Basic Concepts of Conservation for Plant Genetic Resources

General Comments

'Biological diversity, or biodiversity, is the term given to the variety of life on Earth. It is the combination of life forms and their interactions with one another, and with the physical environment that has made Earth habitable for humans. Ecosystems provide the basic necessities of life, offer protection from natural disasters and disease, and are the foundation for human culture' (SCBD 2006).

However, over the last two centuries, both biodiversity and agrobiodiversity have entered a stage where they are at high risk of extinction. The main reason is excessive consumption of resources to sustain rapid population growth. Another reason is the considerable degree of ignorance that exists on biodiversity, leading to its consequent destruction. The plants used by humans do not escape this phenomenon, thus awakening global concern. To conserve this precious variability, which represents humanity's future survival, strategies are being established, two of which are *ex situ* and *in situ* conservation.

Although, as we shall see, the two types of conservation complement each other, this course focuses on *ex situ* conservation.

Information on the Module

This module contains three lessons, each with a rapid evaluation, involving tasks.

Objectives

When you have completed the module you should be able to:

- Justify the raison d'être of conserving plant genetic resources (PGRs)
- Describe the concepts of biodiversity and agrobiodiversity
- Describe strategies for *in situ* and *ex situ* conservation and state their essential differences
- Describe the minimum requirements for *ex situ* conservation

Lessons

1. Genetic resources, biodiversity, and agrobiodiversity
2. Conservation: its raison d'être and strategies
3. Minimum requirements for *ex situ* conservation

Bibliography

Throughout this module, a bibliography is provided for each section, that is, the *General Comments* and each *Lesson*. The bibliographies follow a format of two parts:

1. *Literature cited*, which includes those references cited in the text itself. Some of these citations were used to develop the original Spanish-language course on *ex situ* conservation and may therefore appear in Spanish or Portuguese. However, where practical, references to the English versions of the original Spanish-language documents are provided.

2. *Further reading,* which is a list of suggested readings in the English language. Most cover in depth the topics included in this module.

A list of *Acronyms used in the bibliographies* is also given. The idea is to save space by not having to spell out each institution's full name each time it appears in the references.

Acronyms used in the bibliographies

CGRFA	Commission on Genetic Resources for Food and Agriculture
FAO	Food and Agriculture Organization of the United Nations
IBPGR	International Board for Plant Genetic Resources
IICA	Inter-American Institute for Cooperation in Agriculture
IPGRI	International Plant Genetic Resources Institute
NCBI	National Center for Biotechnology Information
SCBD	Secretariat of the Convention on Biological Diversity

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Contributors to this Module

Rigoberto Hidalgo, Benjamín Pineda, Daniel Debouck, and Mariano Mejía.

Lesson 1 Genetic Resources, Biodiversity, and Agrobiodiversity

Objectives

- To define what is understood by PGRs
- To describe the basic concepts of biodiversity and agrobiodiversity
- To analyze the rationale behind conservation and its benefits

Introduction

Humans depend on plants, which provide food and supply most needs, including clothes and shelter. Plants are also used in industry to make fuels, medicines, fibres, rubber, and other products. However, the number of plants that humans use as food is minimal compared with the number of species existing in nature. Just 30 crops, particularly rice, wheat, and maize, provide 95% of the calories present in the human diet (FAO 1997). Dependency on such a limited number of crops threatens humanity's food security (Valois 1996).

Plant genetic resources are currently of great interest as they are related to satisfying humans' basic needs and to solving severe problems such as hunger and poverty. Today, almost 800 million people are malnourished. Of these, 200 million are children who no more than 5 years old. In the next 30 years, the world's population will increase from about 2500 million inhabitants to 8500 million. To supply food for so many people requires an efficient and sustainable improvement of crop yields (FAO 1996). However, even though they help sustain populations and alleviate poverty, PGRs are vulnerable. They can erode and even disappear, thus endangering the continuity of the human species (Jaramillo and Baena 2000).

Population increase, industrialization, and the expanding agricultural frontier have contributed towards the loss of germplasm, or genetic erosion. To this we must add the adoption of elite germplasm and the modification and/or destruction of centres of genetic variability. This loss of PGRs demonstrates the urgent need to conserve and sustainably use them (Jaramillo and Baena 2000).

What is understood by plant genetic resources?

Plant genetic resources are the sum of all combinations of genes resulting from the evolution of plant species. During evolution, the population of any given species is the receptacle of all past changes and of the results of selections made by the environment. Those changes are conserved in the DNA that constitutes the species genome (Hoagland 1985). In other words, genes contain all the information that defines each trait or character of a living being, in this case, plants. An inheritable trait or character is meticulously reproduced in offspring. Consequently, we find in genes information on adaptation, productivity, resistance to adverse conditions such as pests, diseases, stressful climates, and poor soils, and other characteristics of a population's individuals that are usable by humans to the extent of their knowledge.

In general, PGRs include wild or domesticated plant species that have economic, ecological, or utilitarian potential, whether current or future. The most important of these are those that contribute to food security (IBPGR 1991) and, undoubtedly, are closely related to environmental conservation. Plant genetic resources also include products of classical breeding, biotechnology, and genetic engineering such as transgenic plants, DNA fragments, cloned genes, gene markers, new genetic combinations, silent genes, and chloroplast genomes (FAO 1996; Frankel et al. 1995; Rao and Riley 1994).

Why conserve?

The conservation of PGRs enables humanity to:

- Broaden the diversity of plant foods and related products it can access.
- Improve food crops in terms of yield, quality, adaptability to different environmental conditions, and resistance to pests and diseases.
- Build reserves of breeding materials of native and exotic species that have nutritional or industrial potential. Such potential can be exploited in various ways, for example, in crop improvement programmes that seek higher productivity, resistance to adverse biotic and abiotic conditions, and desired qualities as according to previously established requirements.
- Economically, help nations to increase the productivity and sustainability of their agriculture and even develop it.
- Restore and conserve the environment.

Who benefits from conservation?

Conservation of PGRs directly benefits humanity. As such, investing in conservation generates benefits for society, whether to diversify agriculture or provide environmental services. It is well known that, in the next 30 years, the world's population may easily exceed 8500 million. As a result, its basic needs must be satisfied, both in food and raw materials for food and agricultural industries.

Furthermore, countries that duly conserve their PGRs can better face the challenges of socio-economic development in an increasingly globalized and competitive world. However, programmes must be established to permit the meeting of proposed targets. The spirit of the Convention on Biological Diversity is, currently, of a national character and several countries have PGRs that are not valued within the country as 'national' but may be valued from the perspective of a multilateral system.

Biodiversity and Agrobiodiversity

Biodiversity

This generic term was adopted recently to describe the genetic variability of all living things, as represented by micro-organisms, plants, and animals. Current biodiversity is the result of more than 600 million years of evolution. The number of species existing today is uncertain, being more than 5 million but possibly as high as 100 million (Figure 1).

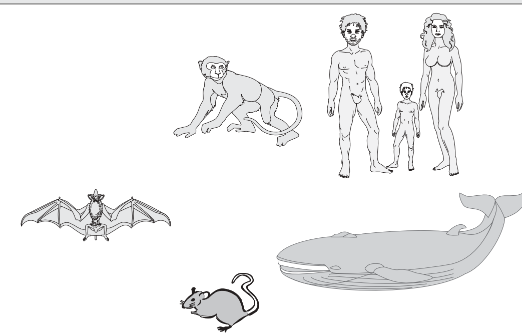
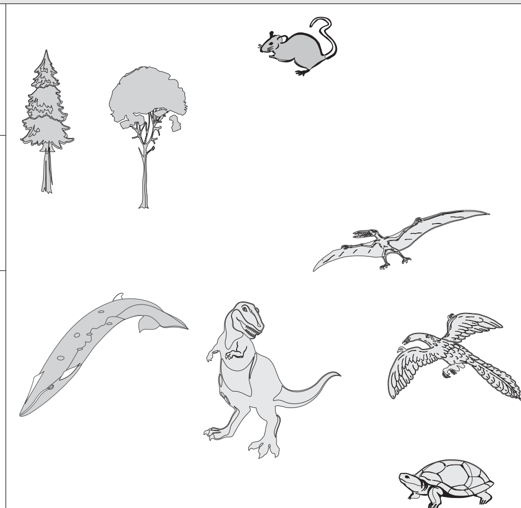
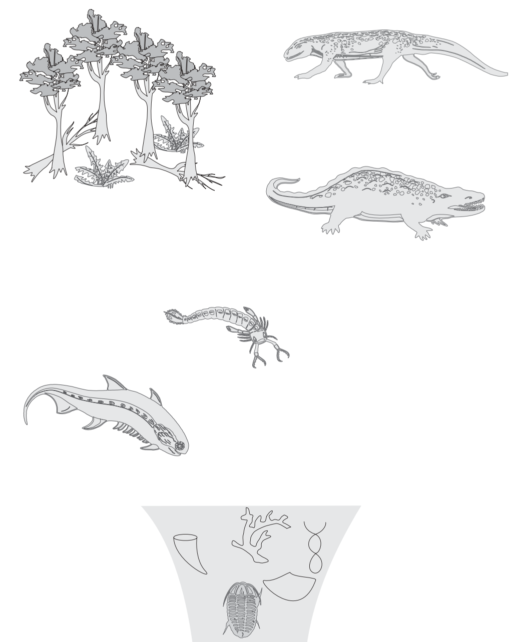
Period	**Epoch**	**Time** (Ma)	**Life forms**	
CENOZOIC ERA (Age of Mammals)				
Quaternary	Pleistocene	1.8–0.1	Humans	
Tertiary	Pliocene	5.0–1.8	Mammals, birds	
	Miocene	23–5	Bony fishes	
	Oligocene	38–23	Modern mammals	
	Eocene	54–38	Modern invertebrates	
	Palaeocene	65–54	Primitive mammals	
MESOZOIC ERA (Age of Reptiles)				
Cretaceous		146–65	EXTINCTION Ancestral mammals Flowering plants	
Jurassic		208–146	Dinosaurs Archaeopteryx (primitive birds)	
Triassic		245–208	EXTINCTION First mammals First dinosaurs Early bony fishes Conifers	

Figure 1. Geological chart, showing species diversity according to era, together with the “Big Five” mass extinctions (adapted from Bryant 2005).

(Continued)

Figure 1. (Continued.)

Period	**Epoch**	**Time** (Ma)	**Life forms**	
PALEOZOIC ERA (Ancient Life)				
Permian		286–245	EXTINCTION Early reptiles Mammal-like reptiles	
Carboniferous		360–286	Giant insects Large amphibians Primitive plants	
Devonian		410–360	EXTINCTION Primitive fishes Primitive plants	
Silurian		440–410	Backboned animals	
Ordovician		505–440	EXTINCTION Invertebrates	
Cambrian		544–505	Invertebrates	
PRECAMBRIAN ERA (Dawn of Life)				
		4500–544		
Unicellular organisms				

A little more than 1.4 million species have been classified. Nearly 1 million correspond to animals (mostly insects) and about 250,000 to plants (Table 1). The least studied have been the micro-organisms but, with the current development of technology, a notable increase in their description is expected in coming years.

Table 1. The number of species described.

Kingdom	Total	%
Viruses	1,000	0.07
Monera	4,760	0.34
Fungi	46,983	3.38
Protista–Algae	26,900	1.93
Protista–Protozoa	30,800	2.21
Plantae	248,428	17.84
Animalia–others	989,761	71.08
Animalia–Chordata	43,853	3.15
Total	1,392,485	100.00

SOURCE: Wilson (1989).

Of the groups of living things, plants and animals have been the most exploited by humans to satisfy their basic needs for food, clothes, housing, and health. To this end, our ancestors began, about 15,000 years ago, selecting those species that were useful to them. During that time, nearly 3,000 plant species were tried, of which only a little more than 100 are currently used. Twenty of these 100 answer the basic needs for sustenance.

Agrobiodiversity

As stated before, of all the species conforming current biodiversity, a special group of plants, animals, and a few micro-organisms was selected by humans for their particular characteristics in answering humans' needs. Since the dawn of agriculture, such species have been under heavy anthropic selection pressures, a consequence of which was the proliferation of many genetic variants of each species. The sum of those selected species and their thousands of variants was recently designated as **agrobiodiversity** (FAO 2004). It is the product of natural evolution plus the effect of selection by humans, which process is known as **domestication**.

Over the last 2 centuries, both biodiversity and agrobiodiversity have entered a stage where they are at high risk of extinction. The main reasons are the concentration of agricultural activities that prioritize only a very few crops, excessive consumption of resources to sustain the world's rapid population growth, and the considerable degree of ignorance about biodiversity. The plants used by humans do not escape this phenomenon, awakening global concern. Strategies are being established to ensure the conservation of that variability, as it represents humanity's future survival.

Germplasm Banks

For conservation strategies to operate, there must be somewhere to identify, store, and maintain the PGRs being conserved. Policies and protocols for their use and distribution must also be put into place. These activities are carried out in germplasm banks, often called gene banks or even germplasm collections. Because of the potential confusion in the use of these terms, we need to clarify them for the context of this course.

As discussed previously, **germplasm** refers to those plant structures that are able to give rise to new generations of a given plant species. By doing so, they carry the total sum of their respective species' hereditary characteristics. Such structures may be seeds, propagules, or DNA (or gene) fragments. A **germplasm collection** therefore brings these structures together in a given place; however, in the world of the genetic resources it is understood more as a collection of genotypes, gene libraries, or alleles of a particular species from different locations or sources (geographic and environmental), used as source material in plant breeding and assembled for conservation (IBPGR 1991). Because of the costliness of their maintenance, most collections are specialized, that is, they focus on particular plant species within a certain context such as conservational, agricultural, research and educational, environmental, historic, aesthetic, or economical.

The place where the germplasm is gathered is the **germplasm bank**, which can be seeds stored in cold rooms, living plants in a field, plants conserved as in vitro or cloned DNA fragments from a single genome; by extension, the germplasm banks are also called as **gene banks**. However, banks are not just physical installations but are also socio-economic-political entities that determine the management of the germplasm being held. Germplasm collections or holdings are therefore the "business" of germplasm banks.

Because of the inclusive meaning of *germplasm*, the term **gene bank** is reserved in the sense of **DNA library** to describe those infrastructures holding only collections of amplified DNA fragments. Perhaps the best known gene bank is GenBank, which is part of the U.S. National Center for Biotechnology Information (NCBI 2006).

Evaluating the Lesson

After this lesson, you should understand the raison d'être for conserving PGRs, the concepts of biodiversity and agrobiodiversity, and the role they play in people's lives.

Before going on to the next lesson you should answer, in your own words, each of the following questions. Write a maximum of one page per question.

- Thinking of the conditions of your own country or region where you live, consider why conservation is necessary.
- What benefits would the adequate conservation of PGRs bring to your country or region?
- Briefly explain the differences between biodiversity and agrobiodiversity.

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Contributors to this Lesson

Rigoberto Hidalgo, Benjamín Pineda, Daniel Debouck, and Mariano Mejía.

Next Lesson

In the next lesson, you will study the rationale behind conservation and its strategies.

Lesson 2 Conservation: Its Raison d'Être and Strategies

Objectives

- To justify the raison d'être for conserving PGRs
- To discuss strategies to conserve PGRs
- To analyze reasons for *ex situ* conservation and its benefits

Introduction

As with all living organisms that develop under natural conditions, the population of individuals that form a plant species is in permanent interaction with its surrounding environment. It must adapt and cope with the continuously changing factors that are part of that environment. These factors are **biotic** (micro-organisms, other plant species, and animals) and **abiotic** (climate and soils). For a plant species to interact with these factors, it uses information contained in its genome according to its needs for surviving in the environment. The result of this adaptive interaction is an accumulation of genetic information that each species keeps, through variants, among the members of its population and transmits to subsequent generations. The information is carried by genes, which enable the species to adapt to changes that may occur in its environment. In other words, the genetic composition of a population also changes over time or, more exactly, it evolves.

As evolutionary processes are dynamic and bring together various forces (according to Theodosius Dobzhansky (1951) mutation, hybridization, selection, and genetic drift), the accumulated changes or information contained in the genes are often lost, and cannot be recovered easily over time. This is when conservation gains raison d'être for its use: to help rescue potentially losable genes, especially those that geneticists and breeders can use.

Conservation Strategies

Species are believed to originate through the action of forces such as genetic variability, natural selection, and speciation. The pertinent information is recorded in the genomes of the individuals that, in nature, constitute the population of each species. We can detect the natural variability contained in the genomes of a species by collecting samples from different places. The samples would comprise reproductive structures or organs that we can grow, classify, and collect such as seeds, stems, bulbs, stolons, cuttings, rhizomes, tubers, and roots. These collections of live plant parts are called germplasm and are conserved in germplasm banks. They form the basis on which to develop conservation strategies.

Because of the heterogeneity of the plants used by humans, no single strategy for conserving the variability of species can be established (Tables 1 and 2). The plants are therefore conserved according to current and future needs and/or usefulness.

Plant genetic resources can be conserved *in situ* in their natural habitats or *ex situ* under conditions other than those of their natural habitats (IPGRI 2004; Jaramillo and Baena 2000). Or the two methods can be combined into a complementary conservation strategy, where *in situ* conservation is used to maintain the natural conditions for the creation of new genetic variability and *ex situ* conservation is used to conserve genetic combinations that

Table 1. Systems of *in situ* conservation of global biodiversity and agrobiodiversity, according to targeted germplasm and expected conservation period.

Class of diversity	Conservation system	Targeted germplasm	Period of conservation
Global biodiversity	Protected areas	• Ecosystems • Wild species (plants and/or animals)	Depends on the degree of stability of protected areas
Agrobiodiversity	Protected areas	Wild ancestral	Depends on life cycle and number of renewals
	On farm	Traditional varieties	Medium or long term
	Gardens	Mixtures of traditional species in communities	Depends on life cycle and number of renewals

Table 2. Systems of *ex situ* conservation of agrobiodiversity, according to targeted germplasm and expected conservation period.

Conservation systems		Targeted germplasm	Period of conservation
Seed type	System		
Orthodox	Seed bank	• Cultivated species • Gene pools	Medium or long term
	Botanic gardens	• Species for classification • Flora (research)	Depends on life cycle and number of renewals
	Cryopreservation bank	Cultivated species	Long term
	DNA bank	Special sequences	
Recalcitrant	*In vitro* bank	• Cultivated species • Wild species	Short term
	In vivo bank (field)	Cultivated species	Depends on life cycle and number of renewals
	Botanic gardens	• Classification • Flora (research)	Depends on life cycle and number of renewals
	Pollen bank	Cultivated species (male plants)	Depends on preservation method
	Cryopreservation bank	Cultivated species	Long term
	DNA bank	Special sequences	Long term

have been shown to be of value and whose existence in nature may be under threat. Conservation is carried out by using collections of live plant parts in:

- Germplasm banks, also known as gene banks (e.g., field, seed, *in vitro*, pollen, or cryopreservation)
- Botanical gardens
- Arboreta and herbaria

Plant germplasm banks are centres of resources for live plant parts. These collections of plant parts operate solely to keep them alive and preserve their characteristics for the future benefit of humankind and the environment. Germplasm banks are also called **plant genetic resources centres** because they give importance to the fact that plants are sources of diversity of genetic characteristics. Conserved plants include economically important food crops (modern and primitive crops, and their wild relatives), horticultural plants, forages, medicinal plants, and trees.

In Situ and *Ex Situ* Conservation

Both *in situ* and *ex situ* conservation belong to the important set of activities that comprises the management of PGRs. *In situ* conservation is defined as the conservation of plant or animal species in the habitats in which they had developed naturally (Maxted et al. 1997). In contrast, *ex situ* conservation is defined as the conservation of a species outside its natural habitat. However, such a definition of *ex situ* conservation is very broad, belying the complexity of its meaning. For the purposes of this course, the following definition is suggested:

> Ex situ *conservation encompasses all the strategies developed by humans to conserve the germplasm of a plant species outside its natural habitat. It is applied especially to agrobiodiversity*.

Although *in situ* conservation is directed mainly at the global biodiversity of wild species through the identification of natural reserves and national parks, some *in situ* strategies can also be applied to agrobiodiversity. For example, the ancestral wild forms of cultivated species, native landraces, and traditional varieties are conserved in regions that have been centres of traditional agriculture over many years. Some of these strategies include conservation on farms and in household gardens (Tables 1 and 2).

When all the variability of a species must be conserved, including its gene pools, then, usually, several *ex situ* and *in situ* strategies must be implemented simultaneously and in a complementary fashion.

Although both *in situ* and *ex situ* conservation have their advantages and disadvantages (Table 3), the most relevant and most discussed disadvantage of *ex situ* conservation refers to the evolutionary consequences for the species. However, we need to understand that this is precisely what is intended: to stabilize and fix the genetic characteristics of a material so we can take advantage of it as it is. Indeed, it is argued, by taking the germplasm of a species out of its habitat to conserve it in a germplasm bank, its evolutionary development is frozen in terms of the environmental changes that continue to take place in the site from where it was taken. However, other factors exist, such as the disappearance or disturbance of centres of diversity, which encourage us to use an *ex situ* strategy as the practical solution for saving the still-existing variability. Particularly in recent decades, this type of conservation has become widespread (Hidalgo 1991).

When speaking of advantages and disadvantages, we also need to include the relative costs of the two types of conservation. *In situ* conservation can be very expensive, compared with *ex situ* conservation, as it requires considerable space to conserve the

Table 3. Relative advantages and disadvantages of *ex situ* and *in situ* conservation.

Type	Advantage	Disadvantage
Ex situ	• Greater diversity of the targeted taxon can be conserved as seed • Easy access for evaluations of resistance to pests and diseases • Easy access for improvement and use • Little maintenance for germplasm conserved over the long term	• Freezes evolutionary developments with regard to environmental changes • Genetic diversity is potentially lost with each regeneration cycle
In situ	• Dynamic conservation with regard to environmental changes • Permits species–pathogen interactions and coevolution • Applicable to many recalcitrant species • Requires active supervision over the long term • Less genetic diversity can be conserved in a single site	• Germplasm is not readily available for use • Vulnerable to disasters, natural and/or man-made • Poorly known methodologies or management regimes

biological communities of the targeted species. Nevertheless, their different advantages and disadvantages imply that the two types of conservation can complement each other by conserving species that the other cannot.

Why ex situ *conservation?*

Applied to cultivated species, *ex situ* conservation aims to conserve, outside their centre of origin or diversity, both the species and the variability produced during the evolutionary process of domestication. *Ex situ* conservation can encompass a broad taxonomic spectrum. It is used to protect species, including their wild ancestral species, weedy or regressive forms, and cultivated varieties, particularly those whose original geographic centres of diversity are now under high threat of disturbance or disappearance.

What can be conserved ex situ*?*

In theory, all species can be conserved *ex situ*, provided we can multiply them. We can conserve individual genotypes outside nature, but not the relationships between them and their ecological environment. Traditionally, *ex situ* conservation has been used for resources important to humans, such as those used for food and agriculture, and whose conservation will provide immediate and future availability, as well as security.

FAO's short *Report on the State of the World PGRFA*, that is, agrobiodiversity (FAO 1996), mentions 1300 registered collections for plant species, which include about 6.1 million accessions of germplasm conserved *ex situ*. The FAO WIEWS database indicates that 48% of accessions conserved are cereals, 16% are food legumes, and each of vegetables, roots and tubers, fruits, and forages account for less than 10% of global collections. For Africa, about 50 countries report having 124 collections that conserve more than 350,000 accessions, that is, 6% of the global germplasm.

Among the agricultural species interesting for research and as a basis of human sustenance is a broad range of materials that can be conserved *ex situ*. These include:

- *Wild species, and regressive and weedy forms* that belong to cultivated genera and constitute a broad range of important materials for research and crop improvement (Frankel et al. 1995; Prescott-Allen and Prescott-Allen 1988).
- *Wild relatives and regressive forms*, which are commonly used as sources of genes to improve traits of interest. They can also provide resistance to diseases and pests. Among the many crops favoured by related wild species, a good example is sugar cane. Modern sugar cane is a complex derived from artificial hybrids, whose pedigree includes the wild species *Saccharum spontaneum*, which contributed to the crop's yield, vigour, and resistance to diseases. Other examples are maize, rice, and tomato.
- *Varieties of traditional agriculture*, including native landraces, primitive cultivars, and species of cultural importance (e.g., for use in religious ceremonies).
- *Products of scientific improvement programmes*, for example, modern and obsolete cultivars, advanced lines, mutants, and synthetic materials.
- *Products of biotechnology and genetic engineering*, including transgenic plants, DNA fragments, cloned genes, gene markers, new genetic combinations, silent genes, and chloroplast genomes. Biotechnology and genetic engineering permit the isolation and transfer of genes of plants of agronomic interest, as well as of genes of almost any plant, animal, or bacterium that had not been previously accessed (FAO 1996; Frankel et al. 1995; Rao and Riley 1994).

Strategies for *Ex Situ* Conservation

Strategies for *ex situ* conservation are determined by the biological characteristics of each species, particularly its reproductive system. Indeed, before deciding on any methodology of *ex situ* conservation, we need to answer the following basic questions in reference to any given species:

- Does it produce sexual seed?
- If it produces sexual seed, is the seed orthodox or recalcitrant?
- If it does not produce sexual seed, does it have vegetative reproduction?
- If it has vegetative reproduction, what is the most suitable propagule for reproducing the species?
- In addition to producing sexual seed, does it also have vegetative reproduction?

The answers to such questions facilitate decision making with regard to the most suitable strategy for the species in question. If the species produces orthodox seeds, then the establishment of a low-temperature seed bank can immediately be considered. However, if the seed is recalcitrant, then it cannot be dried or conserved at low temperatures. Hence, other alternatives need to be sought such as a live field bank or an *in vitro* bank. If the species does not produce seed, then both live field banks and *in vitro* banks can be considered. We point out that most cultivated species can be conserved as *ex situ* collections.

When knowledge on the species is advanced, other additional strategies such as DNA or cryopreservation banks are applied (Table 2). However, these strategies correspond to very different purposes and would be available only to users of advanced technology.

Evaluating the Lesson

After this lesson, you should understand the reasons for conserving PGRs; conservation strategies, and their advantages and disadvantages; and the PGRs that can be conserved.

Before going on to the next lesson you should answer, in your own words, each of the following questions. Write a maximum of one page, per question.

- Under the conditions in which you work in your country or region, what materials specifically are being conserved *ex situ?*
- What principal benefits does your country or region derive from conserving these materials *ex situ*? Would the *ex situ* conservation of this germplasm be advantageous for your country or region?
- What is your opinion of *in situ* conservation?
- If you had to decide on the application of a plan to conserve PGRs, what strategies would you apply?

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Contributors to this Lesson

Rigoberto Hidalgo, Benjamín Pineda, Daniel Debouck, and Mariano Mejía.

Next Lesson

In the next lesson, you will study the minimum requirements for the *ex situ* conservation of PGRs.

Minimum Requirements for *Ex Situ* Conservation

Objective

To define those minimum requirements for the *ex situ* conservation of PGRs, taking into account biological, physical, human, and institutional aspects

Introduction

The conservation of PGRs is a continuous long-term task that implies significant investments of time, personnel, installations, and operation. Such investments should be justified in terms of needs rather than of desire or convenience in conserving a material. The reasons for conserving and targeting specific species should be defined according to logical, scientific, and economic criteria such as need, value, and use of the species, and the feasibility of conserving them (Maxted et al. 1997).

Conservation provides maximum benefit when the activities that compose it are closely articulated. The task's success will be measured in terms of producing the desired result at minimal cost.

Requirements for the *Ex Situ* Conservation of PGRs

Conservation should reduce as much as possible the effects of the new environment on the targeted species. Those who conserve germplasm must acquire an in-depth knowledge of the targeted species, that is, their biology, taxonomy, and genetics so that adequate techniques can be developed for representing their genetic variability and ensuring the stability of the original genotypes. Equally important is the documentation of the germplasm because it allows a better understanding and use of the germplasm's inherent genetic variability, that is, information obtained through, for example, developing passport data, characterization, and evaluation should also be documented.

In general, the minimum requirements for the adequate *ex situ* conservation of PGRs can be grouped as four factors: biological, physical, human, and institutional.

Biological requirements

- *In-depth knowledge of the species' biology*. This includes mainly the plant's life cycle and the biology of its reproduction. This information indicates the type of propagule that should be conserved. That is, by knowing if a given species produces sexual seed (true seed), asexual seed (also called vegetative, e.g., stakes, stolons, tubers, and roots), or has the two options, we can determine the type of bank that should be established for it, whether a seed bank, *in vivo* field bank, or *in vitro* bank. Whatever type is selected, it should conserve, in the most suitable and practical form possible, the germplasm of that species.
- *Type of pollination*. For a species that propagates through sexual seed, knowing its reproduction biology will also help identify the type of pollination of the species, whether it is **allogamous** or **autogamous**. This knowledge is essential for correctly managing the germplasm of a species, as it forms the basis on which to establish agronomic protocols for maintaining a field collection of that germplasm. Such

knowledge will also help develop suitable sampling strategies to maintain the original genetic composition of the conserved accessions.

- *Ecological adaptation*. Knowing the environmental conditions to which a given species is adapted is also essential. The most relevant data include ranges of altitudes and latitudes, day length, and thermo period. Of lesser importance, although also useful, are the physical conditions of soils and response to excess or deficient water supplies. This information is vital for selecting the most suitable sites for multiplying and/or regenerating the germplasm of the conserved species.
- *Physiology of the reproductive structure*. Success in conserving a species depends largely on understanding the physiology of the reproductive structure or organ. These may be botanical seed, meristems, buds, stem pieces, stakes, stolons, tubers, roots, bulbs, or rhizomes. In the case of seeds, principal factors to consider are the determination of **orthodox** or **recalcitrant** behaviour, identification of the seed's cycle of physiological maturity, presence of dormancy, suitable methods for harvesting, and seed health status.

Physical requirements

The facilities in which materials are to be conserved should guarantee isolation from both environmental factors and pests and diseases. Installations may vary in design and dimensions, depending on the number and size of the samples to be conserved. However, they should have access to a constant supply of electric power and equipment that permit the conditioning, preservation, and regeneration of materials. They should be able to protect the materials from fires, floods, theft, plunder, and other disturbances of public order. The infrastructure to use depends on the type of seed the species has, for example:

- *Species with true sexual seed that can be conserved at low temperatures*. Essentially, highly reliable systems are needed to control the temperatures and relative humidity within the rooms where the seeds are conserved. Likewise, suitable seed-drying equipment is needed. To prevent physical damage to the seed, this equipment must be checked before use.
- *Species that propagate through asexual or vegetative seed*. These species need suitably selected fields where they will be able to fulfil their normal biological cycles and that the plant part of interest for use will develop normally. To select such a field, the principal variables to consider are altitude, temperatures, day length, rainfall regimes, soil conditions, easy access, and the possibility of continuous use.
- *Species that must be conserved* in vitro. The laboratory must be located in a place that will guarantee a stable supply of electric power without the trauma of irregular cuts. The location's environmental conditions should permit the easy establishment of aseptic conditions, so that pest infestations or disease outbreaks are not sufficiently chronic to endanger the conservation of the germplasm.

Requirements for human resources

Collections of PGRs should be managed by skilled personnel who are, where possible, from various disciplines (e.g., physiologists, botanists, breeders, and agronomists). They should know the technical aspects of adequately managing the species and the inherent safety procedures of their tasks. Ideally, the collection would depend on a group of people who are work stable—not exclusively the curator—who can provide continuity to the conservation work, and who are free of political pressures or problems of public order. That is, the personnel usually need to:

- Be technical personnel with academic training in genetic resources and/or experience in managing germplasm banks or germplasm collections, preferably of cultivated plant species.
- Be technical personnel who have medium- or long-term continuity, as research on genetic resources usually requires considerable patience and relatively long periods to acquire sound knowledge on the conservation of the species mentioned.
- Receive cooperation and advice from other professionals such as botanists, taxonomists, geneticists, biologists, physiologists, breeders, agronomists, and refrigeration engineers.

Institutional requirements

- *Sustainable institutional, governmental, and political support.* Merely creating a germplasm bank does not guarantee the conservation of PGRs of interest to a country, region, province, or given ecosystem. Conservation requires consistent ongoing institutional support in terms of economic, human, and technical resources for maintaining collections and carrying out conservation activities. This aspect is particularly important for the variability of traditional crops in centres of diversity on all continents as, for example, cultivated rice in Africa. According to focus-group interviews with farmers, self-supply of seeds has declined recently, particularly for floating rice. As dependency on local markets for seed supply increases, the farmers are recognizing that a gradual decline of seeds can lead to the total loss of a variety (Synnevåg et al. nd). Policy decisions that distort institutional objectives may be encouraging this situation, as in Latin America, which suffers recurrent difficulties when the institutional mandate differs from that of the conservation unit. A classical example is when the institution is assigned to the Ministry of Agriculture, which, by nature, is a ministry for 'development', whereas the conservation unit is, by nature, conservative.
- *Long-term planning.* The reasons for conserving targeted species should be defined according to logical criteria. As with any strategic process, the conservation of PGRs implies planning and making decisions based on previous information. Conservation requires the establishment of priorities in terms of types of species to conserve (e.g., species at risk or of interest for food and agriculture), activities to be subsequently carried out with the collected and conserved germplasm, and the resources available to carry them out. Priorities may vary, but the most important objectives are that conservation is for the long term and that the conserved germplasm should be used.
- *Economic resources.* Because the nature of *ex situ* conservation is to ensure perpetuity, it demands the sustained provision over time of economic resources to maintain the physical, human, and technical resources required to upkeep the collections and conduct conservation activities (Koo et al. 2002).

Evaluating the Lesson

After this lesson, you should know what the minimum requirements are for the *ex situ* conservation of PGRs, whether these be biological, physical, human, or institutional.

You have now completed Module 1 of the course but, before going on to the next module, you should answer, in your own words, each of the following questions. Write a maximum of one page per question.

- Under the conditions in which you work in your country or region, what are the minimum requirements for carrying out *ex situ* conservation?
- In your opinion and for your case, which of the requirements mentioned in the lesson would need the most attention?

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Contributors to this Lesson

Rigoberto Hidalgo, Benjamín Pineda, Daniel Debouck, and Mariano Mejía.

Next Module

In the lessons of the next module, you will study aspects of procuring and introducing germplasm.