Introduction

I have been interested in the problem of ecological scarcity for some time. It was, in fact, a main focus of my Ph.D. dissertation in economics in the mid-1980s, which was eventually revised and published in 1989 as the book *Economics, Natural Resource Scarcity and Development: Conventional and Alternative Views*. In that early book, I argued that ecological scarcity involved a fundamental trade-off between, on the one hand, the increased economic benefits arising from development, and on the other, the ability of nature to provide ecosystem goods and services.[1]

Today, I believe that the problem of ecological scarcity has become so pervasive worldwide that we are entering into a new era, the Age of Ecological Scarcity. In another recent book, I compare this current era with past historical periods of economic development, to show how natural resource use and exploitation has influenced patterns of economic development from the Agricultural Transition over 12,000 years ago to the present day.[2] For example, in contrasting the beginning of the twentieth century, when Woodrow Wilson was President of the United States, to the beginning of the twenty-first century, I note how much has changed in our concerns over the environment:

> In Wilson's day, associating "natural resource abundance with national industrial strength" was the norm. Today, we no longer believe that this association holds. Instead, we see our economies and societies potentially threatened by a wide variety of constraints caused by natural resource scarcity. Such problems range from concerns over the cost and availability of key natural resources, including fossil fuel supplies, fisheries, arable land and water, to the environmental consequences of increasing global resource use, degradation of key ecosystems, such as coral reefs, tropical forests, freshwater systems, mangroves and marine environments, and the

[1] Barbier (1989), pp. 96–97. [2] Barbier (2011).

rising carbon dependency of the world economy. Contemporary unease over natural resource scarcity, energy insecurity, global warming and other environmental consequences is to be expected, given the rapid rate of environmental change caused by the global economy and human populations over the twentieth century … At the beginning of the twenty-first century, therefore, we are more accustomed to viewing "the exceeding bounty of nature" to be running out, rather than providing unlimited supplies for "our genius for enterprise." Rather than enjoying a new "Golden Age" of Resource-Based Development, we seem to be entering a different era, the "Age of Ecological Scarcity."[3]

Fortunately, over the past several decades, a number of important developments have occurred that provide some grounds for optimism.

Increasingly, economists, ecologists, and other environmental scientists are realizing that progress in analyzing and mitigating problems of ecological scarcity requires interdisciplinary collaboration.[4] Although calls for such collaboration have been routine for some time, an important catalyst was the Millennium Ecosystem Assessment (MEA), which made two important contributions.[5] First, it confirmed what has been suspected for some time: global ecological scarcity is a serious problem. Approximately fifteen out of twenty-four major global ecosystem services have been degraded or used unsustainably, including freshwater, capture fisheries, air and water purification, and the regulation of regional and local climate, natural hazards, and pests. Second, the MEA offered a succinct definition of *ecosystem services* as "the benefits people obtain from ecosystems." Such a definition has facilitated inter-disciplinary collaboration, because it means that environmental researchers now have shared goals in exploring how the structure and functions of an ecosystem provide various goods and services to humans and in determining the value of these ecosystem benefits.

[3] Barbier (2011), p. 3.
[4] Throughout this book, I use the term "environmental scientist" very broadly, to include not only natural scientists who study various biophysical aspects of the natural environment (e.g., geographers, geomorphologists, hydrologists, soil scientists, etc.) but scholars from history and social science who also study human interactions with the environment (e.g., anthropologists, environmental historians, political scientists, sociologists, etc.).
[5] MEA (2005).

The MEA has been part of a long line of international studies calling attention to the international plight of the global environment and, in particular, how environmental considerations are intricately linked with sustainable economic development. The notion of sustainability received a major boost as a policy objective in the 1980s, thanks to the consensus reached by the World Commission on Environment and Development (WCED).[6] The WCED (1987) defined sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." Sustainability gained further prominence at the 1992 Earth Summit in Rio and the 2002 follow-up in Johannesburg, and the concept has served ever since as a guiding principle for international cooperation on development. Most recently, The Economics of Ecosystems and Biodiversity (TEEB) study is an international effort of collaborative research that draws attention to the global economic benefits of biodiversity and ecosystem conservation to foster policy debate on the practical actions moving forward.[7]

The linking of sustainability and environmental concerns has also helped boost the concept of ecosystems and the environment as *natural capital*. Nature has provided ecosystems and their benefits to us for free. On the other hand, perhaps because this capital has been provided freely to us, we humans have tended to view it as limitless, abundant, and thus perhaps always available for our use, exploitation, and conversion. As this book aims to show, the concept of an ecosystem as natural capital can help us analyze the economic behavior that has led to the development, as opposed to conservation, of so much ecological wealth. If we can understand this behavior better, then perhaps we can also find ways to manage and enhance what is left of our natural endowment.

This concept of ecosystems as a form of wealth is the key theme developed throughout this book. That is, if ecological scarcity is an economic problem, and if ecosystems can be viewed as *natural assets* that produce a flow of beneficial goods and services over time, then the standard approach in economics of modeling natural resources as a special form of capital can be extended to ecosystems. Much of this book involves developing such models as an illustration of this analytical approach to treating ecosystems as natural assets.

[6] WCED (1987). [7] TEEB (2010).

However, this book is much more than about developing conceptual models. It is also about moving interdisciplinary research collaboration forward. From my early career as a Ph.D. student, one of my principal interests in economics has been how the economic analysis of natural resource and environmental problems can benefit from the concepts and lessons learned from other disciplines, in particular ecology. I have been fortunate over my career to have benefited from collaboration with numerous ecologists and other environmental scientists. In writing this book, I am trying to appeal to this broader scientific community just as much as to my fellow economists. Again, this reflects my belief that progress in combating ecological scarcity will require interdisciplinary collaboration, which will only come about if environmental researchers from different disciplines are willing to learn from each other.

Finally, this book is ultimately about improving environmental policy. The role of policy in controlling excessive environmental degradation requires implementation of effective and appropriate information, incentives, institutions, investments, and infrastructure – the five *i*'s as I call them. The last two chapters of the book try to chart both the way ahead for future ecological and economic research to guide better environmental policy and to outline the key policy challenges that the world faces if it wishes to overcome ecological scarcity. I think, in some ways, these are the most important chapters of the book. If our ecological and economic research does not lead to policy change, then the problems of ecological scarcity, energy insecurity, global warming, and other environmental consequences of unsustainable economic development will truly usher in an Age of Ecological Scarcity.

References

Barbier, E.B. 1989. *Economics, Natural Resource Scarcity and Development: Conventional and Alternative Views*. Earthscan Publications, London.

2011. *Scarcity and Frontiers: How Economies Have Developed Through Natural Resource Exploitation*. Cambridge University Press.

Millennium Ecosystem Assessment (MEA). 2005. *Ecosystems and Human Well-being: Current State and Trends*. Island Press, Washington, DC.

The Economics of Ecosystems and Biodiversity (TEEB). 2010. *The Economics of Ecosystems and Biodiversity: Mainstreaming the Economics of Nature: A Synthesis of the Conclusions and Recommendations of TEEB*. TEEB, Bonn, Germany.

World Commission on Environment and Development. 1987. *Our Common Future*. Oxford University Press, New York.

1 *Ecological scarcity as an economic problem*

The fundamental scarcity problem … is that as the environment is increasingly being exploited for one set of uses (e.g., to provide sources of raw material and energy, and to assimilate additional waste), the quality of the environment may deteriorate. The consequence is an increasing *relative scarcity* of essential natural services and ecological functions … In other words, if "the environment is regarded as a scarce resource," then the "deterioration of the environment is also an economic problem."

(Barbier 1989, pp. 96–97)

Introduction

One of the most critical problems facing humankind today is the rapid disappearance and degradation of many ecosystems worldwide. The key question is: How can we humans allow the continued overuse and destruction of nature, which is so essential to life and valuable? A pertinent reply is:

> We are using natural capital because it is valuable; the reason we are losing natural capital is it is free.

Such a reply conveys an important economic view of the global problem of environmental loss: the basic unit of nature – the ecosystem – is a special form of wealth, which we can think of as a stock of *natural capital*. Humans depend on and use this natural capital for a whole range of important benefits, including life support. Hence, our ecological wealth is extremely valuable. But unlike skills, education, machines, tools, and other types of human and human-made capital, we do not have to manufacture and accumulate our endowment of natural assets. Nature has provided ecosystems and their benefits to us for free. However, perhaps because this capital has been provided freely to us, we humans have tended to view it as limitless, abundant,

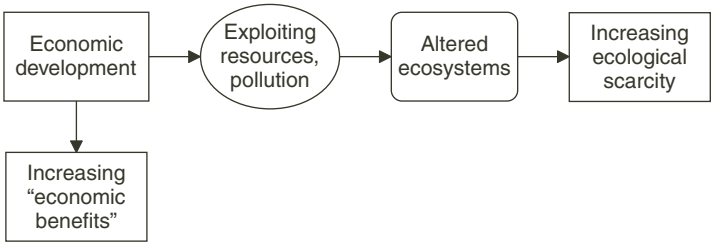

Figure 1.1 The ecological scarcity tradeoff

and always available for our use, exploitation, and conversion. The concept of an ecosystem as natural capital can help us analyze the economic behavior that has led to the overuse of so much ecological wealth. If we can understand this behavior better, then perhaps we can also find ways to manage and enhance what is left of our natural endowment.

The purpose of this chapter is to provide the rationale for the treatment of ecosystems as natural assets. The starting point for this approach, as the above quote suggests, is the growing concern over the economic problem of ecological scarcity. For our purposes, *ecological scarcity* can be defined as the loss of the myriad contributions that ecosystems make to human well-being – or *ecosystem services* for short – as these natural systems are exploited for human use and economic activity.

Ecological scarcity arises through a fundamental tradeoff in our use of the natural environment. This tradeoff can be depicted in a simple diagram (see Figure 1.1). Economic development cannot proceed without exploiting natural resources for raw material and energy inputs or using the environment to assimilate pollution and other waste by-products. On the positive side, economic development also leads to the increased production and consumption of human-made goods and services. As these goods and services contribute to overall human welfare, they can be considered the "economic benefits" of development. However, the exploitation and use of the natural environment by humans for raw materials, energy, and waste assimilation also leads to the alteration of *ecosystems*, which are the interacting systems of biota with their physical environment that are found throughout nature. The disruption and destruction of ecosystems affect, in turn, their various contributions to human welfare, such

as the use of aesthetic landscapes for recreation, the maintenance of beneficial species, the control of erosion, protection against floods or storms, and so forth. The loss of these "ecological benefits," or ecosystem services, as the consequence of economic development is what constitutes increasing ecological scarcity.

Once we begin to see ecological scarcity as an economic problem, it is not difficult to view ecosystems as natural assets. Because ecosystems generate services that contribute to human welfare, they can be considered a form of wealth. The tradeoff of increased economic benefits versus increased ecological scarcity is therefore really about a tradeoff between different assets. On the one hand, we are creating economic wealth; on the other, we are sacrificing our available "ecological wealth" to do so.

The recent literature on ecological services also implies that ecosystems are assets that produce a flow of beneficial goods and services over time.[1] For example, as Daily *et al.* (2000, p. 395) state, "the world's ecosystems are capital assets. If properly managed, they yield a flow of vital services, including the production of goods (such as seafood and timber), life support processes (such as pollination and water purification), and life-fulfilling conditions (such as beauty and serenity)." Ecosystems should therefore be treated as an important asset in an economy, and in principle, ecosystem services should be valued in a similar manner as any form of wealth. That is, regardless of whether or not there exists a market for the goods and services produced by ecosystems, their social value must equal the discounted net present value (NPV) of these flows.

This concept of ecosystems as a form of wealth is the key theme developed throughout this book. That is, if ecological scarcity is an economic problem, and if ecosystems can be viewed as *natural assets* that produce a flow of beneficial goods and services over time, then the standard approach in economics of modeling natural resources as a special form of capital can be extended to ecosystems. For example, an important contribution of natural resource economics has been to treat the natural environment as a form of capital asset (e.g., see Clark 1976; Freeman *et al.* 1973; Dasgupta and Heal 1979; Herfindahl and

[1] See, for example, Barbier (2007, in press); Daily (1997); Daily *et al.* (2000); EPA (2009); MEA (2005); NRC (2005); Pagiola *et al.* (2004); Polasky and Segerson (2009); TEEB (2009); WRI (2001).

Kneese 1974). Initially, this approach focused only on certain valuable renewable and natural resource stocks found in the environment, such as mineral ores, energy reserves, fisheries and forests, as stores of wealth. But even in the early development of natural resource economics, there was growing recognition that the capital approach to the natural environment should be extended to natural areas and ecosystems (e.g., see Freeman *et al.* 1973; Howe 1979; Krutilla 1967; Krutilla and Fisher 1975).

For instance, in the early 1970s, Freeman *et al.* (1973, p. 20) proposed that the environment should be considered a "capital good" for the diverse "services" that it generates:

> [We] view the environment as an asset or a kind of nonreproducible capital good that produces a stream of various services for man. Services are tangible (such as flows of water or minerals), or functional (such as the removal, dispersion, storage, and degradation of wastes or residuals), or intangible (such as a scenic view).

However, it is only in recent years, with rising concern over the problem of ecological scarcity – the continuing disappearance and degradation of many of the world's ecosystems and the subsequent loss in the many benefits they provide – that this natural capital concept has gained more widespread acceptance. As summarized by Barbier and Heal (2006, p. 1):

> A new paradigm is emerging in environmental economics. It views the natural environment as a form of capital asset, natural capital … Natural capital consists not only of specific natural resources, from energy and minerals to fish and trees, but also of interacting ecosystems. Ecosystems comprise the abiotic (nonliving) environment and the biotic (living) groupings of plant and animal species called communities. As with all forms of capital, when these two components of ecosystems interact, they provide a flow of services. Examples of such ecosystem services include water supply and its regulation, climate maintenance, nutrient cycling, and enhanced biological productivity.

The main aim of this book is to demonstrate how the concept of an ecosystem as a capital asset – natural capital – can inform a wide range of conservation and development decisions. Such an approach not only builds on the notion of ecosystems as critical

assets for sustaining economic activity and human welfare but also facilitates analyzing the fundamental ecological scarcity tradeoff depicted in Figure 1.1. Although one of the objectives of the book is to develop and extend an economic model of ecosystems as a natural asset, much of the book is written in a nontechnical style that should broaden its appeal. The book also includes extensive discussion of real-world examples, scientific developments, and policy applications.

In developing and extending its basic natural asset model, the book explores research on ecosystems and their services from economics, ecology, and environmental science. Thus, an additional aim of the book is to discuss the major developments in the ecological and economic analysis of ecosystem services and to identify the areas for further interdisciplinary research collaboration. The topics covered in this book will also interest academic researchers and students from the different disciplinary backgrounds concerned with environmental management, and not just economists.

To summarize, the main purpose of this book is to show how the standard approach in economics of modeling natural resources as a special form of capital can be extended to ecosystems, and why such an approach should be of interest not just to economists but also ecologists, other environmental scientists, and general readers interested in the latest developments in the economics of ecosystems and their services. After all, progress in understanding how ecosystems contribute to human welfare – and what is being lost through increasing ecological scarcity – will require much more interdisciplinary research involving economists, ecologists, and environmental scientists. Such research is also essential to ecosystem conservation and development decisions, which will continue to be a major policy focus for the foreseeable future.

These aims of the book are developed over the subsequent chapters in the following way.

Chapter 2 examines the "capital" approach to ecosystems and ecological services in more detail. It discusses the economic implications of ecosystem services, reviews examples of valuing these services, and looks at how the concept of an ecological landscape can be employed to define ecosystems as natural assets. This background is essential for demonstrating how the standard approach in economics of modeling natural resources as a special form of capital can be extended