Special Article

Agricultural Research Service

Agriculture's Links To Biodiversity

Ecosystems and natural areas are being intensively modified by human activity—including agricultural production. Increasing and widespread extinctions of plant and wildlife species are occurring as natural habitats are destroyed, depleted, or disturbed by industry, agriculture, and urbanization. Current rates of species extinction are conservatively estimated to be 10 times the rate that occurred before human intervention.

The consequences for humanity are difficult to assess. Losses may include species that could provide future medicines, crops, and the genes needed for biotechnology research. Further effects may include the disruption of ecosystems that support rainfall cycles, control floods, and affect basic global climate.

Diverse biological resources—from individual plants' genetic traits, to habitats for birds that consume pests, to the complex interactions of tropical ecosystems—sustain the environment in which living things grow. While biodiversity is an important input for agricultural production, agriculture in turn affects the level and nature of biodiversity through its impacts on land, water, and other environmental resources.

It is generally recognized that greater investment by society in the preservation of biological resources is warranted. To the extent that such efforts are insufficient, economists would point to "market failures"—e.g., the lack of a price associated with threats to biodiversity, or the lack of a private "owner" of the biological resources that are affected.

A critical issue for U.S. agriculture is how America's farmers can continue to produce abundant, low-cost varieties of food and fiber, while preserving and enhancing biological resources. In the past, balancing economic and environmental concerns has proven difficult to achieve, particularly given the broad array of human activities that lead to biodiversity loss. For agriculture, this includes activities such as draining swamps and other wetlands and applying chemicals that may damage land and aquatic habitats.

The 1996 Farm Act recognizes the urgency of protecting the diversity of biological resources, and has included conservation of wildlife habitat as a goal of agricultural environmental programs. The new Wildlife Habitat Incentives Program, although a minor component of the Farm Act, is the first agricultural conservation program created exclusively for the protection and restoration of wildlife habitat.

The Role of Biodiversity

Biodiversity—biological diversity—refers to the biological resources upon which humanity depends for clean air, rainfall, temperature moderation, watershed functions (e.g., filtration), natural seeding and pollination, healthy forests and wildlife populations, soil productivity, germplasm, and species of undiscovered medicinal value. Biodiversity also provides life-enhancing resources for landscape amenities, outdoor recreation, tourism, etc. which enrich our existence.

Diversity in biological resources is the number and variety of the earth's life forms and is generally defined on three levels—plants, animals, and microorganisms (species diversity); the genes they contain (genetic diversity); and the ecosystems they form (ecosystem diversity). The survival of each level of biodiversity is dependent on the health of the other two. Genetic diversity fosters the survival of a species, enabling it to adapt to changes in climate or other conditions. A loss of species disturbs the ecosystem balance, which in turn alters or weakens the ecosystem.

Genetic diversity furnishes the agricultural production system with the means to improve crop and livestock yields and lower costs. Over the last century, U.S. farmers have produced more food and fiber with fewer inputs thanks to selective plant and animal breeding programs that drew on a variety of genetic material. Half of agriculture's productivity increases of the last 60 years can be attributed to genetic improvements.

Before the development of modern varieties, farmers relied on landraces—varieties of crops or livestock that evolved and were improved by farmers over many generations without the use of modern breeding techniques. These varieties are generally very diverse (within species) because each was adapted to a specific environment.

As modern breeding—which selects for specific desirable traits—came into being, crop and livestock yields rose more rapidly. Many of today's plants have been bred for specific desirable characteristics, including pest and disease resistance, shorter growing season, and uniform flowering, maturation, and stature. While these genetic improvements have helped to lower costs and increase yields for producers, the ongoing selection process has resulted in a narrowing of the genetic base as crops have become more genetically uniform.

Genetic uniformity, often reaching across an entire country for some crops, can increase vulnerability to pests and disease. While uniformity does not, by itself, cause vulnerability, uniform species are more likely to share a vulnerable trait—different varieties of a species can often withstand different threats. Uniformity increases the risks of pests and diseases spreading throughout a crop or livestock variety, as occurred in the 19th-century Irish potato famine and the southern corn leaf blight of 1970 in the U.S. The latter epidemic resulted in a 15-percent decline in the national average corn yield that year, with the economic loss to consumers and producers of such an epidemic estimated at more than $2 billion.

Moreover, agricultural producers face pests and diseases that constantly evolve. Varieties developed for a specific pest or disease resistance trait, retain their resistance for an average of only 5 years, while it generally takes 8-11 years to breed new varieties. As breeders continually search for resistance traits to keep high-yielding varieties less vulnerable to pests and diseases, they need biologically diverse genes to maintain (or improve) current yields. Such germplasm comes from infusions of fresh biological material that has not been previously used, including wild relatives and landraces. Thus the collection, preservation, and sustained use of genetically diverse materials have become critical for continued agricultural productivity.

Species diversity is essential to the efficiency of the agricultural system, and some species are imperative for agricultural production. For example, many crops require or benefit from insect pollination. While different pollinators are best suited for different crops, the U.S. has come to rely heavily on honeybees. Honeybees are raised for this specific purpose. At the same time, pesticide use and habitat loss has reduced the level and diversity of other pollinators such as butterflies, hummingbirds, and moths. As a result of this loss in diversity, the continued availability of pollinators is significantly more vulnerable to harm.

This vulnerability was realized this past year when honeybee populations in the U.S. fell significantly, due to parasitic mites. Because of reductions in populations of other pollinators, these species were unable to compensate for the honeybee loss. Consequently, yields for some pollination-dependent crops were reduced in affected regions.

The role of a variety of microorganisms in enhancing and promoting soil productivity is another example of agriculture's direct reliance on biodiversity.

What is Biodiversity?

Biological diversity (biodiversity) refers to the number, variety, and variability among plant, animal, and microorganism species, their genetic diversity, and the ecological systems in which they exist. Biodiversity is defined at three levels.

Genetic diversity refers to the different genes and variations found within a species. The different varieties of wheat are an example.

Species diversity is the variety and abundance of different species in a region. Examples are the number and variety of trees, and the different species of mammals and their populations found within an area.

Ecosystem diversity is the variety of habitats, such as grasslands or wetlands, that occur within a region. An ecosystem is a complex of plants, animals, and microorganisms, interacting with each other as well as with the chemical and physical factors making up their environment. Ecosystems are difficult to define, since the boundaries of ecosystems are inherently fluid—components move in and out. Ecosystems often overlap, or are components of larger ecosystems. This lack of clear delimitation is often a barrier to the effective design and enforcement of ecosystem preservation.

Biodiversity conservation, in its purest form, has the goal of maintaining the variety of the world's biological resources and the potential for those biological resources to continue to exist and evolve.

Not all ecosystems are endowed with an equivalent number of species. Tropical zones generally have a greater abundance of flora and fauna than temperate zones such as the U.S. Furthermore, conservation of ecosystems is not identical to the preservation of biodiversity, but some conservation practices could protect more species than others, depending in large part on the type of ecosystems that are affected.

While most animal or plant species may not directly affect agriculture, a change in a species can alter an ecosystem that does impact agriculture. Population declines have been documented in a number of predatory species—e.g., cougars and wolves—due mainly to habitat loss and direct predator control. This has contributed to rising deer populations. Deer can and do inflict damage to crops and compete for range through foraging. If more natural predators of deer were present, deer populations would be smaller, and impacts on crops reduced.

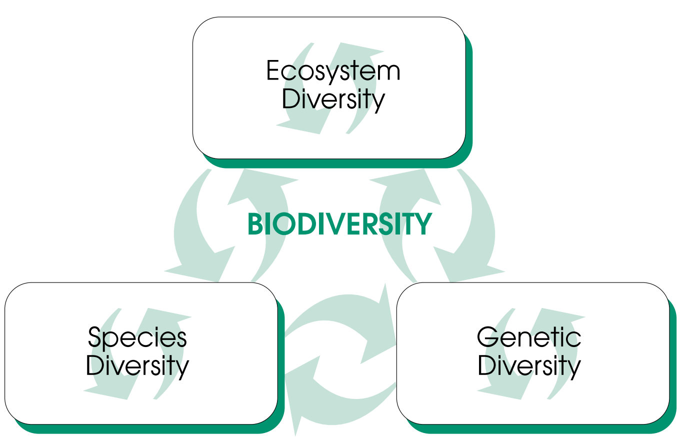
Ecosystem diversity also affects agriculture. Well-functioning ecosystems protect watersheds, prevent soil erosion and flooding, store and recycle organic nutrients and industrial wastes, and help to regulate the climate. Ecosystems also provide oxygen and soil nutrients needed to produce agricultural and timber products. And ecosystems provide habitats for species that benefit agriculture, such as birds and other predators that help control insect pests or serve as pollinators for commercial plant life in surrounding and distant areas.

Ecosystems are complex, and their operations are not completely understood. Nevertheless, diverse resources generally perform these functions at a higher level, with greater efficiency, and with reduced risk of catastrophic effects from naturally occurring threats.

As the diversity of an ecosystem diminishes, a threshold may be approached beyond which the further reduction or elimination of a single component can lead to substantial malfunction of other dependent parts. The introduction of a particular pesticide or predator insect, reduction in water quality or a critical habitat beyond a certain threshold... all represent potential threats, individually or in combination, to an ecosystem. Scientists are unsure how much change ecosystems can sustain and continue to perform their life-supporting functions.

The Value of Biodiversity

Although biodiversity has economic value to society on many levels, the measurement and valuation of biological resources and their diversity are difficult. Current direct uses represent their most visible worth. However, conserved resources not presently being used also have value, albeit uncertain, derived from unknown future uses. Even the information about a conserved resource has economic worth. For example, knowledge about a particular species of potato occurring naturally in the Andes—e.g., that it can be grown at high altitudes—may be of value to agricultural researchers and producers in the future.



Despite the values of biodiversity, efforts to conserve it appear to be insufficient. This apparent shortcoming is regarded by many in the scientific and lay communities as one of the most serious problems facing society today. The primary reason that society does not devote more resources to biodiversity conservation is that the private value—to individuals or firms—of biodiversity is often less than its value to society as a whole. The marketplace often fails fully to reflect nonmarket costs in its prices, particularly when those costs are not well identified, measured, or valued.

The following chain of events resulting from a hypothetical chemical contamination illustrates a "market failure." Suppose a manufacturing company releases industrial pollutants into the surrounding air and water. This causes vulnerable species to die or vacate the area, while also polluting a nearby lake farther downstream. The loss of bird species allows certain insects to flourish, harming local agricultural production. The pollution of the lake diminishes recreation use and property values. Yet the price charged by the company for its product most likely does not include any of these costs.

Or consider the sale of wetlands, which serve an important role in maintaining biodiversity. Wetlands recycle nutrients, provide a sink for absorbing and breaking down wastes, serve as a recreational and aesthetic resource, help regulate the climate, and serve as habitat to many species. An estimated one-third of U.S. bird species depend on wetlands. However, there is not a market for many of these benefits. If a landowner chooses to sell a particular wetland to be used for a housing development, the benefits of the wetland will be lost after development. Nevertheless, the transaction will be based solely on how the buyer and seller value the property, excluding many of the ecological values provided to society as a whole.

The goals of economic development and biodiversity conservation may be at odds. This is reflected not only in private decisions but also in public policies. Agricultural, forestry, transportation, and development policies all have the potential to affect the conservation of biodiversity adversely.

Agriculture: Its Impacts On Biodiversity

Agriculture has the potential to disturb or destroy the balance of an ecosystem through disruptive practices on existing farmland or by converting uncultivated land to farmland. While extensive farming has over time destroyed natural habitats, especially in the Great Plains region, massive expansion of U.S. farmland is no longer a major concern. Agricultural land use has remained relatively stable since 1945, while cultivated area has declined.

Activities associated with agricultural production may affect biodiversity in several ways. Examples of such activities include erosive tilling, improper grazing and animal waste disposal practices, irrigation with its potential for salinity, the introduction of new species into an ecosystem for pest control, and application of agrichemicals with their potential for leaching into ground water, or runoff into streams and other waterways.

As a result of such activities, soil composition may be altered so that naturally occurring, soil-enriching organisms and nutrients are lost. Water distribution and quality may be diminished such that certain naturally occurring plants and animals may no longer thrive. Atmospheric properties may change if carbon dioxide, methane, and nitrous oxide levels are higher than they would be in unmanaged systems. The landscape structure may increase erosion and/or reduce wildlife habitat. Or species interactions may be altered as the diversity of flora and fauna are diminished, thus reducing linkages between species and impairing ecosystem functions.

Agricultural activities vary widely in their intensity and effects on biodiversity—e.g., unmanaged rangeland used periodically for grazing will have higher levels of biodiversity than close-grown field crops that are not rotated. Moreover, agriculture's adverse effects on biodiversity can be mitigated. Agro-ecosystems can even be managed to enhance biodiversity. In the oak range savannah of Central Valley, California, both over- and undergrazing of livestock can lead to biodiversity loss. Adoption of more judicious grazing practices in recent years has aided wildlife production and plant growth by enhancing habitat and reducing shading. This allows a greater variety of plants to grow.

Crop rotations, particularly those involving nitrogen-fixing plants, can restore soil nutrients. Intensive management techniques—e.g., site-specific or precision farming—can use water and agrichemicals more efficiently, helping to prevent degradation of water quality. The use of buffer/filter strips near waterways, and proper crop cover on marginal land, can lower erosion and chemical runoff while improving water quality and creating wildlife habitat. Integrated pest management techniques allow farmers to use pesticides more selectively, and can include the introduction of beneficial insects.

Public Policy & Biodiversity

As public interest in environmental protection and resource conservation has increased over the past 30 years, related government policy and legislation has also evolved. Legislative provisions relying on voluntary or market-based incentives, and on regulation, have been enacted that have helped protect habitat. As a result, some wildlife populations have rebounded.

One of the earlier and better known of the regulatory statutes is the Endangered Species Act (ESA) of 1973, which directly addresses the loss of species biodiversity. The ESA can affect agricultural producers on several fronts, though debates have arisen over interpretation and implementation of the law and over the role of protecting habitat.

USDA's Natural Resource Conservation Service and Forest Service have adopted an ecosystem management philosophy in which policies and practices on natural resource management reflect a consideration of impacts on the larger ecosystem—beyond the individual farm, ranch, or woodlot. USDA has also responded to public interest in resource protection by expanding the environmental focus of its agricultural conservation programs (*AO* November 1996), as well as continuing its support for agricultural breeding research and genetic preservation. In 1994, USDA spent more than $3.5 billion on resource conservation and related programs.

The Federal Agriculture Improvement and Reform Act of 1996 (Farm Act) has built on the natural resource conservation goals of previous legislation—e.g., reducing soil erosion, protecting water quality, slowing conversion of wetlands, and (more recently) restoring wetlands—by adding wildlife habitat as an element of agricultural conservation.

The Endangered Species Act

The Endangered Species Act (ESA) of 1973 is a regulatory statute intended to protect threatened and endangered species by preserving the ecosystems on which they depend. The ESA lists and offers differing levels of protection to vertebrates (fish, amphibians, reptiles, birds, and mammals), invertebrates, and plants. The U.S. Fish and Wildlife Service (FWS) and the National Marine Fisheries Service (NMFS) are responsible for "listing" particular species based solely on their biological status. Nearly 1,000 species that occur naturally in the U.S. are listed, with another 4,000 domestic species candidates for listing.

The ESA prohibits taking, possessing, transporting, or trafficking in listed species, except by permit. Listed plants may not be collected or maliciously damaged, but (unlike vertebrates and invertebrates) this provision only applies to plants on Federal lands or on private lands with the landowner's consent. Under the ESA, Federal agencies do not fund, authorize, or carry out actions that are likely to jeopardize the survival of protected species without consultation with the FWS or NMFS.

Implementation of the ESA has generated substantial controversy in recent years, due to the apparent dilemma of balancing the conservation of species with certain economic activity.

For example, because of the ESA, access to federally supplied irrigation water and land has been restricted. In one instance, the Bureau of Reclamation (Department of the Interior) changed the Central Valley Project (California) water allocation in favor of salmon protection, by reducing water allotments to farmers during the 1992 drought. Perhaps the most famous example involving the ESA was the 1990 ruling that limited logging of "old growth" forests in the Pacific Northwest to protect the habitat of the endangered northern spotted owl.

Special Article

Agricultural Genetic Resources: Conservation & International Access

Conservation of agricultural genetic diversity is undertaken by one of two general methods: on-site or off-site preservation. On-site conservation of agricultural diversity is carried out in the field, often by farmers using a portion of cultivable land to produce the traditional (or selected) variety.

On-site preservation can provide valuable knowledge about species development and evolutionary processes, as well as how species interact. However, it requires land, which can be costly. A farmer must often forgo the opportunity to grow a higher yielding, and potentially more economically rewarding, variety. The *off-site preservation* method removes genetic material from its natural environment for long-term conservation. Botanical gardens and gene banks are examples of off-site conservation strategies.

Gene banks—repositories for many genes—allow for the storage of large amounts of genetic material at relatively low cost. The world's gene banks presently hold more than 4 million samples of crop varieties. Gene banks hold samples of an estimated 79 percent of the world's cereal landraces.

However, still greater investment in collecting, maintaining, and effectively using these resources appears justified for four reasons. First, wild relatives of domesticated varieties are an important source of new genetic material for breeders targeting specific traits. Relatively few of these wild relatives are held in gene banks.

Second, current funding levels for many gene banks are already inadequate to undertake fully all of the activities associated with genetic preservation. The U.S. National Germplasm System (NGS)—maintained by USDA's Agricultural Research Service, is the world's largest collector and distributor of germplasm. However, the NGS does not have sufficient funding to complete varietal listings or to undertake necessary backups and regeneration of varieties.

International gene banks also frequently experience serious funding shortages and information deficits. The International Agricultural Research Centers of the CGIAR (the Consultative Group on International Agriculture Research established by the World Bank and the Food and Agriculture Organization of the U.N.) collect germplasm and maintain several important repositories throughout the world, in addition to breeding seed varieties suitable to tropical environments in developing countries. The CGIAR agricultural research system has experienced a drop in funding in recent years. Also, some non-CGIAR seed banks—e.g., in the former Soviet Union—have been adversely affected by declining funds and/or by political instability.

Third, determining available traits, and how to access them, can be difficult and time-consuming for breeders. Finall with rapid degradation of the existing pool of genetic diversity in many parts of the world (and given current funding levels), potentially valuable traits could disappear before researchers have the opportunity to catalog and analyze them.

International access to genetic resources found in other countries is critical to maintaining the rate of varietal improvement. Tropical—frequently lower income—countries have often provided the raw genetic material for public germplasm repositories, for two reasons. They often lie in geographic centers of diversity, and they have greater quantities of unmanaged land. In fact, almost every plant species of major economic importance to the U.S. has been improved with germplasm from elsewhere.

For example, genes that provide resistance to yellow dwarf disease in U.S. barley varieties were obtained from a Turkish landrace. Another Turkish wild plant related to modern wheat is the source of genes that provide important disease resistance to U.S. commercial wheat varieties. Both sets of genes have resulted in significant commercial savings.

Genetic material was historically regarded as the common heritage of humankind, and developing countries provided free access to their genetic resources. These resources include seeds and other germplasm from farmer-developed varieties as well as from the ancestors of such varieties.

However, international access to genetic resources could change. On occasion, material from a low-income donor country has been transferred to research laboratories in developed countries and incorporated into new or improved varieties which were then sold back to the donor country by private seed companies. While lower income countries generally benefit from this exchange in the form of lower food prices, some countries maintain the system is inequitable.

The 1992 U.N. Convention on Biological Diversity and the resulting Rio Biodiversity Treaty—signed by U.N. delegates in 1992—could change the way germplasm is exchanged (*AO* June 1994). Designed to foster the preservation and equitable use of genetic resources worldwide, the treaty recognizes the sovereign rights of countries to their genetic resources collected after ratification. It also encourages users of plant genetic resources to share with developing countries the benefits of any resulting technology, including new crop varieties.

Sovereign rights allow countries to sell genetic resources, or to refuse access to other countries altogether. Although the U.S. is not a party to the convention and has never ratified the treaty, many of the suppliers of genetic material to the U.S. have ratified the treaty. However, it is not likely to have a great impact on many breeding activities in the U.S., primarily because the treaty grants property rights on only a portion of potentially valuable material—i.e., germplasm collected since treaty ratification. Indeed, some experts estimate that the current supply of germplasm in the seed banks of CGIAR will be adequate for many major needs of the seed industry over the next 20 to 50 years. And breeders may continue to access the vast majority of collected germplasm freely.

Agricultural policy has increasingly emphasized voluntary programs that encourage resource-enhancing activities by farmers. Policies that advance biodiversity conservation include the Conservation Reserve Program, conservation compliance provisions—highly erodible land conservation and swampbuster—the Wetlands Reserve Program, the Environmental Quality Incentives Program, the Wildlife Habitat Incentives Program, and provisions to improve the Everglades' agriculture area.

The Conservation Reserve Program (CRP) was initially authorized by the 1985 Farm Act and has been extended under subsequent farm legislation. The 1996 Farm Act reauthorized the CRP up to a maximum of 36.4 million acres at any one time through the year 2002. Farmers who sign CRP contracts agree to convert highly erodible and/or environmentally sensitive cropland to approved conservation uses for 10-15 years. In exchange, farmers receive annual rental payments and cost-share assistance for converting and maintaining the land.

Initially the CRP's focus was on highly erodible cropland. In 1989, CRP rules were changed to include wetlands, and other provisions focused on water quality. In 1991-92, USDA refined the CRP, etablishing an environmental benefits index to assist in national ranking of applications. The importance of environmental protection, particularly water quality, was heightened by increasing the value placed on environmental protection in the CRP land selection process.

With elimination of the acreage reduction program in the 1996 Farm Act, the CRP is the principal remaining policy with the potential to reduce land availability and crop production. However, USDA has made it clear that it intends to operate the CRP not as a supply control program, but to conserve and improve natural resources.

Crop cover on CRP land provides many environmental benefits that foster the preservation of biological resources, including improved water quality, reduced erosion damage, the preservation of soil productivity, and the creation of wildlife habitat. The CRP has been credited with the regional recoveries of many animal and bird species, including several popular grassland game birds.

The total economic benefits associated with environmental improvements of land enrolled in the CRP between 1986 and 1989 were estimated at $9.6-15.4 billion. This figure includes wildlife viewing, hunting, fishing, and the value of improved water and air quality and soil productivity.

Conservation compliance provisions require producers to implement approved conservation systems on highly erodible land (conservation compliance and sodbuster), and refrain from altering wetlands to make crop production possible (swampbuster), in order to maintain eligibility for most USDA program payments. Besides the wetland protection provided by conservation compliance, USDA manages the Wetlands Reserve Program (WRP) to restore cropped former wetlands. To date, more than 390,000 acres out of a permissible 975,000 have been enrolled in the WRP. By slowing conversion of wetlands to farmland, and restoring wetlands, swampbuster and WRP have together improved water quality and wildlife habitat.

USDA has an extensive water quality program, and water quality is also addressed as part of the new comprehensive Environmental Quality Incentives Program (EQIP). And the 1996 Farm Act also created several new programs with promise for biodiversity conservation, including the Wildlife Habitat Incentives Program (WHIP) and provisions to improve the Everglades' ecosystem. WHIP was created to provide cost-sharing assistance to landowners as an incentive for developing and implementing various on-farm management practices to improve wildlife habitat.

The Everglades Agricultural Area provision earmarks $200 million to conduct restoration activities. These may include land acquisition in the Everglades. An additional $100 million of Federal land in Florida may be sold or swapped for land in the Everglades.

Public plant and animal breeding research, supported by USDA, is working to provide both new and improved varieties, as well as varietal breeding material. Rather than focusing on yields, as in the past, USDA now concentrates on developing varieties resistant to diseases, pests, and environmental stress. The Agricultural Research Service releases about 100 new plant varieties annually with improved resistance and stress tolerance.

As with conservation of natural habitats, public and private incentives to develop and preserve genetic resources often diverge. While genetic improvements in crops and livestock are wanted by society as a whole, there is often insufficient incentive for private breeders to engage in the high-risk, long-term research necessary for such improvements. Public agricultural research funds breeding that would likely be unprofitable for private breeders. Consumers (both domestic and foreign) are the largest beneficiaries of most publicly generated breeding improvements via lower food prices.

Private breeders generally rely on elite germplasm—germplasm already proven to be successful. Public research funds allow government and academic breeders to explore unadapted varieties—wild relatives of domesticated plants and landraces. This is especially important in the breeding of specialty crops such as fruits and vegetables. Incentives and resources for private breeding of minor crops are limited, especially for genetic diversity enhancement.

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