CHAPTER FOUR – ECOSYSTEM SERVICES

Introduction

In contrast to the previous chapter, the sections below concentrate on the potential ecosystem services and the actual benefits to man. When humans directly or indirectly use the environment and products from it, they are receiving ecosystem services. Examples of ecosystem products include clean water, food, lumber, minerals, fiber, etc. (Figure 1). Non-product services include water purification, waste treatment and intangible elements such as recreation and beauty. An ecosystem benefit is the human valuation of an ecosystem service [1].

The Millennium Ecosystem Assessment divided ecosystem services that benefit humans into four classes, 1) Supporting, 2) Regulating, 3) Provisioning, and 4) Cultural. Supporting ecosystem services indirectly benefit humans but are fundamental to the other three categories of services that are more directly enjoyed by people [2]. “Ecosystem Services” is a deliberately anthropocentric phrase that frames the argument for preservation of natural systems in the cost/benefit terminology of economics. It is hoped that this language and demonstration of economic value will foster an understanding of the true value of healthy ecosystems and lead to greater commitment and investment in their conservation. This chapter provides many examples of the economic valuation of ecosystem benefits.

Green infrastructure organizes several elements that provide human and ecosystem benefits. This chapter establishes the typology of ecosystem services and benefits, as well as threats to them, in the context of green infrastructure at the municipal and landscape scale. Components that are managed ecosystems for the explicit purpose of maxi-

Figure 1. Products, like lumber, food and medicine, are the most obvious of the ecosystem benefits but there are many other important services including Air and Water Purification, Waste Decomposition, Soil and Nutrient Cycling, Climate and Radiation Regulating, Habitat Provision, Noise Pollution Control, Aesthetic and Cultural. Photo by Presse03, license CC-BY-SA-3.0.
mizing certain ecosystem products, such as waste-
water treatment, are the subjects of later chapters.
The eight functions and services identified in Fig-
ure 1 interact with each other as discussed below.
They are organized according to the Millennium
Ecosystem Assessment categories.

Human Benefits from Supporting Ecosystem Functions

The provision of seafood, timber, fodder and other
commonly traded natural products are ecosystem
services provided on a scale that is larger than gen-
erally associated with green infrastructure. How-
ever, networks of corridors, spaces, and habitat
areas within the city and county have an impact on
these more distantly derived products. Community
agriculture and forestry, and certainly, residential
and public landscapes depend on the maintenance
of supporting ecosystem services, such as soil
formation and nutrient cycling. Habitat provision,
water cycling, and primary production are three
more examples of supporting ecosystem services
tied to human activities at a scale somewhat larger
than cities but linked to them. Some of the topics
in this chapter will be familiar since they relate to
ecosystem health as discussed in the previous chap-
ter, but this discussion approaches the topics from
an anthropocentric perspective.

Habitat for Humans

In contrast to habitat definitions for animals and
plants, it is surprisingly difficult to define and
understand what human habitat is. We cannot
use the same parameters of temperature, food
sources or associated species as we can with oth-
er organisms. Of course, Homo sapiens evolved
in a particular habitat, but the species long ago
exercised its ability to modify its environment to
allow expansion of the population into areas where
excessive heat, cold, wind, or the lack of support-
ive vegetation and animals would normally limit
habitation. Through the use of natural materials,
and later synthetic ones, man extended the range
of environments that he could occupy far beyond
his evolutionary home.

Modification of the environment is not an
activity peculiar to man. Most organisms modify
the environment to protect themselves and to bet-
ter support their offspring. For example, over time
redwood forests modify the soil chemistry, mois-
ture and temperature, humidity and amount of
sunlight reaching the ground in ways that support
redwood trees and not others that might compete
for space, light or nutrients.

For man, environmental control is con-
scious and sometimes long term, wide ranging and
requiring continuous or occasional use of natural
resources. This store of resources and our ability to
use them to ameliorate hostile environments might
be regarded as man’s contemporary habitat more
correctly than any association with native plant
and animal groups or climatic conditions. Building
materials, energy, and technology to modify the
environment are globally available in the modern
economy. Therefore, the location or origin of the
resources do not define human habitat geographi-
cally. Nevertheless, some cities and towns are more
desirable places for people to live than others.
Since all cities are artificial environments of human
manufacture, we can study why some are more be-
nign. The keys to understanding optimum human
habitat are the dimensions of human health. Many
ecosystem services contribute to human health and
habitat as discussed below.

Despite the enormous number of plant
and animal species, man depends on relative few of
them for food. In fact, a small set has been selected
and modified through hybridization (and more
recently genetic modification) to better serve our
needs. Dependence on this small group of plants
and animals erroneously caused us to behave as
if only they are all that are required for human
well-being. When one or more of the basic set of
plants or animals is diminished through flooding,
drought or disease, the result is often hardship or
starvation. Similarly, if a basic natural resource,
such as oil, is temporarily unavailable, this can
cause great suffering, especially in the extreme
environments where man lives comfortably only
through the constant expenditure of the resource. Human habitat then is increasingly the occupation of land locally incapable of supporting the population without reliance on modified, anthropocentric plants and animals, imported energy, and sometimes imported water, and other materials from sources beyond the region. Man has committed himself to this model and, in terms of population growth over the centuries, it has served the species. However, the more reductionistic the model becomes, as the store of resources declines, due to their un-renewable character or demand from an ever-growing population, then the more vulnerable human societies become. Reducing our risk could come from population reductions or increases in resources or both. We have used technology and fossil fuel subsidies to increase resources and largely ignored the population side of the equation.

More productive hybrids or genetically altered strains of commodity plants and animals, more herbicides, pesticides, artificial fertilizer and specialized farm equipment, and expanding the area dedicated to agriculture may enhance our ability to produce more food. However, it is apparent that this is an increasingly artificial system with an ultimate capacity. More clear is the limit of fossil fuel reserves and the dramatically increasing global demand for oil. Global commodity agriculture is increasingly dependent on fossil fuel but will, presumably, be prioritized as the oil supply decreases.

Since human settlements are increasingly urban and require the support of regional and even global resources for sustenance, huge areas for agriculture and forestland are needed. These land areas, energy production and infrastructure, both nearby and far away, should be included in the definition of human habitat. Although increasingly modified these systems ultimately are based in nature. Hybridized plants, which would be unrecognizable to the humans that first cultivated the species, still require a soil substrate, nutrients, reasonably pure water and light. We substitute naturally occurring nutrients with artificial fertilizers but these are also derived from natural resources. The sections below remind us that indispensable materials and processes are provided to humans by natural and managed ecosystems.

### Soil and Nutrient Cycling

Regulating the flow and availability of nutrients, gases and water by soil is an amazing ecosystem service that is emphasized only rarely but evident in the control difficulties when attempting hydroponic culture of plants. Consideration of simply physically supporting vegetation hints at the magnitude of costs associated with soil destroyed by pollution. The cost for physical support products used in hydroponic agriculture is $22,000 per acre. Of course, soils have been damaged by human activities such as pollution, compaction and erosion. In fact, soil damage by human activities is widespread, impacting almost 20 percent of the vegetated land area of the planet.

Nutrient cycling is an ecosystem service to humans especially in regard to the huge amount of solid waste produced by humans. Waste arising from household garbage, sewage, industry, agriculture, and forestry constitute about a third of the 143 billion tons of dead organic matter produced each year. Organisms decompose this organic waste in addition to soaps, detergents, pesticides, oil, acids, and paper. Some materials are detoxified or the disease causing bacteria, viruses and other pathogens are removed by macrobiotic activity. This is certainly an ecosystem service that we must preserve and one that we can make greater use of to reduce the cost of maintaining a healthy city. The decomposition products are often materials like nitrogen or mulch that can be reused for human benefit. For example, domestic sewage can be “mined” to recover the large quantities of phosphorus it contains for reuse in agriculture. Another emerging prospect is the development of bio-plastics from treated sewage byproducts.

There are many ways to foster soil preservation or soil formation and the natural cycling of nutrients in residential and public landscapes. Prevention of wind and water erosion and the damage to soils during construction of buildings...
and landscapes is an obvious opportunity. Reducing the use of artificial fertilizers and pesticides benefit aquatic environments as well as soil fauna and flora. Using mulch and compost to cover exposed soil reduces erosion and provides the carbon needed by soil organisms to create fertile, healthy soil and nutrients for plants. Threats to natural soil formation and nutrient cycling include deposition of heavy metals, acid rain, herbicides, pesticides, soil compaction, erosion and eutrophication of water bodies.

**Water Cycling**

Water is cycled through phase changes involving local, regional and global systems. Water is concentrated, transported, purified and distributed to human settlements through seven processes, primarily. Water evaporates from surfaces and transpires (Figure 2) from plants to enter the atmosphere as clean water vapor. It condenses on, or precipitates to, surfaces as relatively pure water. Some of the surface water infiltrates into the soil and is available to plants while another fraction percolates to recharge aquifers or moves underground to sustain the base flow of streams and rivers during the dry season.

We can increase the benefit of clean water for human use by encouraging infiltration, percolation, ground water recharge, and base flow through many landscape practices within green infrastructure. Large sedimentation and infiltration basins are usually operated by counties, but small and numerous applications at each residence or commercial building can significantly slow runoff of stormwater, reduce flooding, reduce stream channelization and increase soil infiltration. Planting vegetation as a primary component of green infrastructure has a positive impact on the movement of water into and through the soil. Similarly, plants have a positive impact on the movement of water through evapotranspiration. Plants slow the surface runoff rate and velocity. The example of forest clearing illustrates the impacts of plants on runoff. In a New Hampshire study, the average stream flow increased 40 percent and the peak runoff was 5 times more than before a forest area was cleared [4].

Unfortunately, often the benefits of green infrastructure are needed to compensate for damage caused by human activity elsewhere. We can anticipate the need for an increase of green infrastructure to address changes to the water cycle caused by global warming. In the United Kingdom, climate change will cause water cycle impacts. These include higher rainfall intensity, which is expected to rise by 40 percent by 2080. The cost of dealing with the associated flooding will be four to eight times the current amount [5]. New and retrofitted landscapes designed to detain or retain the increased storm volumes can protect property and reduce the extent and frequency of flooding.

**Human Benefits from Regulating Ecosystem Services**

Wind, temperature and oxidation processes in the atmosphere provide a regulating service through their capacities to clean the air and disperse pollution. Most trace gases emitted into the air are removed through oxidation in a process that would normally maintain the current composition of the atmosphere and climatic characteristics [6].
Climate and Radiation

Climate regulation is an ecosystem service. The atmosphere provides four supporting ecosystem functions including its natural warming. The density of the atmosphere and the ozone layer protect us from radiation, plasma and meteors. It also redistributes the water resources. Finally, the density pressure of the atmosphere allows direct use for sound communication and transportation. Natural ecosystems respond to changes in climate and may in turn moderate them. For example, global warming increases biomass production and decomposition rates. This could decrease or increase the release of carbon dioxide. The importance of these buffering measures is uncertain, in the context of the emerging climate instability. It is clear that climate and ecosystems are closely paired and that the stability of their interactions is important [4].

Green infrastructure can support the efforts to adapt to climate change or mitigate its impacts through encouraging alternate transportation and the sequestration of carbon. Although, reduction in fossil fuel emissions is the most effective measure leading to climate change mitigation, other measures support this effort. For example, 13 tons of carbon dioxide is removed from the atmosphere annually for each set of 100 large mature trees [7]. Since the average per capita carbon emission in the U. S. is more than 17 tons per year, its clear that planting trees in urban forests or reforestation of public lands with millions of trees every year is required to make a significant contribution to climate change mitigation. However, Figure 2 illustrates that there are opportunities to plant millions of trees to serve multiple purposes. Clearly, reduction of CO2 emissions must be tied reduced use of fossil fuels and to other mitigation efforts including reforestation.

In Europe where CO2 emissions are much lower (9.6 tons per capita in Germany) than in the U. S. carbon sequestration is a somewhat more hopeful measure. Urban forestry associated with green infrastructure contributes to a more positive carbon balance through the preservation of dense stands of trees or large scale replanting of deforested areas. High carbon storage in a district of Leipzig, Germany (Figure 3), which contains multi-story residential buildings adjacent to a forested riparian corridor, demonstrates that high population density and high carbon storage can occur in the same urban district. The average carbon storage for the city is 11 metric tons of carbon per hectare, while for the district shown in Figure 3, it is 30.5 metric tons of carbon per hectare [8].

In the past, regulations to reduce harmful emissions have been successful. For example, the Montreal Protocol established the direct global regulation of ozone depleting chemicals used principally in refrigeration. The Antarctic and Arctic holes in the ozone layer have now stopped growing in size but have not yet begun to shrink [6].
Temperature

Consideration of the ecosystem services of the atmosphere shows that the natural capture of heat by the atmosphere resulted in a 33º Celsius (C) shift from -18º C to an average surface temperature of 15º C. This natural rise in the average temperature resulted in a stable climate for the last 10,000 years and supported the evolution of existing ecosystems [6]. The climate today is less stable due to the effects of anthropogenic emission of greenhouse gases. Climate change is compounded by the heat island effect in cities and result in higher summer temperature for extended periods. Unless mitigated with green infrastructure and other measures, this will decrease human comfort, work productivity, water resources and wildlife. Increased mortalities and health problems requiring hospitalization will result. These were the impacts of a heat wave in Europe in 2003. It was responsible for 30,000 more deaths than in other summers. The 2003 conditions are expected to be the new normal for Europe by 2050 [9].

The heat island effect is the elevated temperature in cities and nearby areas caused by urban materials and poor air circulation. The absorption and radiation of heat by metal, concrete and asphalt increase the average temperature in cities. Green infrastructure reduces the impact of the heat island through shading surfaces, lower absorption of radiation and transpiration of water.

The heat island increases the demand for energy to cool buildings. For example, in Athens, Greece the heat island effect triples the amount of electricity demand for cooling. In U. S. cities, each 1ºF increase in temperature, causes 1.5 to 2 percent increase in the peak electrical demand [10]. The higher albedo (reflectance) and higher evaporation and transpiration of water through vegetation and soils from green roofs and street trees reduce urban temperatures.

Studies show that green roofs reduce the maximum ambient temperature above the roof. Direct measurements in one study, at five in the afternoon, revealed a maximum temperature reduction of 7.6º F at 1’ above the roof surface. If widely implemented at the city scale, green roofs could reduce the average ambient temperatures between 0.5º F and 5.4º F. Green roofs on tall buildings have little effect on the heat island effect [10]. Replacing asphalt, concrete and metal roofing with water holding material, such as permeable asphalt embedded with absorbent fibers also significantly reduces temperatures above roofs [11]. The design and performance of green roofs is the topic of Chapter Nine.

Wind

Windbreaks and shelterbelts provide green infrastructure benefits for human comfort and the protection of crops (Figure 5). A dense windbreak can reduce wind velocity for a distance as much as 30 times the height of the windbreak. There are additional benefits to be gained from prevention of snowdrifts on highways and reduce heating costs of buildings with well-placed windbreaks [12].

The increasing investment in wind energy projects worldwide highlights the ecosystem benefit of this natural phenomenon to humans. Competing demands for highly productive locations for wind farms sometimes place recreation, agriculture and wildlife in conflict, in both terrestrial and marine settings. Wind also benefits us in cities where it disperses air pollutants and in agriculture where it pollinates crops such as corn and wheat. Of course, wind is sometimes also an ecosystem disservice associated with hurricane and tornado storm...
damage to human settlements and wildlife habitat. In this case, forests and wetlands can mitigate the destructive force of wind driven storms.

Global wind patterns are created by temperature and moisture differences at various latitudes. Global temperature changes due to climate change and the melting of polar ice are likely to cause a change in wind patterns. These changes will impact marine systems, due to nutrient upwelling, and terrestrial and human ecosystems.

**Humidity**

Changes in humidity impacts both humans and natural ecosystems. A human comfort zone can be describes as an interaction of temperature and humidity. Mortality rates increase due to stress on cardiovascular and respiratory systems, during periods of extreme temperature and humidity. Very low humidity is more problematic than high humidity [13].

Plants and animals are also affected by changes in humidity. Climate change predictions include precipitation, temperature and humidity differences. For example, in Northern Europe an increase in air temperature of 2.3º to 4.5º C and an increase in precipitation of 5 to 30 percent will probably occur by 2100. The increase in precipitation will be accompanied by an increase of cloud cover and frequency of days with rain or snow, resulting in higher humidity. Warmer temperatures will also increase the water holding capacity of the air. A study of the impact of an increase in humidity of seven percent on fast growing trees (aspen and birch) revealed considerable changes in tree respiration rates, photosynthesis, water-use efficiency, biomass allocation, growth, sap flow and other measures. These findings suggest that increased humidity due to global warming will change the functions of forest ecosystems. Adaptation to a new climatic condition may require revision of the usual planting palette in the green infrastructure of cities. Climate models have predicted the temperature and precipitation impacts on various regions. This will allow us to make long-term adaptation plans, which may include planting species to replace those that will die due to an altered climate.

**Disease and Pest Regulation**

Pests and disease occur in cycles that are dampened in healthy ecosystems but sometimes exacerbated in stressed ones. The example of the mountain pine beetle (Dendroctonus ponderosae) in the U. S. and Canada illustrates an interaction of insects and their host population that seems to be out of equilibrium. The beetle is native and formally the number of trees it attacked and killed was limited. However, the current outbreak, which began in the middle of the 1990’s, has affected an area ten times larger than any other infestation on record. The beetle infestations have killed huge tracts of forest (Figure 6). For example, 34.6 million acres (14 million hectares) have been affected in British Columbia. Cold temperatures, in winter and cool temperatures in summer, previously limited the range of the mountain pine beetle. Winter extremes of -40º C limit the population. Lodgepole pines (Pinus contorta) are the principle host trees but other species of pine are also susceptible to attack. Once they are attacked, the trees defend themselves by increasing pitch flow, but trees that are stressed from drought or other causes are particularly susceptible and overwhelmed by swarms of the insects. The changing climate seems to be involved in this ecosystem change.

![Figure 5. Green infrastructure, in the form of windbreaks, protects the crops in the windy Columbia River basin while the ridgeline turbines create energy from this ecosystem service. Photo by author, 2012.](image-url)
eral range of the beetle is expanding due to warmer temperatures and the pines are more susceptible to attack because they are exposed to more severe drought conditions [14]. The natural ecosystem functions that limited the impact of the beetle have been compromised by human caused changes to the climate.

Substantial ecosystem benefit can still be obtained from the beetle-killed forest tracts without compromising the regeneration of the forest. Since the insects attack mature stands, a great amount of merchantable timber can be harvested. While these salvage operations reduce the number of emerging seedlings, their numbers are sufficient for stand regeneration. The harvest of the dead trees generates biomass in the form of tree tops and branches just as it does during the harvest of healthy stands. If left in place, the woody material could foster ground fires that would kill the saplings [15]. However, the harvest slash can be the source of additional human benefits since the woody biomass can be collected and used to make isobutanol or made into chips or pellets to fuel furnaces or wood stoves. Retention of some vertical snags and large trunks or branches on the ground preserves habitat niches within the recovering forest after the salvage operation is complete.

While the outbreak of the mountain pine beetle is, in some ways, an ecosystem disservice to humans, insects more often play a positive role. Natural enemies regulate 95 percent the 100,000 arthropod (invertebrate animals with an exoskeleton) species that can be pests in the world’s agriculture and forestland. The ecosystem benefits of biological pest control can be readily calculated. Each year the value of the biological control of pests in global agriculture is $400 billion [16]. In contrast, there are also significant ecosystem disservices in relationship to agriculture. Either before or after harvest, insects and other organisms destroy 25 to 50 percent of the world’s crops. Similarly, human attempts to manage the ecosystem for food production are constrained when weeds compete for water, sunlight and nutrients alongside planted crops [4].

**Water Regulation and Purification**

In the past when we have pursued economic gain, without the long-term goal of sustained productivity, we have damaged the ecosystem to our detriment. Deforestation is one of the most extensive examples of this shortsighted approach to human well-being. Flooding, soil erosion, siltation of reservoirs, streams and canals, and sometimes even the loss of the capacity of the forest to regenerate disrupt the regulation of the water cycle and deprive us of clean water and other resources of economic value [4].

Only about one percent of the water on the planet is available for human use. The remainder is seawater, ice, clouds and vapor in the air. About 70 percent of the available fresh water is used in agriculture. The water used directly by people is very valuable and the value can be easily calculated. In Britain, the cost of a cubic meter of fresh water is about $1.55 (1 pound). The cost of bottled water is much higher at about $1,086 (700 pounds) per cubic meter. Even at the lower rate, the value of global precipitation is $776 billion (500 billion pounds). The cost of fresh water is expected to rise in response to global warming to a cost of $1 trillion per year by 2020 [6].

The experience of New York City water agency illustrates the economic and ecosystem benefits of green infrastructure to city residents. Today
the city provides about a billion gallons of potable water to residents and visitors each day from its Catskill watershed (Figure 7). During the 1990’s the potable water supply source for New York City was becoming increasingly polluted due to agriculture, urbanization and the discharge of effluent from wastewater treatment plants within the watershed. Faced with the choice of constructing a filtration plant to treat the increasingly polluted water, the city embarked on a watershed protection alternative instead. The city allocated $300 million for land acquisition and purchase of conservation easements in 1997. An additional $241 million was dedicated to this purpose in 2007 to fund activities through 2017. Since 1997, the city has added 121,000 acres (49,000 ha) to the 45,000 acres (18,000 ha) it already owned around the drinking water reservoirs. The state owns an additional 200,000 acres (81,000 ha) of protected watershed in the city catchment areas [17]. An official from the U. S. Environmental Protection Agency estimated that the watershed investments by the city avoided the cost of building a $6 to $8 billion filtration plant, and hundreds of millions of dollars of operating cost, to clean polluted water flowing from an unprotected watershed [18].

Assessment of septic tanks and drain fields and the construction of 70 stormwater management facilities contributed to sustained water quality excellence within the watershed. Secondary ecosystem benefits are biodiversity protection and the provision of 75,000 acres (30,350 ha) of public land available for diverse recreational pursuits [17]. Investments in the watershed environment were the best way to insure a long-term source of pure water for New York and acquire additional ecosystem benefits.

Humans consume the greatest amount of water indirectly (70 percent is agriculture). Irrigated agriculture occupies about 18 percent of the agricultural land area and accounts for 40 percent of its economic value. The supply of water for agriculture and its purity is an ecosystem service of enormous value. However, it is very susceptible to reduction due to global warming [16]. Therefore, aquifer recharge, as well as measures to purify and reuse water, is a strategy to sustain this ecosystem service benefit.

**Protection from Storm Hazards**

Green infrastructure can provide substantial protection from flooding hazard. The case of New Orleans before and after 1930 is an instructive example. When New Orleans was founded, extensive forested swamps and wetlands of various types protected it from the devastating storm surges of hurricanes and tropical storms. A storm surge is a bulge of water that is several feet higher than mean sea level. This wall of water is driven inland by high winds. However, storm surges attenuate as they pass over wetlands. The reduction of the height of the storm surge is variable due to differences in storm characteristics, route and wetland characteristics, but a conservative estimate...
is that five miles of wetlands reduce the height of the storm surge one foot [19]. The shortest distance from New Orleans to the Gulf of Mexico is about 30 miles. Therefore, a healthy wetland buffer would produce a six-foot reduction in a storm surge. Levees contain the Mississippi River since it annually flows at 14 feet (4.3 m) above sea level through New Orleans, which is at or below sea level (Figure 8). In this situation, reducing storm surges by six feet or more is a critical component of the city’s flood protection system. The storm surge delivered by hurricane Katrina was estimated at between 10 and 20 feet.

Unfortunately, the Louisiana wetlands that previously buffered the city had been either eliminated or were unhealthy when Hurricane Katrina struck in 2005. It is really the loss of wetlands due to human alteration and management of the Mississippi River and its delta that is the reason the city was overwhelmed.

While it is true that all of the engineered flood protection measures, including the levees, flood walls and drainage pumps failed during Hurricane Katrina, the tragic loss of property and 1,500 lives can be assigned to the loss of 1,800 square miles (39 miles² per year) of wetlands due to man’s activity since the 1930s [20]. The wetland loss was caused by oil and gas exploration and extraction, levee construction resulting in loss of annual sediment supplied to the wetlands, land subsidence and more recently sea level rise due to global warming. Construction of drainage canals for decades converted swamps and wetlands into agriculture and urbanization. Then levees to protect the dewatered land from flooding deprived other wetlands of the annual sediment that built and sustained them. Today, the sediment is captured behind dams on the Mississippi or settles to the bottom of the thickening riverbed or is discharged beyond the continental shelf in the Gulf of Mexico. Historically, the distribution of river sediment more than compensated for the natural subsidence of the river delta. Without it, salt marshes became seawater coves connected to the gulf, while more inland freshwater ponds and lakes expanded and new pondssubmerged previous wetlands. Furthermore, storms pushed saltwater farther inland damaging the remaining freshwater wetlands. Wide and deep navigation channels connecting the gulf to the city funneled undiminished storm surges into New Orleans.

There are also natural causes of wetland loss. Hurricanes Katrina and Rita in 2005 destroyed nearly 140,000 acres (56,656 ha) of wetlands, although these are quite resilient. Marshes are also damaged by invasive species. The nutria (native to south America) has caused substantial damage by feeding on marsh vegetation [21]. These impacts also need to be mitigated to maintain the landscape infrastructure.

Calculations of the economic value of wetlands as a flood protection measure for New Orleans are reliable because we know that annual maintenance of flood control structures is $461,000 per year [22] and that the federal government estimated the damage caused by the 2005 hurricanes Katrina and Rita and pledged $100 billion to rebuild the gulf coast region around New Orleans [20].

There are other human benefits to be gained from the restoration of the Louisiana wetlands (Figure 9) as well. The biologically dead zone in the Gulf of Mexico, caused primarily by nitrogen rich runoff from agriculture that is discharged by the channelized Mississippi River, is nearly 8,000 square miles (20,720 km²) in size [22]. Reducing the nitrogen levels by discharging water into the delta wetlands and other upstream measures would reduce the nitrogen concentration and restore, the once, prolific fishery in this oxy-

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**Figure 8. The Mississippi River and the City of New Orleans.** Photo by U. S. Army Corps of Engineers, Government Work license.
The freshwater marshes are much less productive in the contemporary delta than marshes elsewhere that have river inputs (Figure 9). The Mississippi delta net primary production will be only half of its potential by 2050. This loss of productivity is a significant economic and food security issue for humans. The productivity of a healthy wetland ecosystem is illustrated by the saltwater marsh near Galveston, Texas. The 1,080-acre (437 ha) saltwater marsh produces 16 million brown shrimp, 15.5 million white shrimp, and 11.3 million blue crab each year [22]. The Mississippi delta represents the largest fishery and most important bird migration flyway in the United States due to its 9,650 square mile (24,993 km2) size and its productivity potential. Just three coastal ecosystem services, 1) abundant fish and wildlife, 2) high capacity to treat polluted water, and 3) high storm protection value illustrate the wealth contained in the Louisiana wetlands.

The flood control and other ecosystem service values of Louisiana wetlands are calculated to be $5,200 per acre per year. Therefore, restoring or recreating the 1,800 square miles (4,662 km2) of wetland lost in the area since 1930 would yield $6 billion dollars of value to humans each year [20]. A similar case can be made for the restoration of the barrier islands near the Louisiana coast. There is also an amenity economic benefit to wetland restoration. Four case studies in the Mississippi river delta demonstrated amenity values of $2.95 per acre. This means that every one-acre increase in wetlands area nearest residences (within the census block) increases the housing value by $2.95. This value per acre declines as distance between the home and the wetland increases [21].

Today subsidence in the Mississippi delta is about ½” per year [22] and sea level rise due to global warming adds another ½” per year to the problem. Within the next 50 to 100 years, the relative sea level rise anticipated at the Louisiana coast is 0.5 to 1 meter [23]. Clearly, corrective measures need to be taken, especially given the vulnerability of the manmade flood control structures and devices. Fortunately, efforts are underway to re-establish lost wetlands and enhance damaged ones. The U. S. Army Corps of Engineers is implementing a plan to restore and protect 58,861 acres (23,820 ha) of wetlands east of New Orleans. The cost will be $2.9 billion for construction, not including engineering and design costs, and real estate acquisition.

Pollination

Pollination is one of those ecosystem services that it critical to human well-being but often taken for granted. It is important because about 75 percent of the plant species that humans consume require insect pollinators, although some commodity crops (wheat, rice and maize) do not require insect pollination [16]. The economic value to the production of the 30 percent of crops that require pollination is almost 10 percent of the value of world agricultural output [16] [4]. Another assessment of the economic value of pollination is illustrated by beekeeping businesses. In Switzerland,
raising bees generates $213 million of economic benefit each year. One hive of bees ensured $1,050 worth of fruit and berries in addition to the $215 value of its honey, beeswax and pollen it produces in a single year [24].

Thoughtful conservation of natural habitat and the planting of green infrastructure in urban areas can support bees and the other 100,000 species of pollinators. Threats to pollinators are habitat loss, and environmental pollutants. A parasitic mite (Varroa destructor) has reduced the unmanaged honey bee colonies in Europe and the United States [16]. The damage caused by the mite is thought to be associated with poor hive health due to the impact of pesticides. Another threat to honeybees in the U. S. is the aggressive African honeybee, which was accidentally released in Brazil in 1956. Through competition and hybridization the African strain threatens the species of honeybee in North America, which was introduced from Europe [4].

The natural ecosystem viability is also dependent on pollinators since over 90 percent of plant species require animal species, such as bats, bees, beetles, birds, butterflies, and flies, for pollination and successful reproduction. Species of natural pollinators from at least 60 genera are threatened, endangered or extinct [4]. Planning for the availability of a wide range of habitat types for the food, breeding and other requirements of pollinators will yield significant benefits to humans.

**Water Treatment**

The potential to use green infrastructure for the treatment of polluted water is tremendous since human settlements generate enormous amounts of stormwater and wastewater. Shifting the approach to treatment of these polluted waters to distributed, biological methods, within green infrastructure, has the potential to generate substantial savings and many secondary ecosystem benefits. For example, a conventional sewage treatment plant in Oregon faced the prospect of upgrading the facility in order to comply with higher standards limiting the amount of phosphorus, nitrogen and temperature of the outflow. Instead the organization implemented a landscape solution (Figure 11).

In a great example of forward thinking, the wastewater authority purchased 340 acres (137 ha) of former agricultural land including degraded wetlands and upland oak-grassland vegetation on valley slopes years ago for eventual use as a biological treatment component (Figure 11). Water,
which already meets secondary water quality standards, is pumped from the wastewater treatment plant and is contained in a newly constructed 2-acre (0.8 ha) wetland for a day. Then the water is distributed over 258 acres (104 ha), including 60 acres (24 ha) of restored native wetlands and 23 acres (9 ha) of created wetlands [25] [26].

The project cost about $10 million compared to an estimated $100 million for upgrading the conventional plant. The savings were probably even greater since a comparable plant upgrade project in another municipality resulted in a final cost of approximately $150 million. The public debt repayment period for the project is three to five years [26]. The amazing economic benefit of this green infrastructure project is matched by the habitat and biodiversity aspects. Land, which would have been developed for suburban housing according to the existing pattern of habitat fragmentation and decreasing connectivity, preserves rare habitats and connects to regional habitat along the adjacent river corridor. The potential to add recreation facilities is high as the city expands in the future.

The multifunctionality of landscapes created to treat polluted stormwater runoff offer opportunities similar to those in the wastewater treatment project discussed above. Trees, plants and soil organisms have the capacity to clean stormwater and influence its flow. Mature trees of selected species can absorb as much as the first \( \frac{1}{2} \)” of rainfall. When multiplied by many trees the effect is substantial. In the U. S. Pacific Northwest 100 trees capture about 54,900 gallons of rainwater, thereby reducing municipal infrastructure costs [7][27].

**Waste Decomposition**

Solid waste management consumes a significant portion of the budget of every city and town. Separation of waste into streams with different treatment requirements and economic values supports the opportunities to recover and reuse the resources. Construction and demolition and other sources of wood waste provide opportunities to create biofuels or bioplastics. Even the managed biological processes of high rate composting provide materials that improve fertility, soil structure, and biodiversity when applied to farmland or degraded sites.

**Human Benefits from Provisioning Ecosystem Services**

**Food**

Community agriculture is an emerging and valuable part of green infrastructure in cities. To avoid conflicts with adjacent residential use and to respond to an alternative market, farmers within and adjacent to the city limit often adopt organic horticultural methods. Avoiding the use of chemical herbicides, pesticides, and artificial fertilizers establishes a sustainable practice that supports ecosystem health on the farm and in the neighborhood. Community agriculture including community gardens and small-scale farms supplement the global food network and increase local food security (Figure 12). Having residents with farming skills increases the social capacity of the city while the local sale and purchase of products supports the local economy to a greater degree than sales in the global economy. Most communities have the capacity to greatly expand the proportion of high value products such as fresh vegetables that are

![Figure 12. This one-acre organic farm produces 45 varieties of vegetables and salad greens for sale in the local farmers market. Photo by Austin, 2011.](image)
produced and consumed locally. This may require the adjustment of zoning laws, and the creation of new networks of food producers, processors and distribution systems. Chapter Ten addresses community agriculture in more detail.

Beyond the city the production impacts of agriculture determine whether the provision of food is an ecosystem service or threat. New concepts of ecological agriculture promote sustainable soil structure and fertility, water quality, and biodiversity of pollinators, birds, and animals. Production and harvest of crops, fruit, fungi, nuts, livestock, fish and shellfish is an ecosystem service even when there are artificial inputs of energy and chemicals but long term damage to the environment compromises the ecosystem service eventually. Instead all agriculture needs to achieve multiple functions. Biological diversity, recreation, education, and aesthetics are compatible with profitable agriculture. The use of hedgerows and shelterbelts and a mosaic of habitat patches, within a matrix of fields, supports biodiversity and recreation. Constructed wetlands that remove excess nitrogen from agricultural tailwater are another example of an ecosystem health measure that can be implemented without reducing growing area while supporting wildlife. Subsurface wetlands using wood chips as the bed media are very effective for the removal of nitrates from water that runs off fields [28].

Because machinery, artificial fertilizer, pesticides and irrigation artificially support so much of agriculture, we tend to ignore the fundamental ecosystem functions that continue to make food production possible. The free ecosystems services provided for the 1.4 billion acres (566,559,900 ha) of global cropland include filtered solar radiation, precipitation, nitrogen, natural global warming and pollination. Basic provision of water, carbon dioxide and oxygen make photosynthesis and respiration possible. As noted earlier, soil and nutrient cycles are important even in the production of agricultural commodities [16]. It is hard to imagine that humans are capable of disrupting such fundamental natural process, but the decline of some of the systems that provide these services are well documented.

Addressing agriculture is important because it affects a large portion of the primary production, which is the basis of food and energy flows through ecosystems. In fact, humans harvest about 30 percent of the net primary production of the planet. Livestock grazes about a third of this and the production of livestock is expected to double by 2050. Marine fisheries are another major protein source, as they provide nearly half of the human population with a significant portion of its protein. Marine fisheries are entirely dependent on natural ecosystem services. About a quarter of the total supply of fish now comes from inland fisheries and aquaculture. Like other domestic livestock operations, aquaculture requires artificial inputs food, pesticides and antibiotics to support high volume, commercial production. As in other agriculture, the treatment of wastes from these operations is required as part of a larger effort to maintain ecosystem health. This is as critical to the future capacity to meet growing demand for food as improved strains of seeds, efficient irrigation or other production enhancements [16].

Preservation of plant biodiversity is necessary for future ecosystem benefits to humans. Existing biodiversity is a source of genetic material that could be of great importance in the future for breeding of crop varieties to improve resistance to drought, disease, and insect damage [16].

Land-use changes have ecosystem benefit implications for humans. Conversion of forest and other habitat into pasture or other agriculture provides food businesses, but they can, also, involve large negative impacts, especially in the tropics. An example is the loss of tropical forest due to conversion to grassland for cattle grazing. The biodiversity impact is significant and the loss of carbon sequestration is a deficit that can’t be accommodated in the current climate change situation. Similarly, the conversion of prime agricultural land to suburban development is a foolish reduction in our capacity to produce necessary food.

Conflicts over water resources are common in the semiarid and arid portions of the United States. Hydroelectric power generation, water demand for agriculture, and preserving minimum
flows necessary to support ecosystem functions produce complex challenges. More efficient power generators, less water consumptive irrigation technologies, new crop varieties, runoff controls and reclamation and reuse of water are ways to meet some of these challenges.

Increasing land area for agriculture, plant hybrids, and dependence on artificial inputs has led to amazing increases in agricultural productivity since 1950. Worldwide 25 percent of the land area is in cultivation but the demand for food will increase by as much as 50 percent by 2030. In fact, the demand for food products has increased faster than the population. Over the course of history, about 6,000 species of plants have been cultivated for food but today only 30 crops comprise 95 percent of the world’s food calories. This dependency on only a few species is really even greater since wheat, rice and corn account for 50 percent of the calorie intake. Similarly, only 14 species of livestock provide 90 percent of global production [16]. In the future we will need to continue the use of artificial fertilizer and monoculture of crops to produce the necessary food. However, it is important to understand that this is primarily an artificially supported system that has significant environmental impacts. It can be managed better to serve multiple functions and to mitigate the impact of unsustainable practices.

**Energy**

Fossil fuels are, of course, ecosystem benefits even if the geologic time scale is involved. While fossil fuels are our primary source, other energy sources are also increasingly important. Even biomass is globally important since it provides about 15 percent of the world’s energy supply and as much as 40 percent of the energy resources in developing countries [4]. Surprisingly, biomass is the fastest growing sector of renewable energy sources in the United States. New technologies are likely to increase its importance.

The development of the process for creating ethanol and more recently isobutanol from plant and wood material represents another significant link between the ecosystem and energy. Isobutanol is a very high quality energy liquid that can be used as jet fuel. It represents a carbon neutral energy supply for military and commercial aircraft that will be available in the near future. The feedstock for the production of isobutanol is woody biomass that is currently piled and burned after commercial forest harvest operations. The biomass can also be generated from fuel reduction operations to reduce wildfires, from thinning forest stands to improve forest health, and from harvest of millions of acres of trees killed by beetles [29].

The direct use of wood as a cooking and heating fuel has been discouraged because of its inefficiency and the particulate air pollution it creates. In the U. S. there are 12 million residential fireplaces and wood stoves. As many as 9 million of these are outdated designs that are very inefficient and emit high levels of particulates, polycyclic aromatic hydrocarbons (PAH), and other pollutants. For example, old wood stoves produce 30 grams or more of particulate pollutants per hour (about the same rate as diesel trucks). This is a significant air pollution contribution in cities. In fact, wood burning is the primary source of urban particulate pollution in winter. Contemporary pellet stoves produce the least particulate pollution and are about 80 percent efficient. The best performing pellet stoves produce about 1 gram of particulate pollution per hour. Modern wood stove designs, with and without a catalytic converter, often approach the performance of pellet stoves. Electrostatic precipitators seem to offer the most promise for secondary pollution control, but the technology is expensive and systems are still being developed for the residential market [30].

Advances in the design of pellet stoves make the prospect of using renewal biomass fuel as the primary heat source acceptable. Using biomass directly, rather than using it to create liquid fuel or electricity, is cost efficient. If the biomass is derived from a sustainable growth and harvest system, then the energy is carbon neutral, which reduces climate change impacts. Using efficient pellet stoves reduces the per capita CO2 emissions by 10 to 20
percent for Americans. This finding is supported by an Austrian study demonstrating that wood pellet stoves reduce annual household CO2 emission by as much as 11 tons compared to other fossil fuels. The improved performance of stoves, furnaces and boilers burning woody biomass suggests that community forestry programs might increase the local supply of energy resources and mitigate climate change trends, especially in non-metropolitan counties. Using woody biomass left after commercial timber harvest to make pellets for stoves provides an additional benefit since this slash is generally burned creating large amounts of particulate pollution and emitting CO2. Oil and gas furnaces produce less particulate pollution compared to the best performing pellet stoves, but oil and natural gas both produce CO2 and exacerbate the climate change problem.

Live vegetation, rather than harvested biomass, also contributes to reduced energy consumption and reductions in CO2 emissions. The positive impact of trees and green roofs on the heat island effect and the temperature of cities have associated energy benefits. Landscape measures reduce energy demands for heating and cooling buildings. In the residential setting in the U.S. Northwest, a single large tree placed on the west or south side of the building reduces home air conditioning cost by an average $7 each year ($16 per year in the South) [7] [27].

Creation of carbon neutral fuels from biomass derived from the culture of algae is an experimental technology. It is an attractive area of research because seawater and wastewater can be used to produce the crop instead of freshwater. Currently, high capital costs limit the commercial applicability of the biofuels, but within a decade or two the technology and lower cost are expected to allow competition with traditional fossil fuels. An atmospheric provisioning service comes from the direct use of wind and waves for power generation. In 2007, the value of global energy created by wind-powered generators was $37 billion. In the same year, $50.2 billion was invested in the technology. With the addition of 2 million new wind turbines, wind power could provide about 20 percent of world energy requirement by 2050 [6].

**Fibers**

The ecosystem provides resources that are the basis of several industries including pulp for paper, cotton for textiles, and lumber for building construction. The residential and commercial building industry is a significant portion of the national economy fueled for two centuries by the harvest of forests in a rapid and unsustainable march across the United States. The largest annual harvest of timber in the U.S. for all products was in 1989 (18.8 billion cubic feet). Since this peak, harvested amounts have gradually declined over the last two decades. Only the southern regions of the nation increased harvest volumes during the last decade. By 2002, slightly more than 15 billion cubic feet were being harvested annually. Only 1.5 billion cubic feet of this came from publicly owned land in 2002, compared to about 4 billion cubic feet in 1989. The timber harvest figures, above, represent all wood products, including fuelwood and pulpwood [31].

Forest health, measured as forest cover, has recovered one third of the loss from previous rapid deforestation of the United States. Today forests occupy 31.2 percent (641 million acres) of the U.S. and dominate the landscape of the Northeast, New England, Mid-Atlantic, Southeast and Northwest regions of the country [32]. More recent concepts of sustainable harvest levels and the management of forests for multiple benefits including recreation, water supply and wildlife have reduced forest harvest amounts on public land dramatically compared to the widespread clear-cutting practices of the 1980s. Sustainable harvest on public land combined with private commercial forest operations can easily supply the demand for lumber in the future. This is evident since excess lumber is still being exported. Log and lumber exports from the west coast of the U.S. amounted to almost 5 million cubic feet during the first quarter of 2012 [33].

**Biochemical**
Nature is the source of material for new products and the inspiration for others. The extraction of oxygen, nitrogen, argon and other gases from the atmosphere is a thriving global industry. Most drugs are based on natural sources such as plants, fungi, and bacteria. Pharmaceuticals are the obvious examples of important biochemical ecosystem services but there is also a long history of study and invention based on natural elements. For example, scientists at the Argonne National Laboratory are attempting to manufacture crystals that are environmentally benign for use in paints, fiber optics and solar cells. The inspiration for this work is the emerald-patched Cattleheart butterfly. Figure 13 shows the crystal nanostructures on the butterfly’s wings that selectively reflect green colors.

Genetic material from wild plants is being used to increase productivity of crops by conferring resistance to disease, drought, pests and other limitations. Biodiversity is the storehouse of this material and will probably have even greater importance as we try to adapt agricultural production to the new circumstances that global climate change will establish. Already, the use of genetic modifications to adjust crop resistance to perturbation is adding about one percent to crop productivity and one billion dollars of value to agricultural production annually. We will certainly need the thousands of varieties of mold and rice, that were researched to derive commercial quantities of penicillin and a rice variety resistant to the grassy stunt virus, as new diseases and agriculture challenges arise [4]. These brief examples suggest that preservation of biodiversity serves us and that efforts to save species from extinction are worthwhile investments in our future well-being.

**Air Purification**

Vegetation within a green infrastructure improves air quality either directly or indirectly to the benefit to humans. Nitrogen dioxide and sulfur dioxide are absorbed through leaf surfaces, while particulate matter is intercepted by the leaves and then deposited when leaves are washed by rain or fall to the ground. Pollution is particularly problematic where high densities of tall buildings create urban canyons where pollutants can concentrate. Recent research indicates that increasing the planting of these canyon spaces with green roofs, green walls and trees would increase the rapid and sustained deposition of nitrogen oxides and particulates. The ecosystem benefit is a reduction of these pollutants by as much as 40 percent for nitrogen oxides and 60 percent for particulates [34].

Reduced temperature due to transpiration and shading reduce ozone levels. Similarly, air quality is indirectly improved when vegetation shades buildings in the summer and prevents heat loss in the winter and, therefore, lowers pollution generated by energy production (especially, energy from coal fired power plants). An assessment of the ecosystem service benefit of sets of 100 trees in the urban ecosystem reveals that pollutants (123 pounds in the Pacific Northwest, 137 pounds in the South) are removed from the human environment [7][27].

**Human Benefits from Cultural Ecosystem Services**

**Aesthetic and Spiritual**

People respond to landscape beauty and
scale. We love the textures, colors, variety and harmony found in the landscape and even images of the landscape. We want to experience the majesty of the Grand Canyon and the mystery of the microscopic landscape. We want to engage all of our faculties to touch, smell, and listen to pristine nature. We want to engage our minds and muscles in the experience of a special landscape or a common and familiar bit of nature.

The image of the Santiam River in Figure 14 suggests the sound and dynamic pattern of the rushing water. We can almost bathe in the cool green color of the forest and draw in the fragrant, humid air. The landscape is unified by the dominance of the enclosing forest but we can find a variety of evergreen and deciduous plants. There is the energizing suggestion on danger in swift white-water and deep pools. A mystery to be solved is presented in the turn of the river beyond our view. We are drawn to explore the gravel bank with its tenacious young tree, to lift the stones to find the mayfly larva in their traveling homes of cemented sand. Surely there are polished pebbles from miles upstream that are captured here. There is also a stone ruin of a manmade structure that hints at the story of a people who lived near this place long ago. The experiential use of the image and, better, a heightened experience in the physical landscape, is healthy and satisfying. We want the green infrastructure network to lead us from where we live to places like the Santiam River in the Niagara County Park.

Human components of the urban landscape can have effects as powerful as those we experience in natural settings, such as along the Santiam River. There are astounding achievements.
in architecture and engineering that are beautiful and amazing. They are testaments to our ability to create and to build. Some of these artifacts of human history are contemporary while others carry the heritage of our civilization. A great building is a frozen bit of social, political, economic or religious history. Seeing and using them should make us want to understand that cultural history better. Historic districts provide an even more complete and varied history of human habitation and endeavor. We want the green infrastructure to lead us to great buildings and through the cultural landscape.

Art and religion abound with reference to natural ecosystems as a source of wonderment, inspiration, peace and rejuvenation. Activities drawing on this source of fulfillment include ecotourism, hiking and camping, bird watching, photography, boating, fishing, and hunting (Figure 15). More domestic examples of this ecosystem service are pets, feeding birds, and gardening. The cultural category of ecosystem services applies to we humans who experience the natural world with our senses and interpret or appreciate it with our minds. Visual perception dominates our suite of sensory experiences and nature rewards us with daily stimulation.

Health and Recreation

The landscape provides an opportunity for the physical activity that, as the chapter on human health illustrated, is inadequate in the lives of most people living in industrialized counties. When the landscape encourages physical activity then it imparts a valuable human benefit. The economic value of physical activity is high. In England, the annual cost of a sedentary lifestyle is over $12 billion (£8 billion) annually. Inactivity due to obesity adds a burden of another $3.8 billion (£2.5 billion) per year. If adult residents of the U. K. would increase their physical activity by a modest ten percent, it would save the nation more than $761 million (£500 million) a year [9].

This economic understanding doesn’t capture the full value of open space and recreation in cities but these are clearly not frivolous amenities to be avoided in the pursuit of acreage for commercial or residential development. Instead they are critical to our physical and psychological health. A second British study found that, in areas where levels of greenery are high, people were three times more active and 40 percent less obese. The positive contribution of the landscape to physical health was confirmed by a study in Scotland. The evidence revealed a strong relationship between access to open space and improvements in mental health and lessening symptoms of chronic disease [9].

Parks are public resources that citizens use instead of purchasing these opportunities in the private sector. A study of Denver showed that the value of using public recreation facilities (Figure 16) by citizens is $452 million per year. The health benefits of public parks calculated for Denver confirms the economic importance that the British study found. The physical activity opportunities in parks can be expressed as the value of avoided medical costs. For Denver this amounts to $65 million per year [35]. The question of how much land a city should provide as recreation and open space is the topic of Chapter Seven.

Figure 15. Nature Photography (of a heron in this case) is a joyful example of a cultural ecosystem service. Photo by Garry Tucker, U. S. Fish and Wildlife Service, Government Work license.
Education

Although urban areas express human values primarily, there is an overlap between the presence of other species and people that is especially important in cities. People are most likely to have experiences with nature if it is present near where they live and work. Here is where daily pleasure, restoration and even education about the natural environment and native species can occur. The city of Austin, Texas capitalizes on the twilight flight of 1.5 million free-tailed bats (Tadarida brasiliensis), and the 100,000 visitors that they attract annually, to provide education as well as foster tourism and civic pride (Figure 17). A local environmental group provides literature and interpretive programs about the ecology of bats and the service that they provide to humans. Riverboat tours and an annual festival organized around seeing and celebrating bats has extended to a bat mascot for a sport team and even a statue of a bat as a expression of sense-of-place and civic pride [36].

That the bats have a constituency that understands their needs bodes well for the animals. Environmental education of the type we see in Austin can be extended. Citizens can engage in science projects gathering data on the presence of species and their numbers. The annual breeding bird count is a long-term example of citizen science in the United States. There are many for other environmental monitoring opportunities, such as the regular review of American rivers by the citizen group River Watchers. More direct activities include ecosystem restoration of streams, wetlands and forests. Examples of these activities are abundant in Chicago and the Chesapeake Bay watershed (Figure 18). In and near Chicago, thousands of volunteers engage in the Chicago Wilderness Habitat Project (http://www.habitatproject.org). The skills and interests of the volunteers are matched to programs that monitor populations of birds, dragonflies, butterflies, frogs and native plants. Volunteers working with professional scientists and resource managers collect seed, restore habitat and eradicate invasive plants.

Tourism

Global tourism was valued at $856 billion in 2007. Not all of this is related to the natural environment but a large portion of both winter and summer tourism for skiing or adventures in a warmer climate are economic benefits of a green infrastructure [6]. Even tourism at a municipal scale is economically important. Tourists often dedicate part of their travel to visiting high quality parks and recreation facilities. This is illustrated in Central Park in New York City. It attracts 40 million visitors each year and is a top tourist destination.

The Trust for Public Land was commissioned by the city and county of Denver to estimate the economic value of the 6,200 acres (2,509
Ecosystem Services

Economic benefit accrues from property tax, direct use, tourism, clean air, clean water, human health, and the social environment. The increased property tax, generated by an increase in value of residences because of their proximity to parks, amounts to more than $4 million annually. Sales tax revenue from non-residents visiting to use city facilities is over $3 million per year. The value of property owned by city residents increased $30.7 million due to park effects. Similarly, residents receive $18 million in net income from tourist spending. The costs of stormwater treatment ($804,000) and air quality improvement ($129,000) were saved by the city due to the effects of park vegetation and soil infiltration. “Friends of” groups are organizations of citizens that improve parks and neighborhoods at a very low cost to the city. These groups provide services that are socially and economically valuable. For example, reductions in antisocial behavior and degraded public facilities reduce city costs an estimated $2.7 million. The park system of Denver thus has an economic benefit of approximately $569 million [35].

Economic Value of Ecosystem Services

Economic development and vitality are cultural factors that can be supported or diminished by the use of land. The traditional view is that only industrial or commercial developments add economic value to a city. This chapter illustrates that the ecosystem directly provides much of the economic value to society and indirectly supports many economic activities. Existing healthy ecosystems provide humans with a great range of products of economic value. Restoring degraded landscapes can also be justified by the economic value of the ecosystem services that they provide. The example of the new National Forest in the United Kingdom confirms this observation. The National Forest is a 200 square mile (518 km2) region of central England. It is being transformed from a degraded landscape into a multifunctional green infrastructure with commercial forestry, tourism and other benefits. The total project cost $54.5 million (€41,974,755). Maintenance and management costs about $7 million (€5,391,253) per year. This investment has created or secured many new jobs in forestry (333 jobs), tourism, and service sectors in a region that was economically depressed. Millions of visitors now come to the area every day establishing a $432 million (€321 million) tourism benefit, based on an analysis of the period from 1991 to 2100. The value of recreation during this period is estimated to be $845 million (€628 million) and lumber products are valued at $15 million (€11 million). Carbon sequestration $281 million, (€209 million), biodiversity $75 million, (€56 million) and landscape restoration and enhancement $154 million, (€114 million) represent a total value of $510 million (€379 million). In total, the economic value of the ecosystems services provided by the restored ecosystem is estimated to be $1.35 billion (€1.005 billion) with a benefits to cost ratio of 4.8 to 1.

For the period 1990 to 2010 the benefit/cost ratio
is 2.6 to 1 [24]. For a discussion of recreation and biodiversity in the National Forest see the Chapter Seven.

An early study of the relationship of open space and residential property has been confirmed many times. The city of Boulder, Colorado purchased thousands acres of open space (Figure 19) using funds from a 0.4 percent city sales tax adopted by the voters. Sales of residential property within 3,200 feet of the newly acquired greenbelt were analyzed. The study revealed that the average value of properties adjacent to the greenbelt were 32 percent higher than those 3,200’ away. The value of residential property decreased $4.20 (1975) with every foot of increase in distance from the greenbelt. In addition, to the free public resource that open space offers all residents, private landowners are willing to pay a premium for proximity to the resource just as they are willing to pay more for a home with more square footage [37].

The increase in property value increases property tax revenue. Since the value of all the homes within the study area rose, property taxes reflect this increase. If fact, if taxes were collected in relationship to this increased value it would result in enough revenue to repay the cost of acquiring the greenbelt land within just three years. Assessment of property value for taxing purposes sometimes doesn’t properly reflect causes for value increases but it could certainly be organized to reflect the effect of proximity to publicly provided resources [37]. The Boulder assessment of property values associated with proximity to the greenbelt is confirmed by similar studies in Europe. A study 2004 study in the Netherlands found that a view of a park raised the house prices by eight percent, and having a park nearby raised house prices by six percent [24].

At the scale of the residence, green infrastructure also provides economic benefits that vary by region according to environmental conditions, energy costs and property values. For example, a single large tree in the urban Pacific Northwest is worth $2,820 ($4,240 in the South) in property value, energy and environmental benefits over its lifetime. This value represents a benefit to cost ratio

![Figure 19. Investments in open space have an economic benefit far greater than their initial cost. Photo by Author, 2012.](image-url)
ranging from 3:1 to 4:1. Over an average lifespan of 40 years, 100 trees in the Northwest provide an ecosystem benefit worth $190,320 ($316,120 in the South) [7].

It is paradoxical that we energetically calculate the economic cost of environmental and weather disasters, while ignoring the value of ecosystem services. For example, the cost of the Hurricane Katrina disaster is estimated at $90 billion. Weather related damage costs in the U.S. average $23 billion per year. However, the less visible cost of climate change is much higher. The estimated cost of damage caused by global warming is anticipated to be $250 billion per year by 2050. The total economic impact of global warming is estimated at $3 trillion to $12 trillion. Clearly, the economic value of the services that maintain a stable climate is many times greater than the losses caused by unusual weather events, but sustaining these services is often ignored by decision makers in all levels of government. Overall, ecosystem services are estimated to be about twice the value of the gross world product (GWP $18 trillion) while the total economic value of atmospheric services is between 100 to 1000 times the gross world product [6].

**Sustaining Ecosystem Services**

The ecosystem in general and specifically the green infrastructure of the city and countryside provides a host of benefits to people. Sustaining those benefits means attending to the health of the ecosystems that provide them. This chapter outlined services that are important but sometimes indirect and undervalued by society. Especially supporting ecosystem functions are less visible and often taken for granted. In fact, the climate change controversy illustrates that we have difficulty even believing that the damage we cause to these less tangible aspects of ecosystem health can be caused by man and affect him so directly and dramatically. Ecosystems that provide economically traded products have a built-in indicator of system health. Gradual reductions in the numbers of oysters harvested, for example, signal an ecosystem health problem. But green infrastructure used for recreation isn’t traded, so its value is sometimes discounted. This is why physical and psychological benefits and avoided cost economic studies serve to remind us of the essential nature of green infrastructure for recreation.

The more obvious ecosystem benefits, such as sustained harvests of timber, crops or seafood, are more clearly linked to human well-being but are subject to pressure from human population growth, economic, and political interests. Enumerating the species that provide products to man would create an overwhelming list. In turn, each of these species is embedded in an ecosystem that must be sustained for continued productivity. This exercise reminds us that we are sustained by the natural world [4].

Our quality of life is, similarly, enhanced by the social and cultural opportunities presented to us in the urban setting. Celebrations of historical and contemporary civilization and technological innovation enrich us. Yet we need physical activity, recreation and natural areas that present the wonders of nature to enhance the quality of our lives. Actually, the enjoyment of nature for health and aesthetic purposes, or the cultural understanding and education opportunities of historic monuments, and even economic products probably now depend on human access to managed ecosystems. Sustained natural biodiversity may also require some degree of human management. These resources (recreational, aesthetic, historic, biological and economic) need to be distributed throughout our communities and metropolitan regions. Subsequent chapters will explore how to plan, design, engineer and locate green infrastructure components to sustain economic, social and environmental benefits.

**References**


