# Conserving Biological Diversity in Agricultural/Forestry Systems

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## Abstract (summary)

Patterns of species diversity in natural, agricultural and forestry ecosystems are examined, and the nature of the current threats to biological diversity is described. It is essential to identify specific ecological strategies and policies that enhance biodiversity in agricultural and forestry ecosystems.

## Full Text

Biological diversity is essential, whether for agricultural and forestry systems, pharmaceutical products, aesthetics, tourist income, evolutionary processes, stabilization of ecosystems, biological investigations, protection of overall environmental quality, or intrinsic worth of all species on Earth (Ehrlich and Wilson 1991, Wilson 1988a). Although approximately 90% of world food for people comes from just 15 plant species and 8 animal species (Wilson 1988a), several thousand other plant species are used as food by humans (Altieri et al. 1987a).

Furthermore, both high agricultural productivity and human health depend on the activity of a diverse natural biota composed of an estimated 10 million (range 2-80 million) species of plants and animals that inhabit the world (Wilson 1988b). The United States is home for an estimated S00,000 species, of which small organisms, such as arthropods and microbes, comprise 9S% (Knutson 1989). As many as 1 million species of plants and animals will be exterminated worldwide during the next 20-year period (Reid and Miller 1989). This high rate of extinction is alarming because these organisms may be vital to the functioning of ecological systems that sustain our planet.

Efforts to curb the loss of biodiversity have intensified in recent years, but they have not kept pace with the growing encroachment of human activities. Many laws (e.g., the National Environmental Policy Act and the Endangered Species Act) still appear to be a patchwork, ad hoc strategy to save species on the brink of extinction. Furthermore, their application has been primarily focused on preserving a small number of species of large plants and animals, while neglecting the small organisms. However, the numerous small organisms, such as insects and fungi, dominate the structure and function of natural ecosystems (Price 1988). Complementary strategies are needed to protect whole ecosystems to conserve total biological diversity.

To date, the prime focus of world biological conservation has been on protecting national parks that cover only approximately 3.2% of world land area (Reid and Miller 1989). Equally vital is the protection of the biological diversity existing in our vast managed agricultural and forest ecosystems and human settlements, which combined cover approximately 95% of the terrestrial environment (Western and Pearl 1989). Even extensive deserts have a few people with domesticated goats and sheep, and tropical rainforests also have people inhabitating them.

This article examines patterns of species diversity in natural, agricultural, and forestry ecosystems; the role of biodiversity in maintaining ecosystems; their viability; and the nature of the threat to biological diversity. The goal is to identify specific ecological strategies and policies that enhance the conservation of biological diversity in agricultural and forestry ecosystems.

BIOLOGICAL DIVERSITY

Most knowledge about species diversity concerns the large plants and animals, such as the flowering plants and vertebrates. The extent of the diversity of the smaller plants and animals remains obscure. Estimates of the number of species are listed in Table 1.

Arthropods dominate the diversity of species and make up approximately 90% of all species. Crop and both natural and managed forest ecosystems have abundant arthropod species (Table 2). They contribute a great amount of biomass and a great number of species to these ecosystems (Paoletti 1988, Paoletti et al. 1989, Pimentel and Warneke 1989). For example, the numbers of arthropod species in temperate and tropical agroecosystems range from 262 to 1000 per ha.

In Italy, a study of the number of aboveground arthropoid predators associated with trees in a forest and a crop ecosystem including weeds reported an average of 11.0 predators per unit sampled in the tree system and 9.8 predators in the same area sampled in the crop/weed system (Paoletti et al. 1989). In another study, Paoletti (1988) found that when the numbers o arthropod species in soil and litter in a forest and in a corn ecosystem were compared, relatively little difference in biological diversity existed between the natural and managed ecosystems: 232 arthropod species were found in the forest, whereas 239 species inhabited the corn ecosystem. Some species occurred in both ecosystems.

Although concern about threats to species diversity tend to focus on impressive species like whooping cranes and tigers, there are equal or greater threats to the small organisms like arthropods and microbes (Dourojeanni 1990). The small organisms often are more specialized and adapted to certain plant species and habitats than are the large animals, and therefore they are more susceptible than large animals to extinction when a tree species or other vegetation type is destroyed (Dourojeanni 1990).

There is prodigious biodiversity in tropical ecosystems. Janzen(1) reports that Costa Rica has 15,000 species of butterflies and moths, whereas only 12,000 species exist in the United States, which is 190 times larger than Costa Rica. Yet, biodiversity is plentiful in temperate ecosystems, too. Janzen (1981), Southwood et al. (1982), and Wilson (1988a) report instances where particular kinds of arthropods are more plentiful in temperate than in tropical ecosystems. Biodiversity conservation is not just a project for people in developing nations of the tropics. Much urgent work also needs to be done to prevent large-scale biodiversity loss in temperate, industrialized nations.

Humans manipulate 70% of the temperate and tropical ecosystems to harvest 98% of their food and all of their wood products (Vitousek et al. 1986). Approximately 50% of the terrestrial area is devoted to agriculture, approximately 20% to commercial forests, and another 25% is occupied by human settlements, which include cities, towns, and villages (Western and Pearl 1989). Only 5% is unmanaged and uninhabited.

Most species are located in the land area that is managed for agriculture, forestry, and human settlements ('Western and Pearl 1989). For example, in West Germany only 35% to 40% of the total of 30,000 species are found in protected areas; the remaining species live in human-managed ecosystems (RSU 1985). In addition to protecting the integrity of parks, the conservation efforts of biological diversity in agricultural, forest, and other managed ecosystems must be expanded.

PRESERVATION OF DIVERSITY: LARGE AND SMALL ORGANISMS

The most magnificent species, the ones that inspire us by their beauty, should receive a good deal of focus and funding in preservation efforts. But large size or anthropocentric notions of aesthetics should not be the only criteria considered in efforts to conserve global biological diversity.

The sheer numbers of insect species suggest that we ought not ignore them. "To a rough approximation and setting aside vertebrate chauvinism," writes Robert May (1988, p. 1446), "all organisms are insects." Insects and other "little things" perform crucial functions that stabilize ecosystems, in ways that are scarcely understood (Wilson 1987).

Elimination or addition of even one species can have profound effects. For example, until recently, pollination of oil-palm trees in Malaysia was done by human hand, an inefficient and expensive way of performing the task. Ten years ago, the government introduced a tiny weevil from West Africa's forests associated with palm pollination. The pollination of oil-palms in Malaysia is now entirely accomplished by the weevil, with annual savings of $140 million (Greathead 1983). In addition, insects are a virtually untapped source of food (DeFoliart 1989), dyes (Metcalf et al. 1962), and pharmaceutical products (Eisner 1990). Various microbes, too, can be more effectively used for nitrogen fixation and recycling wastes (Pimentel et al. 1980).

Ecosystems require a balance among the various organisms that make up the system. Although the small organisms dominate the structure and function of ecosystems, the large organisms also contribute to balance (Terborgh 1988). Both small and large organisms are useful indicators for the relative health of an ecosystem and its capacity to provide various basic services.

Each species has intrinsic value. Earthworms, insects, and fungi are no less fascinating, less threatened, or less worthy of attention and conservation than are the large organisms. Much remains to be learned about adaptation, the vital role that the small organisms play in the function and structure of natural systems, and the consequences of eliminating them. Although a few insects, fungi, and other organisms are pests of humans and crops, these pests make up less than 1% of all species.

CAUSES OF REDUCED SPECIES DIVERSITY

Over the past billion years, adaptation and diversification has tended to increase the number of species. However, with the escalation of human numbers, the movement of humans into wild areas, and industrialization, a decline in species diversity became noticeable (Wilson 1988a). This decline is associated with the destruction of ecosystems.

Within an order of magnitude, we do not know how many species exist today. Nor do we know the number that disappeared during the past few centuries. However, several sources estimated that, at present, approximately 150 species per day are being exterminated (Reid and Miller 1989). Thus, the vast majority of species remain undiscovered and many will never be known because of current extinctions. This observation emphasizes the need for a larger number of systematists and greater support for their research (Wilson 1988b).

The loss of biological diversity results from a wide array of complex factors that operate in the ecosystem. Affluence and its concomitant exploitation of resources, increasing rates of vegetation clearing, habitat destruction, growth of urban areas, and chemical pollution (e.g., pesticides and acid rain) have the greatest impact on species reduction. These trends are accelerated by the ever burgeoning rates of human population growth: a quarter-million humans added each day to the world population of 5.3 billion (PRB 1990).

Each new person requires food, wood, land, water, fuel, and other resources. In many developing countries, where demand for these resources exceeds what is available, the result is increasing human malnutrition and poverty, which contribute to environmental degradation (Brown et al. 1990). However, in developed countries the use of natural resources may be 100-to 60-fold more per capita than in developing countries. This excessive consumption diminishes biodiversity directly. Even where progressive laws and land preservation efforts do exist in developed and developing nations, the increasing resource demands of humans and their industries undermine any chance of progress in biodiversity preservation (Machlis and Tichnell 1985).

To date, humans have destroyed approximately 44% of the world's tropical forests (WRI 1990). Approximately 80% of the total of 20 million ha/yr of deforestation is due to the conversion of forests to agricultural lands (Pimentel et al. 1986).(2) The deterioration of current agricultural land, combined with the increasing population, results in approximately 15 million ha of new agricultural land being needed each year to satisfy human food needs. Furthermore, in some areas of the developed world, agricultural overproduction is related to species decline and extinction (RSU 1985). Also, in developing countries where slash-and-burn agriculture is practiced on short rotations, the impact on soil nutrients and soil organic matter can cause loss of biodiversity as well as reduced agricultural production (Altieri 1990). Therefore, the development of sound ecological agricultural production is an essential factor in all conservation efforts.

The use of toxic chemicals also adversely affects biodiversity. Worldwide, the 2.5 billion kg of synthetic pesticides used annually for agriculture, public health, and other purposes are particularly damaging to wild biota. For example, pesticides alone destroy or damage half a million colonies of honeybees annually in the United States and are equally hazardous to wild bees and other beneficial insects (USDA 1969). Chemical pollutants released into the air and water by agriculture and other industries result in the extinction of some species (Reid and Miller 1989).

The introduction of exotic species into other regions of the world has also reduced species diversity

(Wilson 1988a). Of the more than 1500 insect species that have been introduced into the United States by mistake, approximately 17% of the total became pests requiring the use of pesticides for control (Sailer 1983).

Whether or not a protected park will ultimately be able to maintain its biological biodiversity is largely determined by the surrounding land use and sociopolitical factors. If the land use in the adjacent area is not managed with the objectives of the park in mind, species become extinct.

This relationship has clearly been demonstrated by the fate of 62 bird species in an 86-hectare woodland in West Java. After several kilometers of surrounding woodland was destroyed, 20 bird species disappeared, 4 declined almost to extinction, and 5 more declined noticeably (Diamond et al. 1987). The remaining species appeared to be unaffected. This example highlights the need for regional conservation (Ricklefs 1987) and the need for the integration of biodiversity conservation for both parks and agriculture/forestry systems.

National parks are often protected from mining, logging, and other commercial activities; however, the president of the United States supports mining of oil and other resources in natural reserves, like those in Alaska. Similar situations exist in other developed countries.

Park protection also will be difficult in developing countries because of rapid population growth and the encroachment of human activities. For instance, Kenya's population has an annual rate of increase of 3.8%, which means its population is doubling every 18 years (PRB 1990). Currently, Kenya has approximately 7% of its land in protected national parks; however, three-quarters of the large rangeland mammals live outside of the parks within human-managed systems (Western and Pearl 1989). In addition, an estimated 90% of the other species of animals live outside of the protected parks.

Humans living in or adjacent to national parks threaten the preservation of some parks and reserves by hunting, building settlements, and other human activities (Browder 1990, Western and Pearl 1989). Another typical problem is one occurring in Costa Rica, where, although 25% of its land has been designated as biological preserves, biological diversity is being reduced because intensive agricultural policies are often ecologically unsound (Power 1989).

## BIODIVERSITY AND ECONOMIC AND ENVIRONMENTAL BENEFITS

The cultured species of agriculture and forestry, which provide the basic food, fiber, and shelter to support human existence, contribute several billion dollars annually to the world economy. Agriculture and forestry also probably depend on most of the estimated 10 million natural (noncrop and livestock) species for production and sustainability (Pimentel et al. 1980). The continued viability of agriculture and forestry also depends on wild relatives of the cultured species for genetic resources used in plant breeding to improve crop and forest productivity (Wilson 1995a).

A diverse group of microbes fix nitrogen from the atmosphere for use by crops and forests. For example, an estimated $7 billion of nitrogen is supplied to US agriculture by nitrogen-fixing microbes and an estimated 90 million tons (Hardy et al. 1975) of nitrogen is fixed for use by agriculture worldwide with a value of almost $50 billion annually.

Cross-pollination is essential to reproduction in many crops. More than 40 US crops, valued at approximately $30 billion, are absolutely dependent on insect pollination for production (Robinson et al, 1989). Insects also play an important role in natural vegetation pollination, whereas birds, mammals, and insects are essential in the dispersal of some plant seeds (Reid and Miller 1989).

An estimated $20 billion is spent annually in the world for pesticides. Yet, parasites and predators existing in natural ecosystems are providing an estimated 5-10 times this amount of the pest control. Without the existence of natural enemies, crop losses by pests in agriculture and forestry would be catastrophic and costs of chemical pest controls would escalate enormously.

Fish, other wildlife, and plant materials (e.g., blueberries) harvested from the wild have an estimated annual value of $2 billion in the United States (Prescott-Allen and Prescott-Allen 1986). Natural biota -- especially plants, microbes, and invertebrates -- provide many essential functions for agriculture, forestry, and other sectors of human society. In addition, these natural biota are vital because they preserve genetic material for potential agriculture and forestry products as well. Natural biota, especially arthropods, also serve as food for most species of native fish, many species of birds, and some species of mammals Uanzen 1987, Wilson 1987). Productive agriculture and forestry systems cannot function successfully without the vital activities of the diversity of natural biota.

## PLANT AND ANIMAL BIOMASS AND DIVERSITY

The data in Table 3 indicate that fungi, microbes, and arthropods, along with plants, account for the bulk of the biomass in ecological systems. For example, the fungi alone total approximately 4000 kg/ha, and the arthropods contribute approximately 1000 kg/ha. In contrast, the mammals and birds contribute only 2 kg/ha and 0.03 kg/ha biomass, respectively.

Biological diversity in an ecosystem is often related to the amount of living and nonliving organic matter present in the ecosystem (Wright 1983, 1990). Positive correlations between biomass production and species abundance have been recorded (Elton 1927, Odum 1978, Sugden and Rands 1990).(3) Although some ecologists have questioned the universality of this contention (Krebs 1985), most studies have confirmed the relationship. For example, in New York State, collard biomass in experimental field plots was increased an average of fourfold with respect to control plots (Pimentel and Warneke 1989). In the experimental plots with the highest biomass, the arthropod species diversity rose 40% over that of the control. Similarly, in field tests in the former USSR, the species diversity of macrofauna (mostly arthropods) increased 16% when manure was added to wheat plots (Bohac and Pokarzhevsky 1987). Further, in grassland plots in Japan the species diversity of the macrofauna (again mostly arthropods) more than doubled when manure was added to the land (Kitazawa and Kitazawa 1980).

In a related study, Ward and Lakhani (1977) reported that the number of arthropod species associated with juniper bushes increased fourfold when the number of bushes increased 100-fold. Elsewhere, a strong correlation between plant biomass productivity and bird species diversity was indicated when a 100-fold increase in plant biomass productivity yielded a tenfold increase in bird diversity (Wright 1983, 1990).

Although data for species diversity were not presented, the biomass of arthropods increased from twofold to sevenfold per hectare as manure was added to either wheat or mangold crops in the United Kingdom (Morris 1922, Raw 1967). Also, when manure was added to agricultural land in Hungary, the biomass of soil microbes increased tenfold (Olah-Zsupos and Helmeczi 1987). Assuming that biomass is generally correlated with biodiversity, efforts to increase biomass in agricultural and forestry ecosystems can be one important factor to contribute to the preservation of the wealth of biodiversity.

CONSERVING BIOLOGICAL DIVERSITY

Because agriculture, forestry, and human settlements occupy as much as 95% of the terrestrial environment, a large portion of the world's biological diversity coexists in these ecosystems (Western and Pearl 1989). Therefore, major efforts should be made to conserve the many natural species that now exist in these extensive terrestrial environments. Conservation programs based on ecological principles will help agriculture and forest production be more sustainable while at the same time maintaining biological diversity. An abundance of biomass, diversity of plant species, diversity of habitats, large areas, stable ecosystems, abundant soil nutrients, quality soils, effective biogeochemical cycling, abundant water, and favorable climates benefit species diversity (Westman 1990).

ABUNDANT BIOMASS AND ENERGY. Except for green plants that capture solar energy to feed themselves and certain bacteria that use inorganic material as an energy source, other species of organisms rely on plant biomass as their energy resource. Crop residues are a vital biomass resource that improves agricultural productivity. Crop residues left on the land for recycling not only protect the soil from erosion and rapid water runoff, but they also contribute large quantities (2000 to 15,000 kg [dry]/ha) of nutrients and organic matter to the soil.

Suggestions that crop residues be harvested for fuel and other purposes have often proven to be catastrophic. For example, in China and India, the removal of crop residues has proven to be disastrous for soil quality and fertility, biological diversity, and agricultural produaivity.(4) Also, sediments washed into streams and lakes have a negative impact on aquatic biota and other aspects of the ecosystem.

Cover crops, such as diverse grasses and legumes, are also advantageous for agricultural production because they reduce soil erosion and compaction, reduce water runoff, and increase soil organic matter (Hartwig 1987). In addition, cover crops can increase vegetative diversity in the crop ecosystems, which in turn benefits species diversity (Altieri et al. 1987b). The increase in biological diversity associated with an increase in biomass is also in part due to additional shelter and refuges available in the abundant biomass provided by cover crops.

DIVERSITY OF PLANT SPECIES. In the United States, many plant species exist in managed ecosystems. For example, of the estimated 21,750 plant species approximately 6000 are crop species, including forages; 708 are commercial trees; and 2000 are weeds.

Increased plant diversity can be encouraged in some managed ecosystems. Multispecies gardens support a diverse group of natural biota and help the farmer produce an abundant and wide variety of food. At the same time, the farmer benefits from effective use of soil nutrients and reducing rapid water runoff. Examples of such gardens are found in Java, where small farmers cultivate 607 crop species in their gardens, with an overall species diversity comparable to deciduous subtropical forests (Dover and Talbot

1987).

Diversity in forest production is also advantageous. Janzen (1987) reports that a tropical forest that has included some crop production has a larger number of insect species than a primary forest. The mosaic effect apparently increases the biological diversity. Other studies (Hanson et al. 1991) show that structural diversity is important in forests to protect biodiversity. This diversity can be maintained with adaptive harvesting strategies.

INTERCROPS. When leguminous crops like clover are grown between the rows of crops, such as corn, they serve as an intercrop or living mulch. Not only do legumes fix nitrogen, but they also enhance plant diversity by adding more plant species, conserve soil and water resources, and increase the biomass and animal diversity produced by the ecosystem.

In another system, strips of different crops are grown across the slope of agricultural fields. These strips not only help control soil erosion and water runoff, but they also increase the diversity of vegetation and increase the availability of beneficial predators and parasites for biological control. With appropriate combinations of strip crops grown in rotation, various pests can be controlled with smaller amounts of pesticides and in some cases without pesticides. This pest control occurs, for example, when corn, soybeans, and a hay crop are grown in a strip pattern (Pimentel et al. 1991).

SHELTER BELTS AND HEDGEROWS. Shelter belts for wind control and hedgerows planted along the edges of cropland and pastureland also increase biological diversity, because they reduce soil erosion and moisture loss and increase the biomass present in the managed systems (Elton 1958). Shelter belts and hedgerows frequently provide refuges for beneficial parasites and predators, which can invade crops and pastures to help control pest insects and weeds and thereby reduce the need for pesticides (Altieri et al. 1987b, Paoletti et al. 1989). In addition, shelter belts help reduce moisture loss by buffering winds, which is especially beneficial to crops in areas of low rainfall and may reduce irrigation needs (Kedziora et al. 1989).

BIOMASS AND SOIL AND WATER CONSERVATION. High-quality soils maximize plant productivity and help increase biodiversity. In general, quality soils have the following characteristics: they are rich in nutrients, have abundant organic matter (2-15% by weight of soil), store soil moisture (approximately 20% by weight), are well drained, are relatively deep (>15 cm), and have abundant biota.

Abundant vegetative cover, including nonliving plant residues, prevents soil erosion and rapid water runoff (Follett and Stewart 1985). Organic matter not only harbors large numbers of arthropod and microbial species but, equally important, it sustains the productivity of the soil by improving the water-holding capacity, providing a source of nutrients, and improving soil tilth. Because the organic layer is the first to suffer the effects of erosion, its conservation is essential to maximize biomass productivity and thereby increase biodiversity. In the temperate zone, soil organic matter in well-managed cropland ranges between 1% and 4%, in productive pastures between 4% and 8%, and in forests between 6% and 15% (RSU 985).

The presence of abundant biomass also conserves water by slowing rapid water runoff and increasing the water-holding capacity of the soil. Because all plants and animals require water to sustain life, sufficient water is an essential resource for maintaining maximum productivity and biodiversity. Plants, especially, require large amounts of water for maximal productivity. For example, corn producing 14,000 kg/ha of biomass (dry) during the growing season transpires approximately 4.5 million liters of water per hectare. A strong correlation exists between precipitation and plant diversity, both between temperate and tropical biomes and within biomes (Gentry 1982). In general, water increases the productivity of the ecosystem and in turn increases the plant diversity in the system.

Many technologies (e.g., crop rotations, strip cropping, contour planting terracing, ridge planting, and no-till practices) can be employed to conserve both soil and water resources. The adaptability of each strategy depends on the particular characteristics of the crop or forest ecosystem (Follett and Stewart 1985).

Vegetative cover prevents rapid runoff of rainfall and allows water to percolate into the soil. On barren, eroded soils, as much as 90% of the water runs off and is lost to the crop plants and forest (Lal 1984).

LIVESTOCK MANURE. Livestock manure, properly used, is another valuable resource that increases the biomass on agricultural land and increases biological diversity. Currently in the United States, only 6% of the nutrients in manure is being effectively utilized (Safley et al. 1983). The amount of fertilizer nutrients present in all the livestock manure produced in the United States is approximately equal to the amount of nutrients applied in commercial fertilizer each year. Estimates are that five to ten times more livestock manure could be effectively recycled for agricultural production.

Efficient use of livestock manure would raise the productivity of crops grown on the land, conserve fertilizer nutrients, and thereby decrease expenditures for fertilizers. Also, effective use of manure would add valuable biomass to the soil while reducing water and air pollution. All of these factors would tend to stimulate agricultural production, increase soil organic matter, and ultimately encourage beneficial arthropods in the agroecosystem (Purvis and Curry 1984).

HABITAT DIVERSITY. A variety of habitats helps increase biological diversity. Increasing the diversity of physical habitats increases the diversity of associated plants and other organisms present in an ecosystem (Gentry 1982). Different birds, arthropods, microbes, and other organisms are associated with different crop and forest ecosystems. Arnold (1983) reported that only five bird species were present in a crop ecosystem when the surrounding area was solely farmland, but eight species were found when ditch vegetation was present. The number of species increased to 12 when there was a short hedge, to 17 species when there was a tall hedge, and to 19 species when a strip of woodland was present.

Further, in both the tropical and temperate regions, different groups of species are associated with the same crop (Strong 1979). For example, worldwide the cocoa plant has a total of 1905 pest insect species feeding on it; however, 80% of these species are found in only one region (Strong 1974).

AGROFORESTRY. Agroforestry is the practice of planting various combinations of food and/or forage crops along with trees. Agroforestry increases in biomass conserve soil and water resources by preventing erosion (Figure ). Further, crop losses to pests are reduced because of increased plant diversity (Cromartie 1991). With all these benefits, biological diversity is conserved and in some cases enhanced (Ewel 1986, Kidd and Pimentel in press).

For example, in tropical Central America, conventional corn plantings produce approximately 10,000 kg/ha of fresh biomass, whereas in an agroforestry system with leguminous trees, the corn biomass was nearly doubled to 20,000 kg/ha (Kidd and Pimentel in press). At the same time, 22,S00 kg/ha of leguminous tree biomass was produced. Thus, in the agroforestry system, the total biomass produced was increased nearly fivefold over that of the conventional system. In addition, soil and water resources were significantly conserved, making the agroforestry system more ecologically sustainable and productive than conventional crop production. Combining crops and trees also increases vegetative diversity, which in turn increases species numbers.

Another form of agroforestry combines leguminous trees with pasture grass and livestock production (Kidd and Pimentel in press). The trees in this strategy fix nitrogen, thereby enhancing the total productivity of the system by contributing nitrogen and other nutrients to the pasture system. The trees also serve as a food resource for the livestock, especially during the dry season. As with the former agroforestry system, combining forage crops and trees increases vegetative diversity, which in turn helps conserve biodiversity both in tropical and temperate regions. Trees in agroforestry systems also produce fuelwood, which helps reduce pressure on natural forests.

MIXED FORESTS. Mixed forests have a higher rate of biomass production than a homogeneous stand of trees (Ewel 1986). This difference occurs because each tree species has a specific set of nutrient requirements, and the mixed planting of trees makes effective use of the complex mix of nutrients present in the soil. The mixed forest improves biological diversity because different animal and microbe species are associated with different 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). 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 stands than in areas with high tree species diversity (Metcalf et al. 1962).

Large-scale clear-cutting of forests should be avoided because it reduces biomass and biological diversity. Further, the loss of vegetation results in the rapid loss of 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 serves to increase biodiversity as well as reduce erosion and conserve nutrients. Careful, selective cutting of forests, however, can maintain high biological diversity and a healthy, productive forest ecosystem (Hanson et al. 1991).

PASTURE MANAGEMENT A pasture management strategy that maintains maximum biomass and prevents overgrazing is most productive for livestock (Clark et al. 1986). In addition to providing livestock forage and vegetative cover, high pasture productivity prevents soil erosion and rapid water runoff and provides the biomass needed to support other biota existing in the ecosystem. Overgrazing diminishes biomass, especially forage sources for the livestock, curtails livestock production, and also reduces biological diversity. For example, 139 microarthopod specimens were collected from litter in a half hectare of ungrazed pasture compared with 36 specimens from a half hectare of overgrazed pasture (Petersen et al. 1982).

To prevent overgrazing the pasture should have the appropriate number of animal units per hectare and have a pasture rotation system. For example, it is advantageous to cattle production in the northeastern region of the United States for a pasture to be grazed for one week and rested for two weeks to allow vegetative regrowth.

STABLE ECOSYSTEMS. Although some moderate environmental flux may be associated with increased biodiversity, extreme fluctuations in the amount of water, wind, cold, heat, nutrients, and vegetative types have negative impacts on the biota in both natural and managed ecosystems. Therefore, management programs for crops and forests should attempt to minimize extreme changes in the managed ecosystems to help preserve the natural biota present. The use of hedgerows, forest patches, field verges, ponds, and/or trees serve several purposes. They can buffer an area from extreme microclimate variation, help reduce water loss and erosion, and support biological diversity in crop fields and landscapes.

PESTICIDES AND OTHER TOXIC CHEMICALS. Pesticides severely reduce biological diversity by destroying a wide array of susceptible species in the ecosystem while also changing the normal structure and function of the ecosystem. Concern for the negative effects of pesticides on natural biota and public health has prompted three nations (Denmark, Sweden, and the Netherlands), and the province of Ontario to pass legislation to reduce pesticide use by 50% (Pimentel et al. 1991).

By employing appropriate biological controls and other agricultural practices, pesticides can be reduced and in some cases eliminated while crop yields are maintained or increased. Fortunately, a wide array of proven nonchemical control methodologies can be substituted for pesticides. These techniques include host plant resistance, biological control, crop rotations, use of short-season crops, soil and water management, trap crops, fertilizer management, increasing crop density, altering planting dates, and genetic engineering (Pimentel et al. 1991). Depending on the crop, pest complex, and ecosystem, these controls can be used in concert and in various combinations to minimize the use of pesticides and in some cases eliminate their need.

COMBINED BENEFITS. If agricultural and forest environments are improved and if biological diversity is conserved on managed ecosystems that adjoin protected national parks, the diversity of species in the parks will also benefit. For example, it has been shown that using appropriate plantings of commercial forests adjoining protected forests is helpful in providing a transition zone (Reid and Miller 1989). Improved environments in managed ecosystems are conducive to species migration between managed and natural ecosystems. Clearly, to increase biodiversity in agriculture and forestry depends on employing sound ecological practices, which at the same time improve the productivity and sustainability of agriculture. As Altieri (1990) has pointed out, often the best sources of knowledge and ecologically sustainable agriculture come from looking at places where indigenous farming systems have been allowed to survive. Development of government policies that pay attention to such marriage between ecology and agriculture is needed to preserve and promote sustainable agriculture and forestry and conserve biological diversity (Kidd and Pimentel in press).

CONCLUSIONS

The needs and activities of escalating numbers of humans are changing natural ecosystems at rapid rates. Millions of species live and carry out vital functions in the biosphere and are essential to society. Yet, the importance of most species of animals and plants -- the small organisms that make up more than 95% of all species -- is being overlooked. Because the organisms are small, the benefits to agriculture and forestry of these less-conspicuous organisms, such as arthropods and fungi, are often not recognized. During the past decades, focus has been on saving the relatively low number of large animals. Setting aside parks for these species has heightened public awareness and benefited the fight to save these often beautiful creatures. However, preserving the greater diversity of all species of organisms should be the aim of conservation programs.

The evidence suggests that more biological diversity exists in the agricultural/forestry and other human-managed ecosystems because human-managed ecosystems cover approximately 95% of the terrestrial environment, whereas protected parks cover only 3.2% of this environment. Biological diversity in agricultural/forestry systems can be best conserved by maintaining abundant biomass/energy and plant and habitat diversity; conserving soil, water, and biomass resources; and reducing the use of pesticides and similar toxic chemicals in agriculture and forestry. Maintaining this biological diversity is essential for productive agriculture and forestry, and ecologically sustainable agriculture and forestry are essential for maintaining biological diversity.

We recommend the following policies to enhance the conservation of biological diversity:

* Develop more accurate measures for assessing the value that small and large organisms have for

protecting the quality of the environment and work to disseminate this information to scientists, farmers, foresters, policy makers, and all concerned citizens.

* Encourage ecologically sound and sustainable management practices in agriculture and forestry.

* Adopt biological controls for pests and encourage greater use of biological resources for agriculture and forestry systems to replace pesticides, fertilizers, and other chemicals.

* Encourage society to dedicate itself to protecting biological diversity to provide a quality environment for everyone and to have a productive, sustainable agriculture and forestry. Concern should not be for one species or one factor, but for the integrated management of the earth's natural resources as a whole.

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