Conserving the Wild Relatives of Crops

by

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IBPGR-IUCN-WWF

[redacted]

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Illustrations by Susanah Brown

IBPGR
International Board for Plant Genetic Resources

IUCN
International Union for Conservation of Nature and Natural Resources

WWF
World Wide Fund For Nature

The colorful sunflower owes much of its success as the world's second most important oil crop to genes from its wild relatives.

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About this booklet

The conservation of crop genetic resources—the plants that feed us and their wild relatives—is one of the most important issues for humankind today. We live in a world in which vast population increases are predicted for the remainder of this century and beyond. Also, major changes in climate may disturb our habitat and force us to modify our agriculture. It is essential for our survival that enough effort be put into conserving genetic resources and making them available for breeding programs to produce the new and improved crops of the future on which we will rely.

Despite the promise of biotechnology, for the foreseeable future plant breeders will depend on conventional germplasm for the development of new, highly specialized cultivars of crop plants. The wild relatives of crops provide an important source of this germplasm. Yet the conservation of these wild relatives is a complex and technically difficult task—one hitherto neglected by agronomists and breeders. Conservationists have not fully appreciated the need to safeguard a wide range of variation within each species, variation that is crucial for crop improvement.

The purpose of this booklet is to increase public awareness of these issues by providing a clear and balanced account of why conservation of crop relatives is important, how it can be effected and what actions need to be taken.

One point we want to stress is that both conservation in nature (*in situ*) and off site (*ex situ*) are needed: the two approaches complement each other and the distinction drawn between them is often over-emphasized. It is not realistic to expect that crop wild relatives and their component populations can all be covered by nature reserves, national parks and other protected areas. Nor are protected areas always inviolate—they remain vulnerable to loss or destruction. Likewise, off site seed banks and field genebanks are vulnerable to human failings, natural disasters and technical problems such as power cuts, fires and floods. Also, *ex situ* conservation disrupts the processes of evolution found in wild populations. So both approaches are needed, in varying mixes for different species.

This booklet is concerned primarily with the wild relatives of the world's main food crops. Their conservation is an important part of the mandate of IBPGR, which has worked closely with the Food and Agricultural Organization of the United Nations (FAO) and many other organisations in building up the world's network to conserve plant genetic resources. However, this booklet does not cover the thousands of local crops or wild-collected species that are part of domestic economies, especially in developing countries. Research and conservation of such crops is a neglected field which IUCN and WWF—through their Joint Plant Conservation Programme and the Botanic Gardens Conservation Secretariat—are beginning to address.

The Sierra da Manantlán Biosphere Reserve provides a safe refuge for wild forms of the runner bean, *Phaseolus coccineus.*

The preparation of this booklet is the result of a fruitful collaboration between IBPGR and the Joint IUCN-WWF Plant Conservation Programme. All three organizations wish to thank Mr Erich Hoyt most cordially for researching and writing the text and to acknowledge the work of the editorial team of J T Williams, A McCusker and P Stapleton (IBPGR), V H Heywood (IUCN), and H Synge (WWF).

We hope that this booklet will stimulate governments and other agencies to intensify their efforts in conserving crop genetic resources. They should ensure that the substantial resources, both human and financial, needed for this work are made available. Our survival as a just and civilized world will largely depend on this action.

IBPGR **IUCN** **WWF**

September 1988

1. How our crop plants developed

The rise of agriculture

Agriculture began between 7,000 and 10,000 years ago, when the first farmers gathered the seeds of wild plants and started sowing them to grow food. In the area now known as southwest Asia, the seeds were of wild grasses that would become barley and wheat; in Mexico, of wild corn (maize), squashes, peppers and beans; and in Peru, of wild potatoes. In this way crops originated independently in different parts of the world.

As hunters and gatherers, many of these first farmers would have understood how plants produce seeds and seeds grow into plants. They must surely have been planting seeds in convenient places for thousands of years before agriculture emerged. But as soon as they chose to *cultivate* a favored kind of plant, they set in motion a chain of events that would take that plant and its descendants on a strange and wondrous evolutionary ride.

Farming imposed artificial selection on crop plants. Over the centuries this led to the development of modern crops that provide greater and more reliable food supplies than their progenitors. Once farmed, these plants, called domesticates, were in an artificial environment. For the most part they had lost their ability to compete in the wild and so their survival came to depend on the farmers. One particular reason for this was that farmers selected plants which retained their seeds on the plants rather than dispersed them, so making harvesting much easier. Until domestication, natural selection adapted the plants for survival in the wild, and this included efficient dispersal of their fruits and seeds as soon as they were ripe.

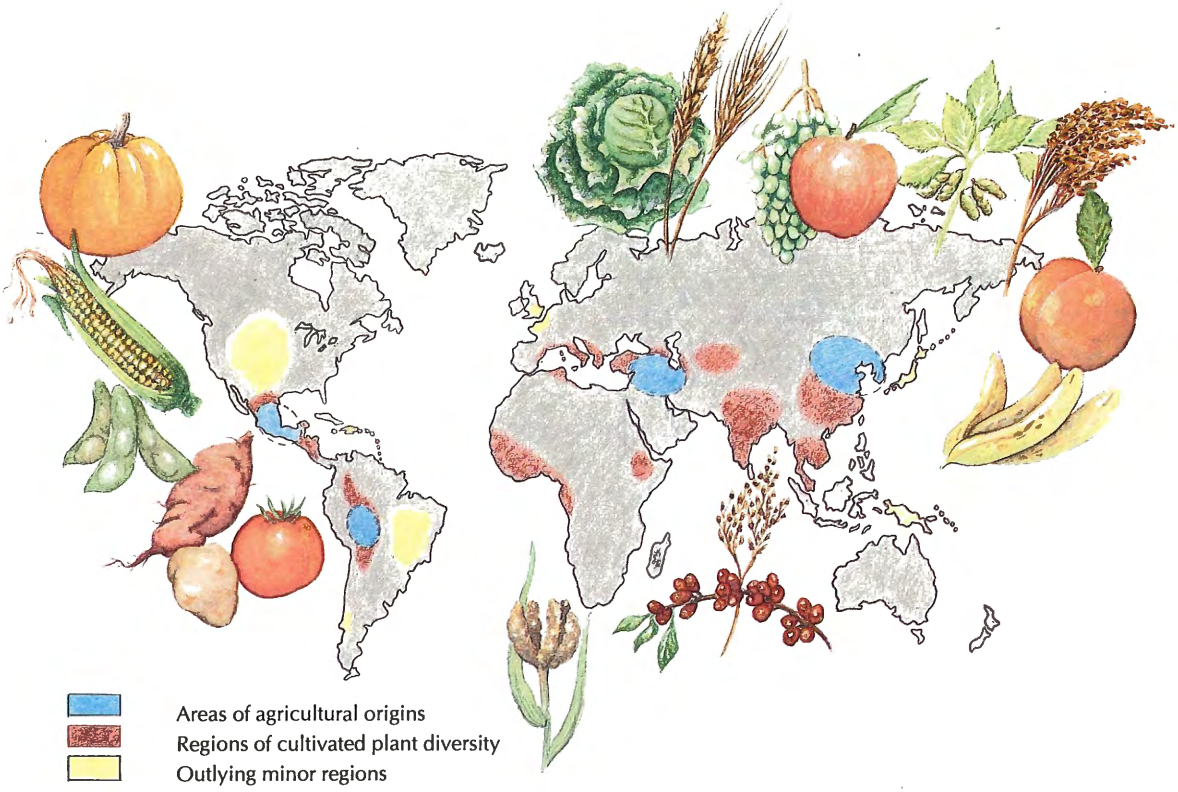
The wild relatives

Many of the species from which the crop plants were selected continue to survive in the wild, even to the present day. So also do their closely related species. This "pool" of wild species comprises the "wild relatives" of crops. Still evolving in nature, wild relatives live by very different rules from crops—survival of the fittest. Many wild relatives have evolved to survive droughts and floods, extreme heat and cold, and they have become adapted to cope with many natural hazards. They have often developed resistance to the pests and diseases that caused so much damage to the related crops. This is partly why they are still so valuable to agriculture today.

The genes of wild relatives contain unknown traits and special strengths—treasures largely untapped. Crops, as we shall see, can benefit from having some of these genes bred into them to allow them to meet the ever-changing conditions of modern agriculture.

The areas where agriculture arose and crops diversified

Botanists have speculated for many years on where individual crops have originated. The region of diversity—where a crop is most diverse—is not necessarily the place where it originated. Following a recent synthesis by J G Hawkes, this diagram shows the four main areas where agriculture originated, ten major regions of crop plant diversity, and eight minor regions. The selection of these areas refines and updates the pioneering work of the Russian botanist Nikolai Vavilov (1887-1943).



Areas of agricultural origins	Regions of cultivated plant diversity	rice	millet	wheat	barley	corn	squash	tomato	potato	bean (*Phaseolus*)
I. N. China										
	1. China									
	2. India									
	3. Southeast Asia									
II. Southwest Asia										
	4. Central Asia									
	5. Southwest Asia									
	6. Mediterranean									
	7. Ethiopia									
	8. West Africa									
III. S. Mexico										
	9. Meso-America									
IV. Peru										
	10. N. Andes									

Gene flow between wild relatives and crops

As agriculture spread around the world, wild relatives of the crops crowded at the edges of farmers' fields, grew as weeds in cultivated plots, and sometimes crossbred with the crops. This interbreeding was a natural process and the gene flow from the wild relatives helped to keep the crops diverse and healthy.

In the case of potatoes, corn, wheat, barley, rice and finger millet, among other crops, chance crosses with wild relatives have improved productivity as well as tolerance to pests, diseases and difficult growing conditions. In crops such as sorghum, crossing with wild species continued for millenia, and the flow of genes constantly created new diversity in the domesticates.

Natural interbreeding has also led to whole new crops welcomed by farmers. The two types of wheat—one for making bread and the other for making pasta—originated from a series of crosses between early domesticates and wild species. These crosses were possible because the cultivated and wild species grew in the same areas. Other crops originated when wild species—which had adapted to the disturbed ground of cultivated fields yet were unrelated to the crops being grown—were selected as a new crop in their own right; rye is an example.

The high yielding varieties arrive

For most of human history, the crops that farmers grew were "land-races"—that is, local crop varieties developed in primitive agricultural systems by human and natural selection over long periods of time. They remained relatively unmodified from the wild species, although they had been selected over many generations by farmers, who sometimes sent them or carried them great distances to new lands. Shaped by the largely unconscious artificial selection, as well as natural selection, land-races adapted to the particular human and environmental influences that confronted them.

In the late 19th century, plant breeders started deliberately and systematically to improve the land-races. From this process emerged a whole series of more advanced cultivars, as cultivated varieties of plants are called. These culminated in the modern high-yielding cultivars, often called elite cultivars, such as have been developed by the international crop improvement centers for crops such as wheat, rice and maize. Typically, high-yielding cultivars are dwarf plants that require artificial fertilizers but enable farmers to double or even triple their production.

In the late 1960s, the prospects of feeding India seemed bleak in view of rapid population growth; famine was predicted for the late 1970s. But the late 1970s came and went without a famine because the new cultivars had been widely planted. By the mid 1980s the population of India had almost doubled but food production, mainly of wheat and rice, had

Walking through the genetic landscape

To a plant breeder, the genetic diversity of the land races and wild relatives, as shown by the differences from one individual plant to another, is a priceless asset in creating and maintaining the health of modern crop cultivars.

Genetic Diversity: The variety of genes and genotypes within a particular species.

- **A gene is the unit of inheritance in all plants and animals.**
- **A genotype is the genetic constitution of an organism, including all its genes which may or may not be expressed in a single plant.**

A species is said to be genetically diverse when the number of genetic variants in the population is large.

Biological diversity may be considered from three points of view:

a) Genetic diversity, which is at the level of genes and chromosomes;
b) Species diversity, which refers to the large numbers of different kinds of plants and animals, and

Genetic Uniformity occurs when the members of a population of a single species all have a similar genetic constitution or genotype.

c) Ecological diversity, which refers to many different types of plant-animal communities and the relationships between them.

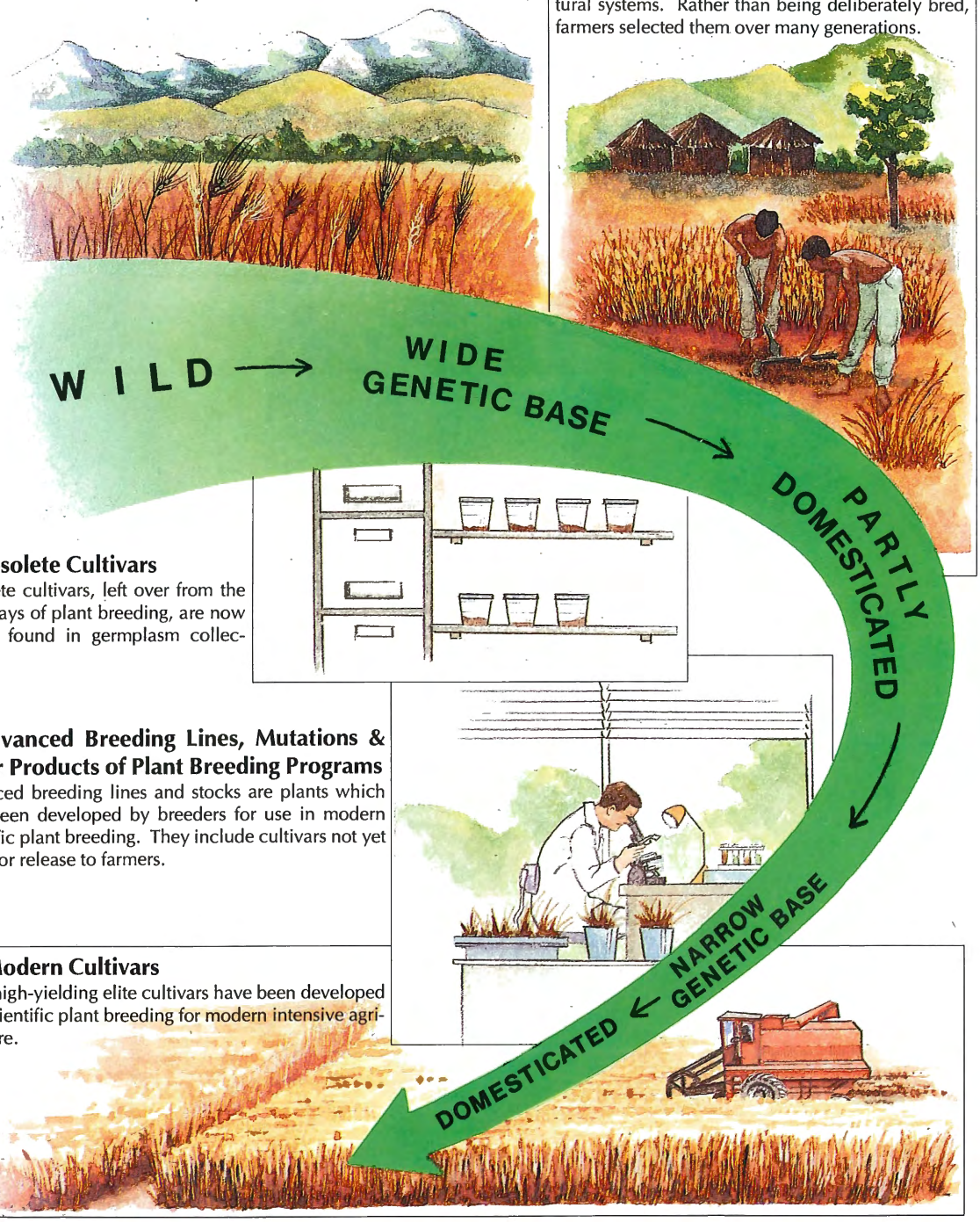
It is important to conserve all three types of diversity.

The spectrum of genetic resources: the five categories of germplasm

These five categories indicate first an evolutionary continuum linking ancient wild forms with modern cultivated varieties (cultivars) and, second, an ecological continuum linking wild with domesticated crops.

1. Wild Relatives
Wild relatives of crops share common ancestors with crops but have remained in the wild as products of nature.

2. Land-races & Primitive Cultivars
Local crop varieties developed in primitive agricultural systems. Rather than being deliberately bred, farmers selected them over many generations.



3. Obsolete Cultivars
Obsolete cultivars, left over from the early days of plant breeding, are now mainly found in germplasm collections.

4. Advanced Breeding Lines, Mutations & Other Products of Plant Breeding Programs
Advanced breeding lines and stocks are plants which have been developed by breeders for use in modern scientific plant breeding. They include cultivars not yet ready for release to farmers.

5. Modern Cultivars
The high-yielding elite cultivars have been developed by scientific plant breeding for modern intensive agriculture.

Together, these five categories cover all the genetic variation past and present of a crop—its genepool. They are the raw material of the plant breeders. All except 1, the wild relatives, are termed domesticates, as they cannot survive in nature.

increased even more. India, China, Indonesia and others have increased crop yields so much that they no longer need to import grain.

Yet worldwide about 15 percent of people are still undernourished. FAO estimates show that this figure has declined from 19 percent, but that because of population growth, the actual number of undernourished people continues to climb. In other words, food production is increasing, but worldwide it is being outstripped by population growth.

The dangers of genetic uniformity

As the high-yielding cultivars have grown in popularity, they have slowly replaced the land-races that had coexisted with the wild relatives and had sometimes crossbred with them. Today farmers only grow land-races in pockets in developing countries; although some land-races were collected and are now stored in gene banks, many disappeared forever in the wake of modern agriculture. Heavy machinery required the use of larger and larger fields. While land-races and wild relatives alike were plowed under, fertilizers reduced the ability of wild plants to compete and pesticides removed many of the natural predators in the ecosystem. In particular, the use of herbicides, often necessary to grow the new cultivars, killed many of the wild relatives that grew as nearby weeds.

The new cultivars, emerging from international crop centers, were from the beginning uniform and very few in number, compared to the great diversity and number of the land-races. And as the unwanted land-races were discarded, the valuable gene flow between land-races and wild relatives diminished. Crops became more and more uniform genetically.

Genetic uniformity can make a crop vulnerable to epidemics of pests and diseases. When farmers all grow the same variety, a pest or disease that strikes one plant quickly spreads over a large area. Farmers saw the dramatic dangers of genetic uniformity during Ireland's potato blight of 1845. The Irish potato crop—then highly uniform genetically because it was descended from a small number of introductions—was wiped out. Over the next few years, an estimated 1 million people starved to death and 1.5 million left the country. In 1943, in India, brown spot disease aggravated by a typhoon destroyed the rice crop and started the "great Bengal famine". In 1953 and 1954, wheat stem rust took most of the hard wheat crop in the United States.

By the late 1960s, pests and diseases began attacking the new high-yielding cultivars, which did not have the variability to resist. During the summer of 1970, southern leaf blight fungus raced across American cornfields at speeds of 80 kilometers or more a day. The disease killed corn plants bred to contain a genetic element called Texas cytoplasmic male sterility factor, cutting the U.S. corn harvest by about 15 percent. That same summer, half way around the world, leafhoppers were busy spreading the deadly tungro virus to high-yielding rice in Indonesia and the Philippines.

The local corns (maizes) such as those stored by Mexican farmer Vincente Gilberto in his corn bin are an important source of genetic diversity for plant breeders.

Restoring genetic diversity

To cope with problems arising from intensive modern agriculture, it is essential to maintain genetic diversity within crop genepools. When the tungro virus began to take over the high-yielding cultivar of rice called "IR8" that dominated in the 1960s, breeders began to look in the genepool for a wider range of agronomic traits. Since then, breeders have released many new cultivars, each confering ever broader resistance, in the effort to stay one step ahead. Yet the more widely grown a cultivar becomes, the more likely it is that strains of its pests and diseases will evolve somewhere to break down the resistance carefully bred into the crop by the breeders. So the breeders run a race against time, trying to keep one step ahead of the rapidly evolving pests and diseases.

To protect their harvests, more and more rice farmers in the Philippines now plant a mixture of cultivars in the same field. In Thailand, some farmers now plant high-yielding cultivars on part of their land during the dry season and sow traditional cultivars during the rainy season. This allows the farmers to take advantage of the productivity of irrigated modern cultivars during dry months and the stability of yield of traditional land-races in the wet season when pest outbreaks are common.

The value of diversity in crops is similar to the value of a diversified portfolio to an investor. If one stock fails, the investor does not lose everything. Nature does not produce individual plants resistant to all diseases, pests and environmental stresses, and neither can the breeder. Natural genetic diversity, in which many *individuals*, each somewhat different genetically, thrive together, allows a *population* to withstand challenges to its survival.

Breeders need to have available a diverse assortment of genes to combat genetic uniformity. Land-races and wild relatives are important sources of such genes.

2. Useful genes from wild species

Wheat is an important staple food crop in almost every country of the world. Genes from many sources, including wild relatives, have helped breeders adapt wheat to vastly different growing conditions—different soils, extremes of temperature, and varying amounts of rainfall. Another widely cultivated plant, the tomato, has a wild relative from the shores of the Galapagos Islands that has given it genes conferring so much salt tolerance that the plants can be irrigated by one-third sea water. A wild relative of soyabeans found growing along roadsides, riverbanks and in fields in Korea and adjacent regions of China and the Soviet Union has provided genes to help the crop adapt to the short growing seasons of Siberia. These are just a few examples of how wild relatives have been used to improve crops through plant breeding.

Fighting pests and diseases

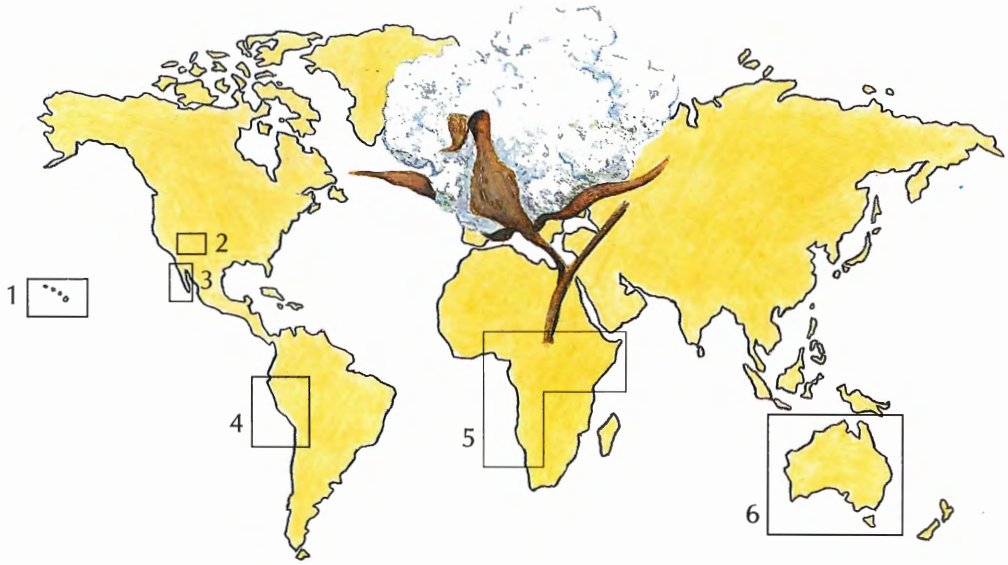
The most common use of wild species has been to breed crops that can resist pests and diseases. The tomato simply could not exist as a commercial crop without the genes from its wild relatives, which have helped it resist a long list of viruses, moulds, wilts, nematodes and other pests. Genes from numerous wild relatives of potato protect it from pests and diseases. Plant breeders first started to cross wild potato relatives with cultivars in the 1890s, a time when most researchers were skeptical about the value of wild species. But new cultivars were developed, some with resistance to late blight and viral disease. More recently, transfering the sticky-tipped leaf hairs from two wild potato relatives to a popular cultivar has armed it with protection from aphids, mites and thrips.

One wild relative of rice has played a key part in providing disease-resistance to the rice cultivars that feed most of Asia. Because rice is the world's number one food, this case is perhaps the most important use of a wild relative. The brown planthopper, a pest that rapidly sucks the rice plant's sap and also transmits a viral disease called grassy stunt, brought epidemics to the fields of South and Southeast Asia from the late 1960s to the late 1970s. Worst hit was the populous Indonesian island of Java. Between 1974 and 1977 in Indonesia, losses caused by the virus and the planthopper exceeded 3 million tons of rice, enough to feed 9 million people for a year.

In the early 1970s, the International Rice Research Institute (IRRI) was completing the breeding of the celebrated cultivar IR36. They had anticipated that grassy stunt virus was going to be a serious problem and had already screened thousands of breeding lines and other germplasm holdings for resistance. They found none. When they tested a hundred samples of related wild species, they found only one variant that proved resistant—a population of *Oryza nivara* collected in 1963 in a water-logged field in the Uttar Pradesh State of India. They grew the seeds

Cotton and its widespread wild relatives

The wild relatives of cotton grow in scattered places around the world. Many of them have made contributions to the development of commercial cotton.



1. **Hawaii**
   - Resistance to lygus bug and other insects
   - Reduction of boll rot

2. **Arizona and northern Mexico**
   - Increase in fiber strength
   - Resistance to budworm, pink bollworm and wilt

3. **Baja California**
   - Resistance to boll weevils, boll worms, leaf worms, jassids and other insects

4. **Ecuador and Peru**
   - Improved cotton fiber
   - Resistance to rust, root knot and not susceptible to cotton wilt

5. **Niger, Nigeria, Cameroon, Chad, Central African Republic, Sudan, Ethiopia, Somalia, Angola, Namibia**
   - Resistance to rust and *Empoasca*

6. **Australia**
   - Very high yarn strength

and found three resistant plants out of the sample of about 30 plants. From these three plants came a gene that was bred into IR36 and is still found today in every high-yielding cultivar of rice grown in tropical Asia.

High yields, good nutrition, good flavor

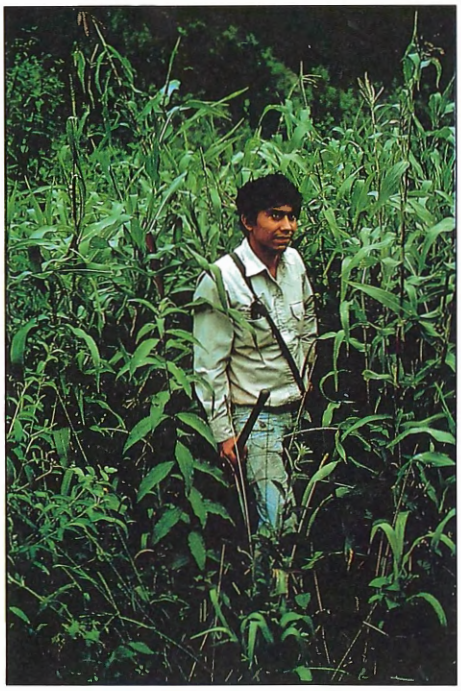
There are many more uses for wild relatives. Part of the tomato's good nutritional value is its high vitamin content, which comes from the gene of a rare wild species from Peru with fruits the size of small cherries. From other wild tomatoes come genes that intensify the fruit's color. From the wild pineapples found in the dry, open Chaco of Argentina, Paraguay and Brazil, breeders have imparted high acidity, high sugar content and a distinctive "wild fruit" flavor to the modern pineapple. Two wild relatives of cassava have increased the protein content of some cultivars, and wild relatives from Canada, California and Chile have given strawberries their extraordinarily high yields.

Problems in using wild genes

For all their demonstrated value and potential, wild relatives are usually considered by breeders to be a last resort and are little used. To improve crops and develop new cultivars, most plant breeders first try to intercross modern or obsolete cultivars. Breeders in general are unfamiliar with wild material and the special techniques sometimes required to use it.

When crossing a wild relative to a crop to transfer a specific characteristic, the breeder inevitably introduces into the progeny many other unwanted traits. These may be poor yield, poor quality, or fruits that shatter and spread the seeds. Breeders try to get rid of these traits by backcrossing, in other words repeatedly crossing the new plant back to the original crop, so as to progressively eliminate the undesirable traits while maintaining the desired characteristic. A disease-resistant wild tomato relative, for example, is first crossed with modern breeding stock. The resulting plants with the highest disease-resistance and the fewest unwanted traits are then crossed with the modern cultivar. This process is repeated many times, testing each generation for resistance to the disease. This step-by-step process is long and tedious. A further problem is that desired genes are sometimes linked with unwanted genes and a breeder may spend years trying to separate them.

To make wild relatives more accessible and easier to use, germplasm enhancement programmes have been started in which wild relatives and land-races are "prebred". The aim is to remove some of the undesirable traits before crossing them with the crop. Through backcrossing with modern breeding stock, prebreeding transfers useful genes from the wild relatives into a genetic environment in which they may be more easily used by plant breeders everywhere. This is a way of "packaging" genes from wild relatives. Prebreeding has already shown promise in wheat, rice, corn, sorghum, potato, tomato and soyabean.



Rafael Guzmán with wild stands of *Zea diploperennis* that he discovered.

Profile of a new wild relative

How valuable is the discovery of a new wild relative for a major crop? In 1977, Rafael Guzmán, a botany student at the University of Guadalajara in Mexico, was searching for a wild relative of corn (maize). He rediscovered a species believed extinct in the wild since the early 1920s—*Zea perennis*. This perennial teosinte produces sterile offspring when it is crossed with commercial corn because it has 40 chromosomes, as opposed to corn's 20. Still, the discovery was significant, because it led Guzmán, by a circuitous route, to another population of perennial teosinte, high up on a mountain. Seeds of that were sent to Hugh Iltis, John Doebley and Batia Pazz, botanists from the University of Wisconsin, who soon realized that Guzmán had in fact discovered a teosinte with just 20 chromosomes. Accompanying Guzmán the following year to the Sierra de Manatlán, they confirmed his find: a species new to science with the same number of chromosomes as commercial corn, and so compatible with it.

Zea diploperennis, as they named it, proved to have distinctive perennial rhizomes. One advantage to a perennial corn is that it could be harvested year after year without replanting, saving time and money. But there would be substantial disadvantages: grain production would drop, as perennial plants must invest substantial resources in developing the rhizomes to allow it to survive the winters. In the U.S. Midwest, perennial corn would also need frost resistance.

Seeds of the new species were sent to some 500 institutions including the Ohio Agricultural Research & Development Center in Wooster. There, attributes of much greater value were uncovered. When the first plants were tested, they were found to be tolerant or immune to seven of nine tropical corn viruses. For three of these diseases—one of them a most serious disease in the U.S.—*Zea diploperennis* is the only source of viral immunity. It may also provide genes for tolerance to poorly drained soil, greater stalk and root strength, and multiple ears on each plant.

The researchers began crossing *Zea diploperennis* with modern corn cultivars. The result grew 3 to 4 meters tall, looked very wild, but held promise as a silage plant. *Zea diploperennis* may in time prove its value, but it will take about ten years of backcrossing and other experiments to find out. Will there some day be a supercorn, mostly disease-free, hardy and wonderfully tasty? No one knows. But the potential gain is enormous.

The promise of genes from wild relatives

The promise of wild relatives can be seen in many crops. As part of the Wild Mango Project of IBPGR, IUCN and WWF, wild mangoes recently collected in Kalimantan, Indonesia, are now being evaluated for their resistance to diseases such as mango bacteriose. Researchers have identified fruits of wild mangoes with distinctive taste, extra sweetness, firm texture, and strong aroma. They have found wild mango trees with the ability to withstand chronically damp or poorly drained soils. Preliminary experiments to graft mango cultivars onto rootstocks of several mango wild relatives and semi-cultivated varieties show that it may soon be possible for Indonesian settlers who are migrating from over-crowded Java to grow productive mangoes on the poor soils of remote, rugged Kalimantan.

Genes from wild relatives may help plant breeders currently trying to develop cultivars for the 1.4 billion rural people who still plant traditional crops. They need more productive cultivars to feed their families and raise their standard of living. New cultivars are especially needed for Africa, where families traditionally grow millet, sorghum, cassava, yams and cowpeas—crops formerly neglected by most plant breeders. The challenge is to come up with useful cultivars in line with traditional farming methods.

The rapid development of genetic engineering through recombinant DNA technology offers a new approach to the genetic improvement of plants. Gene transfers—in which single genes are transferred from one plant to another—may have a real impact on plant breeding in the 1990s. At least in the near future, however, genetic engineering will not replace conventional plant breeding, though plant breeders and crop scientists—working closely with genetic engineers to develop new cultivars—may learn how to make progressively more complex gene transfers without the lengthy backcrossing of conventional techniques. Also, genetic engineering may enable breeders to introduce genes from more distant relatives that cannot at present be used for crop improvement at all. For these reasons, genetic engineering will increase the use of genes from wild plants.

Future plant breeders must have a continual and expanding supply of genetic resources, including wild relatives. In spite of the recorded successes, little work has been done to tap the potential of wild relatives. Yet they have already brought benefits to such important crops as tomatoes, sugar cane, tobacco, wheat and rice.

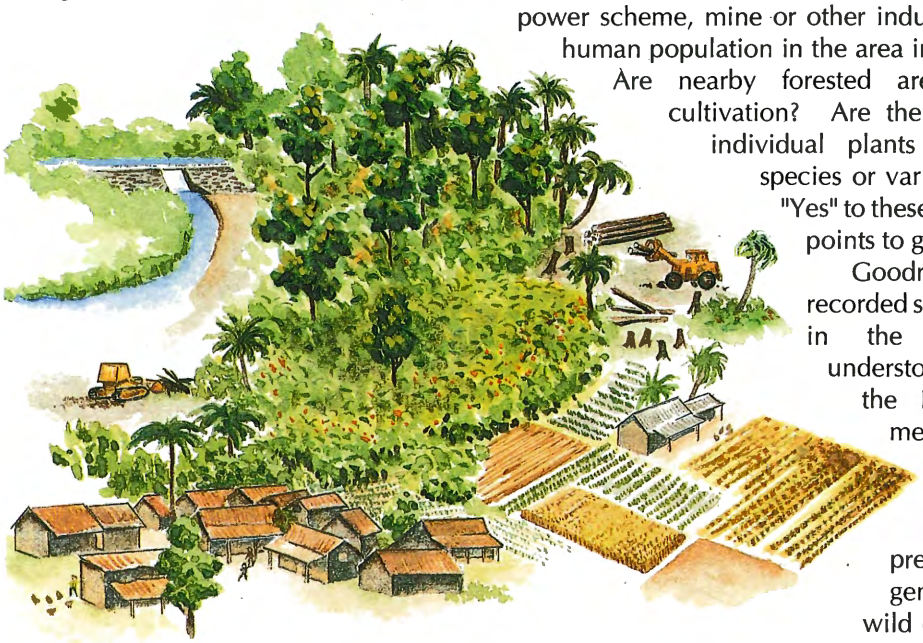
Threats to wild relatives

Wild relatives may be needed now more than ever before to feed a hungry, rapidly expanding world population, but their survival is under threat from

Coffee in Kenya - a profile of genetic erosion

So far, assessing genetic erosion in wild relatives of crops has been largely subjective; for example, a botanist looks for a crop relative where it had been collected before, but cannot now find it. The ideal way to objectively assess genetic erosion is to lay out a grid of permanent sites and then monitor population changes over time. However, even for plants with a narrow geographic range, this is both expensive and time-consuming.

In January 1987, IBPGR sent researcher Justin Goodrich to Kenya to test a cheaper and faster method for monitoring genetic erosion. The method employs a rating system with a long list of factors, each measuring the probability of genetic erosion or the imminent threat of it. The largest factor is change in land use, on site or nearby. Is the site less than five kilometers from a village, hydroelectric power scheme, mine or other industrial site? Is the human population in the area increasing rapidly? Are nearby forested areas suitable for cultivation? Are there less than 500 individual plants of a particular species or variety? The answer "Yes" to these crucial questions points to genetic erosion.



Goodrich ranked several recorded sites for wild coffee in the Kenyan forest understory. Then, to test the IBPGR "shortcut" method, he went to each site on foot. In general, the survey accurately predicted the level of genetic erosion for wild coffee. He found that three wild coffee sites were highly threatened and required immediate action; two sites had disappeared, one of them destroyed for a tourism development; six were possibly threatened and required further monitoring; and only two sites were secure—one in a gazetted forest and the other in a national park. The survey is especially valuable for monitoring and picking up problems with rare or localized wild species with defined habitat and distribution—like coffee.

However, many wild relatives of crops have widespread ranges with complex, diverse habitats. Goodrich also looked at genetic erosion in the wild relatives of forage legumes, but here the survey predicted the real story unevenly. The forage species turned out to be much more widespread and survived well in marginal habitats which did not show up in the survey.

The need for an effective monitoring system for wild crop relatives is acute. As a preliminary to a field survey, remote sensing or other large-scale monitoring will help establish gross habitat changes and could therefore identify areas under threat, which would become priorities for field visits. Then fieldworkers could analyze the situation with local data and confirm it in the field. They could suggest a course of action to save the species from further erosion or even extinction.

the massive and unprecedented destruction of nature around the world. They are threatened by the world-wide clearing of land for farms, roads and industry, by the felling and burning of the tropical forests, of which at least 7.4 million hectares are completely lost each year, and by the widespread over-grazing of grasslands, especially in dry areas.

IUCN and WWF estimate that up to 60,000 plant species—nearly one in four of the world's total—may become extinct or near-extinct by the middle of the next century if the destruction of nature continues at the present rate. How many of these threatened plants are crop relatives is not known. Some wild relatives, being weedy species, may thrive in the new man-made habitats—one example is a wild relative of wheat, *Aegilops cylindrica*, which springs up along the new superhighways of the United States. But others—such as the wild olive of Algeria, Niger and Sudan, cabbages in southern Europe, beets in Portugal and Greece, and coffee in East Africa—are threatened species. The threatened caoba tree from Ecuador, *Caryodaphnopsis (Persea) theobromifolia*, is a relative of avocado resistant to blight, resistance needed by the California avocado growers. When it was discovered in 1977, only 12 trees remained in a tiny relict forest, since protected. Today, almost all the remaining lowland forest in Ecuador has been cut down.

Some wild relatives are threatened as species, yet many more are threatened with genetic erosion—the reduction in their genetic diversity because of loss of individuals or populations. Even local populations of plants can be highly variable and so losing part or all of them can result in some loss of genetic diversity. This is particularly serious in the case of crop relatives, since the breeder needs the plant-to-plant genetic variation, as the rice story from IRRI showed so clearly.

When the habitat where a species occurs is reduced, outlying populations may be lost—populations that often contain special characteristics, such as adaptation to a more extreme environment than the rest of the population, or resistance to a local disease. Genetic erosion is difficult to measure species by species, but the great loss of wild forests, grasslands and other natural habitats around the world leaves no doubt that it is happening virtually everywhere.

Two species of Aegilops are among the wild relatives that give disease-resistance to modern wheat.

Economic Values of Wild Relatives

It is impossible to calculate the full financial value of wild relatives. It is, however, sometimes possible to estimate their value in specific instances. The California Agricultural Lands Project have estimated that:

- A wild relative of wheat from Turkey provided disease-resistant genes to commercial wheat varieties worth US$ 50 million annually to the United States alone.
- A single Ethiopian barley plant has a gene that now protects California's US$ 160 million annual barley crop from yellow dwarf virus, which is fatal to barley plants.
- A wild hop gave "better bitterness" to English beer and in 1981 brought US$ 15 million to the British brewing industry.

The Project also quotes official estimates of the U.S. Department of Agriculture that germplasm in plant breeding is responsible for an annual increase in crop productivity worth of the order of US$ 1 billion annually. (This includes the use of wild relatives and of cultivars.)

As well as helping to prevent famine and malnutrition, the worldwide contribution of wild relatives to crops must be worth billions of dollars a year.

Source: BriefBook: Biotechnology and Genetic Diversity. 1985

3. Conserving wild relatives in genebanks

Plant genes can only be stored in *living systems*—that is, as whole plants or parts of plants that must be kept alive and healthy. To maintain living systems, biologists and conservationists use a number of methods that can be divided into two broad categories: *ex situ* conservation, which means conserving plants out of their natural habitat and is the subject of this chapter; and *in situ* conservation, which means conserving the plants within their natural habitat and is covered in the next chapter.

Most crops lend themselves to *ex situ* conservation, in which seeds, plants, plant parts, tissues or cells are preserved in an artificial environment. Although the storage can be long term, it is not indefinite: cultivated plants must be propagated as they age, seeds and tissues must periodically be grown into whole plants, and new seeds or tissues taken for storage.

If the regeneration is done regularly and meticulously, *ex situ* conservation can be a secure way of preserving genes over hundreds of years. It is also convenient for the plant breeder, as it allows germplasm from many different areas to be brought together at one point. Yet centralization carries a risk. Genebanks, with large collections of germplasm in a very small space, are vulnerable to many factors, any of which can spell disaster: for example, a break in the power supply, a mistake over labelling, or a failure to regenerate the plants in time. So, whenever possible, samples are stored in more than one genebank to avoid the risk of total loss should there be a mishap.

There are three main methods of *ex situ* conservation used for crops and their wild relatives: seed banks, field genebanks and tissue culture. Collections of germplasm using any of these methods are often called genebanks.

Seed banks

Seeds are by far the most convenient parts of plants for storage. They are small and, as the natural germplasm storage organs of plants, are generally well adapted for storage. With few exceptions, every seed has a different genetic constitution so a wide range of genetic variability may be included in a single sample stored in a small, sealed container.

Most plant species have seeds which can be dried to low moisture content and stored at low temperature without losing their viability; such seeds are called "orthodox". According to conventional wisdom and wide practice, the best storage temperature is about -20°C, but further study is needed to find out whether seeds could be kept safely at higher temperatures if first dehydrated below their natural water content. So far the storage of seeds of wild relatives has presented no problems different

Kinds of seeds

Orthodox seeds can be dried and stored at low temperatures for long periods of time. Most crops have orthodox seeds, a group that includes all the major cereals and other grasses from corn, wheat, and rice, responsible for 50% of the world's food, to various forage grasses important for raising livestock. Other plants with orthodox seeds are the onion family, carróts, beets, papaya, pepper, chickpea, cucumber, the squashes, soyabean, cotton, sunflower, lentil, tomato, various beans, eggplant, spinach, and all the brassicas.

Recalcitrant seeds cannot be dried without injuring them. They can only be stored for a few weeks or months—by treating them with a fungicide and keeping them in moist sawdust or charcoal inside a polythene bag with access to oxygen. Therefore, seed banks cannot be used to conserve them. Comparatively few major crops have recalcitrant seeds, but many of these are important, particularly in the tropics: cocoa, coconut, mango, cinnamon, nutmeg, avocado, tea, breadfruit and jackfruit. For good reason, threatened wild relatives of crops with recalcitrant seeds have received the most pressing call for *in situ* conservation.

from the storage of cultivars, although attempts to grow out wild seed are often beset with difficulties.

Under the storage conditions recommended for seed banks, some seeds may survive for perhaps a hundred years but regular checking for viability and damage is necessary. Samples must be grown out before the seeds begin to deteriorate so that a fresh generation of seeds can be obtained for continued storage. Wild species are more difficult to handle during this regeneration process; the conditions required to germinate them are often unknown and many require special treatment to break dormancy. For species that are outbreeders, natural seed production may depend on pollination by insects which were present in the natural environment of the species but do not occur near the seed bank, so hand pollination may be required. In addition the plants may set seed over long periods, making harvesting rather tedious. IBPGR, in collaboration with the University of Reading, U.K., has produced a series of handbooks for genebanks containing information on methods for conserving and testing seeds in seed banks, and for assembling records of germination characteristics of many plant families that include crop species.

The agricultural seed banks stocked with large numbers of crop cultivars and land-races may not be the best places to maintain wild material, and IBPGR is looking for possible alternative seed banks. The newly created IUCN Botanic Gardens Conservation Secretariat is

accepting responsibility for the coordination of *ex situ* conservation of local crop species and other neglected useful plants, in association with IBPGR and other bodies. In both cases, storage of wild relatives in seed banks is likely to be the most efficient method of *ex situ* conservation, as is the case for most cultivars.

Some crops, as well as their wild relatives, have seeds that have only a very limited viability or that will not tolerate drying and freezing. Thus they cannot be stored in conventional seed banks. For this group, other conservation methods must be used until research leads to techniques that will permit storage in seed banks.

Field genebanks

Species that do not readily produce seed and those with recalcitrant seeds have usually been conserved in field genebanks. These are simply areas of land in which collections of growing plants have been assembled. Some are in botanic gardens, arboreta and other plantations; others are alongside seed banks, where the germplasm is maintained as a permanent living collection.

Field genebanks are often established to maintain working collections of living plants for experimental purposes. They are used as a source of germplasm for species such as cocoa, rubber, coconut, mango, cassava and yam.

Field genebanks take up many times the space of a seed bank, yet cannot cover the full range of genetic diversity of a species or maintain it under the full range of conditions that it occupied in the wild. The collections are difficult to protect from natural disasters such as bushfires and are especially susceptible to the spread of diseases. Despite these drawbacks, useful field genebanks have been established in the past and they continue to provide a means of combining conservation with study. Some of the most valuable conserved collections of bananas, plantains, oil palm and coffee are those established long ago in field genebanks.

A field genebank near Manaus in Brazil conserves valuable germplasm of the South American peach palm *Bactris gasipaes*.

Tissue culture

Plant tissue culture—the growing of little plants in tubes of nutrient agar—is now used widely for propagating plants in the horticultural industry. This method is called *in vitro* (literally "in glass").

The *in vitro* method is well suited for mass cloning of a single species or cultivar, as well as storage under "slow growth" conditions. But each species requires specially formulated techniques, and it is difficult and time-consuming to work out the best combination of nutrients and conditions for growing each species. However, for plants which do not form seeds, such as those propagated from bulbs or rhizomes, *in vitro* is the only option. As the method improves, it is being used more and more for plants that set seed infrequently, to store materials collected from the wild when not in flower, and for recalcitrant species.

Wild relatives in seed banks

Only the wild relatives of a few crops such as wheat, potato and tomato have been widely collected and preserved in seed banks. In most cases, wild germplasm represents less than 2 percent of the seed bank holdings for each crop and most wild relatives of crops still thrive only in the wild. IBPGR is helping to focus world-wide efforts to collect and conserve them.

Crop	Wild species held in all seed banks as % of total holdings	Estimated % of wild species still to be collected
CEREALS		
Rice	2	70
Wheat	10	20 - 25
Sorghum	0.5	9
Pearl millet	10	50
Barley	5	0-10
Corn (maize)	5	50
Minor millets	0.5	90
ROOT CROPS		
Potato	40	30
Cassava	2	80
Sweet potato	10	40
LEGUMES		
Beans	1.2	50
Chickpea	0.1	50
Cowpea	0.5	70
Groundnut	6	30
Pigeonpea	0.5	40

Source: IBPGR estimates, 1988

All of the genetic information in a plant is present in every vegetative cell so, in theory, any cell or a culture grown from any part of the plant could be used for germplasm conservation *in vitro*. Embryo and shoot tips are the organs generally used for tissue culture.

IBPGR, in collaboration with Centro Internacional de Agricultura Tropical (CIAT), Colombia, has established a pilot *in vitro* genebank for cassava to assess the strengths and weaknesses of various approaches to this method of storage. Satisfactory techniques for storage *in vitro* have been developed for potato and sweet potato and some temperate fruits, and are being extended to various other crops.

More work needs to be done to increase our knowledge of the long-term genetic effects of storing plants in tissue culture. Improvements are also needed to the techniques of recovering whole plants from these

cultures. If, as scientists suspect, tissue cultures kept under conditions of slow growth are genetically unstable, then this technique has limited prospects for conservation.

The best answer for long-term conservation of germplasm *in vitro* seems to lie in "cryopreservation"—that is, the storage of frozen tissue cultures at very low temperatures, for example in liquid nitrogen (at -196°C), which brings all biological processes virtually to a stop. If this technique could be perfected so as to reduce the damage caused by freezing and thawing, materials could be conserved almost indefinitely.

Much more work is needed to improve tissue culture techniques before *in vitro* conservation can be used widely and with confidence, and it may never match the efficiency of seed storage. However, for species where conservation as seeds is not possible, this method offer a promising alternative.

Ex situ conservation, no matter what method is used, cannot provide the opportunity for a wild relative to continue fully the evolutionary processes that a species undergoes in its natural environment. There is no pressure to adapt to changing natural conditions nor to compete with other species. However, *ex situ* methods keep germplasm safe when plants are destroyed in the natural habitat and have the advantage, for the user, of making material from widely scattered localities available in one place, ready for immediate use.

Conserving genes over time and space

A species is not constant.

- Its genetic composition changes over time. Crops change because breeders cross them, or crops accidentally interbreed with other cultivars and their offspring will carry different genes. Wild relatives change too, though much more slowly, adapting to changing conditions in the wild.
- The genetic composition also changes from one place to another—over space.

To conserve wild relatives for crop improvement, we need to conserve as much of their genetic variability as possible over both time and space.

4. Conserving wild relatives in natural areas

High in the Caucasus Mountains that stretch between the Black Sea and the Caspian Sea, the Soviet Union has established a reserve to protect the wild relatives of wheat and fruit trees. East of the Caspian Sea, in the Kopet Mountains just north of the Iranian border, the Soviet Union has also made a reserve for wild pistachio, apricot and almond trees, and for wild fodder grasses. India has set up its first "gene sanctuary" in the Garo Hills for wild relatives of citrus, and its scientists are planning further sanctuaries for banana, sugar cane, rice and mango. Since 1984, Ethiopia has been conserving wild relatives of coffee in special conservation areas. These new genetic reserves are among the first efforts to protect the wild relatives of crops *in situ*.

In situ conservation means conserving plants in their natural habitats. In crop genepools, only the wild relatives are candidates for *in situ* conservation, because they alone live in natural communities. A great advantage of *in situ* conservation over *ex situ* conservation is that the plants can continue to evolve. When the seeds of wild relatives are collected and stored in seed banks, the evolution stops. For some plants—such as wild relatives that are sources of pest or disease resistance—this is of more consequence than for others. To conserve both genetic diversity and the potential for continuing evolution, the wild relatives should be able to co-evolve with their pests.

Most protected areas—nature reserves and national parks—were set up for wildlife conservation—in some cases to protect a famous landscape, in others to save a rare mammal or bird, but rarely if ever to conserve a wild relative. Over the past decade, under the influence of IUCN and supported by WWF, the driving force for conservation of natural areas, particularly in the tropics, has been to protect a representative sample of each ecosystem. For example, Costa Rica, a model country for conservation, has protected large pieces of dry, lowland, cloud and other types of tropical forest, as 28 or more parks and reserves amounting to more than half a million hectares—about 10 percent of Costa Rica's total land area. In Tanzania protected natural areas amount to about 12 percent of the country; in Botswana, as much as 18 percent. Throughout the world, by 1988, there were more than 3,500 major protected areas established in 125 countries, covering some 4.3 million square kilometers.

Existing protected areas provide a good start for conserving wild relatives, in part because the ecosystem approach insures that a variety of habitats are conserved, but much remains to be done. It is good fortune when an existing nature reserve, set up to conserve a special ecosystem or rare species, happens to include a population of a wild crop relative. Even so, conserving one place where a species grows does not necessarily

Classification of Plants: Taxonomy or systematics

The vast array of plants and animals in the world needs to be divided up into named, individual units for ease of reference and communication. The science which provides this reference system is called taxonomy or systematics.

In modern taxonomy, organisms are classified into families, genera, and species which are then given scientific names—(in Latin), according to an international set of rules "The Botanical Code". The basic unit of classification is the species this is made up of two elements, a genus name (such as *Triticum*) and the species name (such as *dicocum*). Species and genera are placed in larger groupings, called families, such as the Gramineae (grasses) or Palmae (Palms). To a scientist, the name of the plant is the key to all the published information about that plant. For this reason, applying the correct names to plants is vital.

In making their classification, taxonomists use many kinds of information, primarily the appearance (morphology and anatomy) of plants, but also the chemistry, chromosomes or other features. However, the groups that result must be recognizable visually. While the similarity between individuals of a species is clearly due to a similar genetic basis, it is by their outward form that the species are recognized and indeed defined.

Plant breeders, on the other hand, are more concerned with the genetic relationships between groups of plants than with their outward appearance. For this reason they have devised an additional classification into primary, secondary and tertiary genepools. This reflects the abilities of plants to exchange genes with one another. It is described on page 31.

Plant breeders favour the concept of the "biological species", in which all the members of a given species can in theory exchange genes with each other, but not with members of other species. Plant breeders mainly want to know whether plants are genetically compatible—whether they can be crossed to produce fertile progeny. "Biological species" do not necessarily coincide with the species established by taxonomists and commonly used by scientists. In any case, with most plant groups there is not enough information on the breeding relationships of plants to use the "biological species" concept.

Taxonomic classification provides an efficient and convenient way of organizing information about individual plants—a reference and information retrieval system. So far taxonomists have described and recognized about 250,000 flowering plants and estimate that this covers about 90 percent of those flowering plants that exist today. Most species, therefore, now have names, but the information on which species grow where in the world, their habitats and ecology, is fragmentary. Many tropical species have been described and named from only one or two samples; this is clearly an inadequate basis for reliable classification. Ideally, classification should consider species as living and evolving populations. Many scientists now see the lack of taxonomists as the bottle-neck in tropical plant research.

conserve its genetic variation. An approach is needed that is aimed at the special needs of crop relatives.

Despite widespread talk in recent years about the importance of conserving wild "genetic resources" and creating reserves to do so, there is rarely a clear understanding of exactly what that entails—scientifically, logistically, economically and ultimately politically. Many scientific disciplines come into play—population biology, ecology, genetics—but the basic principle behind a genetic reserve is to conserve sufficient genetic diversity to allow the species to realize its full evolutionary potential.

Ecogeographical surveys are the key to good conservation

To conserve a wild relative *in situ*, the genetic variation across its whole geographical and ecological range must first be sampled and compared. Studies that do this are called ecogeographical surveys. They begin with desk research on the geographical distribution and ecological preferences (soil, climate, etc.) of the chosen wild relative. Then, field surveys proceed to collect samples of the plant and to expand the existing data on its ecology and distribution. The field surveys should include a study of diseases and pests, so that the variation in its susceptibility and resistance can be mapped. Next, laboratory analysis of samples, grown out under controlled conditions, allows scientists to separate the environmental from the genetic variation of the species.

An ecogeographical survey can be a lengthy process but, after all the data are gathered, it will establish the best combination of conservation methods (both *in situ* and *ex situ*) to satisfy all the requirements for conservation. Such a survey enables conservationists to decide the best areas and optimum priorities for reserves. Of course, the urgency of the situation—severe genetic erosion or the threat of extinction, for example—can also be a factor in determining the action to be taken. Another factor is the likely requirements of plant breeders: how much of the genetic diversity will likely be used and which part of it, and what are the short- and long-term needs for access to the germplasm?

Certain wild relatives with a narrow range may require immediate protection, and a small reserve may be sufficient. For wild relatives whose diversity extends over whole continents, however, a system of reserves for the more concentrated areas of diversity of the species may be a better answer, relying on *ex situ* conservation to protect the diversity of the remaining populations. This approach may also be best for those wild relatives whose diversity is not yet well understood, such as grapes, yams and onions.

A reserve for a wild relative must contain sufficiently large and diverse populations and types of habitat to sustain the level of genetic diversity necessary for long-term crop improvement. The diversity, this wide genetic base, must therefore be monitored and managed in a program that

The genepool system of classification

To work with germplasm, plant breeders need to sort out the intricate relationships of species, subspecies, varieties and ecotypes, and group them according to degree of relationship in a given crop genepool.

A crop's genepool includes all the cultivars, wild relatives and related wild species containing all the genes available for breeding use. Each crop genepool (GP) can be divided into three "GP" levels. The three GP levels are not taxonomic units or categories, but are simply guides for placing existing classifications into genetic perspective.

The genepool structure of a crop helps a plant breeder determine which wild relatives and cultivars are available for crossing and to estimate how difficult the task must be. It also indicates which wild relatives in a crop's genepool might be most profitably conserved.

GP-1
Primary genepool
Prime breeding material:

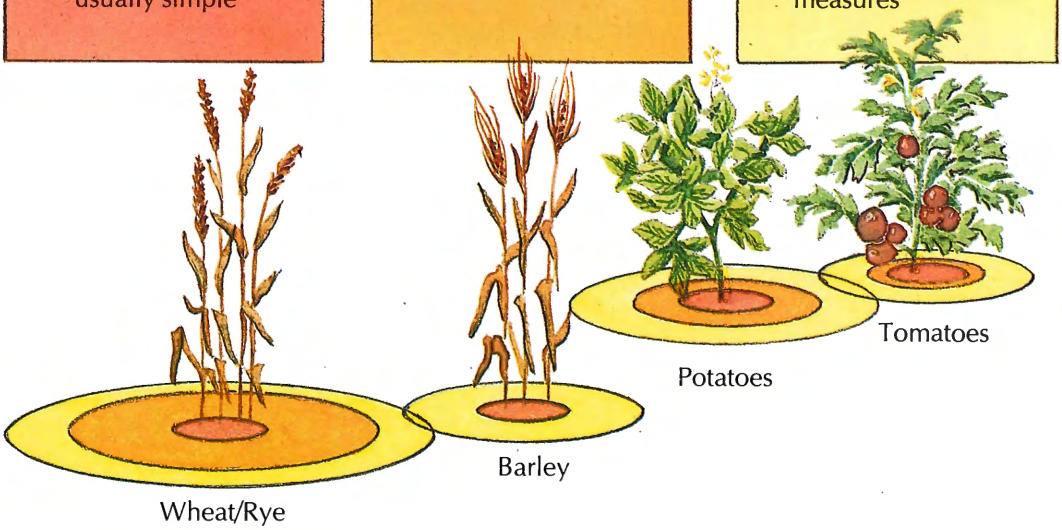
- crossing is easy within primary genepool and hybrids are fertile
- gene transfer usually simple

GP-2
Secondary genepool
Breeders can use with some effort:

- can be crossed with GP-1; hybrids usually sterile but some fertility
- gene transfer possible but may be difficult

GP-3
Tertiary genepool
Extreme outer limit of potential genetic reach:

- can be crossed with GP-1 but hybrids are sterile
- gene transfer only possible with radical measures



Wild relatives may fall into all three categories. Corn's GP-1 includes the cultivar *Zea mays* with the wild relatives *Zea mexicana* and *Zea diploperennis*, while its GP-2 includes wild relatives *Zea perennis* and *Tripsacum* spp. Corn's GP-3 contains more distant wild relatives and related wild species.

samples and studies the selected wild relative in the protected populations. Finally, wild relative genetic reserves, as *in situ* genebanks, must be able to provide research samples for plant breeders and crop scientists.

Taking inventory: which wild relatives are already protected?

In the initial desk research of an ecogeographical survey, one task is to map the range of the wild relative and determine which part of the range may already be conserved in existing protected areas. As part of IBPGR's European Cooperative Programme, distribution surveys were made of 26 species and varieties of wild crop relatives—primarily apples, plums, cherries, peaches, almonds and all the onions (including garlic, leek and chives). This study, one of the first of its kind, had some startling results: there are indeed many nature reserves within the ranges of these plants throughout Europe, but less than 10 percent of these reserves have lists of their plant species. In those that do, only five of the wild relatives were recorded, in six reserves. There was no information on genetic diversity in these established protected areas.

There is only one way to overcome the paucity of data: systematic ecogeographical surveys conducted on a priority basis, genepool by genepool, region by region, wild relative by wild relative. It will be expensive and time consuming, but it has to be done.

Managing the data

As the inventories and surveys are completed, the data could be entered into a computer database so that the germplasm is easily accessible and future *in situ* and *ex situ* conservation needs can be quickly worked out.

The World Conservation Monitoring Centre (WCMC), a consortium of IUCN, UNEP and WWF based in Britain, already has comprehensive databases on threatened plants and on protected areas around the world. The purpose of the WCMC is to provide up-to-date information for planning conservation action. Information in the database is available to government, industry, conservation groups—anyone who needs it. As an overview of the global situation, its Threatened Plants Unit provides data on more plants than any other database—nearly 51,000 species of which about 19,000 are threatened—but there are only limited data on each one. A printout on mangoes, for example, lists 50 species, many of them wild relatives, with the protected areas where they can be found, their regional and world status, and an index of data sources on which the information is based. However, there is nothing yet on the precise location and extent of genetic diversity and the identity of races and ecotypes—the kind of data that will emerge as ecogeographical surveys on mangoes progress. The question is how to handle what will be an enormous amount of data on the comparatively few species that are wild relatives of crops.

The WCMC database contributes to the UNEP Global Resource Information Database (GRID), based in Geneva, which sorts and synthesizes world data on soil, vegetation cover, weather conditions and many other aspects of the world environmental picture. It is based around a Geographical Information System (GIS), on which maps are digitized and recorded on computer. Working with GRID, researchers could compare the specific information on wild relatives from ecogeographical surveys with the various environmental, ecological and land use data sets of GRID, and merge the various datasets together. They could also incorporate the existing computerized inventories of seed banks. In this way GRID, with IBPGR, the WCMC database and data from ecogeographical surveys, could help coordinate the complex information needed to plan *in situ* reserves.

Tropical rain forests contain as many as half the world's wild species, yet are disappearing at an alarming rate.

Biosphere reserves

One type of protected area that is especially suitable for conserving wild relatives is the biosphere reserve. The aims of a biosphere reserve are to (a) conserve genetic resources and representative samples of the world's ecosystems, (b) to provide a focus for scientific research and monitoring; and (c) to promote sustainable development, agricultural or otherwise, in the surrounding area, so serving as a model for that ecosystem. In each of these aims, education and training are priorities.

The aims of a biosphere reserve are accomplished by a special "architecture": strictly protected core areas are first surrounded by buffer zones where research, tourism and education are encouraged. These buffer zones, in turn, are surrounded by large multi-use transition areas with human settlement—an extension of the protected buffer zone. Thus, biosphere reserves are integrated with local populations in a way that helps build the idea of conservation into development and into the fabric of people's lives.

Unesco's Man and the Biosphere Program (MAB) started the idea of biosphere reserves in 1974 and, since then, some 269 protected areas in 70 countries around the world have become inscribed on the Unesco list of biosphere reserves and so are part of the MAB network. There are also numerous other protected areas, founded and managed along the same lines, which are not on the Unesco list. Indeed, most large tropical protected areas today are now managed using the biosphere reserve concept.

The principles upon which biosphere reserves are based—particularly in promoting genetic resource conservation and research—would make an international network of biosphere reserves ideal for conserving many wild crop relatives *in situ*. Some already do: the 23,868 hectare Sary-Chelek Reserve in the Soviet Union (part of the Chatkal Mountains Biosphere Reserve in the Osh region of Kirgiz S.S.R. near the western China border) conserves the wild relatives of various nut trees (especially walnuts) and fruit (apples, pears and part of the *Prunus* family), and maybe more.

Common ground: genetic reserves and nature reserves

Nature Conservation	Held in Common	Genetic Conservation of Wild Relatives
protection goals		
To protect an ecosystem or a multi-species community— sometimes emphasizing a particular threatened species		To protect a significant part of the genepool of a wild relative

Ecosystem conservation is necessary to maintain the genetic diversity of wild relatives. Large vertebrates need the most room: thus a reserve large enough for them will contain many wild plants, perhaps including some wild relatives. The large area often required by a nature reserve helps protect the genetic reserve by creating a large protected buffer zone. Conversely, protecting the desired level of genetic diversity for wild relatives usually means there is adequate nature conservation for the plants and animals that live in association with it. The common ground is strongest with wild relatives that are endemic, threatened or whose greatest and most valued diversity can be found in a fairly small area.

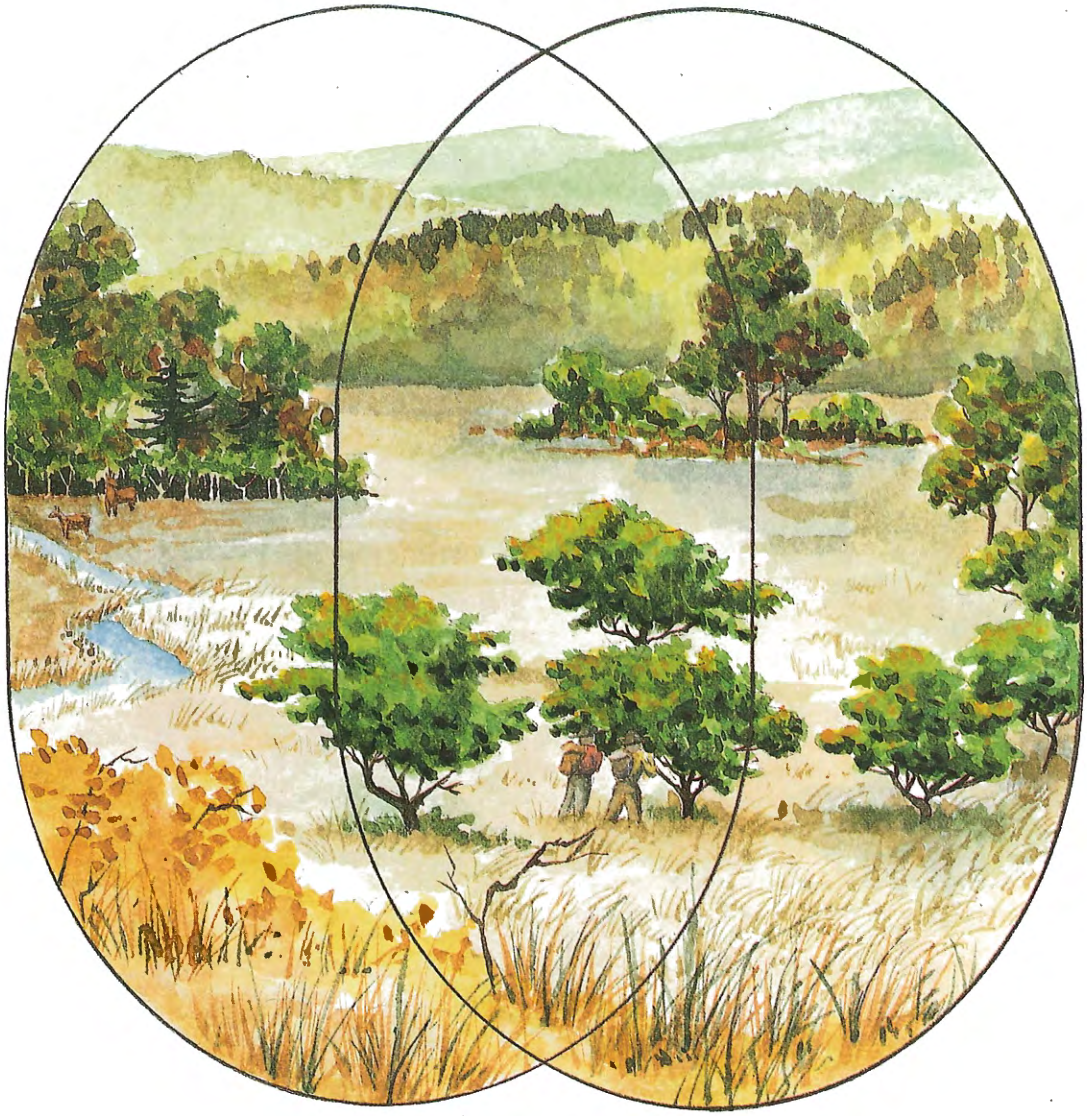
management goals		
Set up for minimal use but often including some tourism		Seeds, pollen or cuttings are taken for breeders; scientific studies are conducted.

A management plan can protect and promote a genetic reserve as well, but there must be provision for taking germplasm. This will not harm nature conservation. Nature conservation managers, with the help of an ecologist and a crop geneticist, can manage a combined reserve.

promotion and education goals		
Protecting a high profile animal or plant helps generate funding and support with nature enthusiasts before and after the reserve is established		Conserving a wild relative that could be economically valuable helps raise money, provides continuing use and value for the reserve and has practical appeal to farmers and breeders.

In both nature and genetic conservation, many relatively unknown animals and plants are protected incidentally. Breeders may come to see nature conservation as the system that helps protected germplasm of potential, though not yet known, value. Farmers living near a biosphere reserve, for example, may see the practical value of conserving wild relatives of crops as part of nature conservation—building the basic concept of conservation into people's lives.

Nature Conservation **Held in Common** **Genetic Conservation of Wild Relatives**



The goals of nature conservation and genetic conservation of wild relatives can better become common goals if crop geneticists, conservation biologists, environmental planners and managers work together on proposals for reserves or protected areas from the beginning. Of course, many proposed nature reserves will not contain wild relatives. By the same token, certain genetic reserves located in uninteresting natural areas or possibly having sufficient variation in small areas will protect few other species. It is important to recognize when there is a basis for common ground and when there is not. In the interests of developing a truly representative system of *in situ* reserves for wild relatives, the science must be done well so the opportunities are not squandered.

Genetic reserves were unheard of when Sary-Chelek was first established in 1959.

In contrast, the Sierra de Manantlán Biosphere Reserve in the mountains south of Guadalajara, Mexico, was established specifically for wild crop relatives. The Mexican government set aside a 139,000 hectare area in March 1988. Near the center of the reserve, atop a 2,880 meter-high mountain chain, are three small plots, totalling at most ten hectares, with the only known stands of the most primitive wild relative of corn, *Zea diploperennis*. Yet the Sierra de Manantlán is much more than a genetic reserve for a wild relative of corn. Animals such as jaguars and ocelots and many endemic plants receive protection too. *Zea diploperennis* is in fact the first wild relative to provide the impetus for nature conservation of a much larger area.

Since the three small plots are the only known areas in which *Zea diploperennis* occurs, the full protection of its known diversity has been achieved. Continued research and monitoring plus the provision of access to the germplasm would make the Sierra de Manantlán function not only as a good nature reserve but also as a good genetic reserve. The Sierra de Manantlán and Sary-Chelek are exceptional in the close attention paid to the wild relatives of crops.

How many other biosphere reserves contain crop relatives? Like most protected areas, biosphere reserves generally lack plant inventories and the plant lists that do exist pay the least attention to wild crop relatives. Preparing plant inventories requires the concerted effort of reserve managers and plant taxonomists. Recently, IUCN-WWF have funded the development of computer software whereby reserve managers can record and log their plants. It is now being tested in the production of complete plant inventories of one biosphere reserve in the United States and one in Mexico. These studies will give an idea of the logistics and costs involved in preparing inventories for other biosphere reserves.

To conserve genetic diversity, biosphere reserves are most effective for wild relatives that are confined to a small area. Besides *Zea diploperennis*, biosphere reserves could perhaps take care of the wild relative germplasm of such major crops as banana, cassava, taro, coconut, breadfruit and jackfruit, as well as citrus and certain other tropical and temperate fruits.

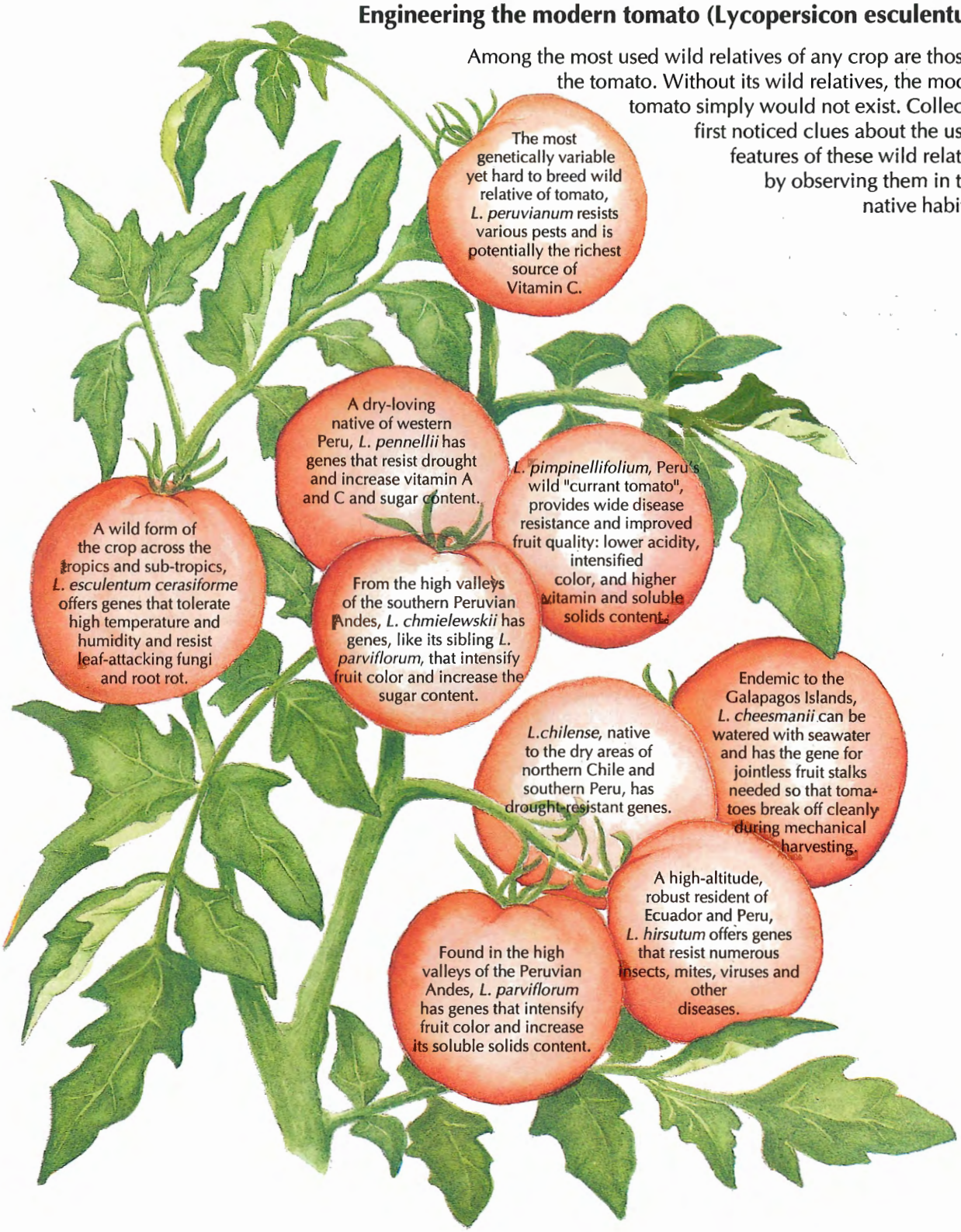
Specially designed genetic reserves for wild relatives

Biosphere reserves are unlikely to be able to conserve many other wild relatives. One or more special reserves, designed through national or regional programs, could help conserve wild sugarcane, perennial wild rice, wild groundnut, wild coffee and certain beet relatives. In addition, special purpose reserves may be useful for the wild relatives of some cereals and other crops, especially to include populations resistant to the diseases endemic in various areas.

Obviously, the cost in time and money—and ultimately the feasibility—of setting up networks of genetic reserves for the many wild

Engineering the modern tomato (Lycopersicon esculentum)

Among the most used wild relatives of any crop are those of the tomato. Without its wild relatives, the modern tomato simply would not exist. Collectors first noticed clues about the useful features of these wild relatives by observing them in their native habitats.



The story of the modern tomato continues and the germplasm collection is comprehensive, well-maintained, and available for future use. The conservation and breeding use of tomato's wild relatives show what is possible for the many little known, little-used wild relatives of other crops.

A wild flower meadow conserves wild relatives of forages such as nitrogen-fixing clovers and medics.

relatives of crop species is a major consideration. This is why those who work to conserve wild relatives must pay attention to whether *in situ* conservation is a priority for that particular species. IBPGR determines the overall conservation priority for each of the crops they cover, based on its socio-economic importance, the requirements of breeders, an assessment of genetic erosion, and the current status of conservation both *in situ* and *ex situ*. Although it is desirable to conserve all crop relatives *in situ*, it seems sensible to give priority to those that cannot be conserved easily *ex situ*, such as those with recalcitrant seeds.

Even for some wild relatives of crops that are a priority, however, the problems of setting up genetic reserves for them may simply be too great. Good candidates for surviving unprotected are species that grow in remote areas, such as mountaintops, or those that thrive amid minor disturbances from humans or animals. Leaving some wild relatives unprotected—especially if they can be monitored and the germplasm partly protected in seed banks—may be the only solution, at least temporarily.

At times proponents of nature conservation must move quickly to save an area—either because of an endangered or threatened species or simply to take advantage of a good conservation opportunity. They may need to move decisively even before detailed inventories or ecogeographical surveys have begun. An educated guess will need to be made about the potential value of the wild relatives and the capacity of the proposed reserve to adequately conserve them. Later, follow-up surveys should be organized to determine whether enough diversity has been conserved. Supplementary proposals for conservation could then be put forward.

A network of effective genetic reserves with well-documented holdings that are readily available to breeders and other scientists would lead to an increased use of wild relative germplasm for crop enhancement. This could bring many more wild relative genes into major world crops. The results in terms of the benefits to crops, while not immediate, would be evident in time.

5. The future for wild relatives: What to do next?

What is the future for wild crop relatives? What can be their future in a world whose population, according to UN estimates, will double from 5 billion to 10 billion before it starts to fall? Land will be at a premium. If tropical rain forests with their marvellous diversity almost disappear, as predicted, can there be adequate *in situ* reserves for cocoa, rubber, mango and other tropical species? The existing protected areas may become eroded at their borders, and there will be pressure to use the land for growing food. Yet the wild relatives conserved in some of these areas may be critical to the survival of many people.

This poses another question: will food production keep up with population growth? There is grave uncertainty as to whether the increases needed in food production in the next century can be met. To have a chance of doing this, plant breeders will need to use all available genetic materials, including wild relatives. Also, agricultural scientists will have to develop a much wider range of crops than those used in modern agriculture today, to include those adapted for local situations and for marginal lands. All this requires the effective conservation of wild crop relatives.

Clearly, the present arrangements, *ex situ* and *in situ*, do not adequately conserve the diversity of wild relatives. To ensure their future, a carefully worked out strategy is needed. It should include the following tasks:

General

- Taxonomic studies on the genepools of wild crops, particularly in the remoter areas that are centers of crop diversity.
- Ecogeographical surveys of wild relatives, especially for the more widespread species, as the basis for conservation planning.
- Training of researchers to work on wild relatives. In general, there are too few scientists and technicians trained in the specialized tasks required. Many bodies, including IBPGR, sponsor training, but more help is needed through universities, national genetic resources programs, and agricultural research centers.
- Research on biochemical techniques to characterize diversity. One of the most promising is electrophoresis, in which a researcher can compare the protein patterns from different plants as a means of assessing their genetic differences.

Ex situ conservation

- Studies to evaluate the existing, relatively small collections of wild relatives in seed banks, many of which are poorly identified, some even mislabelled.
- The creation of additional seed bank facilities, specially equipped to handle replicated collections of wild relatives.
- Implementation of an expanded program to collect the seeds of wild relatives by the early 1990s.
- Increased research on tissue culture and cryopreservation, as a means of storing *ex situ* plants whose seeds are recalcitrant.
- A broadening of the range of species covered so as to include the wild relatives of the numerous local crops, in addition to the relatively few crops of global importance.

In situ conservation

- Inventories of biosphere reserves and other protected areas to determine which wild relatives they already contain; wherever possible, the inventories should be put on computer using the IUCN-WWF methodology.
- Regular monitoring of known wild relatives in existing protected areas, so as to ensure that they survive and are available to plant breeders. In many cases park management plans will have to be altered to cover the special needs of the wild relatives.
- Creation of specially managed genetic reserves where they are shown to be needed by ecogeographical surveys.

The effective conservation of a crop relative can be a mammoth task, demanding the collaboration of field botanists, crop geneticists, agro-ecologists, taxonomists, plant physiologists, and ethnobotanists. For *in situ* conservation, environmental planners, conservation biologists, ecologists and park managers will also be needed. Wild relatives offer a valuable selling point for nature conservation but without attention to their special needs and demands, substantial conservation opportunities will be squandered.

Concern about crop relatives has been included in the recent debates on genetic resources in FAO. In response, FAO prepared an International Undertaking on Plant Genetic Resources, in which governments promise that plant genetic resources will be "explored, preserved, evaluated and made available for plant breeding and scientific purposes". By April 1988, 84 governments had signed it. In 1987, FAO established a fund for plant genetic resources, inviting governments to contribute. To date, however,

Present priorities for conserving the wild relatives of crops *in situ*

In summer 1984, IBPGR assembled a task force in Washington D.C. to look at ecogeographical surveys and *in situ* conservation of wild crop relatives. The task force found that the world's existing protected natural areas were inadequate for wild crop relatives. They felt that new protected natural areas are needed for numerous species, especially in the tropics. They recommended that parts of certain genepools be considered as priorities for *in situ* conservation, while another group might merit consideration after further study. But comprehensive ecogeographical surveys are needed for almost all crops.

Some high priority species are listed below.

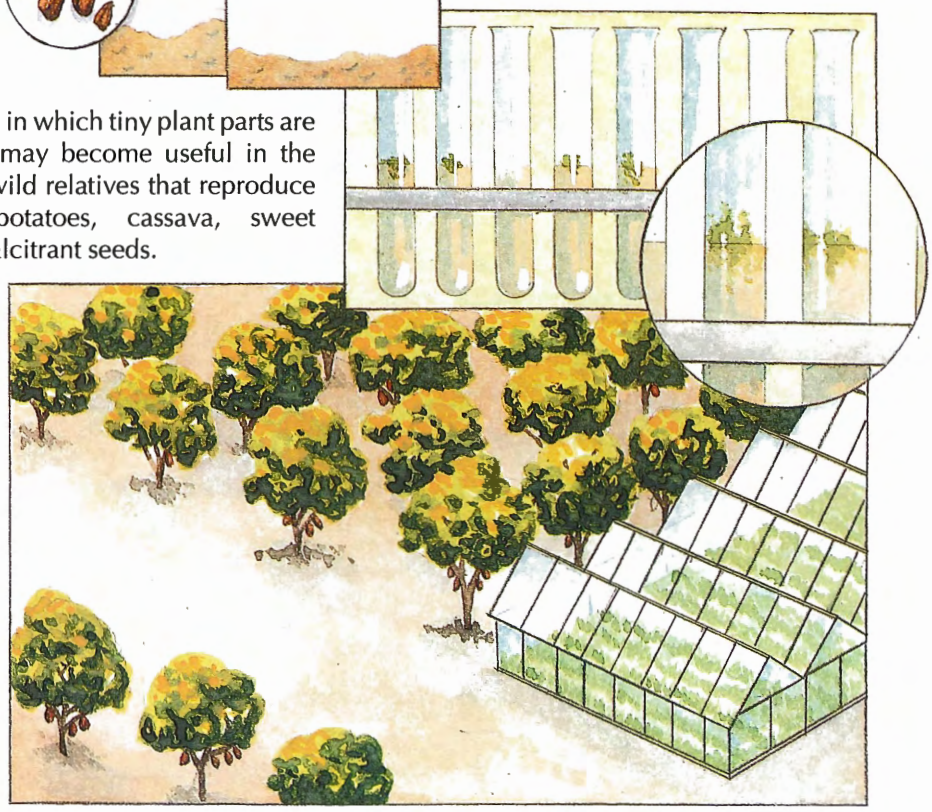
Crop	Wild relatives
Groundnut	perennial *Arachis* species in Latin America
Oil palm	entire *Elaeis* genepool in Africa, and some areas in Latin America
Banana	wild diploid *Musa* species in Asia
Rubber	entire *Hevea* genepool in Amazonia
Coffee	*Coffea arabica* in Africa
Cocoa	entire *Theobroma* genepool in Latin America
Onion Family	some wild *Allium* species on several continents
Citrus Fruit	wild *Citrus* species in Asia
Mango	wild *Mangifera* species in southeast Asia
Cherries, Apples and Pears	wild *Prunus*, Malus and *Pyrus* species in Europe and Asia
Forages	hundreds of different wild species, to be determined in relation to plans for ecosystem conservation.

Ways to conserve wild relatives

Ex situ

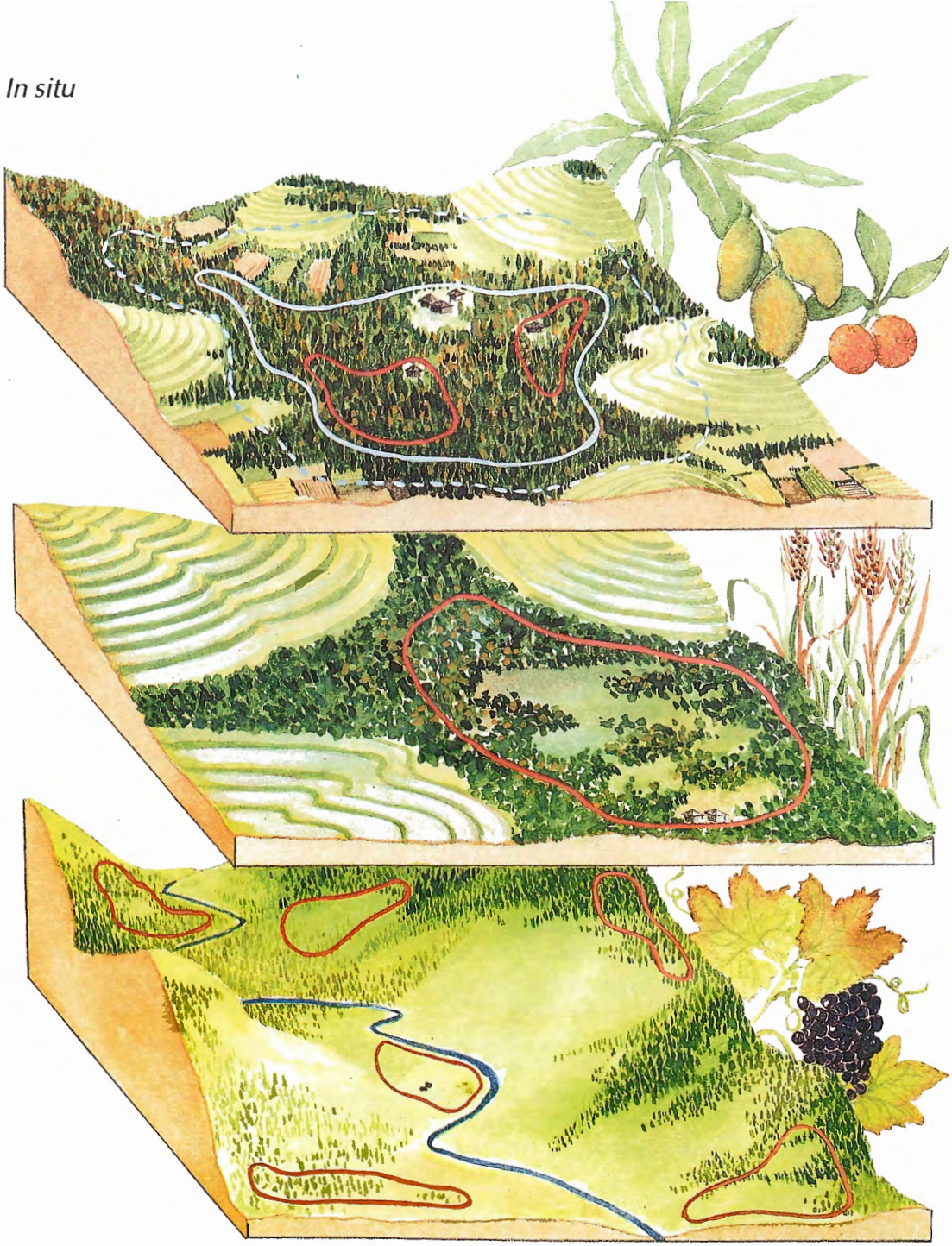
Ex situ: **Seed banks** are the cheapest and most convenient storage method for many crops and wild relatives having orthodox seeds, such as the main cereal crops—wheat, corn and rice.

Ex situ: **Tissue culture**, in which tiny plant parts are stored in test tubes, may become useful in the future for crops and wild relatives that reproduce vegetatively (e.g. potatoes, cassava, sweet potatoes) or have recalcitrant seeds.



Ex situ: **Field genebanks**, in which whole plants are kept alive, provide the best *ex situ* method at present to conserve plants and trees with recalcitrant seeds—seeds unable to tolerate storage in a seed bank—such as cocoa and coconut, as well as crops propagated vegetatively. Only a limited amount of genetic diversity can be represented and the collections are vulnerable to diseases, but this method is convenient for breeders.

In situ



***In situ* or genetic reserves**, located in the wild, are the preferred method for conserving certain wild relatives. Prime candidates include tropical trees with recalcitrant seeds like mangoes and vegetatively propagated perennials such as citrus, shown at top in a biosphere reserve, with two genetic reserve areas outlined in red. The outer area between the dotted and solid blue lines is the transition area. At center, a special-purpose reserve for a wild relative if rice has been established near a rice-growing area for monitoring disease resistances to cultivated rice. At bottom, a network of reserves located in a variety of habitats conserves wild grapes, a plant whose diversity is widely distributed but not fully understood. In each type of reserve, a research team protects and monitors the reserve, samples the wild relatives' genetic diversity and distributes germplasm to breeders.

the issues remain a source of debate and the resources made available so far by governments and other bodies are inadequate.

The aim should be to conserve as much genetic variation of every wild relative as possible, because no one can predict which variants will be needed in future. The more variation that is conserved, the greater the chances that breeders will find the characteristics they may seek in the future. For this reason, wherever possible, both *in situ* and *ex situ* conservation should be used, to compensate for the attendant drawbacks of each approach: *in situ* conservation is expensive, may require large areas of land and may not be practical in some parts of the world. On the other hand, *ex situ* conservation depends on continual human input and, by concentrating a large amount of germplasm in a small space, is vulnerable to outside events; it also arrests evolution. Nevertheless, the top priorities for *in situ* conservation should be those wild relatives with recalcitrant seeds—those that cannot be stored in seed banks. For them, *in situ* conservation may be the only practical way of protecting the major part of their genetic variation.

We must accept that we cannot save everything. Which genes shall we keep for the future? Some difficult, pragmatic decisions—based on the best science we can afford—must be made. It is a costly, time-intensive process which begins with evaluation and ecogeographical surveying and continues through monitoring and long-term management. Then scientists will have to meet with government managers at all levels, and environmental ministries and conservation bodies will need to cooperate to make things happen fast.

To achieve this, government policy decisions and financial backing must be forthcoming. More than 100 countries now have crop seed banks and receive germplasm from collecting missions. As those missions begin to collect more wild relatives and as ecogeographical surveys are completed, a new commitment in time, money and expertise must be made to the conservation of wild relatives. *In situ* conservation, in particular, will require special arrangements and policy directives, backed by substantial financial support.

What is the future for wild relatives? We have come a long way in understanding their unique properties, seeing how useful some of their genes are and glimpsing how useful many others might be. Lately, we have begun to conserve them, but we have a long way to go and only a short time in which to accomplish a great deal. One thing, however, is clear: part of ensuring a future for the world and its growing human population will be safeguarding the future of the wild relatives of crops.

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International Board for Plant Genetic Resources (IBPGR)

IBPGR is an autonomous international scientific organization under the aegis of the Consultative Group on International Agricultural Research (CGIAR). It was established in 1974 and it is situated in Rome at the Food and Agriculture Organization (FAO) of the United Nations. The basic function of IBPGR is to conduct research and to promote an international network of plant genetic resources activities to ensure the collection, conservation, documentation, evaluation and use of plant germplasm and thereby contribute to raising the standard of living and welfare of people throughout the world.

International Union for Conservation of Nature and Natural Resources (IUCN)

IUCN is the largest and most experienced alliance of active conservation authorities, agencies and interest groups in the world. It is unique in acting as an international bridge between scientific and public establishments, governments and private organizations, to allow them to cooperate in their plans for the future.

Founded in 1948, IUCN has over 600 members including sovereign states, government agencies and most of the world's leading independent conservation organizations, in 120 countries. It is an independent, non-profit organization entirely without political or partisan affiliation.

IUCN's mission is to promote sustainable development worldwide and to provide independent international leadership for effective conservation of nature and natural resources.

WWF

WWF — World Wide Fund for Nature — founded in 1961, is the largest world-wide, private nature conservation organization. Based in Switzerland, WWF has national affiliates and associate organizations on five continents. WWF works to conserve the natural environment and ecological processes essential to life on earth.

WWF aims to create awareness of threats to the natural environment, to generate and attract on a world-wide basis the strongest moral and financial support for safeguarding the living world and to convert such suppport into action based on scientific priorities. Since its founding in 1961, WWF has channelled over US$ 130 million into more than 5000 projects in some 130 countries which have saved animals and plants from extinction and helped to conserve natural areas all over the world. It has served as a catalyst for conservation action, and brought its influence to bear on critical conservation needs by working with and influencing governments, non-governmental organizations, scientists, industry and the general public.

IBPGR

IUCN

WWF