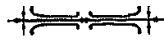


Chapter 1

INTRODUCTION: WHAT ARE ECOSYSTEM SERVICES?

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In the space of a single human lifetime, society finds itself suddenly confronted with a daunting complex of trade-offs between some of its most important activities and ideals. Recent trends raise disturbing questions about the extent to which today's people may be living at the expense of their descendants, casting doubt upon the cherished goal that each successive generation will have greater prosperity. Technological innovation may temporarily mask a reduction in earth's potential to sustain human activities; in the long run, however, it is unlikely to compensate for a massive depletion of such fundamental resources as productive land, fisheries, old-growth forests, and biodiversity.

On a global scale, different groups of people are now living at one another's expense, as is readily apparent in the disruption and overexploitation of earth's open-access resources and waste sinks. For example, whereas the levels of disruption caused by energy use were once small, local, and reversible, they have now reached global proportions and carry irreversible consequences. In fueling their industrialization historically and pursuing their activities today, the developed nations appear to have largely used up the atmosphere's capacity to absorb CO₂ and other greenhouse gases without risk of inducing climate change. In the process, they have foreclosed the option of safely using fossil fuels to sustain comparable levels of industrial activity by developing nations.

And, at the local scale, the tradeoffs between competing activities, and between individual and societal interests, are becoming ever more evident. In

virtually any community, allocation of land or water to various activities often involves a zero sum game, as is apparent in the widespread loss of farmland and water to urban and industrial purposes. Thus, constraints on the scale of the human enterprise typically manifest themselves most tangibly not as absolute limits to a particular activity, but rather as tradeoffs, whose resolution is fraught with increasingly difficult practical and ethical considerations.

This book features contributions from a diverse group of natural and social scientists with expertise in different aspects of these issues, reflecting their own technical training, personal interests, and life experiences. Yet, as a whole, the contributors are oriented around a common set of fundamental premises. First, they share a conviction that, while civilization is presently careening along on a dangerous course, its fate is not sealed. The close of the twentieth century represents a period in history that demands not just a carefully tuned focus on crises of the moment, but also a long-term perspective on challenges to the human future. Second, by different paths they have reached the conclusion that society is poorly equipped to evaluate environmental tradeoffs, and that their continued resolution on the sole basis of the social, economic, and political forces prevailing today threatens environmental, economic, and political security. The chapter authors thus share a sense of urgency for developing analytical and institutional frameworks for the informed and wise resolution of these tradeoffs. Third, such decision-making frameworks must ensure the protection of humanity's most fundamental source of well-being: earth's life-support systems. A tremendous amount is known about the importance and value of the natural systems that underpin the human economy, but this information has neither been synthesized nor effectively conveyed to decision makers or to the general public.

The purpose of this book is to characterize the ways in which earth's natural ecosystems confer benefits on humanity, to make a preliminary assessment of their value, and to report this in a manner widely accessible to an educated audience. An ecosystem is the set of organisms living in an area, their physical environment, and the interactions between them. Although the distinction between "natural" and "human-dominated" ecosystems is becoming increasingly blurred, our focus is on the natural end of the spectrum, for three related reasons. First, the goods and services flowing from natural ecosystems are greatly undervalued by society. For the most part, the benefits those ecosystems provide are not traded in formal markets and do not send price signals of changes in their supply or condition. This is a major factor driving their conversion to human-dominated systems (e.g., agricultural lands), whose economic value is expressed, at least in part, in standard currency. Second, anthropogenic disruptions of natural ecosystems—such as alteration of the gaseous composition of the atmosphere, introduction and establishment of exotic species, and extinction of native species—are

difficult or impossible to reverse on any time scale of relevance to society. Finally, if current trends continue, humanity will dramatically alter or destroy virtually all of earth's remaining natural ecosystems within a few decades.

What Are Ecosystem Services?

Ecosystem services are the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life. They maintain biodiversity and the production of *ecosystem goods*, such as seafood, forage, timber, biomass fuels, natural fiber, and many pharmaceuticals, industrial products, and their precursors. The harvest and trade of these goods represent an important and familiar part of the human economy. In addition to the production of goods, ecosystem services are the actual life-support functions, such as cleansing, recycling, and renewal, and they confer many intangible aesthetic and cultural benefits as well.

One way to appreciate the nature and value of ecosystem services (originally suggested by John Holdren) is to imagine trying to set up a happy, day-to-day life on the moon. Assume for the sake of argument that the moon miraculously already had some of the basic conditions for supporting human life, such as an atmosphere and climate similar to those on earth. After inviting your best friends and packing your prized possessions, a BBQ grill, and some do-it-yourself books, the big question would be, Which of earth's millions of species do you need to take with you?

Tackling the problem systematically, you could first choose from among all the species exploited directly for food, drink, spice, fiber and timber, pharmaceuticals, industrial products (such as waxes, lac, rubber, and oils), and so on. Even being selective, this list could amount to hundreds or even several thousand species. The space ship would be filling up before you'd even begun adding the species crucial to *supporting* those at the top of your list. Which are these unsung heroes? No one knows which—nor even approximately how many—species are required to sustain human life. This means that rather than listing species directly, you would have to list instead the life-support functions required by your lunar colony; then you could guess at the types and numbers of species required to perform each. At a bare minimum, the spaceship would have to carry species capable of supplying a whole suite of ecosystem services that earthlings take for granted. These services include:

- purification of air and water
- mitigation of floods and droughts
- detoxification and decomposition of wastes

- generation and renewal of soil and soil fertility
- pollination of crops and natural vegetation
- control of the vast majority of potential agricultural pests
- dispersal of seeds and translocation of nutrients
- maintenance of biodiversity, from which humanity has derived key elements of its agricultural, medicinal, and industrial enterprise
- protection from the sun's harmful ultraviolet rays
- partial stabilization of climate
- moderation of temperature extremes and the force of winds and waves
- support of diverse human cultures
- providing of aesthetic beauty and intellectual stimulation that lift the human spirit.

Armed with this preliminary list of services, you could begin to determine which types and numbers of species are required to perform each. This is no simple task! Let's take the soil fertility case as an example. Soil organisms play important and often unique roles in the circulation of matter in every ecosystem on earth; they are crucial to the chemical conversion and physical transfer of essential nutrients to higher plants, and all larger organisms, including humans, depend on them (Heywood 1995). The abundance of soil organisms is absolutely staggering: under a square yard of pasture in Denmark, for instance, the soil was found to be inhabited by roughly 50,000 small earthworms and their relatives, 50,000 insects and mites, and nearly 12 million roundworms. And that is not all. A single gram (a pinch) of soil has yielded an estimated 30,000 protozoa, 50,000 algae, 400,000 fungi, and billions of individual bacteria (Ehrlich et al. 1977; Overgaard-Nielsen 1955). Which to bring to the moon? Most of these species have never been subjected to even cursory inspection. Yet the sobering fact of the matter is, as Ed Wilson put it: they don't need us, but we need them.

Ecosystem services are generated by a complex of natural cycles, driven by solar energy, that constitute the workings of the biosphere—the thin layer near earth's surface that contains all known life. The cycles operate on very different scales. Biogeochemical cycles, such as the movement of the element carbon through the living and physical environment, are truly global and reach from the top of the atmosphere to deep into soils and ocean-bottom sediments. Life cycles of bacteria, in contrast, may be completed in an area much smaller than the period at the end of this sentence. The cycles also operate at very different rates. The biogeochemical cycling of carbon, for instance, occurs at orders of magnitude faster than that of phosphorus, just as the life cycles of microorganisms may be orders of magnitude faster than those of trees.

All of these cycles are ancient, the product of billions of years of evolution, and have existed in forms very similar to those seen today for at least hundreds of millions of years. They are absolutely pervasive, but unnoticed by most human beings going about their daily lives. Who, for example, gives a thought to the part of the carbon cycle that connects him or her to the plants in the garden outside, to plankton in the Indian Ocean, or to Julius Caesar? Noticed or not, human beings depend utterly on the continuation of natural cycles for their very existence. If the life cycles of predators that naturally control most potential pests of crops were interrupted, it is unlikely that pesticides could satisfactorily take their place. If the life cycles of pollinators of plants of economic importance ceased, society would face serious social and economic consequences. If the carbon cycle were badly disrupted, rapid climatic change could threaten the existence of civilization. In general, human beings lack both the knowledge and the ability to substitute for the functions performed by these and other cycles (Ehrlich and Mooney 1983).

For millennia, humanity has drawn benefits from these cycles without causing global disruption. Yet, today, human influence can be discerned in the most remote reaches of the biosphere: deep below earth's surface in ancient aquifers, far out to sea on tiny tropical islands, and up in the cold, thin air high above Antarctica. Virtually no place remains untouched—chemically, physically, or biologically—by the curious and determined hand of humanity. Although much more by accident than by design, humanity now controls conditions over the entire biosphere.

Interestingly, the nature and value of Earth's life-support systems have been illuminated primarily through their disruption and loss. Thus, for instance, deforestation has revealed the critical role of forests in the hydrological cycle—in particular, in mitigating flood, drought, and the forces of wind and rain that cause erosion. Release of toxic substances, whether accidental or deliberate, has revealed the nature and value of physical and chemical processes, governed in part by a diversity of microorganisms, that disperse and break down hazardous materials. Thinning of the stratospheric ozone layer sharpened awareness of the value of its service in screening out harmful ultraviolet radiation.

A cognizance of ecosystem services, expressed in terms of their loss, dates back at least to Plato and probably much earlier:

What now remains of the formerly rich land is like the skeleton of a sick man with all the fat and soft earth having wasted away and only the bare framework remaining. Formerly, many of the mountains were arable. The plains that were full of rich soil are now marshes. Hills that were once covered with forests and produced abundant pasture now produce only food for bees. Once

the land was enriched by yearly rains, which were not lost, as they are now, by flowing from the bare land into the sea. The soil was deep, it absorbed and kept the water . . . , and the water that soaked into the hills fed springs and running streams everywhere. Now the abandoned shrines at spots where formerly there were springs attest that our description of the land is true.

—Plato (quoted in Hillel, p. 104)

Ecosystem services have also gained recognition and appreciation through efforts to substitute technology for them. The overuse of pesticides, for example, leading to the decimation of natural pest enemies and concomitant promotion of formerly benign species to pest status, has made apparent agriculture's dependence upon natural pest control services. The technical problems and cost of hydroponic systems—often prohibitive even for growing high-priced, specialty produce—underscore human dependence upon ecosystem services supplied by soil. Society is likely to value more highly the services listed above, and to discover (or rediscover) an array of services not listed, as human impacts on the environment intensify and the costs and limits of technological substitution become more apparent.

Organization of the Book

This introductory chapter is followed by a brief historical overview of modern concern for ecosystem services (chapter 2). Part I explores key philosophical and economic issues of valuation to provide a context for understanding the range of approaches employed in subsequent chapters to describe the importance of ecosystem services. The following two sections (parts II and III) examine a diversity of the major services operating in a variety of ecological systems over a spectrum of scales, from local to global. Part IV reports on a series of services whose nature and value are particularly well documented, typically by virtue of having been consciously exploited at the local level and, in some cases, marketed, at least informally. The book closes with a brief overview of our findings and a discussion of future challenges. Some parts of this structure—especially issues of valuation—merit further introduction, given below.

Valuation of Ecosystem Services

The disparity between actual and perceived value is probably nowhere greater than in the case of ecosystem services. If asked to identify *all* that

goes into making a fine cake, a baker willing to share his or her secrets would most likely first identify its ingredients, and the knowledge and skill required to transform them into a culinary work of art. He or she might also describe the type of oven, pan, and various appliances and kitchen gadgets needed. If pressed further, an astute baker might also point out the need for capital infrastructure and human services to process, store, and transport the ingredients. With a helpful hint or two, he or she may even mention the crop-land, water, chemical, and energy inputs to the whole process. However, the chances of the baker touching directly upon the natural renewal of soil fertility, the pollination of crops, natural pest control, the role of biodiversity in maintaining crop productivity, clean-up and recycling services outside the kitchen—or, indeed, upon *any* ecosystem service involved—are extremely remote. Ecosystem services are absolutely essential to civilization, but modern urban life obscures their existence.

Once explained, the importance of ecosystem services is typically quickly appreciated, but the actual assigning of value to ecosystem services may arouse great suspicion, and for good reason. Valuation involves resolving fundamental philosophical issues (such as the underlying bases for value), the establishment of context, and the defining of objectives and preferences, all of which are inherently subjective. Even after doing this, one is faced with formidable technical difficulties with interpreting information about the world and transforming it into a quantitative measure of value. Chapters 3 and 4 discuss these issues and describe alternative empirical valuation techniques, their applicability to different types of ecosystem services, and the advantages and limitations of their use. The final chapter (20) then reviews the major obstacles that contributors encountered.

This book does not attempt a comprehensive valuation of ecosystem services. Just as it would be absurd to calculate the full value of a human being on the basis of his or her wage-earning power, or the economic value of his or her constituent materials, there exists no absolute value of ecosystem services waiting to be discovered and revealed to the world by a member of the intellectual community. Contributors seek primarily to identify and characterize components of ecosystem service value and to make a preliminary assessment of their magnitude, as a prerequisite to their incorporation into frameworks for decision making.

Our concentration is on use values; aesthetic and spiritual values associated with ecosystem services are only lightly touched upon in this book, having been eloquently described elsewhere. The total value of ecosystem services may be best assessed in terms of physical magnitudes or proportions, such as the amount of human waste processed naturally, the amount of carbon sequestered in soils, the proportion of potential crop pests controlled naturally, and the proportion of pharmaceutical products derived from biodiversity. Where a technological substitute is available for an aspect of an

ecosystem service, the market price of the substitute provides a lower-bound index of the value of the service (in terms of avoided costs). As a whole, ecosystem services have infinite use value because human life could not be sustained without them. The evaluation of the tradeoffs currently facing society, however, requires estimating the *marginal* value of ecosystem services (the value yielded by an additional unit of the service, all else held constant) to determine the costs of losing—or the benefits of preserving—a given amount or quality of services. The information needed to estimate marginal values is difficult to obtain and is presently unavailable for many aspects of the services. Nonetheless, even imperfect measures of their value, if understood as such, are better than simply ignoring ecosystem services altogether, as is generally done in decision making today.

Overarching Services and Services Supplied by Major Biomes

The next two sections provide an overview of some of the paramount services, from the perspective of those operating in most ecosystems, globally, and of those associated primarily with particular biomes. The section on overarching services (part II) opens with two fundamental issues, the interaction between climate and life (chapter 5) and the relation between biodiversity and aspects of ecosystem functioning important for the supply of ecosystem services (chapter 6). Subsequent chapters explore the services provided by soils, by pollinators, and by natural pest enemies (chapters 7–9). The section on services supplied by major biomes (part III) is structured around distinct services operating in four of the world's major biomes: marine, freshwater, forest, and grassland ecosystems (chapters 10–13). These two sections seek to identify the major components of ecosystem service value, to characterize them in terms of function, susceptibility to human disruption, amenability to repair, and societal importance.

Case Studies

This section of the book zeroes in on some of the more tangible and direct benefits derived from ecosystem services. The first two chapters (14 and 15) reveal the vast array of goods that societies extract from natural ecosystems and explain how ecosystem services sustain their production—on land and in the sea. Two subsequent chapters (16 and 17) explore the dependence of local economies—subsistence and modern—on ecosystem goods and services. The final chapters (18 and 19) take a detailed look at ways in which

societies consciously exploit and manipulate particular ecosystem services to satisfy basic needs, such as for waste disposal and abundant clean water. This section thus illuminates the many connections between ecosystem services and aspects of daily human existence, from eating breakfast to shaping our traditions, values, and cultures.

The Policy Interface

Diverse human societies have now attained the status of ecological superpowers. That is, they have the capacity to seriously impair or destroy essential components of earth's life-support systems; moreover, they are currently using this capacity, almost without restraint. The persistence of all societies ultimately hinges upon those superpowers beginning to wisely coordinate and control the wielding of this power. This will especially be so if the magnitude of human influence continues to expand at unprecedented rates to unprecedented levels, through the momentum and inertia associated with population growth, expanding material desires, and the technical means by which fulfilling the latter is pursued. As the most accessible and suitable resources are sequentially exhausted, each additional person, all else equal, exerts greater per-capita impact in necessarily turning to lower-quality resources for the same end.

Historically, human societies have alleviated resource constraints primarily by pushing back intellectual and territorial frontiers. Yet, it would be difficult today for even the most optimistic rates of innovation and of adoption of improved technology (broadly defined) to offset the rates of increase in human disruption caused by rapid population growth and increases in per-capita impacts. Furthermore, opportunities for territorial expansion are now largely foreclosed—or never existed for inherently global impacts, such as those on the composition of the upper atmosphere.

The passage of time leaves in ever sharpening focus a daunting but critical need to tackle social and political frontiers with the same boldness and determination that took the first man to the moon. This will require not only strengthening existing institutions, but also creating entirely new regimes to manage globally human impacts on earth's life-support systems. It will also require an unprecedented level of international cooperation and coordination. It is at these policy frontiers that lie the brightest prospects for resolving the human predicament and converting the world's societies to new and sustainable resource management regimes.

Nature's Services represents an exploration of both the scientific and the policy frontiers. On the scientific front, the book provides a broad, preliminary characterization of the natural functioning of earth's systems; of the

ways in which the human enterprise extracts material well-being from these systems; of the impacts exerted thereon by different human activities; and of the tradeoffs inherent in alternative courses of action. On the policy front, the book attempts an initial appraisal of the economic value of elements of earth's life-support systems. Of course, economic indices are likely to underestimate the total value of these systems. Nonetheless, economic markets play a dominant role in patterns of human behavior, and the expression of value—even if imperfect—in a common currency helps to inform the decision-making process. Making economic institutions sensitive and responsive to natural constraints and explicitly dealing with the limitations of such institutions in doing so are other requisites to effective earth management (Daily et al. 1996).

Present scientific understanding of ecosystem services is substantial, wide reaching, and extremely policy-relevant, and merits urgent attention by decision makers, since current patterns of human activity are unsustainable and threaten to impair critical life-support functions. Failure to foster the continued delivery of ecosystem services undermines economic prosperity, forecloses options, and diminishes other aspects of human well-being; it also threatens the very persistence of civilization. While the academic community remains a long way from a fully comprehensive understanding of ecosystem services, the accelerating rate of disruption of the biosphere makes imperative the incorporation of current knowledge into the policy-making process.

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