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Appreciating the Benefits of Plant Biodiversity

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At first glance, wild potatoes are not too impressive. Most are thin-stemmed, rather weedy-looking plants that underground bear disappointingly small tubers. But do not be deceived by initial appearances, for these plants are key allies in humankind's ongoing struggle to control late blight, a kind of fungus that thrives on potato plants. It was late blight that, in the 1840s, colonized and devastated the genetically uniform potato fields of Ireland, triggering the infamous famine that claimed more than a million lives. The disease has been controlled this century largely with fungicides, but in the mid-1980s farmers began reporting outbreaks of fungicide-resistant blight. These newly virulent strains have cut global potato harvests in the 1990s by 15 percent, a $3.25-billion yield loss; in some regions, such as the highlands of Tanzania, losses to blight have approached 100 percent. Fortunately, scientists at the International Potato Center in Lima, Peru, have located genetic resistance to the new blight strains in the gene pools of traditional Andean potato cultivars and their wild relatives, and now see hope for reviving the global potato crop.[1]

Wild potatoes are but one manifestation of the benefits humans gain from biological diversity, the richness and complexity of life on Earth. Plant biodiversity, in particular, is arguably the single greatest resource that humankind has garnered from nature during our long cultural development. Presently, scientists have described more than 250,000 species of mosses, ferns, conifers, and flowering plants, and estimate there may be upwards of 50,000 plant species yet to be documented, primarily in the remote, little-studied reaches of tropical forests.[2]

Within just the hundred-odd species of cultivated plants that supply most of the world's food, traditional farmers have selected and developed hundreds of thousands of distinct genetic varieties. During this century, professional plant breeders have used this rich gene pool to create the high-yielding crop varieties responsible for much of the enormous productivity of modern farming. Plant diversity also provides oils, latexes, gums, fibers, dyes, essences, and other products that clean, clothe, and refresh us and that have many industrial uses. And whether we are in the 20 percent of humankind who open a bottle of pills when we are feeling ill, or in the 80 percent who consult a local herbalist for a healing remedy, a large chunk of our medicines comes from chemical compounds produced by plants.[3]

Yet the more intensively we use plant diversity, the more we threaten its long-term future. The scale of human enterprise on Earth has become so great—we are now nearly 6 billion strong and consume about 40 percent of the planet's annual biological productivity—that we are eroding the very ecological foundations of plant biodiversity and losing unique gene pools, species, and even entire communities of species forever. It is as if humankind is painting a picture of the next millennium with a shrinking palette—the world will still be colored green, but in increasingly uniform and monocultured tones. Of course, our actions have produced benefits: society now grows more food than ever before, and those who can purchase it have a material standard of living unimaginable to earlier generations. But the undeniable price that plant diversity and the ecological health of our planet are paying for these achievements casts a shadow over the future of the development path that countries have pursued this century. To become more than a short-term civilization, we must start by maintaining biological diversity.[4]

Into the Mass Extinction

Extinction is a natural part of evolution, but it is normally a rare and obscure event; the natural or "background" rate of extinction appears to be about 1–10 species a year. By contrast, scientists estimate that extinction rates have accelerated this century to at least 1,000 species per year. These numbers indicate we now live in a time of mass extinction—a global evolutionary upheaval in the diversity and composition of life on Earth.[5]

Paleontologists studying Earth's fossil record have identified five previous mass extinction episodes during life's 1.5 billion years of evolution, with the most recent being about 65 million years ago, at the end of the Cretaceous period, when the dinosaurs disappeared. Earlier mass extinctions hit marine invertebrates and other animal groups hard, but plants weathered these episodes with relatively little trouble. Indeed, flowering plants, which now account for nearly 90 percent of all land plant species, did not begin their diversification until the Cretaceous—relatively recently, in evolutionary terms.[6]

In the current mass extinction, however, plants are suffering unprecedented losses. According to a 1997 global analysis of more than 240,000 plant species coordinated by the World Conservation Union–IUCN, one out of every eight plants surveyed is potentially at risk of extinction. (See Table 6–1.) This tally includes species already endangered or clearly vulnerable to extinction, as well as those that are naturally rare (and thus at risk from ecological disruption) or extremely poorly known. More than 90 percent of these at-risk species are endemic to a single country—that is, found nowhere else in the world.[7]

The United States, Australia, and South Africa have the most plant species at risk (see Table 6–2), but their high standing is partly due to how much better-known their flora is compared with that of other species-rich countries. We have a good idea of how many plants have become endangered as the coastal sage scrub and perennial grasslands of California have been converted into sub-

Table 6–1. Threatened Plant Species, 1997

Status	Total	Share
	(number)	(percent)
Total Number of Species Surveyed	242,013	
Total Number of Threatened Species	33,418	14
Vulnerable to Extinction	7,951	3
In Immediate Danger of Extinction	6,893	3
Naturally Rare	14,505	6
Indeterminate Status	4,070	2
Total Number of Extinct Species	380	<1

SOURCE: Kerry S. Walter and Harriet J. Gillett, eds., *1997 IUCN Red List of Threatened Plants* (Gland, Switzerland: World Conservation Union–IUCN, 1997).

urban homes and cropland, for example. But we simply do not know how many species have dwindled as the cloud forests of Central America have been replaced by coffee plots and cattle pastures, or as the lowland rainforests of Indonesia and Malaysia have become oil palm and pulpwood plantations.

Increasingly, it is not just individual species but entire communities and ecosystems of plants that face extinction. The inter-Andean laurel and oak forests of Colombia, the heathlands of western Australia, the seasonally dry forest of the Pacific island of New Caledonia—all have been largely overrun by humankind. In the southeast corner of Florida in the United States, native plant communities, such as subtropical hardwood hammocks and limestone ridge pinelands, have been reduced to tiny patches in a sea of suburban homes, sugarcane fields, and citrus orchards. These irreplaceable remnants are all that is left of what southeast Florida once was—and they are now held together only with constant human vigilance to beat back a siege of exotic plants, such as Brazilian pepper and Australian casuarina.[8]

Biodiversity is also lost when gene pools within species evaporate. The closest wild ancestor of corn is a lanky, sprawling annual grass called teosinte, native to Mexico and Guatemala, where it occurs in eight separate populations. Botanist Garrison Wilkes of the University of Massachusetts regards seven of these populations as rare, vulnerable, or already endangered—primarily due to the abandonment of traditional agricultural practices and to increased livestock grazing in the field margins and fallow areas favored by teosinte. Overall, teosinte is not yet threatened with extinction. But because

Table 6–2. Top 10 Countries with the Most Threatened Plants

Country	Total	Percentage of Country's Total Flora Threatened
	(number)	
United States	4,669	29
Australia	2,245	14
South Africa	2,215	11.5
Turkey	1,876	22
Mexico	1,593	6
Brazil	1,358	2.5
Panama	1,302	13
India	1,236	8
Spain	985	19.5
Peru	906	5

SOURCE: Kerry S. Walter and Harriet J. Gillett, eds., *1997 IUCN Red List of Threatened Plants* (Gland, Switzerland: World Conservation Union–IUCN, 1997).

the plant hybridizes readily with domesticated corn, every loss of a unique teosinte population reduces genetic diversity that may one day be needed to breed better-adapted corn plants.[9]

Of Food and Farmers

Nowhere is the value of biodiversity more evident than in our food supply. Roughly one third of all plant species have edible fruits, tubers, nuts, seeds, leaves, roots, or stems. During the nine tenths of human history when everyone lived as hunter-gatherers, an average culture would have had knowledge of several hundred edible plant species that could provide sustenance. Today, wild foods continue to supplement the diet of millions of rural poor worldwide, particularly during seasonal periods of food scarcity. Tuareg women in Niger, for instance, regularly harvest desert panic-grass and shama millet while migrating with their animal herds between wet and dry-season pastures. In rural northeast Thailand, wild foods gathered from forests and field margins make up half of all food eaten by villagers during the rainy season. In the city of Iquitos in the Peruvian Amazon, fruits of nearly 60 species of wild trees, shrubs, and vines are sold in the city produce markets. Residents in the surrounding countryside are estimated to obtain a tenth of their entire diet from wild-harvested fruits.[10]

For the last 5–10 millennia, we have actively cultivated the bulk of our food. Agriculture arose independently in many different regions, as people gradually lived closer together, became less nomadic, and focused their food production on plants that were amenable to repeated sowing and harvesting. In the 1920s the legendary Russian plant explorer Nikolai Vavilov identified geographic centers of crop diversity, including Mesoamerica, the central Andes, the Mediterranean Basin, the Near East, highland Ethiopia, and eastern China. He also inferred correctly that most centers correspond to where crops were first domesticated. For instance, native Andean farmers not only brought seven different species of wild potatoes into cultivation, they also domesticated common beans, lima beans, passion fruit, quinoa and amaranths (both grains), and a host of little-known tuber and leaf crops such as *oca*, *ulluco*, and *tarwi*—more than 25 species of food plants in all.[11]

Over the millennia, farmers have developed a wealth of distinctive varieties within crops by selecting and replanting seeds and cuttings from uniquely favorable individual plants—perhaps one that matured slightly sooner than others, was unusually resistant to pests, or possessed a distinctive color or taste. Subsistence farmers have always been acutely attentive to such varietal diversity because it helps them cope with variability in their environment, and for most major crops, farmers have developed thousands of folk varieties, or "landraces." India alone, for instance, probably had at least 30,000 rice landraces earlier this century.[12]

On-farm crop selection remains vital in developing countries, where farmers continue to save 80–90 percent of their own seed supplies. In industrial nations, by contrast, the seed supply process has become increasingly centralized during this century, as professional plant breeders have taken up the job of crop improvement and as corporations have assumed responsibility for supplying seeds. The power and promise of scientifically based plant breeding was confirmed by the 1930s, when the first commercial hybrid corn was marketed by the Pioneer Hi-Bred Company. Hybrids are favored by seed supply companies because they tend to be especially high-yielding (the bottom line for commercial farming) and because "second-generation" hybrid seeds do not retain the traits of their parents. This means that farmers must purchase hybrid seed anew from the supplier rather than saving their own stock. Some farmers have also been legally disenfranchised from seed-saving; under European Union law, it is now illegal for farmers to save and replant seed from plant varieties that have been patented by breeders.[13]

> Traditional crop varieties are indispensable for global food security.

Although farmers can now purchase and plant seeds genetically engineered with the latest molecular techniques, the productivity of our food supply still depends on the plant diversity maintained by wildlands and traditional agricultural practices. Wild relatives of crops continue be used by breeders as sources of disease resistance, vigor, and other traits that produce billions of dollars in benefits to global agriculture. Imagine giving up sugarcane, strawberries, tomatoes, and wine grapes; none of these crops could be grown commercially without the genetic contribution of their respective wild relatives. With the rescue mission of their wild kin now under way, we can also place potatoes on this list.[14]

Traditional crop varieties are equally indispensable for global food security. Subsistence farmers around the world continue to grow primarily either landraces or locally adapted versions of professionally bred seed. Such small-scale agriculture produces 15–20 percent of the world's food supply, is predominantly performed by women, and provides the daily sustenance of roughly 1.4 billion rural poor. Moreover, landraces have contributed the genetic infrastructure of the intensively bred crop varieties that feed the rest of us. More than one third of the U.S. wheat crop owes its productivity to landrace genes from Asia and other regions, a contribution worth at least $500 million annually.[15]

As we enter the next millennium, agricultural biodiversity faces an uncertain future. The availability of wild foods and populations of many wild relatives of crops is declining as wildlands are converted to human-dominated habitats and as hedgerows, fallow fields, and other secondary habitats decline within traditional agricultural landscapes. In the United States, two thirds of all rare and endangered plants are close relatives of cultivated species. If these species go extinct, a pool of potentially crucial future benefits for global agriculture will also vanish.[16]

There is also grave concern for the old crop landraces. By volume, the world's farmers now grow more sorghum, spinach, apples, and other crops than ever before, but they grow fewer varieties of each crop. Crop diversity in industrial nations has undergone a massive turnover this century; the proportion of varieties grown in the United States before 1904 but no longer present in either commercial agriculture or any major seed storage facility ranges from 81 percent for tomatoes to over 90 percent for peas and cabbages. Figures are less comprehensive for developing countries, but China is estimated to have gone from growing 10,000 wheat varieties in 1949 to only 1,000 by the 1970s, while just 20 percent of the corn varieties cultivated in Mexico in the 1930s can still be found there—an alarming decline for the cradle of corn.[17]

Crop varieties are lost for many reasons. Sometimes an extended drought destroys harvests and farmers must consume their planting seed stocks just to survive. Long-term climate change can also be a problem. In Senegal, two decades of below-normal rainfall created a growing season too short for traditional rice varieties to produce good yields. When fast-maturing rice cultivars became available through development aid programs, women farmers rapidly adopted them because of the greater harvest security they offered.[18]

In the majority of cases, however, farmers voluntarily abandon traditional seeds when they adopt new varieties, change agricultural practices, or move out of farming altogether. In industrial countries, crop diversity has declined in concert with the steady commercialization and consolidation of agriculture this century: fewer family farmers, and fewer seed companies offering fewer varieties for sale, mean fewer crop varieties planted in fields or saved after harvest. The seed supply industry is now dominated by multinational corporations; increasingly, the same companies that sell fertilizers and pesticides to farmers now also promote seeds bred to use those products.[19]

In most developing countries, diversity losses were minimal until the 1960s, when the famed international agricultural development program known as the Green Revolution introduced new high-yielding varieties of wheat, rice, corn, and other major crops. Developed to boost food self-sufficiency in famine-prone countries, the Green Revolution varieties were widely distributed, often with government subsidies to encourage their adoption, and displaced landraces from many prime farmland areas.[20]

In areas where agriculture is highly mechanized and commercialized, crops now exhibit what the U.N. Food and Agriculture Organization (FAO) politely calls an "impressively uniform" genetic base. A survey of nine major crops in the Netherlands found that the three most popular varieties for each crop covered 81–99 percent of the respective areas planted. Such patterns have also emerged on much of the developing world's prime farmland. One single wheat variety blanketed 67 percent of Bangladesh's wheat acreage in 1983 and 30 percent of India's the following year.[21]

The ecological risks we take in adopting such genetic uniformity are enormous, and keeping them at bay requires an extensive infrastructure of agricultural scientists and extension workers—as well as all too frequent applications of pesticides and other potent agrochemicals. A particularly heavy burden falls on professional plant breeders, who are now engaged in a relay race to develop ever more robust crop varieties before those already in monoculture succumb to evolving pests and diseases, or to changing environmental conditions.[22]

Breeders started this race earlier this century with a tremendous genetic endowment at their disposal, courtesy of nature and generations of subsistence farmers. Despite major losses, this wellspring is still far from empty—estimates are that plant breeders have used only a small fraction of the varietal diversity present in crop gene banks (facilities that store seeds under cold, dry conditions that can maintain seed viability for decades). At the same time, we can never be sure that what is already stored will cover all our future needs. When grassy stunt virus began attacking high-yielding Asian rices in the 1970s, breeders located genetic resistance to the disease in only a single collection of one population of a wild rice species in Uttar Pradesh, India—and that population has never been found again since. Conserving and reinvigorating biodiversity in agricultural landscapes remains essential for achieving global food security.[23]

Of Medicines and Material Goods

In a doctor's office in Germany, a man diagnosed with hypertension is prescribed reserpine, a drug from the Asian snakeroot plant. In a small town in India, a woman complaining of stomach pains visits an

Ayurvedic healer, and receives a soothing and effective herbal tea as part of her treatment. In a California suburb, a headache sufferer unseals a bottle of aspirin, a compound originally isolated from European willow trees and meadow herbs.[24]

People everywhere rely on plants for staying healthy and extending the quality and length of their lives. One quarter of the prescription drugs marketed in North America and Europe contain active ingredients derived from plants. Plant-based drugs are part of standard medical procedures for treating heart conditions, childhood leukemia, lymphatic cancer, glaucoma, and many other serious illnesses. Worldwide, the over-the-counter value of these drugs is estimated at more than $40 billion annually. Major pharmaceutical companies and institutions such as the U.S. National Cancer Institute implement plant screening programs as a primary means of identifying new drugs.[25]

The World Health Organization estimates that 3.5 billion people in developing countries rely on plant-based medicine for their primary health care. Ayurvedic and other traditional healers in South Asia use at least 1,800 different plant species in treatments and are regularly consulted by some 800 million people. In China, where medicinal plant use goes back at least four millennia, healers employ more than 5,000 plant species. At least 89 plant-derived commercial drugs used in industrial countries were originally discovered by folk healers, many of whom are women. Traditional medicine is particularly important for poor and rural residents, who typically are not well served by formal health care systems. Recent evidence suggests that when economic woes and structural adjustment programs restrict governments' abilities to provide health care, urban and even middle-class residents of developing countries also turn to more affordable traditional medicinal experts.[26]

Traditional herbal therapies are growing rapidly in popularity in industrial countries as well. FAO estimates that between 4,000 and 6,000 species of medicinal plants are traded internationally, with China accounting for about 30 percent of all such exports. In 1992, the booming U.S. retail market for herbal medicines reached nearly $1.5 billion, and the European market is even larger.[27]

Despite their demonstrable value, medicinal plants are declining in many areas. Human alteration of forests and other habitats all too often eliminates sites rich in wild medicinal plants. This creates an immediate problem for folk healers when they can no longer find the plants they need for performing certain cures—a problem commonly lamented by indigenous herbalists in eastern Panama, among others. Moreover, strong consumer demand and inadequate oversight of harvesting levels and practices mean that wild-gathered medicinal plants are commonly overexploited.[28]

In Cameroon, for example, the bark of the African cherry is highly esteemed by traditional healers, but most of the country's harvest is exported to Western Europe, where African cherry is a principal treatment for prostate disorders. In recent years Cameroon has been the leading supplier of African cherry bark to international markets, but clearance of the tree's montane forest habitat, combined with the inability of the government forestry department to manage the harvest, has led to widespread, wanton destruction of cherry stands.[29]

In addition to the immediate losses, every dismantling of a unique habitat represents a loss of future drugs and medicines, particularly in species-rich habitats like tropical forests. Fewer than 1 percent of all plant species have been screened by chemists to see what bioactive compounds they may contain. The nearly 50 drugs already derived from tropical rainforest plants are estimated to represent only 12 percent of the medically useful compounds waiting to be discovered in rainforests.[30]

Most tragically of all, many rural societies are rapidly losing their cultural knowledge about medicinal plants. In communities undergoing accelerated westernization, fewer young people are interested in learning about traditional healing plants and how to use them. From Samoa to Suriname, most herbalists and healers are elderly, and few have apprentices studying to take their place. Ironically, as this decline has accelerated, there has been a resurgent interest in ethnobotany—the study of how people classify, conceptualize, and use plants—and other fields of study related to traditional medicinal plant use. Professional ethnobotanists surveying medicinal plants used by different cultures are racing against time to document traditional knowledge before it vanishes with its last elderly practitioners.[31]

For the one quarter of humanity who live at or near subsistence levels, plant diversity offers more than just food security and health care—it also provides a roof over their heads, cooks their food, provides eating utensils, and on average meets about 90 percent of their material needs. Consider palms: temperate zone dwellers may think of palm trees primarily as providing an occasional coconut or the backdrop to an idyllic island vacation, but tropical peoples have a different perspective. The babassu palm from the eastern Amazon Basin has more than 35 different uses—construction material, oil and fiber source, game attractant, even as an insect repellent. Commercial extraction of babassu products is a part or full-time economic activity for more than 2 million rural Brazilians.[32]

Indigenous peoples throughout tropical America have been referred to as "palm cultures." The posts, floors, walls, and beams of their houses are made from the wood of palm trunks, while the roofs are thatched with palm leaves. They use baskets and sacks woven from palm leaves to store household items, including food—which may itself be palm fruits, palm hearts (the young growing shoot of the plant), or wild game hunted with weapons made from palm stems and leaves. At night, family members will likely drift off to sleep in hammocks woven from palm fibers. When people die, they may be buried in a coffin carved from a palm trunk.[33]

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Palms are exceptionally versatile, but they are only part of the spectrum of useful plants in biodiverse environments. In northwest Ecuador, indigenous cultures that practice shifting agriculture use more than 900 plant species to meet their material, medicinal, and food needs; halfway around the world, Dusun and Iban communities in the rainforests of central Borneo use a similar total of plants in their daily lives. People who are more integrated into regional and national economies tend to use fewer plants, but still commonly depend on plant diversity for household uses and to generate cash income. In India, at least 5.7 million people make a living harvesting nontimber forest products, a trade that accounts for nearly half the revenues earned by Indian state forests.[34]

Those of us who live in manicured suburbs or urban concrete jungles may meet more of our material needs with metals and plastics, but plant diversity still enriches our lives. Artisans who craft musical instruments or furniture, for instance, value the unique acoustic qualities and appearances of the different tropical and temperate hardwoods that they work with—aspects of biodiversity that ultimately benefit anyone who listens to classical music or purchases handcrafted furniture. Among the nonfood plants traded internationally on commercial levels are at least 200 species of timber trees, 42 plants producing essential oils, 66 species yielding latexes or gums, and 13 species used as dyes and colorants.[35]

As with medicinals, the value that plant resources have for handicraft production, industrial use, or household needs has often not prevented their local or regional decline. One of the most valuable nontimber forest products is rattan, a flexible cane obtained from a number of species of vine-like palms that can grow up to 185 meters long. Asian rattan palms support an international furniture-making industry worth $3.5–6.5 billion annually. Unfortunately, rattan stocks are declining throughout much of tropical Asia because of the loss of native rainforest and overharvesting. In the past few years, some Asian furniture makers have even begun importing rattan supplies from Nigeria and other central African countries.[36]

On a global level, declines of wild plants related to industrial crops such as cotton or plantation-grown timber could one day limit our ability to cultivate those commodities by shrinking the gene pools needed for breeding new crops. More locally, declines of materially useful species mean life gets harder and tougher in the short term. When a tree species favored for firewood is overharvested, women must walk longer to collect their family's fuel supply, make due with an inferior species that does not burn as well, or spend scarce money purchasing fuel from vendors. When a fiber plant collected for sale to handicraft producers becomes scarce, it is harder for collectors to earn an income that could help pay school fees for their children. Whether we are rich or poor, biodiversity enhances the quality of our lives—and many people already feel its loss.

Bio-Uniformity Rising

The cumulative effects of human activities on Earth are evident not just in declines in particular species, but in the increasingly tattered state of entire ecosystems and landscapes—and when large-scale ecological processes begin to break down, conservation and management become all the more complicated. Take the problem of habitat fragmentation, when undisturbed wildlands are reduced to patchwork, island-like remnants of their former selves. Natural islands in oceans or large lakes tend to be impoverished in species; their smaller area means they usually do not develop the ecological complexity and diversity characteristic of more extensive mainland areas. Moreover, when an island population of a species is eradicated, it is harder for adjacent mainland populations to recolonize and replace it.[37]

As a result, when development—large-scale agriculture, settlements, roads—sprawls across landscapes, remaining habitat fragments usually behave like the islands they have become: they lose species. In western Ecuador, the Río Palenque Science Center protects a square-kilometer remnant of the lowland rainforest that covered the region a mere three decades ago; now the center is an island amid cattle pasture and oil palm plantations. Twenty-four species of orchids, bromeliads, and other plants at Río Palenque have already succumbed to the "island effect" and can no longer be found there. One vanished species, an understory shrub, has never been recorded anywhere else and is presumed extinct.[38]

Even with these drawbacks, small areas of native habitat can have enormous conservation value when they are all that is left of a unique plant community or rare habitat. But waiting to protect them until only patches remain carries an unmistakable tradeoff: smaller holdings require more-intensive management than larger ones. In smaller reserves, managers often must simulate natural disturbances (such as prescribed burns to maintain fire-adapted vegetation); provide pollination, seed dispersal, and pest control services in place of vanished animals; reintroduce desirable native species when they disappear from a site (perhaps due to a series of poor breeding seasons); and perform other duties the original ecosystem once did free of charge. Governments and societies that are unwilling or unable to shoulder these management costs will soon find that the biodiversity they intended to protect with nature reserves has vanished from within them.[39]

Invasive species that crowd out native flora and fauna are one of the biggest headaches for managing biodiversity in disturbed landscapes. In certain susceptible habitats, such as oceanic islands and subtropical heathlands, controlling invasives may be the single biggest management challenge. South Africa has one of the largest invasive species problems of any nation, and has a great deal at stake: the fynbos heathlands and montane forest of the country's Cape region hold more plant species—8,600, most of them endemic—in a smaller area than anywhere else on Earth. Fortunately, South Africans are increasingly aware of the threat that exotics pose, and in 1996 the government initiated a program to fight invasives with handsaw and hoe. Some 40,000 people are employed to cut and clear Australian eucalypts, Central American pines, and other unwanted guests in natural areas. It is a measure of the scale and severity of the invasive problem that this effort is South Africa's single largest public works program.[40]

Large-scale ecological alterations also have great potential to combine their effects in unpredictable and damaging ways. For instance, much of the world is now saturated in nitrogen compounds (an essential element required by all plants for growth and development) because of our overuse of nitrogen-based synthetic fertilizers and fossil fuels. Studies of North American prairies found that the plants that responded best to excess nitrogen tended to be weedy invasives, not the diverse native prairie flora. Likewise, plant and animal species already pressed for survival in fragmented landscapes may also have to contend with altered rainfall patterns, temperature ranges, seasonal timing, and other effects of global climate change.[41]

Scientists are already detecting what could be the first fingerprints of an altered global atmosphere on plant communities.

Already, scientists are detecting what could be the first fingerprints of an altered global atmosphere on plant communities. Data from tropical forest research plots worldwide indicate that the rate at which rainforest trees die and replace each other, called the turnover rate, has increased steadily since the 1950s. This suggests that the forests under study are becoming "younger," increasingly dominated by faster-growing, shorter-lived trees and woody vines—exactly the kinds of plants expected to thrive in a carbon dioxide–rich world with more extreme weather events. Without major reductions in global carbon emissions, forest turnover rates will likely rise further, and over time could push to extinction many slower-growing tropical hardwood tree species that cannot compete in a carbon-enriched environment.[42]

Global trends are shaping a botanical world that is most striking in its greater uniformity. The richly textured mix of native plant communities that evolved over thousands of years is increasingly frayed, replaced by extensive areas under intensive cultivation or heavy grazing, lands devoted to settlements or industrial activities, and secondary habitats—partially disturbed areas dominated by shorter-lived, "weedy," often non-native species. A 1994 mapping study by the organization Conservation International estimated that nearly three quarters of our planet's habitable land surface (that which is not bare rock, drifting sand, or ice) already is either partially or heavily disturbed. Moreover, within human-dominated landscapes, relatively diverse patchworks of small-scale cultivation, fallow fields, seasonal grazing areas, and managed native vegetation are being replaced by large, uniform fields or by extensive denuded and degraded areas.[43]

The mixtures of species in different regions are becoming more similar as well. Lists of endangered plants are dominated by endemic species—those native to a relatively restricted area such as a country or state, an isolated mountain range, or a specific soil type. When endemic plants vanish, the remaining species pool becomes more uniform. Finally, the spectrum of distinct populations and varieties within plant species is shrinking, a problem most advanced in our endowment of domesticated plants.[44]

Countries that emerged in a world filled with biodiversity now must gain and maintain prosperity amid increasing biouniformity. We are conducting an unprecedented experiment with the security and stability of our food supply, our health care systems, and the ecological infrastructure upon which both rest. To obtain the results we desire, we must conserve and protect the plant biodiversity that remains with us, and manage our use of natural systems in ways that restore biodiversity to landscapes worldwide.

Stored for Safekeeping

Broad recognition of the need to safeguard plant resources is largely a twentieth century phenomenon. The first warnings about the global erosion of plant diversity were voiced in the 1920s by scientists such as Harry Harlan of the United States and Nikolai Vavilov, who realized the threat posed by farmers' abandonment of landraces in favor of newer varieties that were spreading widely in an increasingly interconnected world.[45]

The dominant approach to conserving plant varieties and species has involved removing them from their native habitat or agricultural setting and protecting them at specialized institutions such as botanical gardens, nurseries, and gene banks. Most off-site collections of wild species and ornamental plants are in the custody of the world's 1,600 botanical gardens. Combined, they tend representatives of tens of thousands of plant species—nearly 25 percent of the world's flowering plants and ferns, by one estimate.[46]

Most botanical gardens active today were established by European colonial powers to introduce economically important and ornamental plants throughout the far-flung reaches of empires, and to promote the study of potentially useful plants. Nowadays many botanical gardens have reoriented their mission toward species preservation, particularly in their research and education programs. Since the late 1980s, botanical gardens have coordinated efforts through an international conservation network, which helps ensure that the rarest plants receive priority for propagation and, ultimately, reintroduction.[47]

Gene banks have focused almost exclusively on storing seeds of crop varieties and their immediate wild relatives. (The principal exception is the Royal Botanic Garden's Millennium Seed Bank in

England, which holds more than 4,000 wild species and is expanding toward a collection of one quarter of the world's flora.) Gene banks arose from plant breeders' need to have readily accessible stocks of breeding material. Their conservation role came to the forefront in the 1970s, following large losses linked to genetic uniformity in the southern U.S. corn crop in 1970 and the Soviet winter wheat crop of 1971–72.[48]

In 1974, governments and the United Nations established the International Board for Plant Genetic Resources (now known as the International Plant Genetic Resources Institute, or IPGRI), which cobbled together a global network of gene banks. The network includes university breeding programs, government seed storage units, and the Consultative Group on International Agricultural Research (CGIAR), a worldwide network of 16 agricultural research centers originally established to bring the Green Revolution to developing countries, and funded primarily by the World Bank and international aid agencies.[49]

The number of unique seed samples or "accessions" in gene banks now exceeds 6 million. The largest chunk of these, more than 500,000 accessions, are in the gene banks of CGIAR centers such as the International Rice Research Institute in the Philippines and the International Wheat and Maize Improvement Center (CIMMYT) in Mexico. At least 90 percent of all gene bank accessions are of food and commodity plants, especially the world's most intensively bred and economically valuable crops. (See Table 6–3.) By the late 1980s, IPGRI regarded a number of these crops, such as wheat and corn, as essentially completely collected; that is, nearly all of the known landraces and varieties of the crop are already represented in gene banks. Others have questioned this assessment, however, arguing that the lack of quantitative studies of crop gene pools makes it difficult to ascertain whether even the best-studied crops have been adequately sampled.[50]

Table 6–3. Gene Bank Collections for Selected Crops

Crop	Accessions in Gene Banks	Estimated Share of Landraces Collected
	(number)	(percent)
Wheat	850,000	90
Rice	420,000	90
Corn	262,000	95
Sorghum	168,500	80
Soybeans	176,000	70
Common Beans	268,500	50
Potatoes	31,000	80–90
Cassava	28,000	35
Tomatoes	77,500	90
Squashes, Cucumbers, Gourds	30,000	50
Onions, Garlic	25,000	70
Sugarcane	27,500	70
Cotton	48,500	75

SOURCE: Donald L. Plucknett et al., *Gene Banks and the World's Food* (Princeton, NJ: Princeton University Press, 1987); Brian D. Wright, *Crop Genetic Resource Policy: Toward A Research Agenda*, EPTD Discussion Paper 19 (Washington, DC: International Food Policy Research Institute, 1996); U.N. Food and Agriculture Organization, *The State of the World's Plant Genetic Resources for Food and Agriculture* (Rome: 1996).

There are additional reasons for interpreting gene bank totals conservatively. The total annual cost of maintaining all accessions currently in gene banks is about $300 million, and many facilities, hard-pressed for operating funds, cannot maintain seeds under optimal physical conditions. Seeds that are improperly dried or kept at room temperature rather than in cold storage may begin to lose viability within a few years. At this point, they must be "grown out"—germinated, planted, raised to maturity, and then reharvested, which is a time-consuming and labor-intensive activity when repeated for thousands of accessions per year. These problems suggest that an unknown fraction of accessions is probably of questionable viability.[51]

Only 13 percent of gene-banked seeds are in well-run facilities with long-term storage capability—and even the crown jewels of the system, such as the U.S. National Seed Storage Laboratory, have at times had problems maintaining seed viability rates. For extensively gene-banked crops (primarily major grains and legumes) where large collections are duplicated in different facilities, the odds of losing the diversity already on deposit are reduced. But for sparsely collected crops whose accessions are stored at just one or two sites, the possibility of genetic erosion remains disquietingly high.[52]

Despite such drawbacks, off-site facilities remain indispensable for conservation. In some cases, botanical gardens and gene banks have rescued species whose wild populations are now gone. They can also help return diversity to its proper home through reintroduction programs. Although the uplands of East Africa are not the center of domestication for common beans, the farmers of the region adopted them as their own several centuries ago, and have developed the world's richest mix of local bean varieties. When Rwanda was overwhelmed by civil conflict in 1994, the height of the genocidal violence occurred during the February-to-June growing season, greatly reducing harvests and raising the prospect of widespread famine. Amid the relief contributions that flowed into the country once the situation had stabilized were stocks of at least 170 bean varieties that had been previously collected in Rwanda and stored in gene banks worldwide. These supplies helped ensure that Rwandan farmers had stocks of high-quality, locally adapted beans for planting in the subsequent growing season.[53]

Still, even the most enthusiastic boosters of botanical gardens and gene banks recognize that such facilities, even when impeccably maintained, provide only one piece in the conservation puzzle. Off-site storage takes species out of their natural ecological settings. Wild tomato seeds can be sealed in a glass jar and frozen for safekeeping, but left out of the cold are the plant's pollinators, its dispersers, and all the other organisms and relationships that have shaped the plant's unique evolution. Gene banks and botanical gardens only save a narrow—albeit valuable—slice of plant diversity. When stored seeds are grown out over several generations off-site, in time they can even lose their native adaptations and evolve to fit instead the conditions of their captivity.[54]

Keeping Diversity in Place

In the end, plant diversity can be securely maintained only by protecting the native habitats and ecosystems where plants have evolved. Countries have safeguarded wildlands primarily through establishing national parks, forest reserves, and other formally protected areas. During this century, governments have steadily increased protected area networks, and they now encompass nearly 12 million square kilometers, or about 8 percent of the Earth's land surface. Many protected areas guard irreplaceable botanical resources, such as Malaysia's Mount Kinabalu National Park, which safeguards the unique vegetation of southeast Asia's highest peak. A few reserves have been established specifically to protect useful plants, such as the Sierra de Manantlan biosphere reserve in Mexico, which encompasses the only known populations of perennial wild corn.[55]

Yet current protected area networks also have major limitations. Many highly diverse plant communities, such as tropical deciduous forests, are greatly under-protected. In addition, many protected areas officially decreed on paper are minimally implemented by chronically underfunded and understaffed natural resource agencies. But perhaps the most fundamental limitation of national parks, wilderness areas, and similarly strict designations arises when they conflict with the cultural and economic importance that plants hold for local communities.[56]

A great deal of the natural wealth that conservationists have sought to protect is actually on lands and under waters long managed by local people. Indigenous societies worldwide have traditionally protected prominent landscape features like mountains or forests, designating them as sacred sites and ceremonial centers. In parts of West Africa, sacred groves hold some of the last remaining populations of important medicinal plants. On Samoa and other Pacific islands, communities manage forests to produce wild foods and medicines, raw materials for canoes and household goods, and other benefits.[57]

Not surprisingly, actions such as evicting long-term residents from newly designated forest reserves, or denying them access to previously harvested plant stands, have generated a great deal of ill will toward protected areas worldwide. Fortunately, workable alternatives are emerging in a number of cases where long-term residents have been made equal partners in managing protected lands. In the Indian state of West Bengal, 320,000 hectares of semi-deciduous sal forest is managed jointly by villagers and the state forestry department, with villagers taking primary responsibility for patrolling nearby forest stands. Since joint management began in 1972, the status of the sal forests has improved, and regenerating stands now provide villagers with medicines, firewood, and wild-gathered foodstuffs. Medicinals also feature prominently in a 4,000-hectare rainforest reserve in Belize, which is government-owned but managed by the Belize Association of Traditional Healers.[58]

Such collaboration between locals and professional resource managers is also crucial to reversing the overexploitation of valuable wild plants. Very few commercially marketed wild species are harvested sustainably, in ways or at levels that do not degrade the plant resource. Despite the lack of progress, however, the foundations of sustainability are becoming increasingly clear. Secure and enforceable tenure is essential—either in the form of rights to harvest a plant or tenure over the land it grows on. Harvesters also need enough economic security to be able to afford the tradeoffs involved in not harvesting everything at once. Access to fair and open markets is important, as is having technology appropriate for the harvesting task. Information about the ecology and productivity of a plant can make a big difference. Consumers willing to pay a premium for well-harvested products also help—like those generated through certification programs for “environmentally friendly” products.[59]

Few wild harvests meet all these criteria, but a growing number of initiatives are coming close. In Mexico, ancient cone-bearing plants called cycads have been heavily exploited for their ornamental value, both for sale domestically and for horticultural export to the United States, Japan, and Europe. Most cycads are wild-harvested by uprooting or cutting, but a botanical garden in the state of Veracruz is working with local villagers to reduce pressures on several overexploited species. In one community, Monte Oscuro, residents set aside a communal plot of dry forest to protect a relict population of cycads in exchange for help with building a community plant nursery. Seeds are collected from the wild plants, then germinated and tended in the nursery by villagers who have received training in basic cycad propagation. Some of the young cycads are returned to the forest to offset any potential downturn in the wild population from the seed harvest. The rest are sold and the profits deposited in a community fund.[60]

Presently the largest hurdle is finding good markets for the young plants the communities are producing; cycads are slow-growing, and horticultural buyers prefer larger plants. Better monitoring and enforcement of the international ornamental plant trade would help, for Mexican cycad species are listed with the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) of 1973, which provides a powerful legal tool for controlling international trade in threatened plants and animals. CITES is generally regarded as one of the more effective international environmental treaties. It prohibits trade in the most highly endangered species (listed in the Treaty's Appendix I), and keeps watch on vulnerable species (listed in Appendix II) by requiring that countries issue a limited number of permits for the species' export and import between signatory countries. Although CITES provides powerful tools for enforcing sustainable harvests, it is still up to the countries involved to use them.[61]

In some rural communities in Zimbabwe, villagers contribute seeds annually to a community seed stock.

Combining local and international strengths also is crucial for sustaining the genetic diversity of our food supply. What is needed most is agricultural development that strengthens rather than simplifies plant diversity to meet the needs and goals of farmers—especially subsistence farmers in developing countries who still maintain diverse agricultural landscapes.

Meeting this challenge requires understanding the particular cultural, economic, and technological reasons why farmers maintain elements of traditional farming, such as unique crop variety mixtures. For instance, native Hopi communities in the southwest United States maintain indigenous corn and lima bean varieties because the germinating seeds are indispensable for religious ceremonies. Mende farmers in Sierra Leone continue to grow native red-hulled African rice for the same reason. Andean peasant farmers still grow pink and purple potatoes, big-seed corn, quinoa, and other traditional crops because that is what they themselves prefer to eat; the commercial varieties they grow are strictly to sell for cash income.[62]

One option to help farmers maintain crop diversity could involve supporting farmers' informal networks of seed exchange and procurement, so as to improve their access to diverse seed sources. In some rural communities in Zimbabwe, villagers contribute seeds annually to a community seed stock. At the start of the planting season, the seeds are redistributed to all community members, a step that gives villagers access to the full range of varietal diversity present in the immediate vicinity and ensures that no one goes without seeds for planting. Grassroots organizations in Ethiopia, Peru, Tonga, and many other countries have sponsored community seed banks, regional agricultural fairs, seed collection tours, demonstration gardens, and similar projects to promote informal seed exchange between farmers, increase their access to crop diversity, and help them replenish seed stocks after poor harvests.[63]

Another approach to maintaining varietal diversity involves reorienting formal plant breeding toward the local needs of farmers. Typically plant breeders create uniform, widely adaptable "pure-bred" varietal lines, and only toward the end of the process are the lines evaluated with farmers. Participatory plant breeding methods involve farmers at all stages. In the most advanced programs, breeders and farming communities work together over several crop generations to evaluate, select, combine, and improve a wide range of varieties, both those available locally and those from other regions. In this way, participatory plant breeding can improve the suite of locally preferred varieties without resorting to varietal uniformity; this approach maintains—or potentially even enhances—the genetic diversity present in farmers' fields.[64]

Participatory plant breeding has been pioneered primarily by grassroots development organizations and innovative national plant breeding programs in developing countries; it has not been taken up by commercial seed producers, perhaps because its benefits tend to be diffuse and not easily appropriated for commercial gain. The CGIAR centers are exploring participatory approaches, but also remain heavily involved in standard breeding programs. For instance, the corn and wheat center CIMMYT recently collaborated with university breeders and seed companies to develop better-yielding corn varieties targeted for highland Mexico—areas where corn landraces continue to be grown by small-scale farmers under diverse environmental conditions. In doing so, CIMMYT chose to focus on hybrid corn varieties. If well tailored to the environmental and economic constraints facing highland Mexican farmers, the new hybrids could boost crop yields—but farmers will be unable to save their seeds and adapt them further to local conditions. The seed companies involved will surely benefit, but past experience suggests that local plant biodiversity may pay the price.[65]

As this last example shows, the most fundamental changes to be made in protecting crop genetic diversity—and plant biodiversity in general—involve changing policies. Governments are often biased toward promoting intensive agriculture dependent on high inputs and genetically uniform crops. Farmers in most southern African countries, for instance, are only eligible for government agricultural credit programs if they agree to plant modern improved varieties. International development aid and structural adjustment policies commonly promote nontraditional export crops, which can trigger habitat conversion (erasing wild plant diversity) and replace indigenous crop mixtures. Until fundamental policy changes are taken to heart by governments, international lenders, and related institutions, the path to sustaining plant biodiversity—wild or domesticated—will remain difficult.[66]

Sharing the Benefits

Governments can begin to chart a new course by resolving the most prominent policy issue affecting plant diversity today: how to distribute biodiversity's economic benefits fairly and equitably. Establishing a system of intellectual property rights to plant resources has proved contentious because of a simple pattern—plant diversity (both wild and cultivated) is held mostly by developing countries, but the economic benefits it generates are disproportionately captured by industrial nations. For most of this century, plant diversity has been treated as the "common heritage" of humankind, freely available to anyone who can use it, with proprietary ownership only granted via patent law to individuals who demonstrate trade secrets or uniquely improve a crop variety or other plant.[67]

Since the early 1980s, however, there has been widening agreement that indigenous people and traditional farmers deserve compensation for their longstanding generation, management, and knowledge of biodiversity. Grassroots advocates argue that indigenous people deserve "traditional resource rights" to the plants they cultivate and know how to use, rights that would have the same international legal standing as that afforded to patent rights. Recognition of such rights requires, at a minimum, negotiating equitable benefit-sharing agreements at the community level whenever plants or indigenous knowledge about them is collected by researchers. An additional way to acknowledge the world's debt to rural communities who safeguard plant biodiversity would be to establish an international fund supporting continued local management of plant resources. Such a step appears the most practical means of compensation for the large amount of plant biodiversity that is already in the public domain (such as the millions of seed accessions in gene banks or plants widely used as herbal medicines), since establishing exactly who deserves compensation for commercial innovations from these plant resources is a Herculean task.[68]

To date, formal agreements for sharing the benefits of plant diversity have been negotiated most extensively in the search for new pharmaceuticals from plants in biodiversity-rich developing countries. The first such "bioprospecting" agreement was announced in 1991 between Merck Pharmaceuticals and Costa Rica's nongovernmental National Institute of Biodiversity (InBio), in which Merck paid InBio $1.1 million for access to plant and insect samples, and promised to share an undisclosed percentage of royalties from any commercial products that resulted.[69]

There are now at least a dozen bioprospecting agreements in place worldwide, involving national governments, indigenous communities, conservation groups, start-up companies, and established corporate giants. Most legitimate agreements have followed the Merck-InBio model, with a modest up-front payment and a promise to return between one quarter of 1 percent and 3 percent (depending on the project) of any future royalties to the biodiversity holders. Bioprospecting proponents argue that with the huge cost ($200–350 million) of bringing a new drug to market, companies cannot afford to share a higher percentage of royalties. Critics, however, suspect many bilateral bioprospecting agreements are not negotiated on an even footing; when a biotechnology firm approached the U.S. government about prospecting for unique microbes inhabiting the geysers and hot springs of Yellowstone National Park, for instance, the Park Service negotiated a royalty share of 10 percent. Moreover, not all bioprospecting agreements automatically uphold traditional resource rights; many have been negotiated on a national rather than community level, involving governments who many indigenous people think do not adequately represent—indeed, sometimes actively undermine—their interests.[70]

In contrast with bioprospecting, resolving who owns the world's crop genetic resources is being negotiated multilaterally, in factious diplomatic arenas. In 1989 FAO adopted a Farmers' Rights proposal that would compensate farmers for their contribution to biodiversity via an international trust fund to support the conservation of plant genetic resources. The 1992 Convention on Biological Diversity also called for incorporating Farmers' Rights, subsequent to further international negotiations. There has been no official endorsement of this concept, however, from the industrial nations who would provide the compensation, and the fund has remained unimplemented. During the most recent round of international negotiations, in June 1998, the European Union appeared ready to support Farmers' Rights, but Australian, U.S., and Canadian diplomats continued to stonewall the issue.[71]

Meanwhile, the intellectual property agenda of industrial countries is being advanced by the World Trade Organization (WTO). All countries acceding to the General Agreement on Tariffs and

Trades are required to establish a system for protecting breeders' rights through plant variety patents. They can either adopt the system of administering patents and breeders' rights followed by industrial nations under the International Union for the Protection of New Varieties of Plants (UPOV), or instead design their own unique system. The UPOV Convention was established in 1978 and substantially revised in 1991; initially it gave farmers the right to save commercial seed for their own use, but the 1991 version allowed signatory countries to revoke this right. Some countries, including India, are looking at structuring their own plant patent systems to also acknowledge farmers' rights, but it is unclear whether the WTO will approve such arrangements.[72]

Despite the foot-dragging in international arenas, de facto boundaries are emerging for what will and will not be tolerated in the expropriation of crop genetic resources. In May 1997, two Australian agricultural centers applied for proprietary breeders' rights on two varieties of chickpeas. Their application sparked an international uproar because the Australian breeders had obtained both varieties from a CGIAR gene bank, which had provided the seeds with the understanding they were to be used for research and not for direct financial gain. Moreover, the Australians did little breeding to improve the two chickpeas, one of which was a landrace widely grown by Indian farmers, and they even appeared to be laying the groundwork to market the chickpeas in India and Pakistan. Ultimately, the Australian government bowed to international pressure and rejected the patent application. The CGIAR subsequently called for a moratorium on all claims for proprietary breeding rights involving germplasm held in trust by CGIAR or FAO-sponsored gene banks.[73]

While blatant gene grabs like that of the Australians may now be beyond the international pale, the current situation remains far from ideal. The lack of a clear, multilateral system of intellectual property rights for plant genetic resources distracts governments from the task of conserving these resources for future generations. The right of subsistence farmers to save and adapt the seeds they plant—arguably the most important mechanism for sustaining crop genetic diversity in fields—still has not been recognized by many governments. Without clear ground rules established, institutions and industries that depend directly on biodiversity for their well-being have little incentive to invest in strategies to help sustain plant diversity in the fields and wildlands where it originates. All countries must redouble their efforts to surmount the political logjam over plant genetic resources, for continued delay puts biodiversity at risk, and ultimately serves no one's interest.[74]

The right of subsistence farmers to save and adapt the seeds they plant still has not been recognized by many governments.

For all of human history, we have depended on plants and the rest of biodiversity for our soul and subsistence. Now the roles are reversed, and biodiversity's fate depends squarely on how we shape our own future. From reducing overexploitation of wild plants to establishing traditional resource rights for biodiversity stewards, many options are available for developing cultural links that support plant diversity rather than diminish it. Such steps are not just about meeting international treaty obligations or establishing new protected areas, but rather are part of a larger process of shaping ecologically literate civil societies that are in balance with the natural world. To maintain biodiversity's benefits, what matters most is how well we meet the challenges of living sustainably with our deeds as well as our words.

Notes

Chapter 6. Appreciating the Benefits of Plant Biodiversity

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