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Economics and Ecosystems

Efficiency, Sustainability and Equity in Ecosystem Management

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Preface

This book shows how the concepts of economic efficiency, sustainability and equity (in other words: people–planet–profit) can be applied in ecosystem management. The book provides an overview of the three concepts, presents a framework for modelling the efficiency, sustainability and equity of ecosystem management, and contains three case studies that illustrate the framework. It also examines how complex ecosystem dynamics, such as thresholds and irreversible responses, influence options for ecosystem management.

The book is based on my PhD dissertation 'Optimising the management of complex dynamic ecosystems: an ecological–economic modelling approach', which I defended in January 2005. The dissertation has been rewritten and updated with the intention of producing a more broadly relevant text, building on the practical experiences with environmental management that I gained as environmental advisor for the FAO/World Bank Investment Centre (1997–2002) and in Shell International (2007–2010).

The book is targeted at students and practitioners with an interest in ecosystem management. The book has a quantitative approach, and provides general formulas for analysing ecosystem dynamics and ecosystem services. The presented modelling framework can be used to quantify the economic efficiency, sustainability and equity of potential ecosystem management options.

I would like to thank Hans-Peter Weikard, Rik Leemans, Ekko van Ierland and Wieteke Willemen, who have reviewed draft chapters. I hope the book will contribute to the design and implementation of enhanced approaches to ecosystem management.

Contents

1. Introduction

1.1 THE CONTEXT

Environmental and natural resources worldwide are under pressure to meet demands for food, fresh water, fibre and energy (e.g. Balmford et al., 2002; Millennium Ecosystem Assessment, 2005). These pressures can be expected to further increase in the coming decades. Global population levels will increase from the current 6.5 billion to some 9 billion in 2050 (medium population scenario, UN, 2003), with a large majority of the increase occurring in developing countries. Growing production and consumption levels, in particular in China and India, will further increase the demand for natural resources. These trends are also reflected in the state of the world's ecosystems. Increasingly, the degradation of ecosystems affects human welfare (Millennium Ecosystem Assessment, 2005).

Hence, there is an urgent need for enhanced management of the remaining ecosystems. Identifying appropriate ecosystem management options requires understanding, among others, the ecological dynamics of ecosystems, the cultural, social and institutional context, and the economic costs and benefits of ecosystem management options. Three criteria are prominent in the evaluation of environmental management options: equity, sustainability and profitability – or, coined slightly differently: people, planet and profit. These three criteria for evaluating management options have now been endorsed by a broad range of actors, including governments, the private sector and NGOs.

Whereas the three criteria have become commonplace in environmental and resource management, their application is often constrained by difficulties in defining and measuring the profitability, sustainability and equity impacts of a policy or project. Assessing environmental management options requires an integrated approach combining insights from, among others, ecology, geography, economics and sociology. Since these disciplines tend to have different conceptual and methodological approaches, their integration is often not straightforward.

In recognition of the need to develop interdisciplinary research and assessment tools in support of environmental management, a number of integrated approaches have been developed, such as integrated (environmental) assessment, human ecology and ecological economics. Among these various approaches, ecological economics may most explicitly aim to integrate ecological and economic approaches in support of ecosystem management (Costanza and Daly, 1987). A key paradigm underlying ecological economics is that, ultimately, the world's natural resource base is finite, and that there is a need to better account for the increasing scarcity of natural resources in decision making (e.g. Boulding, 1966).

1.2 THE PURPOSE OF THIS BOOK

This book is targeted at students and professionals in the field of environmental management. It provides a framework for analysing the economic efficiency, sustainability and equity implications of ecosystem management options. Specifically, the book presents (1) an overview of how the concepts of efficiency, sustainability and equity can be used in relation to ecosystem management; (2) a general framework for the quantitative analysis and modelling of ecosystem management options; and (3) three case studies in which the framework is applied to assess management options for a specific ecosystem.

Specific attention is paid to complex, non-linear responses of ecosystems. Complex dynamics include, for instance, irreversible responses and/or thresholds in ecosystem responses to stress. They have been found to occur in a wide range of ecosystems including lakes, coastal estuaries, forests and rangelands. This book contains a general description of different types of complex ecosystem dynamics, indicates how these dynamics can be included in ecological–economic models, and examines the implications of different types of complex ecosystem dynamics for environmental management.

Around half of the book deals with the modelling of ecosystem management options in three case study sites. The case studies show how the described dynamic systems modelling approach can be applied to analyse the efficiency, sustainability and equity implications of ecosystem management options in a practical setting. The case study sites are, respectively, a hypothetical forest ecosystem, a Dutch wetland (De Wieden) and a semi-arid rangeland in Senegal (the Ferlo). The case studies also illustrate the mathematics that can be used to model ecosystem dynamics and ecosystem services supply.

1.3 GENERAL APPROACH OF THIS BOOK

This book presents a dynamic systems approach for analysing ecosystem management options. It combines insights from ecology, economics and, to some extent, policy studies. Particular topics covered in the book are ecosystem dynamics, ecosystem services analysis and valuation, stakeholder involvement and resource-use optimisation. The approach developed in this book can either be used as an analytical framework, or as a basis for modelling ecology–ecosystem interactions.

The book should be seen as being written in the context of ecological economics rather than environmental economics, even though the valuation approaches applied in the book are grounded in neoclassical welfare economics. Basic valuation approaches, as well as the key pitfalls and limitations of ecosystem valuation, are also briefly discussed. The main aim of the book is to provide guidance on the integrated analysis of efficiency, sustainability and equity aspects in ecosystem management. All three of these aspects provide information required for deciding on ecosystem management options and it is not implied that one of these criteria is, or should be, predominant in ecosystem management.

The book focuses on environmental management at the scale of the ecosystem. An ecosystem can be defined as 'the individuals, species and populations in a spatially defined area, the interactions among them, and those between the organisms and the abiotic environment' (Likens, 1992). Following the interpretation of the Millennium Ecosystem Assessment (2003), ecosystems comprise natural as well as strongly human-influenced systems, including croplands. Ecosystems have also been defined as a 'functional unit' with specific components, hierarchy and processes that distinguish it from other ecosystems. Modelling ecosystem dynamics requires capturing these key components and their interactions (Holling et al., 2002). Following the Millennium Ecosystem Assessment (2003), this book assumes that ecosystems can be identified across a range of spatial and temporal scales, ranging in size from a local fish pond up to the North Atlantic Ocean.

Ecosystem services are a central concept in this book, providing a link between the ecosystem and the economic system. In recent years, a rapidly increasing number of publications has provided frameworks and approaches for analysing and interpreting ecosystem services. In this book, the Millennium Ecosystem Assessment (2003, 2005) provides the main conceptual basis for analysing ecosystem services, with a number of minor deviations according to Hein et al. (2006).

Ecosystem management requires consideration of the impacts of management options on the dynamics and state of the ecosystem and, subsequently, the provision of ecosystem services by the ecosystem. This can only be meaningfully done based on an adequate consideration of the dynamics of the ecosystem – which are only very seldom linear and gradual, and much more often 'complex'. Complex dynamics include irreversible, non-linear and/or stochastic responses of the ecosystem to human and/or ecological drivers (e.g. Holling and Gunderson, 2002). Complex dynamics have been found to be crucial for explaining changes in, among others, freshwater lakes (Larsen et al., 1981; Timms and Moss, 1984; Scheffer, 1998), marine fish stocks (Steele and Henderson, 1984; Steele, 1998), woodlands (Dublin et al., 1990), rangelands (Friedel, 1991), coral reefs (Knowlton, 1992; Nyström et al., 2000) and coastal estuaries (Murray and Parslow, 1999).

The different chapters of this book provide different levels of detail on the concepts of efficiency, sustainability and equity in relation to ecosystem management. A basic description of these three concepts, as well as of ecosystem services and economic valuation of ecosystems, is provided in Chapter 2. Chapter 3 presents a dynamic systems modelling approach that can be used for the quantitative analysis of the economic efficiency, sustainability or equity aspects of ecosystem management options. The approach involves the construction of differential equations to capture ecosystem dynamics and ecosystem services supply in combination with ecosystem service valuation techniques.

Chapter 4 provides a first application of the framework and approach, for a hypothetical forest ecosystem. This chapter also further elaborates on the implications of pursuing efficiency versus sustainability in ecosystem management, as well as related topics such as the Safe Minimum Standard for ecosystem management. Chapter 5 presents a case study that involves pollution control in a specific wetland (De Wieden, the Netherlands), and Chapter 6 analyses efficient stocking rates in a semi-arid rangeland in the Sahel (the Ferlo, Senegal). For both ecosystems, economic efficient management strategies are identified, and sustainability and stakeholder implications of the various management options are discussed. Finally, Chapter 7 provides a general overview of how ecosystem services assessment and the proposed dynamic systems modelling approach can be applied to support environmental management.

2. Ecological–economic concepts

2.1 EFFICIENCY–SUSTAINABILITY–EQUITY

2.1.1 Introduction

In the last decades, a broad consensus has emerged that ecosystem management needs to consider and balance social, economic and environmental criteria (also expressed as people–profit–planet). In general terms, economic efficiency expresses the generation of welfare, based on an optimal use of natural resources and other production factors. Social criteria deal with such aspects as the distribution of welfare among people, and their involvement and representation in decision making. Environmental sustainability expresses, in general terms, whether the use of a natural resource does not exceed the regenerative capacity of that resource and if the resource is maintained at an adequate level to permit future uses.

This section describes these basic concepts of economic efficiency, equity and sustainability in more detail. Clearly, they are not the only criteria for decision making on ecosystem management. For instance, legal and technical criteria will often also determine the design of a project or management strategy. However, the three aforementioned criteria are among the most important ones for ecosystem management. In addition, ecosystem management often involves trade-offs between these criteria, which means that they need to be considered in an integrated manner.

The three concepts are, at times, difficult to apply, and a whole literature is devoted to each of them. This section provides a brief overview, focussing on their general principles and their implications for ecosystem management. In addition, Section 2.1.5 briefly discusses discounting in ecosystem management. Discounting involves the comparison of present and future costs and benefits, and is therefore a crucial element in examining the potential gaps between economic efficient and sustainable ecosystem management. Section 2.1.6 explores market failures and their implications for ecosystem management.

2.1.2 Efficiency in Ecosystem Management

In economics, an allocation of resources is said to satisfy the efficiency criterion if the net benefits from the use of those resources are maximised by that allocation (Tietenberg, 2000). For instance, in the case of reducing pollution in a lake, an efficient reduction of pollution loading involves analysing the economic costs of the pollution as a function of the degree of pollution (e.g. fish mortality), identifying the costs of waste-water treatment, and establishing the amount of pollution loading where the pollution and abatement costs are minimised (and the net benefits of the lake and its uses are maximised). In other words, efficient ecosystem management involves maximising the net economic benefits supplied by the ecosystem, considering both the benefits provided by the ecosystem and the costs of managing the ecosystem.

The ethical basis for assessing efficiency is derived from the Pareto criterion. Following this criterion, *static* economic efficiency implies the following. For some particular initial distribution of property rights, an allocation of resources is efficient if there is no feasible reallocation that can increase any person's utility without decreasing someone else's utility (e.g. Freeman, 1993). Utility indicates the relative satisfaction that a person gains from the consumption of a good or service. Utility can not be empirically observed or measured, and is applied as a relative measure, for instance, to compare the satisfaction levels a person gains from the consumption of different combinations of goods. A central construct of utility is that the utility gained by one additional unit of consumption of a certain good or service (e.g. a piece of chocolate) decreases when the total consumption level of that good or service increases (i.e. decreasing marginal utility). For reasons of simplicity, instead of utility, this book will generally refer to the net benefits of ecosystem management, even though utility is the theoretically more correct measure for analysing the efficiency of ecosystem management options.

There are usually many allocations that satisfy the Pareto criterion. Both Kaldor and Hicks further developed the Pareto approach to identify efficient allocations. According to the criterion proposed by Kaldor, a reallocation is efficient if it is possible for the winners to fully compensate the losers of the reallocation and still leave everyone better off. The Hicksian test asks whether it is possible for the losers to bribe the gainers to obtain their consent to forego the proposed reallocation. If the expected value of the reallocation of the resources for the gainers would be so high that it exceeds the maximum bribe that would be offered by the losers, the reallocation passes the Hicks efficiency criterion (Hicks, 1939). Hence, following the Kaldor–Hicks efficiency criterion, suboptimal allocations can always be rearranged so that some people are better off and no one is hurt by the rearrangement. Following the interpretation of Kaldor–Hicks, the efficient allocation is also optimal. However, additional provisions are needed to define optimal resource management in the case of intertemporal or intergenerational resource allocation, and to deal with social inequity, e.g. in case one stakeholder is poor and is not able to compensate a richer stakeholder for foregoing a loss resulting from the rearrangement of an allocation.

In the case of ecosystem management, the manager is often confronted with *intertemporal* allocation questions, for instance, in the case where it should be decided if a particular resource should be harvested now or at some moment in the future. The formulation of an intertemporal efficiency criterion requires the assumption that it is possible to define the aggregate utility of all living people over time. Given this, an allocation of resources over time is intertemporally efficient if, for some given level of utility at the present time, future utilities are at their maximum feasible levels. In this case, future utility can only be increased at the expense of the current utility. Howarth and Norgaard (1990) showed that effects of initial allocations on equity and efficiency readily translate from a static to an intergenerational context. Following standard neo-classical approaches, future and present costs and benefits can be compared through discounting. By discounting future costs and benefits, the efficient ecosystem management option can be determined, given a certain discount rate. Discounting is further discussed in Section 2.1.5. Note that another important factor in the analysis of intertemporal efficiency is technological progress. Technological progress may lead to a more efficient use of resources in the future, allowing, under a number of conditions, the maintenance of utility levels even at a decreasing capital stock. The topic of technological progress is outside the scope of this book and not further discussed, but see, for instance, Dasgupta (1993) for more information.

Taking income inequalities into account in the identification of optimal resource allocations requires the specification of a social welfare function. A social welfare function allows the analysis of the welfare implications of changes in income for different groups/income levels in a society. Social welfare functions reflect that, in general, an increase in income of 1 euro generates more utility for a poor person than the same increase for a richer person. A range of social welfare functions have been developed; see, for instance, Arrow (1963) and Sen (1970). When both intertemporal aspects and equity are to be considered in the identification of socially optimal allocations, an intergenerational social welfare function is required.

In the case of environmental and resource management, the mathematical basis for analysing the efficiency of resource use is provided by

Hotelling (1931). Hotelling examined how the social welfare from the exploitation of a *non-renewable* resource can be maximised over time. He argued that current extraction involves an opportunity cost, which equals the value that might have been obtained by extraction of the resource at a later date. The difference between the value of extraction in the future and the value of extraction at present is usually referred to as the scarcity rent of the resource. The 'Hotelling rule' states that resource extraction is intertemporally efficient if the increase in rent of the resource equals the social discount rate (Berck, 1995). In the analyses of the efficiency of *renewable* resources use, the growth of the resource needs to be accounted for. In a simple model, this growth depends upon the size of the stock in relation to the environment's carrying capacity for the species involved. For instance, Gordon (1954) and Schaefer (1957) prepared economic models for analysing the efficiency of a fishery, using simple logistic growth curves to describe the growth of the fish stock. Efficient ecosystem management needs to consider the costs of maintaining and managing ecosystems, as well as the benefits derived from ecosystems in the form of various ecosystem services (Odum and Odum, 1972; Bouma and Van der Ploeg, 1975; Hueting, 1980). In assessing the efficiency of ecosystem management, the full set of goods and services supplied by the ecosystem, including non-market benefits, should be considered.

2.1.3 Sustainability in Ecosystem Management

The Hotelling rule compares the intertemporal aspects of resource use on the basis of the social discount rate. However, even at low discount rates, the importance of the welfare of future generations rapidly diminishes. Because of the large weight discounting attaches to the welfare of current generations as compared to the welfare of future generations, this approach has been criticised as ethically questionable. In response to this shortcoming, the concept of *sustainability* was introduced. Sustainable development was first endorsed in the World Conservation Strategy proposed by UNEP and two environmental NGOs (IUCN/UNEP/WWF, 1980). The primarily ecological focus of the sustainable development concept used in the initial report was broadened in the widely known report 'Our Common Future' published by the World Commission on Environment and Development (the 'Brundtland report') in 1987 (WCED, 1987). The Brundtland commission defined sustainable development as: 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (WCED, 1987). Even though the concept is now widely used, the interpretation of sustainable development and, hence, sustainability is not straightforward. This relates, for instance, to the interpretation of the concept 'need': Which consumption level can be regarded as sufficient to meet these needs? And which combination of production factors is required to ensure these needs?

Hence, subsequent to the Brundtland report, many studies have further examined the sustainability concept. A main issue in the interpretation of sustainable development is the assumed degree of substitutability between natural and man-made capital. This has been the subject of much research in environmental and ecological economics. For instance, Pearce et al. (1989), Barbier and Markandya (1990) and Daly (1990) assume a low degree of substitutability between natural and man-made capital. Pearce et al. (1989) and Barbier and Markandya (1990) state that sustainable development invokes maximisation of the benefits of economic development subject to maintaining the services and quality of natural resources over time. Along this line of reasoning, Daly (1990) argues that sustainability requires that: (1) harvest rates of renewable resources (e.g. fish, trees) not exceed regeneration rates; (2) use rates of non-renewable resources (e.g. coal, gas, oil) not exceed rates of development of renewable substitutes; and (3) rates of pollution not exceed the assimilative capacities of the environment.

Others have criticised this strong interpretation of sustainability. For instance, Beckerman (1994) assumed unlimited capital–resource substitutability, from which he derives that 'strong sustainability, overriding all other considerations, is morally unacceptable as well as totally impractical'. Dasgupta (1993) also argued that the substitution possibilities are high, driven by innovation and technological progress. Innovations continuously expand the possibilities to extract resource deposits, use resources in an efficient manner and recycle wastes.

If substitutability is assumed to be high, the well-known Hartwick rule offers some guidance on the maintenance of consumption levels under resource depletion: under many circumstances in a closed economy with non-renewable resources, the rent derived from resource depletion is exactly the level of capital investment that is needed to achieve constant consumption over time (Hartwick, 1977; Asheim, 1986). Hartwick's rule has been widely adopted in environmental policy – many governments have stated the importance of investing rents from natural resource depletion in building up capital in the rest of the economy (Pezzey and Toman, 2002).

An intermediate position on the interpretation of sustainability is that natural and man-made capital can be either substitutes or complements depending upon the characteristics of the economic system and the specific natural and man-made capital involved (e.g. Georgescu-Roegen, 1979; Cleveland and Ruth, 1997). In this view, the rate of substitutability depends, among others, upon the type of ecosystem service involved. For instance, the regulation of climate and biochemical cycles, as well as several cultural services, can only to a very limited extent be replaced by man-made capital (Costanza and Daly, 1992; Victor, 1994). Solow (1993) also follows a more intermediate position. He argues that it is not possible to preserve the full stock of natural capital and suggests a weaker definition of sustainability where partial substitution of man-made and natural capital is allowed.

The issue of substitutability in relation to renewable natural resources can be illustrated with the development of global fish stocks. The ongoing trend of 'fishing down the foodchain' (Pauly et al., 1998; Myers and Worm, 2003) indicates that the availability of fish, in particular top predators such as tuna, is likely to strongly decline in the coming decades. Different groups of people have different possibilities to substitute for declining fish resources (by switching to other fish, aquaculture fish, or other sources of protein). Besides the technical possibility of substituting natural for man-made capital, issues are the degree of substitution possible (taste of tuna versus, for example, cultivated salmon), and, in particular, the cost of substitution. For instance, many coastal populations in developing countries are not able to access alternative protein sources following the decline in fish stocks they traditionally depended upon (Alder and Sumaila, 2004). Hence, at the level of the ecosystem, substitution possibilities are likely to differ among stakeholders, with those groups that are natural resource dependent and with little capital to invest in adaptation being most vulnerable.

Based upon the assumed rates of substitutability, Carter (2001) classifies the different definitions of sustainability into four main categories: (1) very weak; (2) weak; (3) strong; and (4) very strong sustainability. Very weak sustainability allows for infinite substitution between natural and other capital (human and economic). In weak sustainability, it is recognised that certain life-supporting ecosystem services can not be replaced, but otherwise it allows for the substitution between different types of capital. Strong sustainability states that the total natural capital stock should not be further reduced, but that limited replacement of one type of natural capital with other types of natural capital is possible (e.g. reforestation may offset clear-cutting of forest in other locations, or even the destruction of a certain amount of coral reefs). Finally, very strong sustainability implies that no reduction of the stock and composition of natural capital is allowed (Carter, 2001). Other authors have linked sustainability to the maintenance of the integrity of the world's ecosystems. In this approach, particular attention is given to the dynamic relations between and among ecosystems, and the importance of the life-support services of ecosystems.