ECOSYSTEM SERVICES: A PRIMER FOR BIODIVERSITY CONSERVATION

WHY DEVELOPMENT SUCCESS DEPENDS ON THE CONSERVATION OF PLANT, ANIMAL, AND MICROBIAL DIVERSITY AND THE SERVICES THEY PROVIDE

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TABLE OF CONTENTS

ECOSYSTEM SERVICES: A PRIMER FOR BIODIVERSITY CONSERVATION

PREFACE

A radical turning point in human history

Throughout human history, we have spent our natural wealth on improving our lot in life. We have converted forests to farms, impounded and diverted freshwater for agriculture and industry, and driven enormous numbers of species to near extinction. This massive spending of what is often termed our *natural capital* or *natural wealth*, has improved our wellbeing, but by the twentieth century, we discovered that the price we paid was too high. Widespread environmental degradation had become a global reality, threatening the health, livelihoods, and wellbeing of future generations – especially the poor. In response to these threats, environmental programs and conservation efforts grew rapidly to stop the profligate spending of our natural wealth. Unfortunately, too often they were seen as counter to improving the quality of life and not viable alternatives to traditional development. By the dawn of this century, however, the prevailing view among natural and social scientists alike had shifted radically. Proponents of both traditional development and conservation realized that neither could succeed without the other. This radical change in thinking is attributable to the worldwide call to shift from *traditional development* (spending down natural capital to improve wellbeing) to *sustainable development* (improving wellbeing without spending down natural capital). Instrumental to this shift was focusing on *biodiversity conservation*, or the conservation of the diversity of plants, animals, and microorganisms in ecosystems, to provide *ecosystem services*, or the services nature provides us. This modern worldview can be stated as follows:

Development in the twenty-first century must be sustainable, and development is only sustainable if it integrates biodiversity conservation and ecosystem services into its strategy.

What is an ecosystem service?

Grasping the concept of ecosystem services is critical to achieving sustainable development, but most people find the concept confusing. The term, *ecosystem service*, is in wide circulation, but to the majority of people –including managers, decision makers, conservation practitioners, and even researchers and policy makers— there is enormous confusion surrounding what an ecosystem service is. The concept is even more perplexing because it is closely related to both *biodiversity conservation* and *sustainable development*; two additional terms that can be equally confusing. The central premise for this primer is that:

Without achieving greater clarity on what ecosystem services are, progress in achieving sustainable development and the conservation of biodiversity will be limited.

This primer is designed to help clarify what ecosystem services are, what is meant by biodiversity, why the two are inextricably linked, and how sustainable development is ultimately tied to these concepts. This primer is designed to be accessible by all, and serve as a general and basic introduction to the background, science, and principles of biodiversity conservation and ecosystem service development for practitioners.

This primer provides the basic background and information about ecosystem services at a time when almost every government, organization, agency, and developer –not to mention planners and managers— are either being asked to, or simply want to include ecosystem services in their decision making.

There are thousands of publications on the topic of ecosystem services, but they seldom address the importance of the diversity of plant, animal, and microbial species found in ecosystems and why such incredible biological diversity is central to understanding what nature's services are and how to make them effective parts of development projects.

We begin with an overview of what services are and what is meant by *nature's services*. We then provide a guide to key ecosystem services. Follow-up materials relating to this report will examine specific management techniques to improve ecosystem service supply, including agricultural techniques that are mentioned here. For the current document, since land use change for the purposes of agriculture as a means of economic development and poverty alleviation is a serious threat to ecosystem services and conservation, but it is also an opportunity to improve land use management while preserving biodiversity, many examples touch on this development frontier where these issues figure prominently.

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NATURE'S SERVICES

The cost of all those services

When someone helps us make our lives more manageable, productive, or simply more pleasant or rewarding, we value their assistance. We refer to the different kinds of assistance others provide us as services, and if they are free of charge, we are grateful. Few services, however, are truly free, and service providers often request compensation for their efforts. Unless one is entirely self sufficient, most people depend on services provided by others. In this sense, our basic needs are often met by individuals who grow or harvest food biofuels, and building materials, and bring them to market for us to buy.

FIGURE 1: AN ILLUSTRATION OF JUST A FEW OF THE RANGE OF SERVICES HUMANS USE REGULARLY AROUND THE GLOBE.

Of course, all of these services, including cultural services, come with a price. There are as many ways to pay for the services we need or want as there are services themselves. We buy tickets, make donations, or pay taxes for art shows, natural history exhibits at museums, plays and movies at theaters. We pay for books and music sold at stores or through the Internet, or pay taxes to support libraries. Sports organizations charge us to view their games. Religious organizations collect donations. Sometimes we barter, exchanging services we can provide for services others can provide in exchange – we help our neighbor build a barn, they help us harvest during the harvest season. Every service provider gets paid, either directly (when we pay for goods at markets, buy tickets for cultural events, pay the bills service providers send us), indirectly (through taxes for governmental services), or through donations (such as to our religious organizations). Every service provider gets paid one way or another, or the supply is cut off.

Though they may improve quality of life, the costs of all those services can be formidable: the poorer we are, the fewer services we can afford. When service providers charge us for their assistance, we have to either pay or forgo the service. If we are poor, we may have to go without valuable services we would very much like to have because we cannot afford them, like telephone services, schooling, or transportation, forcing us to walk or bike long distances. If we are poor and our funds can only supply us with just enough food and water to survive, it is difficult to afford urgently needed health services like medicines for malaria or HIV, x-rays, antiseptics, anesthetics, blood transfusions, and surgery if our children have been in a serious accident. Poor people in rural regions, even if they might have funds, often do not have access to services in part because most people in their community cannot afford them and in part because service providers often do not invest in rural areas.

Poverty is defined in many ways, but the lack of services, or the inability to afford services that are otherwise available, is a source of considerable hardship for the poor.

Nature's services, ecosystems, and biodiversity

Rich or poor, our lives depend on the availability of many services, and we pay for as many as we can afford. What we seldom realize is that the most vital services provided to us come from nature and, until recently, nature's services have been free of charge. While banks provide financial services, Internet service providers give us access to the worldwide web, and doctors, clinics, and hospitals provide health services for us, we pay for them, sometimes dearly. Almost always we wish such manmade services, especially when they are essential, like health services, would be free or of little cost. In the real world, however, the cost of all of those services can be quite significant, sometimes leaving us little money after we have paid for them. Nature's services, however, though far more fundamental to our lives than many of the services we pay for, have always been free.

Nature's services…

FIGURE 2: AN ILLUSTRATION OF THE RANGE OF SERVICES ECOSYSTEMS PROVIDE THAT IMPROVE OUR HEALTH AND WELLBEING

Clearly, while we can forgo many manmade services, we cannot survive without nature's fundamental services and we are culturally worse off when our natural scenery and wildlife are devastated.

Nature's services are exactly like manmade services in that they make our lives more manageable, productive, or simply more pleasant or rewarding, but they differ in two important ways. First, nature's services are provided by plants, animals, and microorganisms that, unlike people, never charge us for their services. Second, plants, animals, and microorganisms are organized into **ecosystems** (Box 1, page 33), unlike service providers that are organized into institutions like businesses, companies, or governmental agencies. It is common to refer to nature's services as ecosystem services, which are the focus of this primer.

Though far more essential and valuable than manmade services, nature's services seem to have been free because their providers, the diversity of living organisms (termed **biodiversity** - Box 2, page 34) that surround us, have never charged us for their services. It might seem silly to consider plants, animals, and microorganisms sending us bills for their services the way human service providers do, but it is instructive to do so. When people substitute manmade services for nature's services, people will charge us for the services nature gave us for free. For example, when we build a water treatment plant for sewage because the plants, animals, and microorganisms in our wetlands that used to clean our water are gone, when we build a reservoir and filtration plant for potable water because the forests of our watershed have been degraded or cleared, or when we establish fish farms because our ocean stocks of wild fish have been devastated by overfishing, we have to pay people for the substitute sanitation services, water, and farmed seafood. What was once free from nature now has a cost. Invariably, poor people are the worst affected because they already lack funds for most services and now must endure the added hardship of paying for (or forgoing) the sanitation, water, and food they once had for free.

Paying for nature's services

The age of free services from nature is coming to an end. This millennium has been marked by an extraordinary number of efforts by individuals, natural and social scientists (like ecologists and economists, respectively), government and non-government organizations, and even businesses and financial institutions, to change our ways and start paying for nature's service. Generally, all of the work done by these individuals and organizations can be summed up as follows:

The long-term success and wellbeing of people is entirely dependent on how well nature's services are accounted for in our economic development.

This means that if we are to continue to improve human wellbeing, especially for the poor and vulnerable people who make up nearly half of our population of nearly seven billion, we will only succeed if our development plans make securing nature's services their priority.

If we decide to clear cut a forest and replace it with farms of a single crop irrigated with water from a neighboring watershed, the effort may fail if it does not account for the services the forest and watershed once provided. Were the original ecosystems repositories of important species that had medicinal, food, or cultural values? Did the original ecosystems sequester and store carbon, produce and stabilize soil, provide pollinators like native bees and insectivores like spiders, birds, and bats that controlled crop pests, make the local climate more moderate, and resist the spread of invasive species or diseases?

FIGURE 3: LAND USE CHANGE TO BENEFIT ONE SERVICE CAN COME AT THE EXPENSE OF MANY LESS OBVIOUS SERVICES.

It is never easy to recognize that something we once thought was free actually costs us, but in the case of nature's services, the long-term benefits of accounting and paying for nature's services are huge. Natural or unmanaged ecosystems once covered the world, and the services offered by these ecosystems allowed many species to flourish, including humans. Nature's services alone insure basic needs and survival, but ultimately limit growth, and while some species prosper, others can go extinct as environmental conditions change. As people grew in number and exceeded nature's ability to support or provide for us, we used our natural capital, our biodiversity and their ecosystems, to produce manmade capital such as farms, urban ecosystems, and industry. For this manmade capital, we have spent (cut down, burned, drained, covered over, or otherwise converted) 65% of our natural capital and much of what remains is ice, rocks, sand, and the less productive areas of our world.

Humans prospered as they used their natural capital, so this practice of funding human development by spending natural capital was not necessarily a bad thing. However, we spent our natural capital very quickly and very inefficiently. The gains, such as doubling food production and the development of vaccines and beneficial technology like telephones, radio, and computers, appear to be short-term and unequally distributed. The number of poor in the world remains high and environmental problems, such as soil loss, poor air and water quality, emerging diseases, climate change, and pest outbreaks, are worsening.

Why are nature's services no longer free?

Throughout most of human history the services nature provided were rarely, if ever, in short supply. If they were in short supply where we lived, we could move to someplace new. However, things have changed. Now, with 6.7 billion people on Earth, the demand for services far exceeds nature's ability to provide them. How do we know this? Because without fertilizer, irrigation, pesticides, and the vast resources we extract from ancient pools of fossil fuels and ancient aquifers, there would not be enough food to feed us. Some estimates state that humans are currently consuming what would take three or four Earths to provide.

In terms of food, and in many respects, in terms of health and other measures of our wellbeing, we have benefited from traditional development that was based on unsustainable use of natural resources. The benefits of agricultural, medical, and other technological developments, like hybrid crop species, vaccines, and telephones, have benefited mostly everyone. But the benefits have not been distributed evenly and the environmental costs have been high. Nearly half of the world's people make two dollars or less a day and face food and water scarcity, increasing rates of disease incidence (like the resurgence of tuberculosis and malaria), and lack access to many services. To make matters more challenging, add the incredible disparity between rich and poor to the many environmental issues we face, including climate change, collapsing fisheries, sporadic food and energy shortages around the globe, and the increasing frequency of emerging diseases like West Nile Virus, SARS, avian flu and most recently, swine flu. It is clear that traditional development improved some services that nature provided, like food production, while degrading others, like the regulation of climate and disease, and favored the developed world at the expense of the developing world.

Nature's services and the new Millennium

History will remember this millennium for its unprecedented commitments to chart a course for our future that would no longer jeopardize nature's services.

- In 1987, the United Nations World Commission on Environment and Development published an influential report entitled, Our Common Future, which concluded that human development to date, was largely attributable to widespread use of an abundance of natural resources, but that approach was no longer tenable. Development would have to change to a new model, one called *sustainable development*, in which further human growth would be sure not to harm the environment so that tomorrow's generations would have the same opportunities that we did. This was unfortunate for developing countries who felt that calls for conservation and the cessation of traditional development were denying them the same opportunities the developed world had, but with commitments from both parties to sustainable development, the world held its first global summit.

- The Earth Summit, as it is commonly known, was held in Rio de Janeiro in 1992. The UN Convention on Biological Diversity and Convention on Climate Change trace their origins to this summit, along with Agenda 21 which included commitments to ending poverty and hunger and promoting global gender equity, access to fresh water, health care, and education. Our Common Future and the Earth Summit set the stage for a series of global agreements made at the dawn of the new millennium.

- In 2000, members of the UN General Assembly reaffirmed their commitments to the universal development goals of improving human wellbeing in the UN Millennium Declaration. A year later, the UN established the Millennium Development Goals which were explicit commitments to achieving significant progress in these universal goals by 2015.

- In 2000, the UN also began the five-year Millennium Ecosystem Assessment project which recruited over 1300 social and natural scientists from around the world to conduct an objective five-year assessment of the state of the planet and develop a the scientific framework by which sustainable development could be achieved.

The Millennium Ecosystem Assessment based its assessment on ecosystem services and evaluated the state of 24 ecosystem services that are needed by everyone. They found 15 of them to be declining or degraded, meaning that our need for these services could no longer be met. The production of fish, biofuels, naturally occurring medicines and pharmaceuticals, and freshwater have all declined. Virtually all the processes that help to stabilize the environment, such as the pollination of plants, the natural prevention of soil erosion, and the regulation of local climate have similarly degraded. And nature's value as a source of spiritual, religious, and aesthetic inspiration has also declined. The executive board summarized the findings of the assessment as follows:

> "*At the heart of this assessment is a stark warning. Human activity is putting such strain on the natural functions of Earth that the ability of the planet's ecosystems to sustain future generations can no longer be taken for granted."*

For the poor residing in isolated, rural villages, such grand events that mark the beginning of this century and millennium may seem distant, abstract, and of little significance, but they are important because they provide a global consensus and mandate that should empower the poor. The rural poor, based on international agreements, should demand that development plans restore nature's services. Once restored, those services immediately benefit the villages, but they also benefit the global community who should pay for these services.

FOUR KINDS OF ECOSYSTEM SERVICES

The variety of ecosystem services is overwhelming, but scientists participating in the Millennium Ecosystem Assessment recognized that almost every ecosystem service falls into just four categories. They are known as supporting, provisioning, regulating, and cultural ecosystem services. A catalog of detailed examples of these different types of services is provided in section 2 of this primer, but here we provide a brief overview. Note tha in each case, as is true for every ecosystem, the service providers are plants, animals, and microorganisms, that is, **biodiversity**.

Supporting services. Supporting services are the most basic services without which no other services wou be available – they are the services that support or make other services possible. Consider household electric service: telephones, internet, electrical lighting, and any other service that needs electricity will not function without its presence. Similarly, organisms that reside in ecosystems need many services in place before they can function. Oxygen production, for example, is essential for all services that arise from ecosystems in which species need oxygen. In addition to oxygen production, services such as soil erosion, recycling nutrients, sequestering oxygen from the atmosphere, fixing nitrogen, decomposing dead organic material that inevitably accumulates in ecosystems, are just a few of the services that all species, ourselves included, fundamentally need before other services can be provided.

Provisioning services. Once supporting services are in place, provisioning services constitute the next most fundamental set of services. Provisioning services, as the name implies, are those that provide or supply humans with biomaterials, such as food, fuel, and fiber, and any other natural product we harvest or consume. They include biomaterials derived from managed ecosystems, such as food from agriculture or aquaculture, timber from plantations, and biomaterials from unmanaged systems, such as wild mushrooms and medicinal plants, nuts and fruits harvested from forests, or firewood and timber from national forests. It may sometimes be confusing to include biomaterials from farms and plantations with those harvested from national parks or other unmanaged systems, but whether managed (e.g., farms) or unmanaged (e.g., national parks), they are all collections of plants, animals, and microorganisms that function together as ecosystems. The primary difference is that most managed systems provide only a few provisioning services (e.g., a commercial oil palm plantation provides primarily palm oil and little else) while unmanaged systems provide many services (e.g., a national forest provides timber, bushmeat, pharmaceuticals, nuts, mushrooms, fruit, and more).

Regulating services. An important feature of a service is how reliable or predictable it is. Continuing with the example of household electrical service, if electrical service unpredictably surges and damages equipment, if it cuts out without warning, or goes out for days, such irregular service can make life very difficult. In the case of electricity, having electrical repair services available, such as surge protectors, backup generators, and insurance against losses due to power outages, vastly improve electrical services. The same is true for ecosystems. If soil production is high, but is lost every time there is a storm, if water output from a watershed is completely unreliable, if climate warms too quickly, such irregularity compromises the value of ecosystem services. Some ecosystem processes, however, can dramatically reduce or prevent such irregularity. When vegetation reduces soil loss, trees stabilize watershed output, forests absorb excess greenhouse gasses and steady climate change, and naturally occurring predators keep insect pests from reaching high numbers, we consider such services to be regulating ecosystem services. Though often forgotten, these are among the most valued services nature provides.

Cultural services. The final class, cultural ecosystem services, is probably the most difficult to define and quantify, but is important to many people and for some ecosystems are the dominant services. For those who like to hunt for mushrooms, wild flowers, trophies like animal heads or skins, or for those who like to see birds, wildlife, go snorkeling in coral reefs to see exotic fish, or who like to go hiking to experience nature in its more pristine state, ecosystems provide them with what we collectively refer to as cultural services. There many other cultural services, such as the religious or spiritual significance some cultures attach to species or groves of trees. Nature may also inspire us, such as the way those in the United States may find a soaring bald eagle to instill a sense of national pride and patriotism. Note, however, that the bald eagle has no patriotic significance to Canadians or Mexicans whose ecosystems contain these birds. The term cultural is used because the significance of species or ecosystems to humans depends in part on what our culture teaches us. Some may see bats as fascinating creatures that can fly in the dark and eat insect pests, others may fear them because of their dark form and the diseases they carry and would be happy to rid their ecosystem of all bats, while others may have no particular interest or concern about bats. Similarly some cherish jungles while others fear them. In either case, what our parents, friends, schools, media, religion, or our culture teaches us about nature determines its cultural value to each individual. Finally, some systems may be worth more to its residents for their cultural value than provisioning and regulating services, such as the ecotourism that African savannas provide or the value of the Galapagos Islands, a small set of arid islands that is sparsely populated and provides little in the way of supporting, provisioning, or regulating ecosystem services, but is considered an evolutionary treasure valued by many cultures around the world.

Balancing tradeoffs among services

When we do not like the set of services available in our community, we can either learn to live with them, move to another community where we feel the services are better, or we can intervene – we can take actions to change service availability. For example, if there is no electricity, one could learn to live without electricity, move to a community that has electricity, or find a way to raise the necessary funds or encourage the power company to bring electricity to your community. Likewise, we can accept whatever services our ecosystems provide, move to another ecosystem, or change the services provided by altering biodiversity (e.g., removing existing species and adding new ones or favoring some species over others), altering nutrient and water inputs (e.g., adding fertilizers or irrigating), or making other changes. For example, we can learn to live with malaria in our ecosystem by wearing appropriate clothing, using bed nets and window screening, and having health services that can diagnose and treat the disease. We could move to a malaria free ecosystem. Or we could spray the ecosystem with insecticide to kill the mosquitoes that transmit the disease. Using pesticides, we essentially attempt to change the ecosystem services provided – natural pest regulation does not occur at levels we would like, so we attempt to lower pest levels by our own means. Depending on the pesticide, there are likely to be many other consequences of our attempt to change ecosystem services – the pesticide might kill bees that we need to pollinate crops, they might accumulate in the fish or wildlife we eat and pose new health risks, or they may kill organisms that provide cultural values, such as birds that provide us with a chorus of songs. In our attempt to modify an ecosystem because one service (a regulating service) seemed inadequate, we wound up altering our supporting (pollination), provisioning (crop production, due to lack of pollination) and cultural services (the loss of the valued bird chorus).

Development almost always involves interventions to alter nature's services so that they provide more of what we want and less of what we do not want. Adding fertilizer to increase provisioning services, planting trees to improve shore stabilization, introducing exotic fish species to enhance fish production, planting trees to sequester carbon or improve soil retention, killing large mammals that consume crops or attack people, and using pesticides to change pest regulation services are just a few examples. Because all services are linked to one another, there are invariably negative tradeoffs in which an increase in one service leads to loss in another or positive tradeoffs (i.e. synergies), in which a change in one enhances another.

One of the key goals of ecosystem service based development strategies is to understand and include tradeoffs and synergies in planning and execution.

THE ECONOMICS OF ECOSYSTEM SERVICES

Natural capital

If an individual owns a patch of forest, has an axe, sawmill, and vehicle for going to market, he or she can harvest the trees in the forest for its wood and earn a living by selling it to those who value it. Most people recognize that the landowner is providing goods (wood) and services (harvesting, milling, and bringing it to market) and they are willing to pay for these goods and services if they value them. Most people also readily recognize the axes, sawmill, and vehicle as the landowner's *capital*, or the means by which the landowner can produce (or manufacture) the goods and provide their services.

What about the forest?

The forest ecosystem is the means by which the landowner obtains the wood in the first place, thus, though capital has traditionally been a term used to describe labor, machines, and even knowledge (such as how to run the mill). Such things are clearly necessary to make the goods and services flow. Only recently, however, has natural capital been more widely embraced as an equally important concept in economics.

In the case of the forest, the trees are manufactured by the ecosystem, thus the ecosystem is natural capital.

To the non-ecologist, this might seem a strange idea. It would seem the trees just grow and we harvest them, so at best the trees are the capital. In reality, however, the trees very likely depend on fungi (often mycorrhizal fungi) in the soil to acquire the nutrients the trees need to grow. They may depend on insects, bats, birds, or other animals to pollinate them so they can set seed. They depend on hundreds to thousands of species of microscopic insects, worms, and other small animals, and the microscopic fungi, bacteria, protists, and even viruses, that live in the soil and help to break down the old leaves, fallen branches, and rotting logs so that the nutrients in them are returned to the soil. The understory vegetation may be important in retaining the soil water and preventing erosion between the trees. The complexity of an ecosystem is overwhelming, but it is clear that what makes an ecosystem function is the interaction of numerous species, not just the tree.

One could clear away every living thing in the forest, replace the rich organic soil with sand, and grow trees from seed by adding all the nutrients one needs directly to the sand using chemical fertilizer and machines or labor to apply the fertilizer carefully, establish a well controlled irrigation system, then pollinate the trees by hand to get seed for the next generation, and protect the trees from all pests. That would take a lot of labor, a lot of chemical inputs (fertilizer, pesticides, etc.), and mechanization. In such an extremely labor and chemical intensive, highly managed ecosystem, the capital is now all the labor, chemicals, machinery, and extensive knowledge about fertilizers, the biology of trees, the use of pesticides, and agro-forestry science, needed to grow the trees under such biodiversity-free conditions.

It is hard for many to consider the fungi, bacteria, Collembola, millipedes, centipedes, earth worms, wire worms, mites, spiders, moles, shrews, mice, foxes, owls, hummingbirds, sparrows, hawks, squirrels, and onward to thousands of species as part of capital when we are accustomed to only thinking about labor, machines, and knowledge, but this is the transformation in thinking that is the hallmark of twenty-first century environmental science. For our landowner who simply harvested the trees, however, the reality is quite clear. The landowner only needed an axe, sawmill, and vehicle – the unmanaged ecosystem did the rest. In the managed ecosystem, biodiversity is lost, and every single process is controlled by the owner (or owners if it is a cooperative) of the managed ecosystem.

Managed ecosystems swap manmade and human capital for biodiversity.

In more technical terms, ecosystem services are the products of natural capital. A functioning ecosystem, whether relatively unmanaged, like a park or protected area, or highly managed, like a farm or aquaculture, can often be divided into different kinds of stocks and is often the source of many ecosystem goods and services, even if only one is marketed. For example, ecologists refer to the amount of carbon in an ecosystem as its carbon stock. The carbon stock is a just one form of natural capital. The ecosystem also contains nitrogen, soil, plants with pharmaceutical value, and photosynthetic organisms (i.e., all the plants), that produce oxygen. In our example above of the landowner who harvests trees from a forest, only one good and service is being marketed – the wood. The rest, such as water provisioning to the local watershed, soil production, oxygen production, or the cultural value local people might have for the forest, and other services are not marketed.

Collectively, an ecosystem often has many values or provides many services beyond agricultural production, as described in this primer, but often the production of one or two goods and services tend to be the focus of management, which is why carbon stock is a useful metric of natural capital. The ecosystem's carbon stock is simply a proxy for the ecosystem itself. All life is made of organic material to which carbon is the key element, thus, the more carbon found in the living part of an ecosystem, the more stock there is. If the carbon stock is reduced (e.g., by harvesting timber, or growing annual crops that generally result in a loss of carbon from soil), then natural capital has been reduced, and the flow of all goods and services will necessarily decline.

Thomas Lovejoy, a world renowned conservation biologist, once pointed out that while the amount of silicon in a computer might be a measure of the size of the computer, the value of the services the computer provides is vastly more than the value of its silicon stock. Thus, valuing an ecosystem, such as a forest, for its carbon stock is an exercise that should be approached with extreme caution.

Recently, with the advent of global warming and the recognition that it is the modification of the carbon cycle that has led to the dramatic increases in greenhouse gasses we have seen since the industrial revolution, ecologists and economists have sought ways to convert natural capital into to monetary values. There is much emphasis on carbon, because it is readily measured, and there is much activity in creating markets for carbon. What is actually being marketed, however, is vastly more than the carbon stored in the ecosystem, but carbon markets are a promising beginning to a new economy in which natural capital becomes a part of our economies.

Ecosystem services: the missing link between economics and natural capital

No longer leaving ecosystem services out of our deliberations

Ecosystems are made up of plants, animals, and microorganisms whose biological activities transform inorganic matter to organic matter and back again – a description that is scientifically accurate but relatively useless to economics. Economics ultimately involves the values people hold, and if we assume that improving the delivery of valued goods and services to people is the measure of success of economic development, then it is important to be certain that *all* goods and services that impinge upon human wellbeing are included. Unfortunately, aside from the cultural values of biodiversity (e.g., people will pay for the protection of species they value such as pandas and tigers) and some environmental values associated with known ecosystem functions (e.g., restricting land development if it harms wetlands that regulate flood waters), natural capital and ecosystem services have rarely been any part of economic development. This is not negligence, but rather a reflection of the fact that there have been few ways to link the value of ecosystem goods and services into our economic deliberations. All this, however, is changing rapidly as ecosystem services are better understood and better integrated into development strategies.

Valuation

Ecosystem service valuation is perhaps the process that resonates with people because it can translate abstract ecological principles into monetary terms. Ecosystem valuation can be fairly simple—most provisioning services (like corn, timber, fish, and so forth) have markets and market prices for these services provide insight into how ecosystem services are valued. For many other services, however, it can be difficult to perform valuations. For services that lack markets (for example, most supporting services, such as oxygen production and nutrient cycling), indirect methods can be used to conduct valuations. For such non-marketed services, market prices are attached to the supply (or production) of a non-marketed service by either:

- linking supply of the non-marketed service to the supply of provisioning service that does have a market value
- estimating how much 'buyers' are willing to pay to maintain or increase the supply of the non-marketed service or
- estimating the cost of replacing the supply of the non-marketed service.

Each of these indirect valuation methods can be used to attach values to ecosystem services. For example, services provided by carbon in soils can be valued several ways, including by estimating:

- the value of soil carbon for crop production, by correlating the production of a marketable crop with soil carbon content
- the value of carbon sequestration performed by an ecosystem, based on the global willingness to pay for climate regulation, as established in international agreements (the Kyoto Protocol and subsequent agreements) and
- the value of soil carbon in an ecosystem for improving the quality of water provided to people downstream of the ecosystem, based on the cost of building a water purification facility that would replace the role of soil carbon in water filtration.

When ecosystem services are viewed in their proper place as the benefits that accrue to society from natural capital, they form an 'ecosystem service economy' that in many ways operates similarly to conventional service or production economies.

Scales: An important challenge for the economics of ecosystem services

The scales at which ecosystem services are supplied by ecosystems are often different from the scales at which they accrue (or are 'consumed') to society. Many supporting and regulating services in particular are produced at small spatial scales (e.g., a farm or forest), yet accrue at larger spatial scales (e.g., a watershed for water quality, or the globe for climate regulation). The temporal scale often differs as well—this happens when land management decisions made in each year alter the production of a service that accrues over the course of multiple years. A clear example is when management decisions in each year improve carbon sequestration, but the benefit of a better climate is felt only by subsequent generations. The result in either case is that the people whose management decisions produce services are often not the same ones who benefit. The benefits rather accrue publicly in a larger area, to people in the future rather than the present, or to both.

Payment for Ecosystem Services: The Modern Face of Development

Ecosystem services are increasingly being incorporated explicitly into economic decision making, in terms of both public policies and the actions of private individuals. The primary mechanism by which this happens is through payments for ecosystem services (PES).

PES is the concept of compensating those who produce goods and services by those that receive them since many of farming practices that maintain or enhance natural capital provide ecosystem services that benefit people far removed from the farm itself. For example, planting farm edges with perennial plants may help stabilize soil and retain nutrients protecting water quality of nearby streams that are used as drinking water great distances away or provide habitat for fish.

Given the cost of treating water to make it drinkable or the value of selling fish at the market, it is easy to see how it might be in the interest of the user of a particular ecosystem service (in this case, water quality) to provide incentive for the farmer to ensure its continued availability. While this basic concept might be simple, the process of developing such a relationship between those that ensure the services and those that might be willing to pay for them are quite complex and the marketplace for PES is just beginning to take off.

Despite the benefits of managing agricultural landscapes for biodiversity and ecosystem services, farmers may subscribe to management practices that instead diminish their natural capital for short term gain. Among the many reasons for this, maintaining or investing in natural capital may appear to subsistence farmers to be at odds with the need to produce enough yields to maintain their current food security. Committing to practices such adding organic matter to the soil, planting perennial crops to attract beneficial insects, or using improved fallows may require additional time, labor, and investment and without some immediate financial incentive may not be adopted. In fact research and development organizations have had relatively little success spreading practices such as agroforestry despite their aggressive education and outreach programs. Payments for ecosystem services could provide the much needed financial incentive to maintain the natural capital of agricultural landscapes.

By far the most significant development is the rise of markets for carbon credits, which are currently revolutionizing economic views of ecosystem services. As carbon markets become more feasible and more accessible to farmers, one can imagine that agricultural practices that maintain carbon stocks will increase in prevalence. PES programs and policies have been used to target water quality and water quantity, and it is the hope of many that this approach will evolve to embrace a wider variety of services as PES approaches become more established. Similar programs make payments for conservation of biodiversity, either by tying payments to protection of species of conservation concern, or by protecting habitat. To increase the benefits to society from ecosystem services and biodiversity even further, efforts increasingly seek to provide linked payments that improve delivery of ecosystem services alongside the conservation of biodiversity.

PES is an enormous topic, one that needs its own primer, so we will not treat it in more detail here. Rather, we will refer the reader to the Appendix and to the TransLinks website, www.translinks.org for valuable resources that explore payment for ecosystem services in greater depth.

A CATALOG OF ECOSYSTEM SERVICES

SUPPORTING SERVICES

Supporting services are fundamental services necessary for ecosystems to function and deliver other services. These include,

Soil formation – the buildup of living (e.g., microorganisms and soil invertebrates) and non-living material (e.g., dead organic matter, complex organic material such as humus, and soluble minerals such as nitrates and phosphates) that leads to the production of soil

Biogeochemical cycling (e.g., carbon and nutrient cycling) – the cycling of elements important to living process, such as C, H, N, O, P, and S, between their organic and inorganic forms, some important processes being

- oxygen production – production of gaseous or dissolved O_2 by photosynthesis
- nitrogen fixation – conversion of atmospheric N_2 to soluble forms by microorganisms
- respiration – the release of carbon dioxide by organisms that consume organic material (note that all organisms respire, including plants, though some anaerobic organisms do not respire CO_2)

Primary production – the buildup of living plant or algal biomass (i.e., plant or algal growth) from inorganic material by photosynthesis

Heterotrophic production – the buildup of non-photosynthetic microbial and animal biomass, such as the production of soil microbial biomass, wildlife, or livestock

Decomposition – the conversion of dead organic material to inorganic material

While supporting services are necessary for any other service production, just soil formation is explored in this case since the process of soil formation is critical to for land use managers to whom this document is targeted, and also since soil formation touches on many of these other supporting services above. See Appendices (page 36) for information sources on all types of ecosystem services.

Soil Formation

Soil is a complex living material; a mix of hundreds of species of small animals and fungi and sometimes thousands of species of bacteria that takes centuries to build up. Plants obtain their water and nutrients and other materials they need to grow and be productive from soil. "Healthy" soils are able to support the growth of vegetation, and are typically rich in organic matter (an important form of soil carbon), nutrients (like nitrogen, potassium, and phosphorus), microorganisms (especially fungi and bacteria), and have a good capacity to retain water. Negative changes in any of these properties leads to unhealthy soils which means the vegetation, whether crops, pastures, or forests, becomes less productive and often more susceptible to diseases, pests, and invasion by weeds. In relatively unmanaged ecosystems, such as national parks, vegetation and soils change slowly, but soil invariably increases in quantity over centuries. In managed ecosystems, especially farms, effective management can maintain soil formation. Soil health is usually maintained by carefully choosing plant species that are best suited for the ecosystem and by

balancing harvests with inputs. Harvests may consist of collecting vegetation, or harvesting livestock that consume vegetation in a pastoral or grazing system.
Inputs consist of additions of nutrients (i.e., organic or inorganic fertilizer) and water (i.e., through the use of irrigation). Ultimately, both soil volume and soil health are important and if management leads to a decline in either (e.g., soil organic matter loss, nutrient leaching to groundwater or soil erosion), management has to change to reverse the change.

Benefits of Soil Formation

When soil is formed and builds up in an ecosystem, it counters natural levels of soil loss due to wind, rain, or other factors that cause soil to be transported out of an ecosystem. When soil levels improve or remain constant, the following ecosystem services typically increase and improve soil fertility and health:

- Soil hydrological regulation (e.g., greater water retention)
- Nutrient (e.g., nitrogen, carbon phosphorus, and potassium) retention and cycling important for soil fertility.
- Erosion control
- Pest, disease, and weed control

Relationship to other ecosystem services

Productivity of food and fiber: Formation of soil increases the productivity of vegetation, leading to gains in any ecosystems service that depends on the biomass or activity of vegetation.
Water Quality: Soil erosion and agricultural runoff due to excess inputs can lead to siltation and eutrofication (i.e., nutrient enrichment and pollution) of waterways, reduced stream depth, turbidity
Water Quantity: Soil moderates watershed outflow, which can prevent flooding or loss of water needed for drinking, irrigation, industry, and hydroelectric power, and is important for recharging ground water supplies. Thus, soil production is important for maintaining or improving these services.

Techniques that help improve this service

Well managed organic and inorganic nutrient amendments, low impact tillage, managed grazing, and improving vegetation cover to prevent erosion from wind and rain.

Techniques most commonly effective: Agroforestry, Reduced Tillage, Fallows

Key Role of BD in Soil Formation

Soil formation depends critically on an enormous array of plant, animal, and microbial functions that include the production and accumulation of organic matter as well as the production of insoluble nutrients that plants can absorb. Soils benefit most from plants whose rate of growth range from moderate (e.g., woody shrubs) to slow (especially trees). Slow-growing trees produce great quantities of leaves and wood—this greater productivity means more inputs to soils. Their leaves also have high amounts of slowly decomposing organic matter which leads to an accumulation of organic carbon in the soil and improved soil health. Moderately slow growing species (shrubs and faster-growing trees) cannot match these benefits, but many, such as leguminous shrubs, add nutrients like nitrogen to the soil more quickly. Crops are fast-growing plants that may not provide these benefits, though careful management can help maintain soil health. To ensure soil formation, it is therefore necessary to maintain a wide diversity of plant species that provide for a wide variety of inputs necessary for soil formation.

Soil organisms—bacteria, fungi, and invertebrate animals—are also critical to soil formation Soil organisms process plant material and transform it into soil organic matter as well as soil nutrients. Different soil organisms perform different functions in soil production, thus soil production requires a considerable amount of soil organismal diversity. Different soil organisms also prefer different plant species, thus higher plant diversity maintains a richer diversity of soil organisms.

Herbivorous animals, including livestock in managed ecosystems, are also important to soil formation. Herbivores increase rates of nutrient cycling by consuming and breaking down coarse plant material and producing urine and dung which enriches both organic carbon and nutrients in soil.

PROVISIONING SERVICES

When we are extracting living resources from the environment that improve our wellbeing, nature has provided a service from which we can benefit. Examples include water for drinking or irrigation, plants for clothes and food, wood for building or fuel, fish harvested from freshwater and marine ecosystems, among many others.

Examples

Food and Fiber - Agriculture

Food (e.g., grains, cereals, fruits, vegetables, livestock) and fiber (e.g., cotton, flax, wool, silk) are primarily produced in agricultural ecosystems or farms. Increasing yields is important for any farmer, though there is often a tradeoff between short-term and long-term gains. Short term gains are improved by monocropping and high nutrient, water, and biocide inputs, but long-term losses in soil organic matter, water pollution from runoff, or the adverse health consequences of excessive biocide use can negate short-term gains. Increasing yields improves provisioning services, but invariably comes at the expense of many other services. (See *Relationships to Other Services* below)

Benefits from Food and Fiber Production

Greater agrobiodiversity may enable farmers to sustain yields over time, and better equip them to adapt to unpredictable changes, such as rainfall, temperature, or other larger scale climatic influences. Some benefits include:

- improved long term soil quantity and quality
- higher yields over longer periods of time
- reduced need for fertilizers (thus cost savings, improved water quality, and a lower likelihood of soils being stripped)
- reduced use of pesticides, which decreases vulnerability to disease due to minimized resilience
- lower degree of risk over the long term (e.g. if monocropping, unpredictable climatic changes may be more detrimental)
- ability to shift into other products more easily with fluctuating market prices

Relationship to other ecosystem services

Soil production: Agriculture can reduce soil production by reducing soil organic matter, nutrients, and soil organism diversity, though proper management can prevent such adverse consequences

Water Quality: reduction in fertilizer use leads to reduced potential for run-off to negatively impact water quality

Key Role of BD in Cultivated Food and Fiber Production

Agrobiodiversity is important for insuring nutritional balance and it is also an economic safety net. When conditions for one type of crop are not favored (due to bad weather, pests, or diseases), and/or the market prices for one crop falls, a diverse array of crops provides alternatives. The concept of a diversified portfolio to reduce investment risk is as true in financial markets as it is in agricultural markets.

Most effects of biodiversity on food and fiber production are less direct. Biodiversity of plants in fallows, agroforests, and intercrops, helps increase production by improving soil conditions (see “Soil Formation” page 4), crop microclimate, soil nutrient conservation, and soil erosion control. In addition, greater plant biodiversity increases the quantity, quality, and diversity of habitat for other organisms beneficial to agriculture, typically increasing both the abundance and biodiversity of helpful animals and microbes. Some of these species beneficial to food and fiber production are insects and birds that control crop pests, others pollinate crops, and fungi, bacteria, insects, earthworms, and other soil invertebrates improve soil conditions. Increased agrobiodiversity can also decrease the loss of related ecosystem services that are typically lost when farms or pastures use smaller numbers of intensively managed species.

Relationship to other ecosystem services ctd.

Genetic Resources: a more diverse system preserves within and inter-species genetic resources

Pollination: presence of natural habitat for pollinators enables pollination, which improves likelihood of resilient crops through improved genetic diversity

Green manures are organic fertilizers that are usually leaves cut from trees or shrubs, or a crop planted for the purpose of use as fertilizer. They can be planted as part of a crop rotation, and in regions without a long dry season, as a cover crop after the crop is harvested. Once green manures are harvested, they are mixed into the soil.

Techniques that help improve this service

Crop Management: Agroforestry, Relay crops, intercropping, perennial cropping, green manures

Physical Management: Hedgerows, terracing

Woodland Management: Wood lots

Techniques most commonly effective: Agroforestry, Green Manures, Fallows

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Food and Fiber - Wild

Although the monetary and non-monetary benefits are similar to cultivated crops (food, fuel, fiber), the difference between wild and cultivated agricultural products is where they are found and to what extent their habitat is managed. Non-cultivated food and fiber materials (sometimes referred to as non-timber forest products or NTFPs) typically originate in forested or brush areas. These materials may be gathered through selective harvesting or traditional foraging practices that aim to reduce the physical impact on surrounding areas – benefiting from the product extracted while enabling the rest of the surrounding flora and fauna to exist as it normally would. For instance, liana, used for basket weaving in East Africa, is extracted from forested mountain regions, but by leaving the majority of the other plant and trees species behind, they can continue to serve as habitat for other species, as well as provide supporting and regulating services. However, the prosperity of wild products is often dependent on specific environmental and/or habitat conditions: these materials are therefore threatened when over-harvested or subjected to ecosystem modification.

Benefits of Collecting wild food and fiber

- No need for expensive inputs like fertilizer or pesticide — Native plants are better equipped to adapt
- Generally implies the preservation of wild areas, which can result in the promotion of biodiversity (multiple benefits discussed above)
- Promotion of pollinators
- Preservation of buffer zones for resistance to disease

Key Role of BD in Wild Food and Fiber Collection

Since wild food and fiber products are not cultivated in the traditional sense, they are especially reliant upon the maintenance of biodiversity. Indeed, it is this diversity that produces such a variety of materials that can be consumed, used for construction, carved, collected, sold, used as medicine, and much more. One of the most compelling arguments for conserving biodiversity globally is that a mere 10% of the worlds species have been described. In these wild spaces there may be extremely valuable materials to date undiscovered. Biodiversity preservation is of particular importance if what is being harvested are not plants but animal products; the maintenance of the habitat, including their food, enough area for territory, breeding grounds, and other biological needs are critical to maintain their populations.

Less directly, when a wild or unmanaged area is near a cultivated one, this patch may include species that do not provide monetary value to a farmer but provide habitat for pollinators, or serve as a physical barrier to reduce the ability of invasive species or disease to spread.

Relationship to other ecosystem services

Pollination: Preservation of native species and undisturbed peripheral regions surrounding managed landscapes enhances habitat for pollinators, and in turn improves pollination of both cultivated and non-cultivated species.
Pests and Disease: monocultures facilitate and are more susceptible to the spread of disease. Buffer zones created by less managed landscapes or mosaic landscapes can protect agricultural areas, and improve resilience.
Climate: The sustainable harvest of NTFPs discourages deforestation, and trees not only sequester carbon, this practice can affect microclimates since large stands regulate temperature, impact wind speed and direction, and increase local water retention in soils to improve overall soil health.

Techniques that help improve this service

Crop Management: Agroforestry, cover crops, relay crops, intercropping, bush and forest fallows
Physical Management: Hedgerows, terracing, reduced tillage, fire management
Woodland Management: Improved woodland management

Techniques most commonly effective: Improved Woodland Management, Agroforestry, Fallows (esp. Bush and Forest Fallows)

Fuelwood and Timber

Fuelwood is usually unprocessed woody vegetation (branches, logs, twigs) that is collected and burned to generate energy – for cooking, heating, water purification, or other household needs. Timber generally refers to trees and collected wood large enough for building, pulp and paper production, or construction. In developing countries fuelwood and timber can comprise 80% of all trees felled. While urban regions have substantial resource demands, most timber products are consumed in the locales where they are collected. Collection practices may include foraging and provisional gathering, or involve plantation-style or silvicultural production systems. Arboreal resources include forests, mangrove swamps, buffer zones, wooded mountainsides, agroforestry systems, and plantations – some of which are more diverse than others. For example mangrove forests are not as biologically diverse as many other arboreal systems, but the services they provide for flood regulation and fish habitat are highly valued. As with all ecosystem services, care must be taken to preserve long-term resource viability. Overharvesting can lead to deforestation, loss of biodiversity, and degradation of

Key Role of BD in Wild Fuelwood and Timber

As in the case for food and fiber crops, the biodiversity of any group of organisms (plants, animals, microorganisms) can affect production of fuelwood and timber. Producing a wider selection of forestry goods increases plant biodiversity, and can increase overall production and income. Benefits from biodiversity are most likely when producing one or a few goods. Varietal, genetic, spatial, and temporal aspects of plant biodiversity, here tree biodiversity, help control the risk of pest and disease outbreaks.

Indirect effects of biodiversity on fuelwood and timber production are similar to those in food and fiber systems, but wood production systems often doubly serve as habitat for a wide variety of organisms. Plant biodiversity, including planted trees, naturally regenerating trees, and shrubs and herbs in the understory, helps increase production by improving soil conditions (see "Soil Formation" page), microclimate, soil nutrient conservation, and soil erosion control. Greater biodiversity of trees and other plants provides better habitat for other organisms, and the biodiversity of many of these organisms improve wood production—especially insects and birds that control tree pests and pollinate trees, and soil organisms that improve soil conditions.

woodland ecosystems. This means that timber harvesting should correspond to sustainable forest management practices that both preserve woodland resources and recognize long-term economic interests.

Benefits of Well- managed Fuelwood and Timber

In any area where a population is increasing, due to the necessity of energy production and growth of physical structures; there are multiple benefits for sustainably managing this highly valued provisioning service:

- Managed systems minimize deforestation
- Reduced collection distances save human resources
- Availability of timber has been linked to food from home to food produced for commercial production – supply and demand of individuals may affect agricultural choices.
- Surpluses enable selling and profiting
- Maintenance of soil quality (see page 16)
- Avoidance of conflict (from seeking timber or fuelwood further and further away into other people's territory)
- Alternative to dung for energy production, enabling dung to be used as fertilizer

Relationship to other ecosystem services

Soil sustainability: With their substantial root systems, trees prevent erosion, and their canopies increase shade, improving water content of soils.
Water Quality: As deforestation can increase erosion, soils and the nutrients within them are more likely to run-off and contaminate water sources.
Climate Regulation: Reduced forest cover has both direct and indirect implications for climate change – felled trees to be burned result in trees changing from a carbon sink to a carbon source. Indirectly, less forest cover results in exposed and less stable soils.

Techniques that help improve this service

Crop Management: Agroforestry, Natural Fallows (long)
Physical Management: Hedgerows, Terracing
Woodland Management: Woodlots, Improved woodland management

Techniques most commonly effective: Woodlots, Improved Woodland Management, Agroforestry

Genetic Resources

Genetic resources refer to genes that benefit plant and animal breeding, biotechnology, the pharmaceutical industry, and other businesses. Genetic resources also include species that may have commercial value such as new microbial species for fermentation or other industrial processes, as sources of new biomaterials such as biological matrices for the regeneration of bone and nerve tissues, new foods, new biocontrol agents, or other uses. Species that are the ancestors of commercially valuable domestic species are also important genetic resources for plant and animal breeding. With less than 2% of all species on Earth having been described, genetic resources potentially represent an untapped source of wealth harbored in biodiversity. With each extinction it is possible that valuable genetic resources are permanently lost.

Ownership of genetic resources is a source of much controversy. For example, the Rosy Periwinkle of Madagascar, *Catharanthus roseus*, long cultivated for its medicinal values, possessed genes that produced vinblastine and vincristine, two important drugs used in the treatment of leukemia. These gene products benefited the pharmaceutical companies that patented and marketed them and patients who used the drugs, but not the people of Madagascar who owned the genetic resources. The Neem tree, *Azadirachta indica*, a native of India and other Asian countries, is also the source of many pharmaceuticals, one of which the United States attempted to patent and led to a long dispute of ownership between India and the United States. Incidences such as these, often termed *biopiracy*, have created considerable concern over protecting ownership and intellectual property rights for products developed from genetic resources belonging to the nations where the species are native. In the 1980s, 80% of medicines, including antibiotics, antimalarials, anti-cancer drugs, pain relievers, immunosuppressants, and many more, were derived from genetic resources. Today, many drugs are synthetic and not naturally derived, and while possibly less than 50% of new drugs are from genetic resources, these resources remain an important ecosystem service.

Key Role of BD in Genetic Resources

The more closely related species are, the lower the diversity of genes, thus many closely related species are likely to have few novel genes among them compared to the same number of species that are distantly related to one another. For this reason, microorganisms, such as bacteria, whose genetic differences are far greater than genetic differences among plants and animals, are believed to have vast stores of genes that may produce biological materials, such as pharmaceuticals, while plants and animals are likely to have fewer. However, because there are potentially millions of species of plants and animals that have yet to be described, it is relatively unknown what genetic resources are likely to be stored there. Protected areas, seed banks, botanical gardens, zoos, and biodiversity reserves all potentially protect extraordinarily valuable genetic resources.

Benefits of Preserving Genetic Resources

Genetic resources cannot be improved, but can be protected and preserved by biodiversity conservation.

Relationship to other ecosystem services

Biodiversity of food/fiber: When unpredictable changes occur, farmers are able to draw upon other crop varieties

Pest/disease regulation: genetically diverse individuals are better able to draw on defenses from pests and disease, likewise, diverse crops prevent the spread of pests and disease since usually only one species is the target host.

Soil Formation/Sustainability: crop diversity helps preserve and sustain proper soil nutrient balances

Climate Regulation: adaptation to climatic changes are facilitated by within-species genetic diversity

Techniques that help improve this service

Establishment of Seed Banks**:** Preservation of germ lines of domestic plants is important for plant breeding. Establishment of protected areas and biodiversity reserves: Conservation, preservation and the protection of native species insures that untapped genetic resources are not lost to extinction.

Techniques most commonly effective: In situ conservation (e.g. parks and protected areas) is often the most desirable, but ex situ conservation (e.g. seed banks, botanical gardens) is an equally critical technique. These strategies and others must work together.

REGULATING SERVICES

Natural ecosystems have inherent feedbacks that can regulate ecosystem function and serve as natural insurance against floods, pest outbreaks, devastating fires, fishery collapse, or other dramatic deviations from normal levels of ecosystem functioning.

Examples

Pollination

Pollination, the transfer of pollen for fertilization and sexual reproduction in plants, plays a vital role in maintaining healthy ecosystems and productive agricultural systems. Animal pollination is required to produce seeds and fruits in up to 80% of the world's flowering plants, and 75% of the world's food crops (mostly fruits and vegetables). Many plant species rely on animal pollinators, which are mostly insects such as bees, moths, flies and beetles, and include some birds and bats. Maintaining pollination always requires that pollinators have habitat close to the plants they pollinate, and in addition the biology of some species (especially bees) reduces their ability to survive in small 'islands' of habitat. To ensure successful pollination and maintain production of pollinator-dependent crops, land management should conserve and encourage healthy populations of as many pollinator species as possible.

Key Role of BD in Pollination

Through the recombination of genetic material pollination allows for greater genetic diversity of flowering plants and crops, which increases resilience. Pollinator diversity increases the chance that one or more pollinator species will survive ecological disasters (such as drought and fire), pests, and emergent anthropogenic pressures (such as logging and other land-use changes). Further, population genetic variability is necessary for natural selection and biological evolution.

Pollination is vulnerable to the loss of pollinator species. Declines of pollinators are mostly due to loss of habitat from agricultural expansion into natural areas, and when agriculture is intensified by increasing cropping frequency. Animal pollinators themselves rely on their food sources (the plants whose flowers they pollinate) for survival and the habitats they require for reproduction. For these reasons, pollinators depend on favorable land use types (and the distribution of favorable types in a landscape) and the diversity and abundance of plant species in the area.

Benefits of Improved pollinators

Considering that pollination is important in both natural ecosystems as well as agricultural lands, there are many benefits of preserving this ecosystem service:

- Improves livelihoods by increasing food security and increased production
- Important in the production of 30% of all crops, fibers, edible oils, and medicinal plants
- Sustains biodiversity of flowering species
- Sustains genetic diversity of flowering species, improving resilience and adaptability

Relationship to other ecosystem services

Productivity of food and fiber: Many agricultural products and non-timber forest products depend on pollination for overall productivity and survival. Therefore, protecting pollinators will result in increased crop and forest food productivity

Genetic Resources: By promoting genetic recombination via sexual reproduction, pollination improves variety in genetic resources, making species more resilient and adaptable to environmental fluctuations and pressures

Pest/disease regulation: Natural regulation supports pollinators since pesticides and exotic species can reduce pollinator or eliminate pollinator populations, or eliminate the prey of pollinators.

Supporting services: Pollinators are critical to most flowering species thus sustain vegetation that is necessary for most supporting ecosystem services.

Techniques that help improve this service

Crop Management: agroforestry, crop rotations, cover crops tree intercropping, improved fallows, reduced monocultures
Physical Management: hedgerows, refugia for pollinators in agricultural landscapes
Woodland Management: **Stepping stone spatial pattern**, improved woodland management, woodlots

Techniques most commonly effective: Fallows, Improved Woodland Management, Agroforestry

Stepping stone spatial pattern: Many agricultural landscapes are a mosaic in which small (less than 5 ha) patches of crop fields, woodlots, agroforests and natural or semi-natural habitats form a complex pattern, with each patch of these land use types separated from their own type. In such landscapes, stands of trees and natural or semi-natural habitats may provide a variety of supporting and regulating ecosystem services to other land uses nearby in the mosaic.

Water Quality

Whether agricultural lands are rain fed or irrigated, a sufficient supply of unpolluted water is critical to ensure optimal crop yields. As water demands increase from all sectors, (currently agriculture accounts for over two thirds of surface water use worldwide and water use increased six fold in the last century), there is a corresponding decline in water availability and water quality. Water quality is an index of the chemical, physical, and biological aspects of water as they pertain to established water standards. Agricultural areas are increasingly facing water scarcity and/or dealing with water polluted with excess nutrients, heavy metals and other pollutants that can both be harmful to human and crop health. If left unchecked, water quality within an agricultural system may diminish due to soil erosion and agricultural runoff caused by excess inputs. This in turn leads to siltation and eutrofication of waterways, reduced stream depth, and damage to aquatic resources. Algal blooms are a common result of high nutrient input, which create anoxic conditions that can cause fish kills and imperil other aquatic resources. When land is not cleared entirely, but fragmented, a path is created for pests and disease to choke out these native "living filters" that reduce the natural capacity of vegetation to provide this service

Benefits of Improved Water Quality

Pollutants such as metals, viruses, oils, excess nutrients, and sediment are processed and filtered out as water moves through wetland areas, forests, and riparian zones. This purification process provides clean drinking water and water suitable for industrial uses, recreation, and wildlife habitat to ensure:

- expected yields can be maintained

Key Role of BD in Water Quality

Both terrestrial and aquatic biodiversity influences water quality in agricultural landscapes. Reduction of plant biodiversity, such as during the clearing land for agriculture and development, reduces the capacity for natural vegetation to serve as a filter for nutrients and pollutants that accumulate in run-off. The biodiversity of wetland plants such as reeds, rushes and marsh grasses is particularly critical for maintaining hydrological filtration, along with the biodiversity of plants specializing in riparian forests and other terrestrial habitats along waterways. Vegetation also provides a canopy over streams and rivers, which maintains water temperature. When removed, increased exposure to sunlight can increase water temperatures and affect the ecosystem within the water.

Some species are more sensitive to particular pollutants and monitoring their populations can serve as an early warning to environmental change. Maintaining healthy natural communities make these changes easier to detect. Intact aquatic ecosystems are also better equipped to resist pathogens, which indirectly improves human health if this water is used for drinking, agriculture, or is otherwise consumed.

- salinity is managed: salts in soil or water can reduce water availability to such an extent that yield is affected.
- infiltration rates are improved: relatively high sodium or low calcium content of soil or water reduces the rate at which irrigation water enters soil to such an extent that sufficient water cannot be infiltrated to supply the crop adequately from one irrigation to the next.
- Ion toxicity is avoided: certain ions (sodium, chloride, or boron) from water can accumulate in soil leading to damage of crops that are sensitive to ionic concentrations high enough to cause crop damage and reduce yields.
- Improved health of livestock and people who rely on local sources of water for drinking

Relationship to other ecosystem services

Soil Production: pollution, salinization, and other adverse impacts on plants and soil organisms can limit or reduce soil production.
Pest/Disease regulation: wastewater and polluted surface and groundwater can increase densities of disease vectors such as mosquito larvae, increase toxic algal densities, or reduce populations of biocontrol or pollination species.
Climate Regulation: Excess nitrogen can result in acidification, changes in plant and animal life, loss of biodiversity, decrease in soil fertility, and conversion of inorganic or organic nitrogen into greenhouse gases such as NO and NO_2.

Techniques that help improve this service

Crop Management: crop selection (e.g. selecting those more resilient to salinity or toxicity), cover crops, crop rotations
Physical Management: reduced tillage, fire management
Woodland Management: woodlots via increased tree coverage

Techniques most commonly effective: Agroforestry, Reduced Tillage, Cover Crops (and in hilly areas, Terracing)

Regulation of pests, diseases and weeds

Reducing the impact of pests, diseases, and weeds are particularly relevant to land holders deriving services from their terrain. Agriculture in all its forms has become increasingly reliant upon biocides such as pesticides, herbicides, fungicides and insecticides to protect crops from infestations. The importance of controlling pests, diseases and weeds that can damage crops directly or by increasing competition for critical resources is evidenced by the high levels of biocide use. However, these practices have resulted in the spread of toxins in the environment that are harmful to non-target species (including many pollinators and predators of pests) and human health. In recent years, because the effectiveness of many biocides is decreasing while the detriments to the environment and human health are growing, measures are being taken to enhance the environment's natural ability to regulate pests and disease. Pest control systems that draw on natural predator/prey relationships, such as Integrated

Key Role of BD in Pest, Disease, and Weed Regulation

Native biodiversity is a source of predators of insect pests and can resist or slow the spread of plant pathogens, diseases, and invasive species. Agrobiodiversity works similarly, resisting pests, weeds, and disease, while monocultures provide substantially less resistance. Agricultural systems are therefore often less vulnerable to infestations when they have greater crop diversity or when they separate different crops from one another by alternating species among adjacent fields or rotating crops over time. Biodiversity is important beyond the actual site where crops occur; maintaining natural habitat near agricultural ecosystems can support naturally occurring biocontrol species, such as predatory birds, bats, and arthropods.

Pest Management (IPM), have been proven to be effective alternatives as chemical sprays but without the negative environmental externalities.

Benefits of Improved Regulation

- Reduction of uncontrolled weeds increases crop yield and quality, and prevents weeds from harboring pests and diseases that can spread to the crop
- Reductions in biocide application saves money
- Reductions in biocide-related losses in non-target beneficial species, such as biocontrol species and pollinators
- Reductions in adverse consequences of biocide use to human health and water quality
- Improved food security

Relationship to other ecosystem services

Water Quality: increased biocide usage in the absence of naturally occurring pest regulation increases the risk of water contamination

Food and fiber production: naturally occurring biocontrol can provide greater yields, greater security, and lower costs of production

Pollination: pesticides may inadvertently kill pollinators, thereby reducing the capacity of birds and other insects to pollinate both natural and agricultural species

Techniques that help improve this service:

Integrated pest management that uses combinations of pesticides and biocontrol species, crop rotation, and stepping-stone spatial pattern- a technique in which individual crop species are planted adjacent to others to prevent contiguous monoculture stretches that are more prone to attach by pests.

Techniques most commonly effective: Integrated Pest Management, Crop Rotation

Water Quantity/Water Availability

The timing and magnitude of runoff, flooding, and aquifer recharge can be strongly influenced by changes that effect the water storage potential of a system, such as the conversion of wetlands or the replacement of forests with croplands or croplands with urban areas. Meanwhile, over-extraction of groundwater for irrigation can lead to soil salinification (salt buildup) and deprive other ecosystems of water, leading to loss of biodiversity and reductions in ecosystem services provided by the drained systems. In arid and semi-arid areas, rain falls only during a few months of the year, but is unreliable even during those months. It typically comes in a few heavy storms, and much of the water runs off the surface, causing flooding and erosion. Water conservation relies on trapping as much of this water as possible and storing it on the surface (in tanks or reservoirs) or allowing it to sink into the soil in order to raise the water-table and increase the soil-moisture level. More water can seep in if it is spread over a large area of soil rather than being concentrated into fast-running streams.

Key Role of BD in Water Quantity

Management of water availability includes having access to water when it is needed, and also mitigating the effects of too much water, such as erosion and reduced soil infiltration from flooding. Bordering rivers, streams, and marsh and wetland ecosystems can absorb high volumes of water and reduce downstream peak flows. This storage and slowing of water can also serve as a source for recharge to groundwater reserves. Biodiversity of trees, shrubs, and other plants that have moderate-to-high productivity, and that improve soil carbon stocks, have a critical role in creating soil conditions that stabilize the seeping of water into the soil. The result is the recharge of ground water, while also reducing runoff and erosion of soil that clogs waterways. This benefit of biodiversity for reducing runoff also improves aquatic biodiversity downstream, by reducing its exposure to sediment and pollutants.

Thus, water-conservation efforts focus on stopping the water from becoming concentrated in the first place (by ensuring a protective cover of vegetation on the soil surface), slowing down the flow of running water (for example, with pits and dams), and spreading the water out over a large area (for example, with terraces).

Benefits of Improved Water Quantity

Effective irrigation produces the desired crop response and efficient irrigation makes the best use of available water.

- Adequate water supply reduces crop stress and wilting
- Water quantity increases one's ability to produce crops in the off season, and as a result diversify cropping, thus increasing food and economic security
- A well-managed water supply encourages system stability and reduces fluctuations in availability
- Promotes equitable and continuous resource access
- Typically entails improved water quality, pressure, and sanitation.

Relationship to other ecosystem services

Pest control: Water stress weakens a plant's ability to resist attacks by pests.
Soil formation: Soil type affects its ability to hold water, and for plants to remove water from the soil. Coarser soils are able to move water in and out more easily than dense soils

Techniques that help improve this service

Crop Management: Agroforestry, cover crops, relay crops, perennial crops, mulching
Physical Management: Terracing, reduced tillage
Woodland Management: Stepping stone tree pattern
Techniques most commonly effective: Agroforestry, Improved woodland management

Climate Regulation

The way we manage ecosystems can both contribute to and mitigate climate change. Common practices like slash burn agriculture, land clearing for livestock grazing, and the production of petrochemical based fertilizers are responsible for greenhouse gas emissions. Conversely, oceanic and terrestrial ecosystems are important "sinks" for carbon dioxide; vegetation absorbs carbon dioxide from the air, and stores carbon in the plants, or as soil carbon. When carbon is stored in plants or soils for a long period of time, it is being sequestered from the atmosphere. From an agricultural perspective, carbon sequestration and emissions vary between crops, land use types, soil types, regional climates, and management practices. Increasing sequestration relies on agricultural management that reduces emissions while also improving the capacity of on-farm vegetation to store carbon removed from the air. The biodiversity of plants that play key roles in carbon sequestration are most commonly lost when agricultural management replaces older tree-based systems, fallows, and forests with annual crops or short-rotation plantations of fast-growing tree species. Of course, just as carbon stocks do not represent the value of a forest, carbon cycling does not tell the whole story of climate regulation. On a local scale, land cover patterns can influence rainfall and temperature.

Benefits of Improved climate regulation

Global

- More predictable climatic shifts
- Reduced frequency of droughts/floods
- Avoidance of cumulative risks

Local

- Carbon sequestration can lead to increased soil organic matter, nutrient and water retention, and increased root biomass to result in overall increased land productivity
- Low-cost implementation

Relationship to other ecosystem services

Soil formation: When land is cleared, not only are there local climatic impacts and a potential role in global carbon cycling, soil is exposed and erosion and the associated problems like compaction, reduced infiltration are more likely.

Water Quality: The downstream impacts of erosion are the increased likelihood of nutrification of waterways, reduced stream depth, turbidity, all of which can affect aquatic resources as well as agricultural water demands.

Food Fiber: Improved climate regulation on both the local and global scale is important for cultivating appropriate crops at appropriate times to ensure their growth is optimized with ideal temperatures and precipitation. Likewise, in a poor year for non-cultivated vegetation, the result is a reduction in herbivore populations, and populations of those that consume the affected species all the way through the entire food web for the region.

Techniques that help improve this service

Crop Management: Agroforestry, cover crops, relay crops, intercropping, natural fallows (short and long), perennial cropping

Physical Management: Hedgerows, terracing, fire management, reduced tillage

Woodland Management: Improved woodland management, wood lots

Techniques most commonly effective: Agroforestry, Improved Woodland Management, Fallows (and in hilly areas, Terracing; in dry areas, Fire Management)

Key Role of BD in Climate Regulation

Management of agricultural landscapes that reduce plant biodiversity typically decreases the potential for carbon sequestration. Deforestation is currently estimated to account for 20% of global greenhouse gas emissions. Where financial incentives do not exist to preserve biodiversity (i.e. where it is more profitable to cut down or sell natural capital), carbon markets have provided more incentives to leave forests standing and therefore reduce emissions. Not only does the conservation of habitat and ultimately biodiversity reduce the impact of climate change, biodiverse areas are also better able to adapt to changes that do occur. Older forests, tree-based systems and fallows have more long-lived, slow-growing trees, which effectively store carbon in wood, leaves, and soils. These plants are a key source of functional diversity, that is, variation in each of the many roles that different plant species play in sequestering carbon, as well as improving the resilience of the ecosystem to ongoing climate change. Indirect effects of climate change can also be mitigated by the biodiversity of other key plant groups. For example, disturbances such as flooding can be mitigated by maintaining plant biodiversity in habitats like wetlands or mangrove forests. Meanwhile, farmers facing a lack of rainfall or more pests due to climate change will benefit from conserving a range of crop and tree species, enabling a shift to more drought- or disease-resistant species.

CULTURAL SERVICES

Cultural services are typically less tangible than material services, but are nonetheless valued by people in all societies. Local populations derive a variety of non-material benefits from ecosystems, including: recreation, tourism, aesthetic appreciation, inspiration, spiritual, and educational value. In fact, a number of traditional practices exist in tandem with complementary ecosystem services. These culturally significant, traditional practices may play an important role in developing social capital and enhancing both individual and communal wellbeing.

Examples

Inspirational and Spiritual Value – Sacred Groves

For centuries, nature has played an important role in people's belief systems and spirituality. For instance, groves of trees have often been used as places of religious worship and spiritual enlightenment. Historically, these sacred groves have been found throughout most parts of the world including Europe and the Americas. Currently they predominantly exist in India and several West African countries. Cattle grazing, hunting, and non-timber forest product collection is often banned in these areas due to cultural traditions. Therefore, sacred groves are important in the maintenance of ecosystem services, since they often serve as relatively undisturbed forest stands within a landscape mosaic of developed agricultural and pasture land. Sacred groves are also important since they promote local people's relationship with nature, allowing them to maintain traditional cultures and belief systems.

Benefits of Promoting Spiritual Value

Considering that preserving sacred groves aids both the conservation of mature forest stands as well as people's traditional belief systems, there are many benefits to promoting spiritual value including:

- Increased biodiversity in a given landscape by preserving mature forest groves
- Promotion of local people's relationships with nature, which preserves cultural traditions and traditional ecological knowledge
- Possibly improving water quality and regulation to nearby communities by maintaining large forest stands
- Serving as a refuge for animals that may be hunted in other nearby areas that are not regulated by spiritual traditions

Key Role of BD in Spiritual Value

When nature is worshipped or conserved for religious or spiritual reasons, the conservation status of the species or ecosystem type or specific natural area is usually improved because there is a perceived value in maintaining its existence. Laws to prevent cutting trees within a protected area may be less effective in affecting behavior as social norms associated with protecting a cultural or religious natural space. The direct benefits to maintenance of biodiversity are clear: when a natural area remains relatively intact, the plants, animals, and microorganisms are also preserved. In highly populated regions, these small protected areas may be the only habitat for a species without cultural value that otherwise would be eradicated.

Conversely, an individual species that has high cultural value can also be a vehicle to protect many other species. The panda or the tiger are charismatic species used by conservation organizations to generate interest in protecting areas where they live (along with many other valuable species that in an intact ecosystem can provide other valuable ecosystem functions). In Canada, one such umbrella species is the "spirit bear", a white bear in the coastal temperate rainforest. It is simply a black bear with rare genes, but because of the cultural significance to native people in the region, the value attached to it by citizens, and portrayal by the media, vast tracts of rainforest have been protected, benefiting regional watershed, air quality, and thousands of other species.

Relationship to other Ecosystem Services and Biodiversity

Biodiversity: Sacred groves maintain mature forest stands in areas that are highly susceptible to land-use change

Water Quality and Quantity: Sacred groves may improve water quality and quantity for nearby communities through filtration of rainwater as it travels through soil to the water table

Pollination: The preservation of pollinators may be promoted by sacred groves by providing refugia in an otherwise developed landscape

Techniques that help improve this service

Physical Management: Ensuring that land-use changes and development do not alter sacred groves

Techniques most commonly effective: Allowing and enabling local people to maintain traditional cultures and belief systems

Recreational and Aesthetic Value

The environment plays an important role in people's lives, even if they do not directly depend on the land for their livelihoods. This is because nature offers many benefits that are not directly tied to people's economic needs. For instance, people often enjoy spending time in nature, whether that is through hiking, camping, canoeing, or other various outdoor activities. In addition, looking out onto a beautiful landscape often evokes happiness and an appreciation of the natural beauty that Earth has to offer. These values, termed recreational and aesthetic values, are important since they often strengthen people's connection with nature, which may result in increased conservation of natural areas, resources, and subsequently, ecosystem services.

Benefits of Promoting Recreational and Aesthetic Value

There are many benefits to preserving recreational and aesthetic value such as:

- Increasing biodiversity through the creation of national parks, camping grounds, and hiking trails
- Promoting people's relationship with nature
- Serving as an environmental educational tool increasing awareness and appreciation of nature
- Possibility of increasing the quality and quantity of water through the preservation of mature forest stands

Key Role of BD in Recreational and Aesthetic Value

National parks are often thought of as a destination for recreation, to experience nature, but they are also important living preserves of the natural landscape. In some regions protected areas are the only places where native ecosystems remain relatively intact. Protected areas not only preserve wildlife by maintaining appropriate habitat in one location, a series of protected areas are critical to ensuring diversity within species and maintaining population size. In East Africa parks including the Serengeti and Masaai Mara are critical to maintain the migration of 1.5 million ungulates annually, moving them to different grazing areas. By preventing overgrazing in any one location, the wildebeest, zebra and gazelles are also able to sustain their populations, just as the animals that prey on them are able to sustain theirs. Corridors of protected areas enable migration to take place, which in the case of birds may be essential to get to breeding grounds or weather appropriate for a particular time of year. Genetic diversity is also at stake, when populations of species remain isolated, their within-species diversity declines, which reduces fitness. With fewer options in the genetic pool, their ability to readily adapt and evolve to unpredictable changes is hindered.

- Serving as refugia for animals, including pollinators, by conserving natural forested areas

Relationship to other Ecosystem Services and Biodiversity

Biodiversity: The creation of parks and recreation areas can increase biodiversity through preserving natural habitat and forest stands.
Water Quality and Quantity: Promoting recreational and aesthetic value may lead to increased water quality and quantity through the preservation of forest stands that result in filtration and retention
Pollination: The preservation of pollinators may be promoted by national parks and recreational areas by providing refugia in an otherwise developed landscape

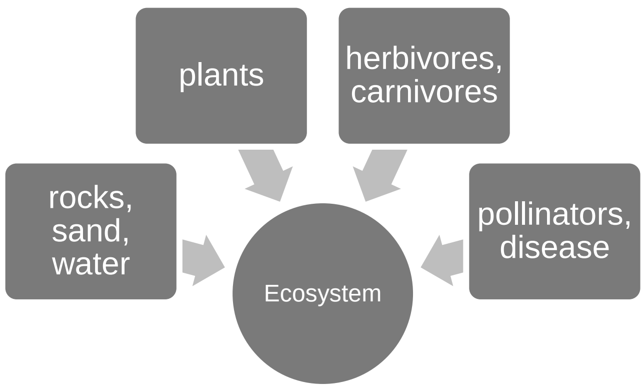
Techniques that help improve this service

Physical Management: creation of national parks and other recreational areas

BOXES

Box 1. What is an ecosystem?

"Ecosystem" is a common term that is used in a variety of ways, but its scientific meaning is rather specific. The best way to explain the term to someone is to ask them to conduct the following thought experiment. Imagine a large container of sterile rocks, sand, and water with some space in the top for air. Anyone would recognize that such a place is a rather static and dull place and if it is truly sterile, it will remain unchanged for centuries. Add, however, some microorganisms and small animals commonly found in the ground, like tiny insects, mites, and worms, and the sand and rock would be transformed into soil. Add some plants to produce oxygen and remove carbon dioxide from the air, then add some herbivorous animals to help keep the vegetation from getting out of hand, some carnivores to keep the herbivores from getting out of hand, or some omnivores that feed on both plants and animals, some pollinators, and though it might seem cruel, some disease organisms that would also help keep any species from growing uncontrollably and jeopardize our microcosm of the Biosphere. Do the same to the water by adding phytoplankton, zooplankton, and fish. The entire container would now be an ecological system, or ecosystem.



At what point did the pile of sand, rock, water, and air become an ecosystem? Technically the minute one added even a single species to the system and that species survived long enough to change the chemical and physical properties of the container. For example, if we added even one species of bacteria that thrived, its respiration would have changed the atmosphere and its consumption of nutrients in the sand or on the surfaces of the rock would have changed the chemistry of the system. It might change the color of the surfaces of the water and the system might change temperature because its new color and chemistry would lead to a warming when exposed to the sun.

An ecosystem is therefore any system in which biological processes influence the chemical, physical, and biological structure of a community. A fishbowl with fish and plants in it, a forest, a field of wheat, a small stream or giant lake, even a city or town, basically wherever life is found, we have ecosystems. Not everyone would agree with this definition and prefer to think of ecosystems as habitats where there are no humans or no significant influence of humans on its chemistry, physics, and biology.

Box 2. What is biodiversity?

The most extraordinary feature of life on Earth is its diversity, ranging from gigantic blue whales to tiny hummingbirds, from single-celled algal species to 115 m tall redwood trees, from iridescent beetles to practically invisible nematode worms in soil. The extraordinary range in shape, color, size, and form is certainly a striking feature of the diversity of life on Earth, but it is also a distraction. Biodiversity refers to all elements of variety in life, not just what species look like, but how old or recent they are from an evolutionary standpoint, how abundant or rare they are, where they are found in the landscape (i.e., narrowly distributed or found over large areas), do they live for a long or short time, are they active all year, or do they hibernate, are they stationary or do they migrate, how genetically diverse they are (i.e., are they all the same or genetic clones of one another or are individuals different in their genetic makeup), do they have a strong or weak influences over environmental processes (for example, legumes can enrich nitrogen in soil while non-legumes often reduce nitrogen levels), are they resistant or sensitive to environmental change (e.g., some plants with only surface roots practically disappear during a drought while others whose roots are deep enough to reach groundwater are unaffected), and so forth. The term, biodiversity, thus refers to all aspects of the diversity of life, not just the number of species. For example, if a landscape had only 100 species of plants, but was made up of forests, wetlands, grasslands, it is more diverse than a landscape with 200 species if that landscape consists of only one type of grassland.

Of all the many aspects of biodiversity, none is as important to ecosystem services as functional diversity. Taxonomic diversity is concerned with the number of species present. Evolutionary or phylogenetic diversity is concerned with how many ancient or more recent species are found in an ecosystem. Functional diversity concerns the variety of ways species influence their environment. Every organism has impacts on its environment, both chemically and physically. Trees remove water from the soil by transpiration, pants remove carbon dioxide from the atmosphere by photosynthesis, nitrogen fixing bacteria take nitrogen molecules from the air and add it to the soil, and burrowing mammals such as gophers or earthworms, physically overturn soil. Even at a simple level, if a species is an herbivore, it consumes plants which may lead to a reduction in photosynthesis which leads to a reduction in the amount of carbon dioxide an ecosystem sequesters.

Functional diversity can be difficult to measure when little is known about species' relationships to their environment. Just as there are number of ways of measuring taxonomic or phylogenetic diversity, there a number of ways of measuring functional diversity, most of which require measuring or knowing what kinds of impacts species have on an their environment and how they respond to environmental change. In most cases, such information is lacking, which limits our ability to accurately quantify ecosystem function. To address this needs, many groups around the world are now collecting this information, so with every year, the problem is less and less challenging.

APPENDICES

This list is a partial, annotated listing of useful resources. We include web, published articles, and books. Our selection is based on those that correctly found their treatments on the abundance and diversity of life in ecosystems.

Internet/Web resources

At ActionBioscience (http://www.actionbioscience.org/), a general resource for ecological and environmental issues, contains Ecosystem Services: A Primer (http://www.actionbioscience.org/environment/esa.html) adopted for the Ecological Society of America's publication (http://www.esa.org/education_diversity/pdfDocs/ecosystemservices.pdf). The site provides a brief, useful overview with many additional links. Some of its material dates from 2000.

Alternatives to Slash-and-Burn Program (http://www.asb.cgiar.org/)
ASB is a global research network of international organizations and partners in West and Central Africa, the Amazon basin, and Southeast Asia. ASB scientifically assesses smallholder agricultural strategies that integrate improvement of agricultural goods production, climate change reduction and mitigation, and other ecosystem services, and works to translate this scientific knowledge into policy and programmatic action.

The Beijer Institute of Ecological Economics (http://www.beijer.kva.se/)
The Beijer Institute is a research institute under the Royal Swedish Academy of Sciences, that houses the Stockholm Resilience Centre, and publishes two journals, Ecology and Society and Environment and Development Economics. Their outputs are on the cutting-edge of ecosystem services and stability, ranging from more academic to more practical.

Ecological Society of America (http://www.esa.org/)
The ESA is a world leader among ecological organizations, and provides a variety of materials for free on its website. Among other scientific journals, ESA publishes Frontiers in Ecology and the Environment, which is accessible to a wide audience of readers—the February 2009 issue on ecosystem services (http://www.esajournals.org/toc/fron/7/1?cookieSet=1) details some recent major advances in the science of ecosystem services.

Ecosystem Challenges and Business Implications
(http://www.wbcsd.org/includes/getTarget.asp?type=d&id=MjE3Mzk)
This publication was produced by Earthwatch Institute (Europe), the World Conservation Union (IUCN), the World Business Council for Sustainable Development (WBCSD), and the World Resources Institute (WRI), and uses scientific knowledge from the UN's Millennium Ecosystem Assessment and interviews with business leaders to understand and act to reduce the negative effects of ecosystem service decline.

The Ecosystem Services Project (http://www.ecosystemservicesproject.org/)
The Ecosystem Services Project is coordinated by the Sustainable Ecosystems group of Australia's Commonwealth Scientific and Industrial Research Organization (CSIRO) with The Myer Foundation and other partners. The website provides materials and case studies to help bring together science, local residents, and government policy on ecosystem services.

EcosystemValuation.org (http://www.ecosystemvaluation.org/)
This website developed and written by University of Maryland researchers explains the essentials of how ecosystem service valuation is conducted.

Payments for Environmental Services from Agricultural Landscapes (FAO)
(http://www.fao.org/es/esa/pesal/index.html)
A website from the Food and Agriculture Organization of the United Nations, that provides information on how agriculture and ecosystem services can be brought into better balance though Payments for Environmental Services (PES) programmes, including materials to better link practitioners, prospective providers and users, and facilitators of setting up PES schemes.

People Land Management and Ecosystem Conservation (PLEC)
(http://www.unu.edu/env/plec/index.htm)
PLEC is a United Nations University (UNU) Project that brings together researchers and smallholder farmers throughout the global tropics, toward developing agricultural strategies based on local knowledge together with science.

The Natural Capital Project (http://www.naturalcapitalproject.org/)
A partnership between the Woods Institute for the Environment at Stanford University, The Nature Conservancy and World Wildlife Fund, it brings together academic researchers and conservation organizations to develop tools and collaborations for improving management of ecosystem services and conservation of biodiversity in the public, private and non-profit sectors.

Resilience Science (http://rs.resalliance.org/)
"Resilience Science" is a weblog, an online source for current information on agricultural sustainability (and sustainability otherwise). Operated by Garry Peterson, a professor at McGill University, the weblog has an academic tone, but moderately so.

World Agroforesty Centre (ICRAF) (http://www.icraf.org/)
ICRAF is a global leader in the research and advancement of agroforestry. Many of the agricultural techniques suggested in this document benefitted from ICRAF investment in their development. Their website provides a variety of learning materials (http://www.worldagroforestry.org/af/learning#1), along with a vast selection of scientific papers and reports (http://www.worldagroforestry.org/af/publications).

Specific Web Documents

IUCN and UNEP
Developing International Payments for Ecosystem Services: Towards a greener world economy.
http://www.unep.ch/etb/areas/pdf/IPES_IUCNbrochure.pdf

US Forest Service
Ecosystem Services
http://www.fs.fed.us/ecosystemservices/

Research Network for Environment and Development
Ecosystem services and biodiversity in developing countries. Proceedings and conclusions of the ReNED Conference, Eigtveds Pakhus, Copenhagen, 17- 18August 2005. Research Network for Environment and Development, Copenhagen: http://www.geogr.ku.dk/projects/rened/Proceedings_Ecosystems.pdf

World Resources Institute
Ecosystem Services – A Guide for Decision Makers. Janet Ranganathan, Karen Bennett, Ciara Raudsepp-Hearne, Nicolas Lucas, Frances Irwin, Monika Zurek, Neville Ash and Paul West. March, 2008.
http://www.wri.org/publication/ecosystem-services-a-guide-for-decision-makers

Nature's Benefits in Kenya: An Atlas of Ecosystems and Human Well-Being 2007
http://www.wri.org/publication/content/9373

World Resources Institute Corporate Ecosystem Services Review
http://pdf.wri.org/corporate_ecosystem_services_review.pdf

Ecological Society of America
Ecosystem Services: Benefits Supplied to Human Societies by Natural Ecosystems. Gretchen C. Daily, Susan Alexander, Paul R. Ehrlich, Larry Goulder, Jane Lubchenco, Pamela A. Matson, Harold A. Mooney, Sandra Postel, Stephen H. Schneider, David Tilman, George M. Woodwell
http://www.ecology.org/biod/value/EcosystemServices.html#references

Millennium Assessment
"Freshwater Ecosystem Services" from Current State & Trends Assessment, Millennium Ecosystem Assessment Report. Volume 1, Chapter 7.
http://www.millenniumassessment.org/documents/document.276.aspx.pdf

"Food Ecosystem Services" from Current State & Trends Assessment, Millennium Ecosystem Assessment Report. Volume 1, Chapter 8.
http://www.millenniumassessment.org/documents/document.277.aspx.pdf

"Timber, Fuel, and Fibre Ecosystem Services" from Current State & Trends Assessment, Millennium Ecosystem Assessment Report. Volume 1, Chapter 9.
http://www.millenniumassessment.org/documents/document.278.aspx.pdf

Katoomba Group
A tale of two continents. Ecosystem services in Latin America and East and southern Africa. Katoomba Group, 2006
http://www.ecosystemmarketplace.com

International Institute for Sustainable Development
Markets for Ecosystem Services
www.iisd.org/pdf/2007/economcs_markets_eco_services.pdf

Natural Environment Research Council
NERC's Ecosystem Services for Poverty Alleviation has a list of downloadable documents for different countries/regions of the world here:
http://www.nerc.ac.uk/research/programmes/espa/resources.asp

Primary Literature

Abate T, van Huis A, Ampofo J.K.O. 2000. Pest management strategies in traditional agriculture, an African perspective. *Annual Review of Entomology*. 45: 631–659.

Balvanera, P., Kremen, Claire, and Miguel Martinez-Ramos. 2005. Applying Community Structure Analysis to Ecosystem Function: Examples from Pollination and Carbon Storage. Ecological Applications, 15(1):360-375.

Balmford A, Bruner A, Cooper P, Costanza R, Farber S, Green RE, Jenkins M, JeVeriss P, Jessamy V, Madden J, Munro K, Myers N, Naeem S, Paavola J, Rayment M, Rosendo S, Roughgarden J, TrumperK, Turner RK (2002) Economic reasons for conserving wild nature. *Science* 297:950–953

Bulte E, Hector A, Larigauderie A. 2005. ecoSERVICES assessing the impacts of biodiversity changes on ecosystem functioning and services. Science Plan and Implementation Strategy. DIVERSITAS Report No. 3

Butler, C. D., and W. Oluoch-Kosura. 2006. Linking future ecosystem services and future human wellbeing. Ecology and Society 11(1): 30.

Chan KMA Shaw MR Cameron DR Underwood EC Daily GC. 2006. Conservation planning for ecosystem services *PLoS Biology* 4 (11): 2138-2152

Chapin FS III, Zavaleta ES, Eviner VT, Naylor RL, Vitousek PM, Reynolds HL, Hooper DU, Lavorel S, Sala OE, Hobbie SE, Mack MC, Diaz S. 2000. Consequences of changing biodiversity. *Nature* 405:234–242

Cork, S.J., Proctor, W., Shelton, D., Abel, N., and Binning, C. 2002. The ecosystem services project: Exploring the importance of ecosystems to people. *Ecological Management and Restoration* 3: 143 - 146.

Constanza R, d'Arge R, de Groot R, Farber S, Grasso M, Hannon B, Limburg K, Naeem S, O'Neill RV, Paruelo J, Raskin RG, Sutton P, van den Belt M. 1997. The value of the world's ecosystem services and natural capital. *Nature* 387:253–260

Carpenter, Steve, Brian Walker, J. Marty Anderies, and Nick Abel. 2001. From Metaphor to Measurement: Resilience of What to What? *Ecosystems* 4: 765–781

Daily GC, Walker BH. 2000. Seeking the great transition. *Nature* 403, pp243-245

Daily GC, Alexander S, Ehrlich P, Goulder L, Lubchenko J, Matson PA, Mooney HA, Postel S, Schneider SH, Tilman D, Woodwell GM. 1997. Ecosystem services: benefits supplied to human societies by natural ecosystems. *Issues in Ecology 2*. Ecological Society of America, Washington DC

DFID UK, DG Development EU, UNDP, World Bank . 2002. Linking Poverty Reduction and Environmental Management. Policy Challenges and Opportunities. The World Bank, Washington DC

Fischer J, Lindenmayer DB, Manning AD. 2006. Biodiversity, ecosystem function, and resilience: ten guiding principles for commodity production landscapes. Frontiers in Ecology and the Environment 4,2:80-86.

Loreau M, Naeem S, Inchausti P, Bengtsson J, Grime JP, Hector A, Hooper DU, Huston MA, RaVaelli D,Luque S, M Kallio. 2009. Approaches to ecosystem services assessment and drivers of change in forest ecosystems. IOP Conference Series: Earth and Environmental Science 6(30): 302024

Mertz O, Ravnborg HM, Lovei GL, Neilsen I, Konijnendijk CC. 2007. Ecosystem services and biodiversity in developing Countries. *Biodiversity Conservation*. 16:2729-2737

Myers N . 1996 . Environmental services of biodiversity. *Proceedings of the National Academy of Sciences* 93:2764–2769

Naidoo R, and Ricketts TH. 2006 . Mapping the economic costs and benefits of conservation. *PLoS Biology* 4:2153-64

Nature and the Marketplace: Capturing The Value of Ecosystem Services. 1997. Issues in Ecology. Ecological Society of America. http://www.esa.org/science_resources/issues/FileEnglish/issue2.pdf>

Nelson, E. 2009. Modeling tradeoffs between Ecosystem Services and Biodiversity. *Frontiers in Ecology and the Environment*.

Pagiola S, von Ritter K, Bishop J . 2004. Assessing the economic value of ecosystem conservation. Environment Department Paper No. 101. The World Bank Environment Department in collaboration with IUCN, New York

Polasky S, Nelson E, Lonsdorf E, Fackler P, Starfield A. 2005. Conserving Species in a working landscape: Land use with Biological and Economic Objectives. *Ecological Applications* 15: 1387-1401.

Schmid B, Tilman D, Wardle DA. 2001. Biodiversity and ecosystem functioning: current knowledge and future challenges. *Science* 294:804–808

Tilman D, Polasky S, Lehman C. 2005. Diversity, productivity and temporal stability in the economies of humans and nature. *Journal of Environmental Economic Management* 49:405–426

Tscharntke T, Klein AM, Kruess A, Steffan-Dewenter I and Thies C. 2005. Landscape perspectives on agricultural intensification and biodiversity – ecosystem service management. Ecology Letters 8(8): 857 – 874.

Shenan, C. 2008. Biotic interactions, ecological knowledge and agriculture. *Philosophical Transactions of the Royal Society B-Biological Sciences*. 363(1492): 717–739.

Books

Daily G, Ed. 2007. Nature's Services: Societal Dependence On Natural Ecosystems, Island Press, New York.
Nature's Services represents one of the first efforts by scientists to provide an overview of the many benefits and services that nature offers to people and the extent to which we are all vitally dependent on those services.

Daily G and Ellison K. 2002. The New Economy of Nature: the quest to make conservation profitable. Washington, DC: Island Press.
Describes the interplay of science, economics, business, and politics that is involved in establishing these new approaches and examine what will be needed to create successful models and lasting institutions for conservation.

Heal G, 2000. Nature and the Marketplace: Capturing The Value Of Ecosystem Services, Island Press, New York.
Nature and the Marketplace presents an accessible introduction to the concept of ecosystem services and the economics of the environment. It offers a clear assessment of how market approaches can be used to protect the environment, and illustrates that with a number of cases in which the value of ecosystems has actually been captured by markets

Kumar P, Muradia R. (Eds) 2009. *Payment for Ecosystem Services (Ecological Economics and Human Well-Being)*. Oxford University Press, UK.
More than 30 leading experts in the field of ecological economics address a large range of issues dealing with the valuation of ecosystem services, as well as the design and performance of compensation schemes as effective tools that may considerably reduce the cost of such management. The contributors also propose PES as a redistributive mechanism between different social groups that is framed in the context of inequality concerns in rural-urban dynamics.

Loreau M, Naeem S, Inchausti P. 2002. Biodiversity and ecosystem functioning: synthesis and perspectives. Oxford University Press.
This volume provides the first comprehensive and balanced coverage of recent empirical and theoretical research on the question of how biodiversity loss will affect ecosystem function. It reviews the evidence, provides bases for the resolution of the debate, and offers perspectives on how current knowledge can be extended to other ecosystems, other organisms and other spatial and temporal scales. It cuts across the traditional division between community ecology and ecosystem ecology, and announces a new ecological synthesis in which the dynamics of biological diversity and the biogeochemical functioning of the Earth system are merged.

Millennium Ecosystem Assessment. 2005. Ecosystems and human well-being. Synthesis. Washington, DC: Island Press.
The volume presents a snapshot of the health and prospects for each of the main services that ecosystems provide, including the provision of food, water, timber, fuel, climate regulation, disease prevention, and others. The Synthesis Report provides a quick, but nuanced, understanding of the state of Earth's ecosystems.

Naeem S, Bunker DE, Hector A, Loreau M, Perrings C (Eds). 2009. Biodiversity, Ecosystem Functioning, and Human Wellbeing: An Ecological and Economic Perspective. Oxford University Press, USA.

This volume summarizes recent advances in biodiversity-ecosystem functioning research and explores the economics of biodiversity and ecosystem services. It takes research on biodiversity and ecosystem functioning further than it has ever gone into the human dimension, describing the most pressing environmental challenges that face humanity and the effects of diversity on: climate change mitigation, restoration of degraded habitats, managed ecosystems, pollination, disease, and biological invasions.

National Research Council. 2005. Valuing ecosystem service: towards better environmental decision-making. Washington, DC: National Academies Press.
This report identifies methods for assigning economic value to ecosystem services—even intangible ones—and calls for greater collaboration between ecologists and economists in such efforts.

Ninan KN (Ed), Steiner A (Foreward). 2009. Conserving and Valuing Ecosystem Services and Biodiversity: Economic, Institutional and Social Challenges. Earthscan Publishing Ltd, London.
Comprehensive book to address at a global scale the economic, social and institutional difficulties in conserving biodiversity. It covers a wide range of issues such as biodiversity, ecosystem services and valuation in the context of diverse ecosystems such as tropical forests, marine areas, wetlands and agricultural landscapes, non-timber forest products, incentives and institutions, payments for ecosystem services, governance, intellectual property rights and the protection of traditional knowledge, management of protected areas, and climate change and biodiversity. (Global examples and perspective)

Ruhl JB, Kraft SE, Lant CL. 2007. The Law and Policy of Ecosystem Services. Island Press, Washington DC.
A comprehensive exploration of the status and future of natural capital and ecosystem services in American law and policy. The book examines the geographic, ecological, and economic context of ecosystem services and provides a baseline of the current status of ecosystem services in law and society. It identifies shortcomings of current law and policy and the critical areas for improvement and forges an approach for the design of new law and policy for ecosystem services.

Turner RK, Button K, Nijkamp P. 1999. Ecosystems and nature: economics, science and policy. Edward Elgar Publishers, Cheltenham.
This book provides readers with a broad interdisciplinary perspective on the major issues in biodiversity, including economics, natural science, management and ethics.

Walker B, Salt D, Reid W. 2006. *Resilience Thinking: Sustaining Ecosystems and People in a Changing World* (Paperback). Island Press.
An accessible introduction to the emerging paradigm of resilience. The book arose out of appeals from colleagues in science and industry for a plainly written account of what resilience is all about and how a resilience approach differs from current practices. Rather than complicated theory, the book offers a conceptual overview along with five case studies of resilience thinking in the real world.