16 Conservation of Biological Diversity in Agricultural, Forestry, and Marine Systems

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The present rate of species loss projects that half of all existing plant, animal, and microbe species on Earth will become extinct by the end of this century (Myers, 2003a; Wilson, 2003). This projected high rate of extinction due to human activities is alarming because many of these organisms are vital to the safe and productive function of ecological systems that sustain our planet and the global economy (Dirzo and Raven, 2003). Indeed, agricultural productivity and public health depend on the activities of diverse natural biota. From 10 to 50 million species of plants, animals, and microbes fulfill the ecological needs on Earth (Pimm et al., 1995; Pimm, 2002).

Although efforts to curb the loss of biodiversity have intensified in recent years, we have not been effective in countering the accelerating human population growth and the increasing destruction of natural habitats. The introduction of alien invasive species throughout the world continues to alter and damage natural and managed ecosystems (Pimentel, 2002). Moreover, additional complementary strategies are needed to protect small organism species, such as insects, bacteria, and fungi, which are essential to the structure and function of natural ecosystems (Wilson, 1987; Price, 1988; Soil Organisms, 2004).

Establishing national parks has been the prime focus of world biological conservation. Often overlooked but equally vital is the protection of biological diversity existing in our vast agricultural and forest ecosystems, as well as within human settlements (Pimentel et al., 1992; Daily et al., 2001; Ricketts, 2001; Vandermeer, et al., 2002; Homer-Devine et al., 2003). Together these cover approximately 78% of productive terrestrial ecosystems (AAAS, 2001).

In this chapter, we examine the necessity of species diversity in maintaining healthy and productive ecosystems as well as specific threats to biodiversity. The goal is to identify ecological strategies and policies that help enhance the conservation of biological diversity in natural, agricultural, forest, marine, and natural ecosystems.

CAUSES OF REDUCED SPECIES DIVERSITY

Over the past billion years, the natural processes of adaptation and diversification have tended to increase the number of species. However, especially over the past several centuries, the rapid escalation of human numbers (PRB, 2003) and the movement of humans into wild areas have resulted in a major and continuous decline in species diversity (Wilson, 1988; Novacek, 2001).

The rapid disappearance of animal and plant species is clearly illustrated in Britain. Thomas et al. (2004) report that butterfly species have declined 71% during ~20-year period, bird species declined 54% over 20 years, and native plants species showed a 28% decline over 40 years.

In developed countries, the use of natural resources is 100–600 times more per capita than in developing countries (Conservation Issues, 2003; Pimentel and Pimentel, 2003). Even where progressive laws and land preservation efforts exist, the increasing demands of humans and their industries undermine biodiversity preservation and the value of various ecosystems (Machlis and Tichnell, 1985; Pimentel and Pimentel, 2003).

When the demand for resources necessary for sustaining the increasing human population exceeds what is available, the result is increasing malnutrition and stress. More than 3 billion people are currently malnourished worldwide—facing shortages of calories, protein, vitamins A, B, D, and E, iron, and iodine (WHO, 2000). This is the largest number of malnourished people in history.

DEFORESTATION AND DESTRUCTION OF NATURAL HABITATS

Tropical forests occupy only 6.5% of the world's terrestrial ecosystems, but are home to about 70% of the world's species (N. Myers, personal communication, Oxford University, 2004; Pimm, 1991, 2002; Pimm and Brown, 2004). To date, humans have destroyed more than half of the world's tropical forests. For example, two-thirds of the forest area in Central America has been converted to agriculture for livestock production (Robbins, 2001; Rainforest, 2003). About 19 million ha of forests (about the size of Florida) are destroyed each year worldwide (World Bank, 2002), and approximately 60% of this deforestation is due to the conversion of forests to agricultural lands to maintain fiber and food production (Earthscan, 2002; Deforestation, 2003).

The destruction of even one tree species can have cascading effects resulting in significant losses of species, because up to 1000 arthropod species, including parasites and predators, may be associated with that single tree species (Erwin, 1983). Also, approximately 30 associated animal and microbe species die out for every plant species that becomes extinct (Edwards, 1998).

Equally disturbing to the loss of plant species is the rapid loss of crop genotypes now occurring. Crop genotype diversity is vital to farmers in different climatic and regional conditions, as they encounter different complexes of pest insects, weeds, and plant pathogens (James, 1999).

Soil Erosion and Salinization

Each year an estimated 10 million ha of cropland worldwide are abandoned due to lack of productivity caused by soil erosion (Faeth and Crosson, 1994). Another 10 million ha/year are critically damaged due to salinization, in large part as a result of irrigation or improper drainage methods (Thomas and Middleton, 1993).

Erosion rates on cropland in Asia, Africa, and South America average 30–40 t/ha/year (Taddese, 2001). In some regions, like Ethiopia, erosion rates on cropland may average as high as 100 t/ha/year (Taddese, 2001). While the current rate of soil erosion from cropland in the United States is less than in many developing countries, it is still about 10 t/ha/year, which is 10 times faster than the soil formation rate (NAS, 2003; Uri, 2001). The economic cost of erosion in the United States is estimated at about $38 billion per year (Uri, 2001), while for the rest of the world economic losses are estimated to be $400 billion per year (Myers, 2003b).

The first component of the soil loss, due to erosion by rainfall and wind, is soil organic matter. This loss directly reduces the biomass of soil, vital to the survival of plants, animals, and microbes. In addition, the reduction of soil depth can hinder or totally destroy the land's productivity (Uri, 2001).

In streams and lakes, the eroded sediment clouds water, reduces sunlight, and kills fish and other biota (Ontario, 1987; Uri, 2001). Also, the addition of nitrogen, phosphorus, and other nutrients to waterways may increase "undesirable" algae and other aquatic weeds and cause oxygen shortages (hypoxia), making the water inhospitable to fish and other animal species (USDA, 1999). For example, approximately 40% of U.S. fresh water is deemed unfit for recreational or drinking water uses because of erosion-induced contamination with dangerous microbes, pesticides, and fertilizers (UNESCO, 2001).

Finally, a growing number of acres are sacrificed to urban and economic development. Presently, nearly 16 million ha of U.S. land are devoted to roads and parking lots (Brown, 2001). Each person requires 0.4 ha of land for urbanization and highways (Anok and Peace, 2003), plus 0.5 ha of cropland, and 1.8 ha for pasture and forests (USDA, 2002). As the human population expands, so do the number of hectares required for economic development.

Alien Biological Invaders

Rapid human population growth and loss of natural habitats are reducing species numbers, but equally important are biodiversity losses due to the invasions of alien biological species (Pimentel et al., 2000; Sala et al., 2000; Pimentel, 2002). To date, more than 50,000 alien invasive species have been introduced into United States, and some are causing more than $120 billion in damages and control costs each year (Pimentel et al., 2005a). Harmful competition, predation, and parasitism from invasive species are causing an estimated 40% of all native species extinctions in the United States and forcing other native species to become endangered or threatened (Pimentel, 2002).

Human activities are facilitating the introduction of alien species and removing native vegetation in natural ecosystems for crops, livestock, and urbanization, and thereby contributing to the decline in species diversity (Tuxill, 1999; Henry, 2001; Pimentel, 2002).

Chemical Pollutants

Globally, one of the major factors causing species loss is the growing presence of chemicals throughout the world (Environmental Threats, 2003; Do or Die, 2003). Humans worldwide use 100,000 chemicals. More than 500,000 kg of synthetic pesticide chemicals are applied annually for U.S. agriculture, public health, and other purposes (Pimentel, 1997). Even the recommended use of pesticides destroys many beneficial species each year. Pesticide use in U.S. agriculture, for instance, kills more than 72 million adult birds each year, damages a half million colonies of honey bees, and is equally hazardous to wild bees (Pimentel, 2005). Additionally, some pesticides wash into streams and lakes, destroying fish and other aquatic organisms (Pimentel, 2005). In addition to animals, there are 300,000 human poisonings with 45 deaths in the United States and 26 million human poisonings worldwide with 220,000 deaths (Pimentel, 2005).

Marine Ecosystems and Aquaculture

Although studies most often focus on loss of terrestrial biodiversity, the oceans and other aquatic ecosystems are also suffering tremendous species losses. The Food and Agricultural Organization (FAO, 2003b) estimates that 47% of the world's fishery stocks are fully exploited and 28% are overexploited. Today, the estimated biomass of large predatory fish is only 10% of preindustrial levels (Myers and Worm, 2003), and marine foodwebs have significantly changed (Pauly et al., 1998). Although pollution, climate change, and invasive species threaten marine ecosystems, the fishing industry exerts the greatest pressure, even though fish make up a relatively small part of the world's human diet (0.01% of calories or 16% of animal protein (FAO, 2002a)). In seeking target fish for harvest, many nontarget fish are caught and destroyed. For every kilogram of shrimp harvested, 8–9 kg of "trash" fish are mangled and discarded as bycatch (Earle, 1995).

Some suggest that aquaculture will replace ocean fishing. Already, aquaculture is supplying nearly 30% of the world's fishery products (FAO, 2003b). However, overlooked is the fact that the production of aquaculture fish requires the harvesting of ocean fish. For instance, each kilogram of farm-fed salmon requires from 3 to 5 kg of ocean fishmeal (Goldberg et al., 2001). In this way, aquaculture is putting additional pressure on ocean fisheries rather than reducing pressure.

About two-thirds of fish species have an early stage of development in coastal wetlands (Ramsar, 2000). Thus, when coastal wetlands are drained or destroyed, fish production is seriously affected.

There are also economic consequences of reduced marine biodiversity. For example, if a fishery collapses, thousands of fishermen may lose their jobs. This happened in 1992 when 40,000 fishermen on the eastern coast of Canada lost their jobs because of the collapse of cod fishery due to overfishing (Harder, 2003).

Global Climate Change

Many birds and insects have already extended their distributions northward or to higher altitudes, mainly attributed to global warming. In response to climate change, many species in the 25 biodiversity hotspots will be forced to extinction (Myers, 2003b). In the coming decades, projected global climate change could seriously damage the world's species (Hansen et al., 1996; WRI, 2002). Moreover, many species, like trees, may not be able to change their distributions rapidly enough to keep up with the changing climate (Krajick, 2001, 2004; WRI, 2002). The World Conservation Union projects global warming may threaten 37% of the world's species by 2050 (Thomas et al., 2004).

Marine ecosystems are also at great risk due to climate change. For instance, even mild increases in ocean temperatures cause major epidemics of coral bleaching. Such increases in 1998 resulted in a loss of one-sixth of the world's coral colonies (Goreau et al., 2000; Earthscan, 2002; Dennis, 2002).

BIOLOGICAL DIVERSITY

Although about 90% of the global food supply today comes from 15 plant and 8 animal species (Pimentel and Pimentel, 1996), throughout history people have used as many as 20,000 plant species for food, out of the more than 80,000 species that could be utilized (Vietmyer, 1995; Tuxill, 1999). Humans obtain 99% of their food and all of their wood products by harvesting them from 70% of terrestrial temperate and tropical ecosystems (Pimentel et al., 1999; AAAS, 2001). Of the Earth's terrestrial area, approximately 11% is devoted to cropland, 37% to pasture land, 30% to forests, and about 5% to urbanization and highways (UNESCO, 2002; AAAS, 2001; Wiebe, 1997). The remaining 17% consists of unproductive areas, including mountains and deserts. Overall, most species are located on land area that is maintained for agriculture, forestry, and human settlements (Western and Pearl, 1989; Pimentel et al., 1992; FAO, 2004). Therefore, major efforts should be made to conserve the many species that now exist in these extensive managed, terrestrial environments (Paoletti, 1999a).

Current data suggest that 10–50 million species exist on Earth (Pimm et al., 1995). Most of what is known about biodiversity pertains to large plants and animals, such as flowering plants and vertebrates. The extent of the diversity of small organisms like bacteria, fungi, insects, mites, and other minute organisms remains relatively obscure. The United States is home to an estimated 750,000 species, of which small organisms, such as arthropods and microbes, comprise 95% (Pimentel et al., 1992; Dorworth, 2002).

In temperate crop ecosystems, the numbers of arthropod species range from 600 to 1000 species per hectare, while an estimated 20,000 bacteria species may be present in a favorable soil habitat (Table 16.1). Worldwide, arthropods make up

TABLE 16.1
Plant, Animal, and Microbe Species and Biomass Potential in a Favorable Soil Ecosystem with Ample Soil Organic Matter and Moisture

No. Species/ha		Sources	kg/ha	Sources
Bacteria	20,000	a,b	3.000	a
Fungi	50	a	3.000	c
Algae	5	d	100	c,e
Protozoa	60	a	100	c
Nematodes	30	a	50	c
Earthworms	15	a	3.000	a,f
Mites	114	g	10	a
Collembola	70	a	3	c
Enchytraeids	22	a	70	a
Termites	60	a	30	a
Ants	40	a	100	a
Isopoda	4	a	1	h
Beetles	46	i	70	a
Diptera	10	a	400	a
Arachnida	62	i	400	a
Total				

[a] Lavelle and Spain (2001).
[b] Wayne et al. (1987).
[c] Metting (1993).
[d] Masyuk (2002).
[e] Alexander (1977).
[f] Edwards and Bohlen (1996).
[g] Osler and Beattie (2001).
[h] Thimmayya (1998).
[i] Rushton et al. (1989).

the majority (~90%) of multicellular species. To illustrate, in a tropical forest in Uganda, on 80 trees of just two tree species, a total of 1352 beetle species were identified. In Borneo on 10 trees, a total of 2800 arthropod species were reported (Table 16.2). Arthropods and microbes, such as bacteria and fungi, contribute large amounts of biomass and large numbers of species to soil, crop, and forest ecosystems (Tables 16.1 through 16.3).

Marine ecosystems also have an abundance of species. For instance, 1 L of seawater may contain from 100 to 1000 species of bacteria (Fred Dobbs, Old Dominion University, personal communication, 2004). On coral reefs, for example, it is estimated that only 10% of the species have been described; over one million species are thought to inhabit these ecosystems making reefs rivals of rainforests in terms of diversity (Thorne-Miller, 1999).

TABLE 16.2
Arthropod Biodiversity in Various Ecosystems

		Arthropod	
Ecosystem	**Location**	**Species**	**Source**
Alfalfa (per ha)	New York	600	a
Corn (monoculture)	Minnesota	600	b
Cotton (monoculture)	Arkansas	600	c
Pasture (per ha)	Britain	1.000	d
Two tree species (80 trees)	Uganda (beetles)	1352	e
Forest tropical (10 trees)	Borneo	2800	f

[a] Pimentel and Wheeler (1973).
[b] Warters (1969).
[c] Whitcomb and Godfrey (1991).
[d] MacFadyen (1961).
[e] Wagner (2003).
[f] Stock (1988).

TABLE 16.3
Biomass of Various Organisms per Hectare in a Temperate-Region Pasture

Organism	**Biomass (kg fresh weight)**
Plants	20,000[a]
Fungi	4000[b]
Bacteria	3000[b]
Arthropods	1000[a]
Annelids	1320[b]
Protozoa	380[b]
Algae	100[c]
Nematodes	50[c]
Mammals	1.2[d]
Birds	0.3[d]

[a] Estimated.
[b] Richards (1974).
[c] Metting (1993); Alexander (1977).
[d] Walter (1985); Xerces Society (2001).

PRESERVATION OF BIOLOGICAL DIVERSITY—LARGE AND SMALL ORGANISMS

Clearly, plants, fish, birds, and mammals are invaluable contributors to the health of the ecosystem (Krajick, 2001). An estimated 275,000 species of plants have been identified, and perhaps as many as 100,000 more plant species have yet to be discovered (IUCN, 2002a). Despite their general resilience, the survival of many plants is now in peril: for every ten species of plants and animals that are listed as endangered, approximately six of these species are plants (IUCN, 2002a). According to Walter and Gillett (1998), at least one of every eight known plant species is threatened with extinction.

The fate of larger organisms too remains a concern: one in every four mammals and one in every eight birds are facing a high risk of extinction in the near future (IUCN, 2004). However, the importance of small organisms that dominate the basic structure and function of ecosystems cannot be overstated (Terborgh, 1988; USGS, 2003). Small organisms, such as insects, are useful indicators for the overall "health" of an ecosystem and its capacity to provide vital services to humans (Paoletti, 1999b; ESA, 2003). Insects and other "little things," like bacteria and fungi, perform crucial functions that sustain ecosystems in ways that are still scarcely understood, including pollinating plants and degrading wastes (Wilson, 1987; Price, 1988; FAO, 2003a). Because small organisms may be more specialized and more closely associated with a plant species than larger animals, they are likely to be more susceptible to environmental changes (Dourojeanni, 1990; IUCN, 2002b). For example, it is estimated that for each tropical plant species facing extinction, approximately 20 species of arthropods feeding on a particular plant may also be forced to extinction (Erwin, 1983).

In general, ecosystems require a sound relationship among the various species that make up the system. The elimination or addition of even one species to a relatively balanced ecosystem can have profound, cascading, and largely unpredictable effects (Fritts and Rodda, 1998).

BIODIVERSITY AND ECONOMIC AND ENVIRONMENTAL BENEFITS

U.S. agriculture and forestry depend upon most of the estimated 750,000 species of natural plant, animal, and microbe species for production and sustainability (Pimentel et al., 1997). Plant, animal, and microbe species provide the basic food, fiber, and shelter to support U.S. agriculture and forestry and contribute more than $15 trillion dollars annually to the U.S. economy (USBC, 2002).

A most vital activity carried out primarily by invertebrates and microbes is recycling wastes produced by agriculture, forestry, and human activities. A conservative estimate of the annual benefits of these processes in the United States alone is $62 billion annually (Pimentel et al., 1997).

Moreover, approximately two-thirds of the world's flowering plants depend on insect and other pollinators for reproduction and survival (Native Pollinator, 2003). Specific pollinators are sometimes vital to a particular species of plant (LaSalle and Gould, 1993; Comba and Corbet, 1998). This cross-pollination by bees is essential to about one-third of the crops grown in the United States and has a value of about $40 billion per year (USBC, 2002). Some seed-eating birds and mammals, like rodents, are essential in the dispersal of some plant seeds as well (Reid and Miller, 1989).

An estimated $10 billion is spent annually in the United States for pesticides to control crop pests. But the parasites and predators that exist in natural ecosystems provide an estimated $40 billion per year in benefits for pest control. Without the existence of natural enemies, crop losses by pests in agriculture would increase 10%–20%. Then the amount of pesticides and costs of chemical pest control would escalate (Pimentel et al., 1997).

Fish, other wildlife, and plant materials harvested from the wild in the United States alone have an estimated annual value of $45 billion (USBC, 2002). For instance, the livelihood of more than 30 million fishers and fish farmers worldwide (most of which live in developing countries) comes from fisheries (FAO, 2002b). The United States alone has a $25 billion fishing industry (USBC, 2002). In addition, approximately 25% of all pharmaceuticals manufactured in the United States, valued at $20 billion, are obtained directly or indirectly from plant materials (Tuxill, 1999).

Sustainable and productive agriculture and forestry systems cannot function successfully without the vital activities contributed by a wide diversity of natural plants, animals, and microbes.

PLANT, ANIMAL, AND MICROBE BIOMASS AND DIVERSITY

Biological diversity in an ecosystem is related to the amount of living and nonliving organic matter present (Elton, 1927; Wright, 1983; Sugden and Rands, 1990; Mishra and Dhar, 2004).

In addition to plants, the data in Table 16.3 indicate that fungi, bacteria, annelids, and arthropods contribute the bulk of the nonplant biomass in a pasture ecosystem. The fungi alone comprise about 4000 kg/ha (wet), bacteria about 3000 kg/ha (wet), earthworms 1300 kg/ha (wet), and arthropods 1000 kg/ha (wet). In contrast, mammals and birds contribute only 1.2 and 0.3 kg/ha (wet) biomass, respectively. Because the abundance of biomass is most often positively correlated with biodiversity, efforts to increase biomass in agricultural and forestry ecosystems are an important factor in the preservation of the wealth in biodiversity (Elton, 1927; Wright, 1983; Sugden and Rands, 1990; Mishra and Dhar, 2004).

STRATEGIES FOR CONSERVING BIOLOGICAL DIVERSITY

Because agriculture, forestry, and human settlements occupy about 78% of the terrestrial environment, a large portion of the world's biological diversity coexists with humans in these ecosystems (Western, 1994). Therefore, major efforts should be made to conserve the many species that now exist in these extensive, managed, terrestrial environments. Conservation programs based on sound ecological principles will assist agriculture and forestry production in becoming more sustainable, while at the same time maintaining biological diversity (Heywood, 1999; NAS 2003).

Species diversity benefits from abundant biomass, habitat diversity, stable ecosystems, abundant soil nutrients, high-quality soils, effective biogeochemical cycling, abundant water, and healthy marine systems (Westman, 1990).

Abundant Biomass—Except for green plants that capture solar energy for themselves and certain bacteria that use inorganic material as an energy source, all other organisms rely on plant biomass as their primary or secondary energy source. Crop and forest residues are biomass resources that are vital to agricultural and forest production. They not only protect the soil from erosion and conserve water, but, when recycled, also contribute large quantities (2000–15,000 kg/ha [dry]) of nutrients and organic matter to the soil (ERAB, 1981; NAS, 2003). Suggestions that crop residues be harvested for fuel and other purposes have proven catastrophic (Fenster, 2003; Pimentel and Wen, 2004). In China and India, the removal of crop residues has increased the rates of soil erosion and rapid water runoff approximately 10-fold and reduced soil quality and fertility (Fenster, 2003; Pimentel and Wen, 2004). In addition to reducing soil erosion and water runoff, cover crops are also advantageous for agricultural production because they reduce soil erosion, compaction, suppress weeds, conserve soil nutrients and moisture, and increase soil organic matter (Pimentel et al., 2005b). Furthermore, cover crops can increase vegetative biomass and diversity in crop ecosystems because they provide additional shelter and refuges for many species.

Plant Species Diversity

Approximately half of the plant species in the United States exist in managed ecosystems. Of the estimated 17,000 plant species in the United States (Morin, 1995), approximately 6000 are crop species and 2000 are weed species (Pimentel et al., 2000).

Increased plant diversity, with associated species diversity, can be encouraged in some managed ecosystems. Multispecies crop systems support a diverse group of natural biota that increase productivity. At the same time, farmers benefit from the effective use of soil nutrients and reduced water runoff. Examples of such cropping systems are found in Java, where small farmers cultivate more than 600 crop species in their gardens, making for overall species diversity comparable to subtropical forests (Dover and Talbot, 1987). In Guatemala, about 279 species were reported in the tropical-humid gardens (IPGRI, 2004). Similarly, nearly 80% of the farmers in West Africa and Latin America intercrop their gardens, raising upwards of 100 different crop species on their small plantings (Thrupp, 1998). By increasing the number of plant species on their farms, farmers were able to increase food production with a high degree of diversity.

Intercropping

When leguminous crops, such as clover, are grown between crop rows, such as corn, they serve as an intercrop or living mulch. Not only do legumes fix nitrogen in the soil, but they also conserve soil and water resources, and at the same time increase the associated biomass and animal and plant diversity present in the ecosystem (Sigvald and Yuen, 2001).

Strips of different crops are especially helpful when planted across the slope of agricultural fields. Such strips not only help control soil erosion and water runoff, but also increase the diversity of vegetation and thus increase the availability of beneficial parasites and predators for biological control (Francis et al., 1986; Fortin et al., 1994; Ramert, 2002). With appropriate combinations of strip crops grown *in rotation*, various pests can be controlled with little or no pesticides. Such pest control occurs, for example, when corn, soybeans, and wheat are grown in rotation in strip patterns (Pimentel et al., 1993, 2005b).

Shelter Belts and Hedgerows

Shelter belts and hedgerows planted along the edges of cropland and pasture land also contribute to biological diversity because, like intercrops, they reduce soil erosion and moisture loss as well as increase the biomass and structural and habitat diversity present in managed ecosystems (Elton, 1927; NAS, 1988; HMSO, 1995). Organic hedgerows are superior to hedgerows associated with conventional agriculture. For example, in Denmark, organic hedgerows were comprised of 27% more plant species than conventional hedgerows (Aude et al., 2003). Furthermore, shelter belts and hedgerows frequently provide refuges for beneficial parasites and predators, like ground beetles, that help control pest insects and weeds, thereby reducing the need for pesticides (Paoletti et al., 1989; Whalon, 2002). In addition, shelter belts help reduce erosion and moisture loss from crops by buffering winds and are especially beneficial in areas with low rainfall and high winds (Kedziora et al., 1989; Lu and Lu, 2003).

Biomass and Soil and Water Conservation—High quality soils maximize plant biomass productivity and help increase biodiversity. In general, quality soils are rich in nutrients; high organic matter (5%–10% of soil by weight); store soil moisture (about 20% by weight); are well drained and relatively deep (>15 cm); and have abundant soil biota (Doran and Parkin, 1994).

Abundant vegetative cover, including nonliving plant residues, prevent soil erosion and rapid water runoff (Hayes, 1996). Organic matter not only harbors large numbers of species but, equally important, sustains the productivity of the soil by improving water-holding capacity, providing a source of nutrients, improving soil tilth, and increasing the number and diversity of soil biota (Table 16.1). Because soil organic matter is the first to suffer the effects of erosion, soil conservation is vital to maximize biomass productivity and biodiversity.

A strong association exists between precipitation, plant diversity, and productivity. Because all plants and animals require water to sustain themselves, sufficient water is vital for maintaining maximum productivity and biodiversity (Neveln, 2003). Plants require large amounts of water for photosynthesis. For example, a corn crop producing 18,000 kg/ha of biomass during the growing season requires about 9 million L of water per hectare (Pimentel et al., 2004a).

Many technologies can be employed to conserve water and soil resources (crop rotations, strip cropping, contour planting, terracing, ridge planting, no-till, grass strips, vegetative cover, drip irrigation, intercropping, and shelter belts) (Troeh et al., 1999).

The adaptability of each technique depends on the particular characteristics of the crop or forest ecosystem (Troeh et al., 1999). In general, the presence of abundant biomass also conserves water by slowing rapid water runoff and increases the water holding capacity of the soil.

Livestock Manure

Livestock manure, when properly used, is a valuable resource that increases the biomass and biodiversity in agricultural systems. For example, when manure (100 t/ha wet) was added to agricultural land in Hungary, the biomass of soil microbes increased 10-fold (Olah-Zsupos and Helmeczi, 1987).

Habitat Diversity

Increasing the diversity of physical habitats increases the diversity of associated plants and other organisms present in the ecosystem (Allee et al., 1949; Fletcher, 1995). For example, when the habitat area was increased 10-fold, the number of bird species increased 1.6- to 2.5-fold (Avian Ecology, 2003).

Arnold (1983) reported that only 5 bird species were present in a pure farming ecosystem surrounded solely by farmland. The bird species increased to 12 when there was a short hedge, 17 species when there was a tall hedge, and 19 species when a strip of woodland was present.

Corridors between habitats are essential for many large predators, such as coyotes and mountain lions, which actively move between suitable habitats (Rodriguez et al., 2003).

Agroforestry

Agroforestry is an ecologically based, natural resource management system that integrates trees into cropland and rangeland systems (Leakey, 1997). Agroforestry increases biomass and conserves soils and water resources by preventing erosion (Kidd and Pimentel, 1992). Further, crop losses due to pests are often reduced because of increased plant diversity (Schroth et al., 2000). In addition to all these benefits of agroforestry, biological diversity is conserved and in some cases enhanced (CGIAR, 2003; Griffith, 2000).

For example, in tropical Central America, conventional corn plantings produce approximately 2000 kg/ha of dry biomass, whereas in an agroforestry system with a leguminous tree, the corn biomass was approximately doubled to about 3800 kg/ha (Kidd and Pimentel, 1992). At the same time, 4500 kg/ha of leguminous tree biomass was produced. Thus, in the agroforestry system, the total biomass produced was increased more than four times over that of the conventional system.

Similarly, in Indonesia, for example, agroforestry increased plant diversity above that in conventional farming with some farmer gardens having 50%–80% of the plant diversity found in natural forests (Leakey, 1997; Nobel and Dirzo, 1997). When the forests in the Tamaulipas region of Mexico were managed as agroforestry systems, they contained more than 300 plant species (Perfecto et al., 1996).

Mixed Forests

Mixed forests produce approximately 20% more biomass than a homogenous stand of trees (Ewel, 1986; Moore, 2002). The benefits are attributed to the differing nutritional need of the trees in the forest. In addition, mixed forests improve biological diversity because of the multiple arthropods and microbes associated with each tree species.

Moreover, in commercial forestry, as well as in natural forests, tree diversity increases biomass production by diminishing pest attack on tree hosts (Ewel, 1986; Allen, 2003). For example, the attack of the white-pine weevil on white pines and the Douglas-fir tussock moth on Douglas fir are significantly more severe in areas with single species forest than in areas with high tree species diversity (Allen, 2003).

Careful selective cutting of forests, however, can maintain high biological diversity and a healthy productive forest ecosystem (Hansen et al., 1996). Large-scale clear-cutting of forests should be avoided because it not only reduces biomass and biological diversity, but also removes nutrients from the soil, which eventually reduces the productivity of the entire ecosystem. Both biomass production and biological diversity decline as a result. Planting trees along streams is another helpful strategy to increase biodiversity as well as reduce erosion and conserve nutrients (Streams for the Future, 2004).

In addition, important agroecosystems are also found below ground in mature forests. When forests are cleared, vital mycorrhizal fungi and other micro-flora and fauna are reduced or exterminated (Tallis, 2002).

Pasture Management

A pasture management strategy that maintains maximum biomass, while preventing overgrazing, is the most productive strategy for livestock and ecosystem biodiversity (Clark et al., 1986; McIntyre, 2001). In addition to providing livestock with forage and vegetative cover, pasture productivity prevents soil erosion and rapid water runoff. Parol (1986, 2003) reports that increasing the plant species diversity in pastures can increase the productivity of the pastures up to 10%.

To prevent overgrazing, the pasture should have the appropriate number of animal units per hectare and should employ a sound pasture rotation system (Beetz, 2001; Rotational Grazing, 2004). For example, in the northeastern region of the United States, maximum production of livestock was achieved when pastures were grazed for several weeks and then rested for several weeks to allow vegetative growth (Yohn and Rayburn, 2004).

Pesticide Reduction

Pesticides severely reduce biological diversity by destroying a wide array of both harmful and beneficial species in agricultural ecosystems. In this process, they change the normal structure and function of the ecosystem. Concern for the negative effects of pesticides on natural biota and public health has prompted some nations to reduce pesticide use. For example, Sweden has reduced pesticide use by 68% and

Indonesia by 65% without reducing crop yields. In the case of Indonesia, crop yields actually increased 12% (PCC, 2002; Oka, 1991).

By employing appropriate biological controls and other environmental practices in agriculture, pesticide use can be reduced, and in some cases eliminated, while maintaining or increasing crop yields (Pimentel et al., 1993; NAS, 2000).

Conserving Fisheries

While many national and international fishery agreements do exist, they have not been enforced, as evidenced by the declining fish catches in recent years. Pauly and Watson (2003) recommend stricter regulations, including banning certain types of fishing gear. Furthermore, aquaculture that currently produces carnivorous fish, such as salmon, requires large quantities of fish meal (Goldberg et al., 2001). Alternatively, to be sustainable, aquaculture might have to rely increasingly upon herbivorous fish, such as catfish and tilapia (Gomiero et al., 1999; Swing, 2003).

Protected Parks

The maintenance of protected parks and wildlife refuges occupy about 12% of the terrestrial ecosystem (Chape et al., 2003). However, these parks are not protected from outside assault. For instance, about one-third of the tropical parks are already subject to encroachment by landless individuals who live in poverty (Myers, 2002). Many of these poor people who have an income of less than $1 per day are forced to attempt to find food or produce food in parks. As for protecting and effectively managing national parks, wildlife refuges, and other protected areas, it is reported that less than one quarter of the declared areas in 10 key forested countries were well managed, many had no satisfactory management at all (Heywood, A.H., personal communication, University of Reading, UK). Further support of this concern comes from the World Wildlife Fund study entitled, "How Effective are Protected Areas?" (World Wildlife Fund, 1999).

The further concern is that most parks are too small to insure the conservation of the majority of species they contain. For instance, the succulent Karoo biome in South Africa covers a relatively small area; however, this biome holds more than 6000 plant species, of which 40% are endemics, in addition to many endemic animals (Rodriguez et al., 2003). In Mexico on the El Eden Ecological reserve, only 73 species of slime molds are present, compared with 244 species in all of Mexico (Gomez-Pompa, 2004). Similarly, in Kenya, about 7% of its land is in protected national parks; however, 75% of the wildlife lives outside parks and within human systems (Western and Pearl, 1989; Muriuki, 2003). Including arthropods and microbes, more than 90% of species live outside of protected parks (Rodriguez et al., 2003).

Marine reserves, which comprise less than 1% of all marine ecosystems (WRI, 2002), have been widely promoted as conservation and fishery management tools. The benefits of marine reserves are indisputable, for within and around marine parks, fish populations increase dramatically and adjacent fisheries are improved up to 90% (Roberts et al., 2001). In addition, marine protected areas can provide substantial tourism revenues. For example, Australia's Great Barrier Reef Marine

Park yields over $1 billion per year in revenue for the local economy while costing a mere $20 million to manage (Hinrichsen, 1998).

Global Climate Change

With only 4% of the world's population, the United States is responsible for more release of carbon dioxide than any other nation in the world (about 25% of the total releases) (PRB, 2003). Reducing the rate of release of carbon dioxide and other greenhouse gases and slowing global warming will require a major effort by Americans and other people of the world. Hopefully, the United States will become the leader instead of an opponent of international climate policy. The United States could save as much as $430 billion per year on energy costs while reducing carbon dioxide emissions 30% below 2004 levels in 10 years (Pimentel et al., 2004b).

CONCLUSION

The present rate of species loss suggests that half of all species on Earth may be lost at the end of the twenty-first century. Millions of species of plants, animals, and microbes carry out vital functions in the biosphere, especially for agriculture, forestry, and aquatic systems. The prime threats to biodiversity result from rapid human population growth, and include habitat loss, urbanization, chemical use, introduced alien species, pollution, and global warming.

Conservationists are dedicated to protecting biodiversity and implementing sound conservation policies. Unfortunately, most conservation policies are established by economic planners, agriculturists, foresters, and corporations, and do not come from conservationists themselves (Myers, 2002). In the light of species loss and growing pressures on biodiversity worldwide, it appears that the only way that biodiversity can be saved is by saving the total biosphere (Myers, 2002).

One win-win approach is to strive for sustainable agriculture and forestry systems because most plant, animal, and microbe species exist in these ecosystems that cover 78% of the terrestrial ecosystem (Pimentel et al., 1992; Daily et al., 2001; Ricketts, 2001; Vandermeer et al., 2002; Homer-Devine et al., 2003). Also, agriculture and forestry ecosystems are the most favorable systems in terms of moisture, soil, nutrients, and temperatures. Maintaining biological diversity is essential for sustainable and productive agriculture and forestry systems. Biological diversity can best be protected by maintaining abundant biomass and habitat diversity; conserving soil, water, and nutrient resources; reducing water, soil, and air pollution; and reducing global warming.

The public as well as political leaders, must give high priority to protecting biodiversity and the total biosphere. We recommend that the United States and other nations adhere to the following policies to enhance the conservation of biodiversity:

- Encourage and implement ecologically sound and sustainable management practices for agriculture, forestry, and fishery systems.
- Implement policies to prevent the introduction of alien invasive species in the United States and other nations.
- Implement various international agreements, including the Convention on Biological Diversity, Framework Convention on Climate change,

and the Convention on the Law of the sea (J.A. McNeely, personal communication, Chief Scientist, IUCN, The World Conservation Union, Gland, Switzerland, 2004).
- Reduce water, air, and soil pollution that threaten species survival.
- Conserve and reduce fossil energy consumption to reduce greenhouse gases and global climate change.
- Set aside more ocean as enforced marine protected areas.

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