and potential competition between function use is discussed in more detail, as well as several other issues related to the ecological assessment of environmental functions such as the problem of scale and classification of environmental functions, the ranking order and completeness of the function list.

Socio-economic valuation of environmental functions
Once the most important functions of a given ecosystem or natural area are known, their full socio-economic importance (based on sustainable use levels) can be assessed. As this thesis has attempted to show, human welfare and the quality of life depend on the availability of environmental goods and services in many ways. The 37 main functions cover a wide range of ecological, social, cultural, scientific and economic values, in addition to the intrinsic values that many people attach to nature and wildlife. In chapter B-3.1, a brief discussion is devoted to these values and their relation to the various function-categories.

Monetary valuation
A further step in the evaluation procedure is represented by attempts to measure human preferences for a given function by quantifying these values in monetary terms (B-3.2). For some functions and types of values this is relatively

simple and can be directly related to market prices. For other functions, more or less complicated shadow-pricing techniques are necessary to arrive at a monetary value. Since monetary valuation of environmental functions is a difficult and somewhat controversial procedure, an important aspect of the discussion in this part of the thesis is devoted to two questions: (a) *should* nature be quantified in economic/monetary terms (on benefits, drawbacks and ethical considerations) and (b) *can* nature be quantified in monetary terms. From the case studies discussed in this thesis it is clear that for many functions it is, indeed, possible to quantify their socio-economic value in monetary terms (and that this monetary value is often considerable). On the other hand, there are some functions and values for which monetary valuation is more difficult. With the help of shadow pricing techniques it is in theory possible to arrive at a monetary value for all functions but for some information functions such as the spiritual value of nature, it can be questioned whether the monetary figures found provide useful (realistic) information. Objections against monetary valuation of environmental functions therefore mainly relate to attempts to measure the intrinsic (ethical) value placed on nature and wildlife.
Yet, decisions will have to be made and a certain "ordering system" for measuring human preferences is essential and unavoidable. Consciously or sub-consciously, preferences are ordered in any decision-making situation and it is therefore better to provide as much information as possible on the costs and benefits of the various planning alternatives, including monetary information, than to take decisions based on incomplete information on the economic importance of nature, as is now often the case.

An important argument in favour of monetary valuation of environmental benefits is the fact that the economic value of environmental goods and services is still gravely underestimated or completely ignored in most financial appraisals in planning and decision-making. As a result there has been, and still is, a strong market incentive for destructive use of natural ecosystems (with logging and widespread clearing of primary forest as a sad and notorious example).
Assessments like the method presented in this thesis can help to increase awareness about the many functions and great socio-economic value of intact natural ecosystems and stimulate investments in their conservation and sustainable utilization. Already after two years, income from sustainable use of some products provided by tropical rainforests, for example, is greater than that from clear-cut and agricultural profits combined (see chapter A-4.1). Not only for tropical moist forests, but also for most other natural ecosystems, it can be stated that their conservation and sustainable utilization is usually more beneficial, also in economic terms, than non-sustainable use of only one or two functions. Natural ecosystems should therefore be seen as a productive natural capital which could provide many goods and services indefinitely if conserved and used in a sustainable manner.

Capital value

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 economic "net-present value" of the area or ecosystem concerned. In this thesis, it is argued that the annual benefits should be seen as the *interest* on the natural capital (i.e. the ecosystem) which provided these functions. Assuming an average interest rate of 5%, the capital value of the conservation and sustainable utilization of all functions of the three case study areas presented in part A (chapter 4) of this thesis 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.
Incorporating information on the capital value of natural ecosystems could help to prevent further destruction and, instead, stimulate investments in maintaining and enhancing this natural capital. Thus, we should live of the interest of this natural capital as much as possible, not reduce it at the expense of our children and grandchildren.

Environmental planning and decision-making
The last part of this thesis (B-4) is devoted to a discussion of the various application possibilities of function-evaluation as a tool in environmental planning, management and decision-making. An important conclusion which can be drawn from the previous chapters is that better information on the (economic) value of natural areas and ecological processes alone is not enough. Somehow, ecological information must be structurally integrated in the planning and decision-making process, otherwise solving most environmental problems will prove difficult, if not impossible.

Project evaluation
Early in the planning process, it is important to obtain a clear insight into the environmental trade-offs involved. Thus far, conventional environmental impact assessment (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, including the socio-economic consequences.
Economic and monetary information on environmental functions and hazards is also important to give nature a more correct "weight" in decision-making instruments and project evaluation techniques such as cost-benefit analysis and multi-criteria analysis. Many environmental goods and services are still considered to be "free" and losses of environmental functions are seen as "external effects". Since many functions of natural ecosystems cannot (as yet) be expressed in market values, traditional cost-benefit analysis inadequately reflect the true environmental and socio-economic value of natural resources and ecosystems.
The concept of environmental functions, and the function-evaluation method described in this book, can help planners and decision-makers to better include the "free services" and "external effects" in the project evaluation and to obtain better insight into all the costs and benefits involved. Since the publication of

part A of this thesis in 1992, it has been used for this purpose by various authors (e.g. Bouwhuis, 1993, Crabbe, 1992, v.Pelt, 1993, Rees & Wackernagel, 1993). From these, and other, studies, it can be concluded that function evaluation provides a useful basis in various phases of the planning process. A critical point, however, is the fact that much information that is needed to describe the relevant functions is still fragmentary or not available at all. Possibly the amount of information needed could be condensed further once proper indicators are found to describe the availability and maximum sustainable use level of the various functions. Once 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.

Environmental or ecological economics

Another important field of application is the use of the function-approach in the developing discipline of environmental or ecological economics, notably for ecological pricing and adjustment of national accounting systems.

Ecological pricing

The current market price of many products does not adequately reflect the true environmental costs involved in the production and distribution of these products. Environmental damage caused by the extraction of natural resources needed, and the environmental pollution caused by the production and distribution of a given product are usually not accounted for in the price of the product. That these "external effects" do have a price-tag is, however, clear from the enormous amounts of (tax)money used to mitigate the environmental and socio-economic consequences of air, soil and water pollution, erosion, etc. 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. As long as environmental friendly products (like biologically grown agricultural products) are more expensive in the store than their chemically treated counterparts, their market share will remain marginal.

The integration of the costs of the loss of environmental functions in <u>all</u> human activities through adjustment of taxing and pricing system would, in a way, bring man closer to nature again. Realistic ecological prices make both producers and consumers more aware of the links between human behaviour and the quality of the environment. It would reverse the current economic (mo-netary) incentives which stimulate the squandering of space and resources for the benefit of a few at the expense of many, including future generations, and discourages or even punishes environmental friendly behaviour. Environmental pollution and degradation can therefore only be stopped with proper economic incentives through the application of environmental pricing and taxing. A shift in taxes on labour to the use of natural resources and environmental space would be an important step in the right direction.

National accounting
The use of Gross National Product (GNP) as a welfare measure increasingly receives criticism because it only measures the "goods" but not the "bads" that are associated with the economic production process. To determine whether an economy is evolving sustainable, 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 economic values. By including both the goods and services provided by the economic ("grey") capital and the natural ("green") capital as separate entries into national accounting systems, it will become clear that an increase of the grey capital, especially in the market sector, often goes at the expense of the green capital. The net-effect of many so-called development activities on human welfare is thereby greatly reduced, and may sometimes even be negative. 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.

Investing in natural capital
Information on the economic value of the natural environment is also useful for the development of instruments that provide structural support for the conservation and sustainable utilization of nature and natural resources. In addition to the market-instrument (see above) the "polluter-pays-principle" should be applied more structurally in cases where economic activities cause incidental or chronic damage to the environment.
With the function-approach, it is possible to make a systematic review of the consequences of environmental damage by human actions. In addition to the repair- or clean-up costs, a certain sum should be calculated for the loss of environmental functions and values which could be seen as a type of compensation cost. This compensation-sum could be used to finance longer-term conservation activities in the area in question or pay for the (re)creation of substitute areas. To manage these compensation fees, payments for irreparable damages to the environment should be deposited in a type of "environmental damage fund" (or 'Ecofund').
Also for chronic impacts on the natural environment, like the occupation of space for infrastructural works like roads and housing, a certain compensation payment should be required. Depending on the environmental values lost, a certain sum should be charged for each m^2 occupied (or each m^3 of waste discharged). The funds raised in this manner should be deposited in the aforementioned Ecofund to pay for compensation or mitigation measures and to stimulate structural investments in the maintenance and the re-creation of natural capital.

Environmental education and awareness
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 of natural ecosystems to human society, and thereby for measures needed to reduce and prevent further environmental deterioration. In order to structurally integrate environmental constraints in economic evaluation and accounting procedures a constructive dialogue between ecologists and economists, and others involved in planning and decision-making, is essential.
A satisfying method to quantify the importance of environmental functions to human society may never be found, but the discussion could bring ecologists and economists somewhat closer in their approaches to solving environmental problems. 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 (environmental) economic accounting procedures which integrate 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.

As is the case with most research projects, many questions are answered but at the same time new ones arise. 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. I hope this thesis can contribute to this difficult task but realise that an evaluation method of this scope and complexity will surely need continuous updating. I therefore welcome constructive criticism to improve the proposed methodology and see this thesis not only as the end of a research period but also as the beginning (or better continuation) of a dialogue to share ideas how to bring human activities more in harmony with environmental constraints.

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SAMENVATTING EN CONCLUSIES

(Evaluatie van milieu-functies als hulpmiddel bij ruimtelijke ordening, milieubeleid en -beheer)

De mens is op vele manieren afhankelijk van het goed functioneren van natuurlijke ecosystemen. Ondanks het groeiende bewustzijn van deze afhankelijkheid gaat de aantasting en vervuiling van het natuurlijk milieu op grote schaal door. Een belangrijke reden hiervoor is het feit dat het belang van de natuur en een gezond leefmilieu nog steeds geen volwaardige plaats inneemt in economische planning en besluitvorming. De structurele onderwaardering van de natuur leidt tot over-exploitatie van grondstoffen en excessief gebruik van het natuurlijk milieu als receptor van menselijk afval met als gevolg vele zogenaamde "externe effecten" zoals vervuiling, erosie, en verlies aan natuurwaarden. Langzamerhand wordt duidelijk dat deze "externe effecten" van het economisch produktieproces niet zo "extern" zijn als we zouden willen en de gevolgen van niet-duurzame ontwikkeling in het verleden kosten ons nu miljarden aan pogingen om de aangerichte schade, zowel aan het natuurlijk milieu als aan onze gezondheid, te herstellen of te neutraliseren, voor zover dit (nog) mogelijk is.

Om het economisch ontwikkelingsproces in een meer duurzame richting te buigen zouden milieu-overwegingen meer structureel in planning en besluitvorming ingepast moeten worden. Een belangrijk probleem daarbij is de vertaling van ecologische gegevens in bruikbare informatie voor planners en besluitvormers. De toepassing van huidige waarderings- en afwegingsmethoden in het besluitvormingsproces, zoals milieu-effect rapportage en kosten-baten analyses, geven onvoldoende rekenschap van de werkelijke ecologische en sociaal-economische betekenis van natuurlijke ecosystemen, en de 'goederen en diensten" die zij leveren.
Een belangrijke doelstelling van dit proefschrift is daarom, bij te dragen aan de ontwikkeling van methoden die ecologische gegevens meer objectief en systematisch kunnen vertalen in bruikbare informatie voor het besluitvormingsproces ten behoeve van milieu-beleid en beheer.

Ecologische evaluatie van milieu-functies
Om ecologische informatie beter in planning en besluitvorming in te kunnen passen is betere kennis omtrent de vele baten van de natuur essentieel. Voor dit doel is het concept van "milieu-functie" nuttig. In dit proefschrift zijn milieue-functies gedefinieerd als "het vermogen van natuurlijke processen voor het leveren van goederen en diensten die bijdragen aan het menselijk welzijn, direct of indirect". Met behulp van het functie-evaluatiesysteem als beschreven in dit proefschrift is het mogelijk de ecologische complexiteit van natuurlijke processen en componenten te vertalen in een relatief gering aantal milieu-functies.
In totaal worden in dit proefschrift 37 milieu-functies onderkend die over 4 hoofd-groepen verdeeld worden: (1) *regulatie functies*: de bijdrage van natuurlijke en semi-natuurlijke ecosystemen aan de regulatie van essentiële ecologische

processen en, daardoor, aan de handhaving van een gezond leefmilieu, (2) *draagfuncties*: de "leverantie" van ruimte en een geschikt substraat voor menselijke activiteiten zoals (duurzame) landbouw en recreatie, (3) *produktie functies*: de leverantie van natuurlijke grondstoffen en hulpbronnen voor, bijvoorbeeld, voedsel, medicijnen, bouwmateriaal, en energie, en (4) *informatie functies*: het belang van natuurlijke ecosystemen voor geestelijke ontplooiing, als inspiratie-bron voor kunst en wetenschap en de esthetische en ethische natuurbeleving.
Met behulp van deze lijst van 37 functies is het in principe mogelijk alle "baten" van het natuurlijk milieu voor de mens op een complete en systematische manier te beschrijven. Alhoewel de nadruk in dit proefschrift ligt op een analyse van de functies van natuurlijke ecosystemen kan de methode ook toegepast worden op semi-natuurlijke en zelfs gecultiveerde landschappen.
Om het voorgestelde functie-evaluatiesysteem in de praktijk te toetsen zijn een aantal case studies uitgevoerd waaronder een analyse van de functies en waarden van het Nationale Park "De Hoge Veluwe", het Nederlandse deel van de Waddenzee, het Darien National Park (een pre-montaan regenwoud op de grens tussen Panama en Colombia) en Galapagos, een groep vulkanische eilanden in de Stille Oceaan, ca 1000 km ten westen van Ecuador. De resultaten van deze case studies, en een algemene beschrijving van de evaluatie-methode zijn in 1992 in boekvorm gepubliceerd ("Functions of Nature", deel A van dit proefschrift). Op grond van deze case studies, en uit de reacties ontvangen sinds de publikatie van het boek, bleek de functie-benadering zeer waardevol en in deel B van dit proefschrift worden een aantal methodologische aspecten, alsmede de belangrijkste toepassingsmogelijkheden nader bediscussieerd.

Milieu-eigenschappen en evaluatie parameters
Een belangrijk aspect m.b.t. de praktische toepasbaarheid van functie-analyse is de relatie tussen milieu-eigenschappen en milieu-functies. Het vermogen van een bepaald (eco)systeem voor het leveren van "goederen en diensten" is afhankelijk van de ecologische eigenschappen (natuurlijke processen en componenten). Omdat de ecologische eigenschappen van ecosystemen van elkaar verschillen zullen ook de functies van regenwouden, estuaria en vulkanische eilanden (deels) verschillend zijn. Toch is in dit proefschrift geprobeerd een algemeen toepasbare lijst van parameters (milieu-eigenschappen) te ontwerpen waarmee het belang van een bepaald ecosysteem voor een bepaalde functie kan worden geanalyseerd. In appendix A-1 is een lijst met 65 verschillende parameters opgenomen en in vier verschillende matrices is de relatie tussen deze parameters en de individuele functies per hoofdgroep aangegeven.
Een probleem bij het vinden van de meest geschikte combinatie van functies en parameters is het feit dat veel functies worden beïnvloed door meerdere parameters en dat één parameter van belang kan zijn voor meerdere functies. Deze verwevenheid van functies en parameters illustreert duidelijk waarom veranderingen in een bepaalde milieu-eigenschap (zoals vegetatie-structuur of luchtkwaliteit) vaak meerdere functies beïnvloeden waardoor omgekeerd weer andere milieu-eigenschappen veranderen zodat een kettingreactie kan optreden welke de volledige degradatie van het systeem tot gevolg kan hebben. De functie-benadering kan helpen bij het inzichtelijk maken van deze

terugkoppelingsmechanismen en onderstreept het belang van systeem-ecologisch onderzoek naar het functioneren van natuurlijke en semi-natuurlijke ecosystemen.
Afgezien van de wetenschappelijke problemen bij het vaststellen van de relatie tussen milieu-eigenschappen en milieu-functies is er ook een tijdsprobleem. Ten behoeve van het besluitvormingsproces moeten de benodigde gegevens voor een analyse van de belangrijkste milieu-functies die daarbij een rol spelen binnen een redelijke termijn beschikbaar zijn. Er moeten daarom keuzes gemaakt worden en de selectie van de belangrijkste parameters voor de functie-beschrijving is van groot belang voor de praktische toepasbaarheid van het voorgestelde functie-evaluatiesysteem. Een eerste aanzet is in dit proefschrift gegeven maar dit is één van de onderwerpen waar verder onderzoek nodig is.

Duurzaam gebruik van milieu-functies
Een belangrijk aspect bij de analyse van milieu-functies is, dat het gebruik gebaseerd moet zijn op duurzaamheid. Voor bepaalde functies, zoals hulpbronnen van biotische oorsprong (wilde planten en dieren) is het in principe altijd mogelijk duurzame gebruiksnivo's aan te geven. De draagkracht van een systeem voor het gebruik van regulatie functies zoals de zuiveringsfunctie van wetlands voor organisch afval en nutrienten is moeilijker te bepalen en hangt o.a. af van de mate waarin het gebruik tot (on)omkeerbare veranderingen leidt in de natuurlijke levensgemeenschappen. Er moeten daarom standaards ontwikkeld worden voor de fysische, chemische en biologische randvoorwaarden voor het behoud van milieu-functies, en daarmee het behoud van "gezonde" ecosystemen.
Een apart probleem vormen de niet-hernieuwbare goederen en diensten zoals het gebruik van ruimte (voor draagfuncties) en de uitputting van minerale en fossiele grondstoffen. Aan het gebruik van dergelijke functies moeten fysieke limieten gesteld worden om een zeker evenwicht te vinden tussen de belangen van huidige en toekomstige generaties.

Sociaal-economische waardering van milieu-functies
Als de functies van een bepaald ecosysteem of natuurgebied bekend zijn, kan geprobeerd worden het economisch belang van deze functies, gebaseerd op duurzaam gebruik, te bepalen. In dit proefschrift is getracht te demonstreren dat het menselijke welzijn op vele manieren afhangt van de beschikbaarheid van milieu-functies en dat, derhalve, aan deze functies vele verschillende waarden toegekend kunnen worden. Naast de intrinsieke waarde die veel mensen aan "de" natuur toekennen, kunnen nog ecologische, sociale, culturele, wetenschappelijke en economische waarden onderscheiden worden. In hoofdstuk B-3.1 worden deze waarden nader beschreven alsmede hun relatie tot de diverse functie-categorieën.

Monetaire waardering
Na het onderscheiden van milieu-functies en het toekennen van waarden daaraan, is een volgende stap in de evaluatie-procedure het meten van preferenties voor de beschikbaarheid van de functies. In de economie wordt daartoe geld als een belangrijke indicator gebruikt. Voor sommige functies is het vaststellen

van een monetaire waarde relatief eenvoudig en kan direct aan markt-waarden gerelateerd worden. Voor andere functies zijn meer of minder gecompliceerde, zogenaamde schaduwprijs methoden nodig om tot een geldswaarde te komen.
Aangezien monetaire waardering van milieu-functies een moeilijke en enigszins controversiële procedure is, wordt in dit deel van het proefschrift nader stilgestaan bij twee vragen: (a) *moet* de waarde van de natuur in geld uitgedrukt worden (over de voor- en nadelen van monetaire waardering, inclusief de ethische aspecten), en (b) *kan* de waarde van de natuur in geld uitgedrukt worden (over methodische aspecten). Uit de case studies die in het proefschrift beschreven staan kan afgeleid worden dat het, in principe, mogelijk is de sociaal-economische betekenis van milieu-functies in geld uit te drukken, en dat deze geldswaarde vaak aanzienlijk is. Aan de andere kant blijkt dat er enkele functies en waarden zijn waarvoor monetaire waardering moeilijk is. Met behulp van schaduwprijs-methoden is het in theorie mogelijk voor alle functies tot een geldswaarde te komen maar de vraag is in hoeverre de gevonden monetaire indicatie, bijvoorbeeld voor de intrinsieke waarde die veel mensen aan de natuur toe kennen of van spirituele natuurbeleving, iets zegt over de werkelijke "waarde" voor de betreffende persoon of gemeenschap. De relativiteit van geld als indicator voor het meten van preferenties geldt overigens niet alleen voor milieufuncties maar ook voor vele door de mens geproduceerde goederen en diensten. Toch moeten er (dagelijks) beslissingen genomen worden en een zekere "ordening" van menselijke voorkeuren is noodzakelijk en onvermijdbaar. Bewust of onbewust worden er voortdurend afwegingen gemaakt en het is daarom beter zoveel mogelijk informatie aan te leveren over de werkelijke kosten en baten van bepaalde plan-alternatieven, inclusief de monetaire consequenties, dan besluiten te nemen op grond van onvolledige informatie over de economische (en monetaire) betekenis van de natuur, zoals nu vaak het geval is.
Een belangrijk argument ten gunste van monetaire waardering van milieufuncties is het feit dat de economische betekenis van natuurlijke goederen en diensten nog steeds sterk wordt onderschat (of genegeerd), in economische analyses en daarom ook in het plannings- en besluitvormingsproces. Het gevolg daarvan is dat er nog steeds een sterke marktprikkel is voor niet-duurzaam gebruik van natuurlijke ecosystemen, met de kaalkap van oerbossen t.b.v. houtextractie (zowel in de tropen als in andere regio's) als een triest en algemeen bekend voorbeeld. Analyses zoals de functie-evaluatie methode in dit proefschrift kunnen ertoe bijdragen dat het bewustzijn over de grote economische betekenis van het behoud en duurzaam gebruik van de functies van intakte ecosystemen toeneemt. Voor tropische regenwouden, bijvoorbeeld, is berekend dat al na twee jaar de baten van duurzaam gebruik van de vele produkten (en "diensten" zoals erosie-preventie, water opvang en klimaatregulatie) van het intakte bos groter is dan de gezamenlijke opbrengst van kaalkap en (meestal niet-duurzame) landbouw (zie hoofdstuk A-4.1).
Niet alleen voor tropische regenwouden, maar ook voor veel andere natuurlijke ecosystemen kan gesteld worden dat bescherming en duurzaam gebruik van alle functies van het systeem niet alleen ecologisch maar vaak ook economisch zinvoller is dan de over-exploitatie van slechts enkele functies.

Kapitale waarde
Mits duurzaam gebruikt, kunnen natuurlijke ecosystemen goederen en diensten voor onbepaalde tijd blijven leveren. Om het economisch belang van een betreffend ecosysteem of natuurgebied goed weer te geven zouden daarom de toekomstige baten van de functies verdisconteerd moeten worden naar vandaag. Om de totale kapitale, of "net present value" van een betreffend ecosysteem te bepalen zou men ook kunnen stellen dat de jaarlijkse monetaire baten gezien moeten worden als de "rente" op het natuurlijk kapitaal. Een belangrijk aspect bij de bepaling van de kapitale waarde van milieufuncties is de keuze van de discount rate of rentevoet en in hoofdstuk B-3.4 wordt dit probleem nader besproken. Voor de case studies die in hoofdstuk A-4 beschreven staan is berekend wat de kapitale waarde zou zijn bij een rentevoet van 5%. Voor de Galapagos eilanden komt dit op ongeveer 2,400 US$/ha, voor het Darien regenwoud op 10,000 US$/ha, en voor de Nederlandse Waddenzee op 120,000 US$/ha. Ter vergelijk: nog niet zo lang geleden verkocht Bolivia vele hectaren tropisch regenwoud voor nog geen 50 US$/ha voor kaalkap door een internationale houtmaatschappij. Alhoewel dit proefschrift de betrekkelijkheid van monetaire waarden benadrukt, en men deze kapitale waarden met de nodige voorzichtigheid moet interpreteren en gebruiken, is het duidelijk dat informatie over de werkelijke economische betekenis van het "natuurlijke kapitaal" in veel gevallen kan helpen om verspilling en verdere vernietiging te voorkomen. Het zou ons aan kunnen zetten om meer in het behoud en de vergroting van dit kapitaal te investeren en om zoveel mogelijk van de "rente" te leven, in plaats van het te verbruiken op kosten van onze kinderen en kleinkinderen.

Milieubeleid en besluitvorming
Het laatste deel van dit proefschrift (B-4) is gewijd aan een discussie over een aantal toepassingsmogelijkheden van het voorgestelde functie-evaluatiesysteem als een instrument in milieubeleid, milieubeheer en economische planning en besluitvorming. Een belangrijke conclusie van het onderzoek dat ten grondslag ligt aan dit proefschrift is dat het niet voldoende is om betere informatie over de functies en economische (en monetaire) betekenis van natuurlijke ecosystemen en ecologische processen aan te leveren. Veel milieuproblemen zullen alleen opgelost kunnen worden als deze informatie structureel wordt ingepast in economische instrumenten en in het plannings- en besluitvormingsproces. Een aantal opties worden navolgend kort besproken.

Project-evaluatie
Vroeg in het planningsproces van een voorgenomen project is het van belang duidelijk inzicht te krijgen in de milieu-kosten en baten. De "traditionele" milieu-effectrapportage, voor zover die toegepast wordt, is meestal beperkt tot een analyse van de eventuele directe milieu-effecten van het project. Het zou echter beter zijn als ook de indirecte effecten, in de vorm van veranderingen in milieufuncties, in de analyse betrokken zouden worden aangezien veranderingen in een bepaalde milieu-eigenschap vaak vele neveneffecten kunnen hebben die misschien niet direct zichtbaar zijn maar op termijn wel aanzienlijke milieurisico's tot gevolg kunnen hebben.

Aangezien vele functies van natuurlijke ecosystemen nog steeds niet in marktwaarden kunnen worden uitgedrukt, geven kosten-baten analyses een onvolledig beeld van de werkelijke ecologische en economische consequenties van een gepland project of ingreep. Betere ecologische én economische informatie over milieu-functies en -risico's is van belang om "de" natuur meer gewicht te geven in besluitvormingsinstrumenten zoals kosten-baten analyses en multi-criteria analyse. Het functie-concept, en de voorgestelde functie-evaluatiemethode kan behulpzaam zijn bij het inzichtelijk maken van de "gratis diensten" van de natuur en de "externe milieu-effecten" in project evaluatie en kosten-baten analyses. Sinds de publikatie van deel A van dit proefschrift in 1992 is het voor dit doel gebruikt door verschillende auteurs (o.a. Bouwhuis, 1993, Crabbe, 1992, v.Pelt, 1993, en Wackernagel,et.al. 1993). In hoofdstuk B-4.1 worden deze toepassingen nader besproken waaruit geconcludeerd kan worden dat de functie-benadering nuttige diensten kan bewijzen in diverse stadia van het planningsproces. Een probleem daarbij is nog wel dat veel informatie die nodig is voor een goede functie-analyse nog zeer fragmentarisch is en soms in het geheel niet voorhanden is. De benodigde hoeveelheid informatie zou wellicht nog verder gecondenseerd kunnen worden door het vinden van geschikte indicatoren voor het beschrijven van de beschikbaarheid en het duurzaam gebruiksnivo van milieufuncties. Met behulp van goede richtlijnen voor de evaluatie van de functies en waarden van de belangrijkste ecosysteem complexen moet het mogelijk zijn de benodigde informatie voor project evaluatie en draagkracht studies in een relatief korte tijd te verkrijgen.

Milieu- of ecologische economie

Een ander belangrijk toepassingsgebied is het gebruik van het functie-concept in de steeds belangrijker wordende discipline van de milieu- (of ecologische) economie. Te denken valt daarbij met name aan de vaststelling van "ecologische prijzen" en de aanpassing van nationale welvaartsindicatoren.

Ecologische prijzen

De huidige marktprijs van veel produkten is geen weerspiegeling van de werkelijke milieu-kosten die ontstaan bij de produktie, distributie en het verbruik. Dat deze milieu-kosten vaak aanzienlijk zijn blijkt uit het enorme bedrag dat jaarlijks uit algemene (belasting)middelen betaald wordt om de ecologische en sociaal-economische effecten van lucht-, water- en bodem-vervuiling tegen te gaan. Om het economisch plannings- en besluitvormingsproces meer ontvankelijk te maken voor milieu-aspecten is het essentieel dat er wegen gevonden worden om de kosten van deze "externe effecten" en het gratis gebruik van milieu-functies te internaliseren in economische methoden voor prijsberekening van álle goederen en diensten. Zolang milieuvriendelijke (of minder milieu belastende) produkten zoals onbespoten landbouwprodukten duurder zijn dan de chemisch behandelde alternatieven zal hun marktaandeel marginaal blijven. De huidige economische prikkels stimuleren de verspilling van ruimte en natuurlijke hulpbronnen, op kosten van toekomstige generaties, en ontmoedigen milieu-vriendelijk gedrag. De vervuiling en aantasting van het natuurlijk milieu kan alleen gestopt worden door het doorberekenen van de wérkelijke kosten van het gebruik (en verlies) van milieufuncties door het economisch produktieproces. Een verschuiving in de belastingdruk van arbeid naar het gebruik van natuurlijke hulpbronnen en andere milieufuncties zou een belangrijke stap in de goede richting zijn.

Nationale welvaartsindicatoren
Het gebruik van het Bruto Nationaal Produkt (BNP) als de belangrijkste maatstaf voor het meten van de collectieve welvaart staat steeds meer bloot aan kritiek, o.a. omdat het voornamelijk de "baten" maar niet de "kosten" van het economisch produktieproces meetelt. Om vast te stellen of een economie zich duur-zaam ontwikkelt zou "het" milieu nadrukkelijker in het BNP opgenomen moeten worden door de kosten van milieudegradatie, milieuschade en herstelmaatregelen, ervan af te trekken. Hiertoe moeten speciale "stock and flow accounts" voor natuurlijke hulpbronnen geconstrueerd worden, zowel in fysieke als economische eenheden. Door zowel de goederen en diensten van het economische ("grijze") als het natuurlijke ("groene") kapitaal als aparte onderdelen in nationale welvaartsberekingen op te nemen zal in veel gevallen duidelijk worden dat een toename van het grijze kapitaal vaak ten koste gaat van de beschikbaarheid en kwaliteit van het groene kapitaal. Het netto-effect van veel ontwikkelingsprojecten wordt daardoor sterk verminderd, en is soms zelfs negatief. Er is daarom een dringende noodzaak om traditionele economische rekenmethoden en welvaartsindicatoren aan te passen en te vervangen door prikkels die meer gericht zijn op behoud en duurzaam gebruik van het natuurlijk milieu.

Investeren in "natuurlijk kapitaal"
Informatie over de economische betekenis van natuurlijke ecosystemen is ook van belang voor de ontwikkeling van instrumenten ter bevordering van structurele investeringen in het behoud en duurzaam gebruik van natuur en natuurlijke hulpbronnen. Met behulp van functie-analyse kan een completer inzicht verkregen worden in de vele directe en indirecte effecten van het menselijk handelen. Dit maakt het eenvoudiger om het principe "de vervuiler-betaalt" structureler en consequenter toe te passen, zowel in het geval van incidentele vervuiling (door ongelukken e.d.) als de meer sluipende chronische vervuiling en aantasting van het milieu. In aanvulling op de directe kosten van schoonmaak en herstel (voor zover dit mogelijk is) zou een zeker "compensatie-bedrag" berekend moeten worden, afhankelijk van de mate waarin milieu-functies en waarden aangetast worden. Dit compensatie-bedrag zou gebruikt moeten worden voor lange-termijn maatregelen gericht op herstel of substitutie van de verloren functies (cq het betreffende gebied), en/of voor activiteiten die gericht zijn op voorkoming van toekomstige schade. Ditzelfde principe zou toegepast kunnen worden op het gebruik van niet-vernieuwbare hulpbronnen (voor de ontwikkeling van, liefst duurzame, alternatieven) en voor het structurele ruimte-beslag door infrastrukturele werken zoals wegen en gebouwen. Afhankelijk van de mate waarin beslag gelegd wordt op de "milieugebruiksruimte" (zowel in de vorm van vervuiling als gebruik van ruimte en grondstoffen) zou een zeker bedrag in rekening gebracht moeten worden. Deze compensatie-gelden zouden in een soort "milieu-schade fonds" of "eco-fonds" gestort moeten worden van waaruit compenserende maatregelen

gefinancierd kunnen worden, alsmede structurele investeringen gericht op behoud en herstel van het natuurlijk kapitaal.

Milieu-educatie en bewustmaking
Beter inzicht in de vele functies en waarden van het natuurlijk milieu kan helpen om meer bewustzijn en begrip te genereren voor maatregelen gericht op het terugdringen van de nog steeds voortschrijdende milieudegradatie. Om milieu-overwegingen meer structureel in economische berekingssmethoden te integreren is een constructieve dialoog tussen ecologen en economen, en vele anderen betrokken bij het plannings- en besluitvormingsproces, essentieel. Een bevredigende methode voor de bepaling van de economische (en monetaire) betekenis van milieu-functies voor de mens zal wellicht nooit gevonden worden, maar de discussie kan er wel toe bijdragen dat het de vele belangengroeperingen wat nader tot elkaar brengt. Duurzame ontwikkeling zal pas echt mogelijk worden wanneer ecologische principes een geïntegreerd onderdeel zijn geworden van het economisch plannings- en besluitvormingsproces gebaseerd op het samenvoegen van natuurbehoudsdoelstellingen en economische belangen tot één gezamenlijk doel: behoud en duurzaam gebruik van de functies van natuurlijke en semi-natuurlijke ecosystemen.

Zoals het geval is met vele onderzoeksprojecten worden een aantal vragen beantwoord maar tegelijkertijd komen nieuwe vragen naar boven. Om te pogen de veelheid aan functionele betrekkingen tussen de mens en het natuurlijk milieu systematisch te beschrijven en in te passen in een praktisch en algemeen toepasbaar evaluatiesysteem is een gewaagde onderneming. Ik hoop dat dit proefschrift een bijdrage levert aan deze moeilijke opgaaf en ben mij ervan bewust dat de gepresenteerde methode zich goed leent voor regelmatige aanpassing aan actuele ontwikkelingen en nieuwe inzichten.
Ik stel constructieve kritiek en suggesties voor verbetering daarom zeer op prijs en zou dit proefschrift niet alleen willen zien als de afsluiting van een onderzoeksperiode maar tevens als het begin (of beter: voortzetting) van een dialoog gericht op het uitwisselen van ideeën hoe het menselijk handelen meer in harmonie gebracht kan worden met de beperkingen (en mogelijkheden) van het natuurlijk milieu.

CURRICULUM VITAE

Rudolf Steven de Groot was born in Voorburg (The Netherlands) in March 1955 and began his study in Biology at the University of Utrecht in 1972. He specialized in ecology with as main interests landscape ecology and animal ecology. MSc-projects were carried out for the Universities of Wageningen (under supervision of Prof.dr. M.F. Mörzer Bruyns), Groningen (Prof.dr. R. Drenth), and Utrecht (Prof.dr. A.M. Vôute). During his MSc-education, he spent almost 2 years in the Galapagos Islands, Ecuador (from August 1978 to July 1980) where he became exposed to nature conservation "in the field"; the first year as a tour guide, the second year while studying the ecological differentiation and conservation of the owls in Galapagos, one of his MSc-projects.
Upon his return to the Netherlands he obtained his masters degree in 1981 (cum laude) and, largely as a result of his experiences in the Galapagos Islands, started a project on the development of a methodology for assessing the ecological and socio-economic importance of natural ecosystems. This research was carried out as a guest associate of the Nature Conservation Dept. of the Agricultural University Wageningen under supervision of Prof.dr. C.W. Stortenbeker. This project was formally completed with the publication of the book "Functions of Nature" in May 1992. This book, together with other publications and presentations, forms the basis for his PhD-thesis.

Apart from his work in the field of environmental evaluation, he became interested in the issue of climate change in 1987, mainly as a result of his participation in the Young Scientists Summer Programme of the International Institute for Applied Systems Analysis (IIASA) in Laxenburg, Austria. In 1988 he was invited to participate in the scientific and organisational preparations for an international conference on assessing the landscape ecological impact of climate change on European ecosystems which was held in December 1989 in Lunteren, the Netherlands. After completing the proceedings for this conference in 1990, he, together with Prof. Stortenbeker, initiated a survey among the departments of the Wageningen Agricultural University to investigate interest and support for the formation of a working group on research related to the enhanced greenhouse effect and climate change. This initiative led to the provisional establishment of the Climate Change Research Center in 1991 with de Groot as coordinator. This Center merged formally in 1993 with the Center for Environment Studies into the Center for Environment and Climate Studies where he continued to work as (part-time) coordinator of the climate section. Within the "climate issue" his main research interest lies with the possible consequences of climate change for the conservation of natural ecosystems and maintenance of biodiversity in Europe. Since 1990 he is coordinating an international Working Group on Landscape-ecological Impact of Climate Change (LICC).

Parallel to his activities in the field of climate change, de Groot continued working on his function-evaluation research. He carried out various assignments on the application of the function-concept to issues related to conservation and (sustainable) development, and from 1990 - 1993 he chaired an international Expert Panel on Environmental Evaluation of the Commission on Environmental Strategy and Planning of the IUCN (World Conservation Union).

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Shortly before his death at the age of 80, Sir Peter Scott gave permission to use his sketch of the Bewick's swans, Romeo and M'cJuliet, to adorn the cover of this book.

Sir Peter Scott was a man of remarkable talents and a founding father of the global nature conservation movement. As a distinguished painter, his work transmitted his dedication to the natural world, not only for its beauty and capacity to inspire science and the arts, but also because nature is the very foundation of human life.
His love of waterfowl and his concern for their protection led him to found the Wildfowl and Wetland Trust at Slimbridge. Here, Bewick's swans 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. Although she should have been named Juliet, because of a particular bill-pattern she was obliged to bear the prefix Mac.
One may think of the tundra as an ecosystem of little or no value. Yet, each year Romeo and M'cJuliet manage to find their way across 2600 miles carrying the message that even such inconspicuous ecosystems have an important function in maintaining the natural balance and biological diversity.

The continued survival of the Bewick's swans is, in a way, an indication of the quality of life on earth, which is what this book is all about. To stress this message and in honour to Sir Peter Scott, Romeo and M'cJuliet were choosen to appear on the cover of this book.

H.