PLANT AND ANIMAL GENEBANKS

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Summary

This article is concerned with *ex situ* approaches for the conservation of plant and animal genetic resources. Genetic resources comprise the diversity of genetic material in plants and animals, which determines their characteristics and hence their ability to adapt and survive. The introduction and historical background provided explain how the process of domestication over many years together with the advent of modern breeding strategies during the twentieth century entailed a narrowing of the total genetic base in both crop plants and animal breeds. *Ex situ* conservation methods emerged and evolved as a response to growing global recognition over the twentieth century of the need for deliberate conservation measures to safeguard against continued losses of valuable genetic diversity in plant and animal species.

Several types of genebanks exist, depending on the type of plant or animal material to be conserved, ranging from seed genebanks used for many food crops, to *in vitro* conservation facilities, including cryopreservation genebanks and DNA libraries for both plant and animal germplasm. The state-of-the-art techniques used in each case is described in detail along with a summary of major advantages and limitations. A discussion of the need for a more holistic approach to conservation follows, describing how complementary conservation strategies employing an appropriate combination of conservation methods can increase the total genetic diversity conserved, its security, accessibility, and the overall cost efficiency of the conservation effort.

In the concluding sections, attention is drawn to future research priorities, with particular reference to the implications of rapid technological developments and relevant policy and legal frameworks.

1. Introduction

Genetic resources comprise the diversity of genetic material contained in traditional and modern crop varieties and animal breeds, including their wild relatives and genetic stocks, as well as in other wild species that can be used now or in the future. Biological diversity occurs at three different levels:

- at the ecosystem level, as the different combinations of plant and animal species and the interactions between them
- at the species level, as the number of different species
- within species, as different combinations of genes

It is this genetic diversity that gives species the ability to adapt to changing environments, including new pests, diseases, and climatic conditions. In addition, it provides breeders and farmers with raw material for continuous improvement of crops and farm animal breeds.

The importance of genetic diversity in crop and animal improvement, and hence in agricultural development, with particular attention drawn to the unprecedented rates at which this diversity is being lost and the urgent need for conservation action to protect plant and animal resources from increasing threats of genetic erosion is presented in another essay (see *Conservation of Plant Genetic Diversity*).

This article is concerned with the conservation of these valuable resources for their continued availability and use into the future. Conservation of animal and plant genetic resources can be broadly classified into two principal approaches, i.e. *in situ* and *ex situ* conservation. *In situ* conservation is concerned with the maintenance of species within their natural environments. *Ex situ* conservation comprises methods that allow for the maintenance of the genetic integrity of collected germplasm samples outside their natural habitat. The main focus in this article is on *ex situ* conservation methods, where genetic resources are maintained outside their natural habitats and managed under artificial conditions in facilities known as genebanks. The primary concern of genetic resources programs is the diversity found within species (i.e. intraspecific diversity). Genebanks are an important component of such efforts. Other approaches to genetic resources conservation, such as on-farm and *in situ* conservation, which are concerned with the maintenance of genetic diversity at all levels, will only be touched upon within the context of complementary conservation strategies.

In the first section, the history of genetic resources conservation is presented and the various types of genebanks are described in general terms. A presentation of various germplasm storage and maintenance methods and a discussion of current perspectives and future trends with respect to the use and effectiveness of these methods follow this. In the concluding section, attention is drawn to research directions, with particular reference to the implications of developments in technology and relevant policy and legal frameworks.

2. Historical Background

2.5. Plant and Animal Domestication

The plant and animal species upon which humanity relies for food and agriculture are the result of a long process of domestication, which has involved targeted human selection and management over many centuries and in many parts of the world (see *Historical Origins of Agriculture*). In this process, only part of the total genetic diversity available in nature, i.e. the genetic variability inherent in the original population of plants or animals recruited from the wild, was used as the raw material for generating new progeny. Thus, it is essentially only a subset of the total genepool of each species that contributed to the development of the early domesticates. In many species, this limited genetic base was further narrowed through more focused human selection, recombination, and propagation of a relatively small number of plants and animals with economically important agronomic characteristics. Traditionally, farmers have played a crucial role in the creation and maintenance of genetic diversity in crops and farm animals and continue to play this role in many parts of the world. Today, on-farm management practices of genetic diversity are widely recognized as a vital part of the conservation and sustainable use of these resources *in situ.*

2.6. History of Plant Genetic Resources Conservation

Modern plant breeding started at the end of the nineteenth century following the discovery of the heredity laws by Gregor Mendel. Its rapid development during the twentieth century expedited the human-steered evolution of crop species resulting in significant increases in the productivity of major crops such as maize, wheat, and rice. In many of these crops, however, modern plant breeding has entailed further narrowing of the total genetic base available to future generations, which had already been significantly reduced through the domestication process. Professional plant breeders used highly specific criteria in deciding which particular plants with useful genetic characteristics to include in their crop improvement programs. This focus on a relatively small number of genotypes with desirable traits meant that a large amount of potentially useful genetic variability was excluded from breeding programs. This resulted in significant losses in valuable crop genetic diversity. It was within this context that recognition of the value of genetic diversity and the need to ensure the continued availability of crop genetic resources arose. Indeed, the idea of assembling samples of plant germplasm and conserving them *ex situ* first started with the establishment of breeders' working collections maintained by breeders for use in their improvement programs.

In the 1950s and 1960s, major advances in plant breeding brought about the Green Revolution which resulted in the wide-scale adoption of high-yielding and genetically uniform modern cultivars of staple crops, particularly wheat and rice. Global concern about the loss of genetic diversity in these crops and its implications in terms of food security increased as farmers throughout the world abandoned their locally adapted landraces and traditional varieties, replacing them with the improved yet genetically uniform products of modern plant breeding.

In response to this concern the International Agricultural Research Centers (IARCs) of the Consultative Group on International Agricultural Research (CGIAR) started in the 1960s to assemble germplasm collections of the major world crop species within their respective mandates. For example, the International Rice Research Institute (IRRI) and the International Center for the Improvement of Maize and Wheat (CIMMYT: Centro Internacional de Mejoramiento de Maiz y Trigo) took the lead in assembling global *ex situ* collections of rice, maize, and wheat, respectively. These collections were built up through collaborative collecting expeditions with national partners and the incorporation of material contributed by research and breeding programs around the world.

It was within this context that the International Board for Plant Genetic Resources (IBPGR) was established in 1974 to coordinate the global effort under way to systematically collect and conserve the world's threatened plant genetic diversity. Today, IBPGR's successor—the International Plant Genetic Resources Institute (IPGRI, a member Institute of the CGIAR)—is the largest international organization devoted to the conservation and use of plant genetic resources through the development of appropriate technologies and strategies.

The large-scale international collecting efforts, many of which were supported by IBPGR during the late 1970s and 1980s, were focused primarily on the world's major food crops, including cereals, some legumes, and a few root crops. Many of these crops produce orthodox seeds, which can tolerate extensive desiccation and exposure to low temperatures without losing their viability. A convenient procedure was thus worked out for conserving such species by drying their seeds to a low moisture content and storing them at low temperatures. Continued research, aimed at optimizing conditions for seed storage, led to the adoption of a two-tiered conservation strategy:

- long-term conservation of *base collections*, and
- short-term storage of active collections

These procedures and conditions were widely adopted as the conventional method for *ex situ* conservation of orthodox seeds in facilities known as seed genebanks.

The limitations of conventional seed storage procedures, and the historical context in which the early *ex situ* collections of plant germplasm were established, resulted in a relative overrepresentation of orthodox seed-producing food crops in the world's major genebanks. Alternative methods were needed for conserving vegetatively propagated crops for which seed conservation is not appropriate, e.g., potato, cassava, banana, and so on. Hence, the establishment of field genebanks—collections of plants maintained as living specimens—was given due attention. Such field collections were also established for conserving species that produce recalcitrant seeds. Recalcitrant seeds do not survive when dried to low moisture content and hence are not amenable to storage at low temperatures, e.g., many of the tropical fruit and nut species. Compared with seed genebanks, however, the adoption of field genebanks has been relatively limited. This is because of the high costs involved in the maintenance of living collections of plants in the field and the vulnerability of the material conserved in this way to pests, diseases, and natural calamities.

In recognition of the need for more effective ways for *ex situ* maintenance of vegetatively propagated and recalcitrant-seed producing species, subsequent research attention focused on the development of alternative conservation technologies for such difficult plants. In the early 1980s, IBPGR initiated research projects on *in vitro* conservation, i.e. the maintenance of plant tissue in an artificial medium in test tubes. This resulted in the development of practical methods that allow secure and relatively cost-effective conservation of plant material in the laboratory. The application of these methods on a larger scale led to the establishment of *in vitro* genebanks for medium-term maintenance of vegetatively propagated crops such as banana, cassava, potato, and yam. Tissue culture conservation methods were later complemented by a special technique for long-term storage of plant material in liquid nitrogen known as cryopreservation. This same method has also been widely used for the conservation of animal genetic resources as described in the section below.

Largely as a result of the developments in biotechnology, the concept of genebanks has further broadened to include the maintenance of both plant and animal gene sequences in facilities known as DNA libraries/genebanks.

2.7. History of Animal Genetic Resources Conservation

The need to conserve farm and aquatic animal genetic resources emerged as a global concern years after the conservation of plant genetic resources was recognized as an important worldwide priority. Yet, basic techniques for conserving animal semen had already been developed and were in use as early as the 1950s when artificial insemination began in cattle breeding.

Artificial reproduction methods have since been well developed and are now widely employed in breeding programs for farm animals (including cattle, pigs, goats, sheep, and horses).

Concern about genetic erosion in domesticated animals came about in much the same way as in the case of plants. Advances in breeding programs, particularly in Europe and much of the developed world, have largely influenced the current composition of farm animal populations used for food production. Modern breeding of farm animals, which involves intensive selection of highly productive superior breeds, excluded the valuable genetic diversity inherent in local breeds.

Local farm animal breeds are the result of a long process of domestication and improvement through selection in the particular production systems to which they are adapted. Increasingly, modern animal breeds—characterized by high productivity and intensive use of drugs against diseases— replaced the locally adapted breeds.

About 50% of the total genetic variation in farm animal species is believed to be within breeds. The loss of a particular breed can therefore substantially reduce the genetic variation within a species. The resulting decline in the diversity of animal genetic resources is most notable in Europe. According to the Domestic Animal Diversity Information System (DAD-IS, 1988–1994)—a database currently maintained by the Food and Agriculture Organization of the UN—only 332 cattle, 407 sheep, 123 goats, 156 pigs, and 213 horse breeds are to be found in the 37 Western European countries listed. A similar trend can be observed in Central and Eastern Europe where increasing farm animal production through modern breeding programs is among key development priorities.

Concerted international efforts to address this decline in animal genetic diversity did not begin until the late 1980s. It was not until 1995, for example, that the FAO Commission on Plant Genetic Resources (originally established in 1983) broadened its scope and mandate to embrace all components of agricultural biodiversity—plant and animal genetic resources. This contributed to increased recognition of the need to ensure the continued availability of animal genetic resources, leading to the establishment of proper animal genebanks for long-term *ex situ* conservation of their genetic resources, primarily in the form of cryopreserved semen, i.e. in sperm banks. The maintenance of live animal populations or pedigree herds outside their production environments is also a widely practiced *ex situ* conservation strategy.

The need to devise methods for using cryopreserved material for generating new progeny has been more compelling in animal breeding given the complexity of their reproduction systems. Hence, methods for thawing out cryopreserved semen, and for realizing acceptable levels of conception through artificial insemination, have been well developed for most farm animal species. Cryopreservation techniques have been applied to other reproductive material. The cryopreservation of embryos has become a relatively routine procedure in most domestic animal species. Germplasm conservation in the form of embryos which are diploid is thus considerably more efficient than storage of germplasm in the haploid state, i.e. in the form of spermatozoa. This is because the embryo provides the full genetic makeup of the breed or species. Cryopreservation of embryos also has added advantages: the risk of disease transmission is less in embryos than in sperm cells, and cryopreserved embryos provide a more portable and less costly way for transporting/exchanging genetic resources.

Advances have also been made in cold storage of oocytes. As in the case of plants, the use of these *ex situ* conservation methods was regarded as an adequate conservation strategy for animal genetic resources, but there is wide consensus regarding the vital role to be played by *in situ* conservation of animal genetic resources by maintaining populations within their original production systems.

Systematic global efforts to conserve fish genetic resources began at an even later date. In 1995, following a series of international meetings on fish genetic resources, including expert consultations held by FAO, the FAO Commission on Genetic Resources further broadened its mandate to include aquatic genetic resources. The concept of genebanking was rigorously appraised in the context of fish genetic resources conservation at a landmark international conference held in 1998. The overall situation for genebanking of aquatic organisms is significantly different from that of plant and farm animals. Indeed, the genebank concept takes on an even broader meaning in the context of aquatic genetic resources. Owing to the short history of the domestication of most farmed aquatic species, relatively few systematic fish breeding programs have been established, either at national or international levels. Still, an estimated 85% of the world's aquatic products are harvested from the wild rather than farmed. In many parts of the world, fish breeders still depend on the broodstock available in wild and farmed populations. Conservation of aquatic genetic resources is thus particularly urgent because genetic erosion has become a critical concern in many of the world's fisheries at a time when relatively limited progress has been made in aquatic animal breeding.

Consensus on the precise role of *ex situ* conservation in aquatic genetic resources is lacking. However, it is believed that fish genebanks comprising both fish in aquaria and cryopreserved fish sperm can help improve the current situation considerably by ensuring the continued availability of the genetic resources, particularly of endangered species.

Although the principles for germplasm cryopreservation originated in the dairy industry, the advances made in the cryopreservation of fish spermatozoa have been significant.

These techniques have expanded the use of cryopreservation and improved genetic resources management approaches in a number of farmed species such as carp, catfish, salmon, tilapia, and trout. Thus, sperm banks and egg or embryo banks, in the event that techniques for their cryopreservation are developed and can be applied routinely, are likely to play an increasingly significant role in the *ex situ* conservation of aquatic animals.

However, in the absence of routine gamete and embryo cryopreservation protocols for the vast majority of aquatic species, and the limitations of costly *ex situ* aquaria which only allow the maintenance of a limited range of genetic diversity within a species, *in situ* management of aquatic animals remains the most practical conservation option in many cases.

A comprehensive approach comprising both living fish populations and cryopreserved fish sperm genebanks has been used in the few well-established national programs such as the Norwegian Atlantic Salmon Gene Bank. The CGIAR Center concerned with the sustainable management of aquatic resources—the International Center for Living Aquatic Research Management (ICLARM) has acquired some experience in the *in situ* management of aquatic organisms in protected areas. ICLARM has also supported the establishment of an *ex situ* germplasm collection of Nile tilapia (*Oreochromis niloticus*), comprising cryopreserved spermatozoa and living collections in tanks and ponds. In addition to promoting the efficiency of farm animal and fish improvement programs, DNA libraries wherein animal genetic resources are maintained in the form of specific gene sequences, are also expected to play an increasingly important role in the *ex situ* conservation of animal genetic resources.

2.8. Plant and Animal Genebanks: General Similarities and Differences

Although strong analogies exist at many levels, the fundamental differences in the reproductive biology and mating systems of plants and animals translate into different considerations in terms of *ex situ* conservation and use of their genetic resources. At a general level, the underlying strategic concerns converge when considering the ultimate purpose of both plant and animal genetic resources conservation—which is to ensure their continued availability for use.

From a conservation perspective, the basic biological differences between plants and animals become most evident when one considers that convenient methods analogous to seed storage are lacking in animals. This has direct implications in terms of the differences in the scale at which plant and animal *ex situ* conservation efforts can be applied. On the other hand, because of the broad applicability of *in vitro* techniques and particularly, cryopreservation, there is considerable overlap between the relevant technical procedures and considerations involved in the maintenance of plant, farm animal, and fish genetic resources using such methods. However, major differences arise between plants and animals when it comes to the technical practicalities of using the conserved genetic material to generate new organisms. In animals, this entails an additional step after thawing and conditioning the cryopreserved material, involving the use of elaborate techniques such as artificial insemination, *in vitro* fertilization techniques (which are at a relatively early stage of development for most animal species), and embryo transfer. In the case of plant species, a similar situation would apply only if pollen and/or egg cells were being conserved rather than seeds.

Although still at a relatively early stage of development, the use of DNA conservation techniques is perhaps the only approach wherein the fundamental differences in plant and animal reproductive systems will have little bearing on the conservation and use of their genetic resources.

As described above, the concept of a genebank, which originated in the context of plant conservation, with the establishment of the first long-term seed storage facilities, has broadened considerably over the years within the realm of both plant and animal genetic resources. Hence, it is difficult to articulate a general definition of a genebank, which applies to all groups of organisms. The term has been used to refer to all types of *ex situ* germplasm collections maintained in different ways. Table 1 summarizes the historical context in which the concept of genebanking emerged and evolved in plant and animal genetic resources conservation.

In the case of plants, a broader concept of genebanking has emerged with the development of improved and/or alternative techniques for conserving plant material and their application to a wider array of species with diverse biological characteristics. In animals, the significance and role of genebanks has evolved with the application of *in vitro* techniques to different types of animal reproductive material, and with the improvement of artificial reproduction methods.

In both plants and animals, *ex situ* conservation methods have preceded deliberate attempts to conserve genetic resources *in situ*. By the early 1990s, there was wide recognition that a viable conservation strategy could not be achieved through *ex situ* methods alone. The coming into force of the Convention on Biological Diversity in 1993 marked a shift from the long history of focus on *ex situ* methods conservation of genetic resources to emphasis on the maintenance of plants and animals in their natural habitats.

Plant genetic resources	**1950s**	**Animal genetic resources**
Rapid expansion of modern plant breeding techniques Establishment of breeders' working collections of plant material—precursors of the first seed genebanks		1949: *Beginning of modern cryobiology:* mammalian spermatozoa were first frozen and thawed successfully *Ex situ* maintenance (cryopreservation) of farm animal semen for breeding purposes
Major advances in modern plant breeding led to the Green Revolution: wide- scale adoption of high-yielding genetically uniform modern cultivars of staple crops	1960s	Advances in farm animal breeding improvement of artificial insemination techniques
Heightened global concern regarding genetic erosion in crop plants led to large international plant collecting missions 1974: IBPGR established	1970s	1972: first success in cryopreserving mammalian embryos (freezing/ thawing without losing viability)

Procedures for long-term storage of orthodox seed producing species established 1983: The International Undertaking on Plant Genetic Resources adopted by the FAO Commission on Plant Genetic Resources for Food & Agriculture as a nonbinding set of rules to promote international conservation efforts and stem the rapid erosion of crop plant diversity Establishment of field genebanks, e.g., major international field genebanks for potato (CIP) and cassava (CIAT).	1980s	Concerted international efforts on farm animal genetic resources started in Europe
Research initiated on alternative methods for conserving vegetatively propagated and recalcitrant-seed species, e.g., pilot *in vitro* genebank of cassava		
By the early 1990s more than 1000 germplasm collections had been established around the world	1990s	Heightened global concern regarding genetic erosion in farm and aquatic animals 1993: FAO launched special action program for Global Management of Farm Animal Genetic Resources
1993: Convention on Biological Diversity came into force		
Shift in emphasis from only *ex situ* to also include *in situ* conservation strategies 1996: Global Plan of Action for the Conservation and Sustainable Utilization of Plant Genetic Resources for Food and Agriculture adopted by 150 countries at the IVth Technical Conference on Plant Genetic Resources, Leipzig, Germany		1993: International Network on Genetics in Aquaculture: launch an international initiative aimed at improving management and production of major tropical fin fish involving 13 African and Asian countries, ICLARM and UNDP 1995: FAO Commission on Genetic Resources broadened its mandate to include farm and aquatic animal genetic resources Advances in techniques for cryopreservation of animal reproductive material and artificial insemination 1998: *Action Before Extinction*: international experts convene to lay down conceptual framework for the role of *ex situ* methods and genebanks in the conservation of fish genetic resources
Major advances in molecular genetics: powerful new techniques for the conservation and use of genetic resources establishment of plant and animal DNA libraries		

CIP: Centro Internacional de la Papa -member institute of the CGIAR
CIAT: Centro Internacional de Agricultura Tropical - member institute of the CGIAR

Table 1. Historical evolution of plant and animal genebanks: summary of global developments

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Biographical Sketches

Johannes M.M. Engels graduated from the University of Wageningen, The Netherlands, in 1974, and obtained his Ph.D. from the same university in 1986. He worked from 1975 until 1988 for the German Agency for Technical Cooperation (GTZ) in Costa Rica and Ethiopia in the establishment of genebanks, and then joined the International Board for Plant Genetic Resources (IBPGR, now called the International Plant Genetic Resources Institute, the IPGRI) where he occupies the position of Director of the Genetic Resources Science and Technology Group. He is the author of 23 papers in refereed journals, author or editor of 7 books and catalogues, author of 11 book chapters, series editor of 2 IPGRI series, volume editor of 2 IPGRI publications, and author of more than 60 research communications.

Hareya Fassil is a graduate of the University of California at Berkeley (US), from where she obtained her Masters degree in Environmental Health Sciences following a BSc. in Biology from Mills College (Oakland, CA, US). She has been working as Scientific Assistant at the International Plant Genetic Resources Institute (IPGRI) since 1994. In her current position within the Genetic Resources Science and Technology group, she has gained considerable experience in the management and operation of genebanks and been involved in a variety of activities most of which fall under the Institute's research work on *ex situ* conservation technologies and strategies. She has contributed to a number of IPGRI's technical publications and information products including databases, particularly in the areas of seed conservation and genebank management. Before joining IPGRI, Hareya worked as a postgraduate fellow in the Pharmaceutical Division, Communications Department of Ciba-Geigy, Ltd. (Basel, Switzerland).