MODULE 6:

CONSERVATION AND SUSTAINABLE USE OF GENETIC RESOURCES FOR FOOD AND AGRICULTURE

Overview

This module describes the nature of genetic resources for food and agriculture and outlines why these resources are essential for climate-smart agriculture. After a brief description of the expected impacts of climate change on genetic resources for food and agriculture, the module highlights their role in climate change adaptation and mitigation.

Examples from around the world are used to demonstrate how the conservation and use of the rich genetic diversity of plants and animals both between and within species used for food and agriculture can benefit present and future generations.

Key messages

- Genetic resources for food and agriculture are the basis for sustainable agriculture and food security. They are essential elements for increasing the efficiency and resilience of food systems.
- Genetic resources are the raw materials that farmers, breeders and researchers rely upon to improve the quality and the amount of food produced, and to respond to new conditions, including changes in climate.
- The conservation and sustainable use of genetic resources provide important options for adapting agricultural production to the impacts of climate change. Consequently, any loss of genetic diversity is a threat to the well-being of present and future generations.
- A proper understanding of genetic resources (e.g. inventory, characterization, and monitoring) is a prerequisite for coping with climate change. A conservation strategy that uses a combination of ex situ and in situ techniques is most likely to safeguard the genetic diversity required to meet the needs of present and future generations.
- Ensuring that the appropriate genetic resources with the relevant traits for climate change adaptation and mitigation are available and accessible is crucial. In most countries, a significant part of the genetic diversity used in food and agriculture originates from other countries. Countries, both developed and developing are thus interdependent, when it comes to getting access to these genetic resources to safeguard their food security.

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6.1 Genetic resources for food and agriculture

Agriculture, including livestock keeping, forestry, aquaculture and fisheries, depends on the three components of biodiversity: the diversity of species, the diversity within each species and the diversity of ecosystems. The diversity of genetic resources for food and agriculture (i.e. plants, animals, aquatic resources, forests, micro-organisms and invertebrates) plays an essential role in meeting basic human food and nutritional needs and maintaining essential ecosystem services, such as pest and disease regulation. Genetic diversity gives rise to the diverse characteristics that enable different plants and animals to fulfill different roles in the environment. Their genetic make-up also influences how they will respond to environmental challenges, such as extreme temperatures, drought, flooding and pests and diseases; it also regulates the length of the growing season and production cycle and the sensitivity of organisms to inputs, such as fertilizer, water and feed. Genetic resistance to pests, diseases and drought found within crop and animal genepools, have been key priority of conservation and breeding programmes to improve crops varieties and animal breeds.

High diversity of genetic resources may appear redundant at one point in time, it however may become important when the environment changes. Such redundancy will allow for the continued functioning of the ecosystem and the provisioning of ecosystem services because different genotypes perform slightly different roles and occupy different environmental niches (Lin, 2011). This is why the diversity of genetic resources for food and agriculture is essential for maintaining and enhancing the efficiency and the resilience of agro-ecosystems and food systems.

Centuries of selection and domestication by farmers and breeders, combined with natural selection, have led to the development of thousands of varieties of crops. For generations, this rich diversity has allowed people to obtain food and sustain their livelihoods in difficult terrain and under extreme climatic conditions. It has helped agricultural communities to cope with unexpected changes. Likewise, rural communities have developed livestock breeds that can support livelihoods in some of the most inhospitable areas on Earth, from Arctic tundras and high mountains to hot dry deserts, where crop production is often difficult or impossible (see also Module 8 on livestock).

However, genetic diversity is being lost at an alarming rate. Among the main threats to biodiversity are climate change, loss of natural habitats and environmental degradation. Changes in consumer demand and the use of only a few species, varieties and breeds also contribute to genetic erosion. For example, it is estimated that currently only 30 crops provide over 90 percent of human food energy needs, and just five of them (rice, wheat, maize, millet and sorghum) provide about 60 percent of the energy intake of the world's population (FAO, 2010c). While the number of plant species that supply most of the world's energy and protein is relatively small, the diversity within these species is often immense. For example, there are an estimated 100 000 distinct varieties of the rice species Oryza sativa. Farming communities in the Andes cultivate more than 175 locally named potato varieties (FAO, 2009). In addition there are 50 000 to 60 000 species of crop wild relatives which are potential gene donors for crop improvement. It is this diversity within species that allows for the cultivation of crops across many different regions and under many different environmental conditions (see also Module 7 on crop production systems).

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Of the approximately 8 300 recorded livestock breeds, 22 percent are at risk of extinction, and 8 percent have already become extinct (FAO, 2012a). Food production from livestock is also heavily concentrated in a small group of species. While more than 30 mammalian and bird species have been domesticated, three species (cattle, chickens and pigs) account for about 88 percent of the world's annual meat production from livestock, two species (cattle and buffaloes) for about 96 percent of milk production and just one species (chickens) for about 92 percent of egg production (figures for 2011 as recorded in FAO's statistical database FAOSTAT).

The world's aquatic ecosystems contain over 175 000 species of fish, molluscs, crustaceans and aquatic plants (FAO, forthcoming). The widespread domestication and selection in aquatic species has only recently begun, but rapid progress is being made. FAO estimates that over 350 species of fish and aquatic invertebrates and plants are farmed around the world. However, only ten species (comprised of shellfish, crustaceans, plants and fin fish) account for half of the total aquaculture production (FAO, 2013a). The processes of domestication and selection have created significant inter- and intra-specific diversity (see also Module 10 on fisheries and aquaculture).

Forests are home to over 80 percent of terrestrial biodiversity. Genetic diversity provides the fundamental basis for evolution of forest tree species, enabling them to adapt to changing and adverse conditions (see also Module 9 on forestry). There are over 80 000 tree species, but less than one percent of these have been studied in any depth for their present and future potential. As a result of pressure on forest lands and the effects of unsustainable use of forest resources, the great potential of forest genetic resources, including their potential for coping with climate change, is at risk of being lost forever, before it can be identified, let alone utilized (FAO, 2013c).

Micro-organisms (e.g. bacteria and fungi) and invertebrates (e.g. insects, arachnids and earthworms) are the most numerous groups of species on Earth. They contribute to the delivery of essential ecosystem services, including regulating services, such as disease and pest control; and supporting services, such as the decomposition of organic matter and nitrogen fixation, which contribute to maintaining healthy soils. Micro-organisms and invertebrates are also essential in many food and agro-industrial processes, including fermentation (e.g. for yoghurt and cheese) and bioremediation, (e.g. the use of micro-organism metabolism to remove pollutants or other contaminants). Pollination services by animals, especially insects, affect 35 percent of the world's crop production and increase the outputs of 87 of the world's leading food crops (FAO, 2013b).

The exchange of genetic material among farmers, local communities and breeders has been common practice in the food and agriculture sector. Production systems and technologies, including their associated genetic diversity, have frequently been transferred to other countries and regions. As a result, a significant part of the genetic diversity used in food and agriculture today is of exotic origin, and few countries are self-sufficient in terms of their genetic resources for food and agriculture (Palacios, 1998). Most countries need to access genetic resources from elsewhere for their agricultural production and food security. Consequently, these countries should be regarded as interdependent when it comes to genetic resources. In the future, it can be expected that the challenges posed by climate change will increase the trend towards greater international exchange of genetic resources for food and agriculture (Schloen *et al.*, 2011).

6.2 Genetic resources for food and agriculture: a prerequisite for climate-smart agriculture

Climate change and genetic resources for food and agriculture have a two-way relationship. On the one hand, climate change severely threatens genetic resources. On the other hand, there is a growing recognition that conserving and using genetic diversity is essential for coping with climate change.

Climate change puts stress on and poses many risks to genetic resources for food and agriculture. In general, climate change is expected to change species distribution, population sizes, community composition, the timing of biological events and the behaviour of many species. Climate change will also affect ecosystem dynamics in various ways. Potential consequences include asynchrony between crop flowering and the presence of pollinators, and increasingly favourable conditions for invasive alien species, pests and parasites. As ecosystems change, the distribution and abundance of disease vectors are likely to be affected, which will have consequences for the epidemiology of many crop and livestock diseases (Pilling and Hoffmann, 2011; Jarvis *et al.*, 2009).

Climate change threatens the crop and animal genetic resources that might be used in adapting production systems to future conditions. On the one hand, extreme weather events (e.g. heat waves, droughts and floods), which are predicted to increase in frequency because of climate change, can pose an immediate threat to the survival of breeds and varieties that are only raised in specific and very limited areas. On the other hand, as conditions change, varieties and breeds may be abandoned by farmers and livestock keepers, and may be lost forever if steps are not taken to ensure their conservation.

Climate change scenarios also indicate that genetic resources for food and agriculture will need to move geographically, even from one country to another. The knowledge needed for the most appropriate use of those genetic resources, whether scientific, traditional or indigenous, will also need to be shared and made available to new users. The transfer of resources and knowledge will not simply be a natural and spontaneous process. It will need to be implemented and supported by effective international cooperation.

Natural forests are unlikely to be able to migrate quickly enough to "follow" the climates to which they are adapted. At least in the short term, natural forests will have to rely on "plasticity", the peculiar ability of trees to change their characteristics in response to changes in the environment without changing their genetic structure. In the future, some assisted migration is likely to be necessary. For example, trees can be grown in plantations, either as seeds or seedlings, and transported to sites where the future climate is expected to match their requirements. Although assisted migration of tree species and populations within species is recognized as a potentially important response to climate change, the approach has not yet been widely used. The example presented in Box 6.1 is an exception (Loo *et al.*, 2011) (see also Module 9 on forestry).

Box 6.1
Changes in seed transfer guidelines in response to climate change: an example from Canada

During the 1980s, the Canadian province of British Columbia adopted the concept of seed zones. Provenance trials were established for commercially important tree species, and the province's forest land was classified on the basis of geography, climate and vegetation. The boundaries of seed zones were identified by relating the adaptive characteristics of the tree populations to the ecological classification of the land.

Increasing concern about the effects of climate change led to a new approach in which the potential effects of climate change were assessed using an ecosystem-based climate envelope model. The results predicted that tree species whose northern range limit lies in British Columbia could gain suitable new habitat at a rate of at least 100 kilometers per decade.

On the basis of this and similar work, seed transfer policies in the province were re-examined and British Columbia now claims to be the first jurisdiction to have modified seed transfer standards specifically in response to climate change. The modest modification allows seeds of most species in most areas to be moved 100 to 200 meters upwards in elevation. The new policy is an implicit recognition of the need for assisted migration to ensure that tree plantations in the province will be adapted to future climatic changes.

Sources: Ying and Yanchuk, 2006; Hamann and Wang, 2006; Wang *et al.*, 2006; British Columbia Ministry of Forests, Lands and Natural Resource Operations, 2008

However, in some cases, moving existing genetic resources for food and agriculture and knowledge will not be enough. There will be a constant need to improve the level of characterization, selection, reproduction and deployment in the field of the suitable genetic resources adapted to the new climate. These activities will need targeted and forward-looking investments. Generating new knowledge in this area will increasingly be essential to cope with climate change in the future.

Genetic resources for food and agriculture will continue to represent key resources for building the resilience of agro-ecosystems and providing suitable varieties and breeding stocks with which to adapt production to changing conditions, in particular, changing climatic conditions. Crops, animals and other genetic resources that the world relies on to ensure food security and nutrition will need to adapt to the impacts of climate change. The conservation and sustainable use of a wide range of genetic diversity are fundamental in developing resilience to shocks, shortening production cycles and generating higher yields, ideally with better quality and higher nutritional content. Breeding activities need to continue addressing a variety of factors to ensure that genetic resources for food and agriculture are able to adapt to new production conditions.

The traits that may be important for climate change adaptation include:

- capacity to tolerate high temperatures and droughts;
- fire resistance and tolerance, especially for trees;
- resistance or tolerance to diseases and parasites;
- capacity to utilize scarce and poor quality feed and soil;
- tolerance to lower water quality, especially for aquatic organisms (e.g. lack of available oxygen, acidification, increased or reduced salinity, increased turbidity and siltation, increased levels of pollutants);
- in livestock, capacity to range over harsh terrain in search of feed and water;
- phenotypic plasticity; and
- fecundity and fertility rates.

The nutrient contents of different varieties and breeds can vary considerably and can play a significant role in food security and nutrition. Nutritional value should be considered in breeding activities. Commonly consumed species and varieties are not necessarily the ones with the richest nutrient contents. For example, potato is a predominant staple in some countries. There are over 5 000 varieties of potatoes, and nutrient contents vary significantly among these varieties. Iron content of different varieties of potatoes ranges from 0.14 to 10.4 milligrams per 100 grams edible portion. This wide variation in iron content can lead to significant differences in the iron nutritional status of consumers (Burlingame *et al.*, 2009).

The use of the appropriate genetic resources for food and agriculture will help farmers, pastoralists, fisher folk, fish farmers and forest managers to reduce their vulnerability to risks associated with climate change (e.g. harvest losses due to pests, diseases or droughts) and improve their livelihoods.

Aquatic ecosystems and their biota account for the largest carbon and nitrogen fluxes on the planet and serve as its largest carbon sinks (Pullin and White, 2011). In addition, the role that natural forests and tree planting can play in mitigating climate change through carbon sequestration has been widely recognized. However, the significance of genetic variation within species is less well appreciated. Trees can only provide mitigation services if they are well adapted to their surroundings and have the potential to adapt to future changes. Moreover, in the case of smallholder agro-forestry systems, trees will only become established if they provide clear livelihood benefits. Current payment mechanisms to reward farmers for sequestrating carbon by growing trees are generally inefficient and provide only limited rewards. The main reason farmers plant trees will continue to be the desire to obtain the products and services directly provided by the trees. The genetic attributes that enable the trees to provide these products and services are crucial (Loo *et al.*, 2011).

Micro-organisms play an important role in the sequestration of carbon in soil organic matter. They also release carbon in the form of carbon dioxide (CO_2) when soil organic matter decomposes. Given the enormous amount of carbon stored in the world's soils, micro-organisms are extremely significant to climate change mitigation (see also Module 4 on soils). Their contribution to carbon sequestration can be promoted by practices such as amending soil with organic fertilizers, the proper management of crop residues, no-tillage agriculture, maintaining cover crops on the soil surface, avoiding flood irrigation and carefully managing the use of fertilizers (Beed *et al.*, 2011).

The report of the Intergovernmental Panel on Climate Change (IPCC) indicates that agriculture contributes about 47 percent and 58 percent of total anthropogenic emissions of methane (CH_4) and nitrous oxide (N_2O), respectively. However, there is a range of uncertainty in the estimates. The main sources of non-CO_2 emissions from agriculture are CH_4 from enteric fermentation (38 percent) and N_2O emissions from soils (32 percent) (IPCC, 2007). Globally, cattle are the major source for enteric CH_4 emissions. Dietary manipulation and improved feeding systems can reduce CH_4 emissions and nitrogenous emissions and contribute to climate change mitigation. A better understanding of the micro-organisms involved in the digestive processes in the rumen will provide a basis for interventions that improve the efficiency of digestion and reduce the amount of pollutants produced by ruminant livestock (McSweeney and Mackie, 2012) (see also Module 8 on livestock).

Using and conserving genetic resources for food and agriculture

In agricultural systems, breeds and varieties of livestock and crops that are abandoned by farmers or pastoralists (i.e. are no longer used for production) often face the risk of extinction. The abandonment of particular genetic resources can be caused by increasing availability and popularity of alternative varieties or breeds (usually those developed through intensive breeding programmes), changes in consumer demand and changing agricultural practices and production systems.

When the survival of breeds or varieties is threatened because they are falling out of use, efforts should be made, where feasible, to promote alternative uses for them. In this regard, there are opportunities, particularly in developed countries, to develop niche markets for specialized products (see Box 6.2) and to use grazing animals in the management of landscapes and wildlife habitats.

Box 6.2
Marketing to promote locally adapted breeds and improve livelihoods

Throughout the world and over centuries, small-scale livestock keepers and pastoralists have developed animal breeds that are well-suited to local conditions. Hardy and disease-resistant, many of these breeds can survive on little water and scant vegetation. They can continue producing meat and milk in areas where modern, imported breeds cannot survive without expensive housing, feed and veterinary care. Traditional breeds allow people in inhospitable areas to earn a living and maintain valuable traits for future breeding efforts. However, these breeds are often in danger of disappearing, pushed out by modern production techniques and more competitive exotic breeds. Finding niche markets for these products is one way of ensuring the survival of these breeds and enabling the people who keep them to earn more.

FAO has compiled eight cases from Africa, Asia and Latin America where outside interventions have attempted to develop markets for specialty products from locally adapted breeds. The products include wool, cashmere, meat, hides, milk and dairy products, from dromedaries, Bactrian camels, sheep and goats. The countries included in the case studies are Argentina, India, Kyrgyzstan, Mauritania, Mongolia, Somalia and South Africa. Some of the initiatives targeted urban markets within the country; others were aimed at export markets.

Source: FAO, 2010a

The use of genetically diverse varieties and breeds should be promoted as it improves the resilience of agro-ecosystems, preserves future breeding options and helps to reduce genetic erosion. Broadening the accessible genetic resource base enables more effective management of genetic resources for food and agriculture. For example, a wide range of accessible plant genetic diversity allows farmers to change crops, varieties and farming systems to meet changing climate conditions (Asfaw and Lipper, 2011).

A number of traditional production systems increase the diversity of genetic resources and employ specific techniques for ensuring their optimal use. These systems can influence the agro-ecosystem in such a way that it becomes more able to cope with some of the expected secondary effects of climate change. Rice-fish agricultural systems, which co-evolved with wet rice cultivation in China about 2 000 years ago, are an example (see Box 6.3). These systems are sustainable and can provide a valuable source of protein, especially for subsistence farmers practising rainfed agriculture.

Box 6.3
Rice-fish agriculture systems in China

The rice-fish cultural system is practised in a mountainous area of the southern Zhejiang province in China, in Longxian Village in Qingtian County. In this system, rice fields are irrigated using gravity-fed methods that draw water from streams. Fish swim though the streams and live in the paddies.

The system creates an ecological symbiosis. Fish provide nutrition and fertilizer to rice, regulate micro-climatic conditions and eat larvae and weeds in the flooded fields. Their presence reduces the cost of labour needed for fertilization and pest control. The extension of the shallow water surface in rice fields and the disturbances caused by the activities of the fish help maintain high levels of oxygen in the water, which is essential for fish growth.

Because little or no chemical fertilizers and pesticides are used in the paddy fields, the system also supports the conservation of agricultural biodiversity, including: traditional rice varieties; native breeds of carps (red, black, white); and other wild aquatic species, such as frogs, toads, newts, salamanders, snails, rice field eels and loaches.

By enabling communities to sustain themselves, the rice-fish agriculture systems create favourable eco-environmental conditions that help conserve other crop species cultivated in home gardens (e.g. lotus roots, beans, taro, eggplant, Chinese plums, mulberry and forest tree species of ethno-botanical and medicinal uses).

All the services provided by the rich biodiversity of the rice-fish agricultural system strengthen the resilience of the whole wetland ecosystem. The system can help farmers adapt to changing climate conditions and contribute to the development of climate-smart agriculture. The application of integrated rice-fish farming is now being validated through field activities in Mali and in Burkina Faso, where there is considerable potential for the integration of irrigation and aquaculture (reviewed in Halwart and Dam, 2006).

Source: GIAHS, 2013a

Farmers and herders interact with the ecosystems in which they live. Similarly, domesticated crops and animals also interact with species in the wild. Nomadic and semi-nomadic pastoral systems foster particularly valuable interactions between domestic and wild species.

Box 6.4
Sustainable practices of nomadic pastoralists

In the Islamic Republic of Iran, the highly diverse vegetation of the rangelands has evolved together with the livestock and land management systems of pastoralists. Wildlife has also evolved side by side with nomadism. Nomadic pastoralists describe how throughout time livestock have grazed side by side with wild ungulates.

They speak of “the brotherhood of livestock and wildlife.” The Qashqai nomadic pastoralists have sophisticated scouting and early warning systems that enable them to predict droughts, take preventive measures and adopt coping strategies.

Over time, the Qashqai have developed irreplaceable techniques of habitat management and rangeland rehabilitation for maintaining the diversity of bio-ecological systems. Most Qashqais know the names and properties of every botanical species on the rangelands. They can provide comprehensive descriptions of their value for medicine, food, feed and manufacturing, and their place in the ecosystem.

Under the indigenous management systems of the Qashqai, the cutting of living trees, other than in extreme need and with sustainable use in mind, is prohibited and considered a sin. Sustainable use of non-timber products (e.g. gums, medicinal and veterinary plants, vegetable dyes, mushrooms and other edible herbs and fruits) are relied on for subsistence and only occasionally sold at markets.

The Qashqai’s sustainable hunting practices have preserved wildlife for centuries. Adaptive methods for capturing and storing water in drylands and maintaining springs and water holes for their livestock have also provided water for wildlife.

Source: GIAHS, 2013c

Mobile systems usually provide pastoralists with the flexibility needed to adapt to changing climatic conditions and erratic and unpredictable availability of resources. Livestock trampling, browsing and seed dispersal, and the deposition of manure on grazing lands and along migration routes, help to maintain rangeland productivity and biodiversity and make the grassland more resilient to changes. The removal or drastic reduction of grazing often results not only in lower long-term productivity, but also changes the landscape, which becomes dominated by shrubs.

In situ conservation

The Convention on Biological Diversity defines *in situ* conservation as the maintenance and recovery of viable populations of species in their natural surroundings and, in the case of domesticated or cultivated species on-farm, in the surroundings where they have developed their distinctive properties. This definition encompasses two distinct concepts, namely *in situ* conservation sensu strict (in the strict sense), and on-farm conservation. While *in situ* conservation primarily deals with wild species in natural habitats and ecosystems, on-farm conservation deals with domesticated species in traditional farming systems. However both concepts are generally referred to as *in situ* conservation. By managing organisms in their natural state or within their normal range, *in situ* conservation maintains both the population and the evolutionary processes that enable the population to adapt. *In situ* conservation of wild relatives is most commonly carried out by protecting the sites where important populations of the target species are present and designating these sites as genetic reserves.

Forest tree species are typically long-lived, highly genetically diverse organisms that have developed natural mechanisms (e.g. with huge capacity of dispersal of pollen and of seeds over wide areas) to maintain high levels of intraspecific variation. These mechanisms, combined with native environments that change considerably over time and across wide areas, have contributed to the evolution of forest tree species into some of the most genetically variable organisms on Earth. For forest species, the term circa situm (also "circa situ") has been used to refer to conservation within altered agricultural landscapes (e.g. agroforestry systems, home gardens) outside the species' natural habitat but within its native geographical range (FAO, 2013c).

Genetic resources for food and agriculture play an integral part in agricultural and food production systems. The maintenance and evolution of these genetic resources strongly depend on continued human intervention and, in many cases, on traditional knowledge passed from generation to generation over centuries. Box 6.5 provides an example of how an ancient technique has allowed the conservation and sustainable use of genetic resources essential for food and nutrition security.

Box 6.5
Temperature regulation and soil fertility in the southern Peruvian Andes


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In the southern Peruvian Andes, over 4 000 metres above sea level, farmers cultivate several varieties of potatoes and other native crops, such as quinoa. They use "raised fields" locally known as waru-waru: a platform of soil surrounded by ditches filled with water. During the day, these water-filled trenches are warmed by sunlight. When temperatures drop at night, the water gives off the heat that protects the crops from frost. The system also helps maintain soil fertility. In the canals, silt, sediment, algae, and plant and animal residues decay into a nutrient-rich muck which can be dug out seasonally and added to the raised beds. This productive and inexpensive technique requires no modern tools or fertilizers. However, it is highly specialized and requires specific expertise and traditional knowledge that has been developed over centuries.

Source: GIAHS, 2013d

Capture fisheries are the only remaining major source of food that is based on wild resources. The sustainable management of these wild resources requires *in situ* conservation. Because they are common property, unmanaged open-access fisheries tend to be overexploited, which has the potential to drive local species into extinction. The private sector, national governments, regional fishery management bodies and scientific institutions are all involved in conserving these resources in their natural environments, so that fisheries can continue to provide the services that communities and economies depend on. Maintaining the health of wild aquatic resources, their gene-pool and the ecosystems that support them will allow fisheries systems and fishers to adapt to new climatic conditions (see also Module 10 on fisheries). Box 6.6 provides an example of a subregional programme for improving fish for aquaculture and protecting native gene pools.

Box 6.6
Tilapia Volta Project in West Africa

The Tilapia Volta Project brings together national fisheries institutions and national environmental institutions from six West African countries (Benin, Burkina Faso, Côte d'Ivoire, Ghana, Mali and Togo). The project protects native gene pools of tilapia by characterizing wild genetic resources, which can also serve as a measure for adapting to climate change, and establishing a conservation plan that includes the identification of conservation zones. At the same time, the project is developing an improved aquaculture strain of Nile tilapia (the cichlid species Oreochromis niloticus), which is one of the two principal species used in West African fish culture and is native to the Volta River Basin. The improved strain will have better production characteristics (e.g. improved growth rates).

Source: FAO, 2010b

When managed in an integrated way, entire agro-ecosystems, including useful species (such as cultivated crops, forages and agroforestry species) and their wild and weedy relatives, can be highly productive and resilient systems (see more on landscapes in Module 2). For example, the Kuttanad Wetland, the only farming system in India in which rice is cultivated below sea level (see Box 6.7), contributes to the conservation of biodiversity and ecosystem services and supports the livelihoods of local communities.

Box 6.7
Kuttanad below-sea-level farming system

In India, local people have transformed the swamps located below sea level, which form the Kuttanad Wetland, into cultivable, fishable and habitable lands. They have done this through the natural reclamation of flood deposits, sediments, sand, silts and the buried remains of timber of huge trees and natural litters. The Kuttanad agro-ecosystem can be categorized into three ecosystems: rice fields (Karapadam); wetlands (Kayal); and buried lands (Kari). The local communities have intelligently and prudently managed these three ecosystems through a farm system that supports a wide variety of plants (e.g. Oryza sativa, Cocos nucifera, Areca catechu, Mangifera indica, Artocarpus hirsuitus, Vigna unguiculata, Sesamun orientale, Musa paradisiaca, and some tuber crops), endemic fish, clams, mangroves and associated species. The rice fields are popularly known as Puncha Vayals, which traditionally favoured only rice cropping, now have turned into diversified cropping and rotational systems with inland and estuarine fish cultivation. The Kuttanad below-sea-level farming system has allowed the development of specific genetic resources that can grow in saline soils and then be conserved on-farm. The sustainable use of these resources and the knowledge that has been generated to manage them represent a local response to community needs that can help famers cope with the impact of climate change.

Source: GIAHS, 2013b

Ex situ conservation

Ex situ conservation is the maintenance of genetic material outside of the natural environment where the species have evolved. This type of conservation maintains the genetic integrity of the material at the time of collecting and is a static form of conservation. Gene banks, botanical gardens and zoos are typical examples of *ex situ* conservation facilities.

When it is not cost-effective or not possible to conserve genetic resources *in situ* or on-farm, the best option is to collect these resources and conserve them in gene banks, where their diversity can be easily made accessible and available. When properly characterised and evaluated, genetic resources from *ex situ* collections can reveal valuable genetic characters (adaptive traits) for adapting agriculture to changing climatic conditions and help farmers cope with potential losses (Snook *et al.*, 2011). The Seeds for Needs project in Ethiopia has demonstrated the value of *ex situ* collections for climate change adaptation (see Box 6.8).

Around 7.4 million samples of crop diversity are stored in 1 750 gene banks around the world (FAO, 2010c). Nevertheless, there is a risk that material conserved in gene banks might get lost. One attempt to provide insurance against the loss of seeds in gene banks, as well as a refuge in which seeds can be safeguarded in the event of large-scale crises, is the Svalbard Global Seed Vault. The seed vault conserves a wide variety of plant seeds in a dry and cold underground cavern. These seeds are duplicate samples, or "spare" copies, of seeds held in gene banks worldwide.

Box 6.8
Seeds for Needs project in Ethiopia

The Seeds for Needs project in Ethiopia uses ex-situ collections to help farmers, mainly women, cope with climate change. The project created climate profiles of all the accessions maintained at the Ethiopian National Genebank's Institute of Biodiversity and Conservation. The accessions most likely to be adapted to future growing conditions in areas with similar environmental profiles were identified using the collecting, characterisation and evaluation data from germplasm collections and Geographic Information System technology. These varieties were then tested by selected farmers who cultivated them based on their own experience, indigenous knowledge and adaptation strategies. After the testing process, the best performing and most adaptable varieties were distributed to farming communities for multiplication with the support of local community gene banks and agribusinesses.

Source: Bioversity International, 2013

For fish species, techniques and technologies for the maintenance of genetic material are in the early stages of development. The common carp (*Cyprinus carpio*) is one of the oldest cultured and most widely domesticated fish in the world. It has been cultured in China for more than 2 500 years (Zhu *et al.,* 2005). The species is very adaptable both in the wild and in aquaculture (Bakos and Gorda, 2001). In Hungary, the genetic improvement of common carp started in 1962 at the Research Institute for Fisheries, Aquaculture and Irrigation (Bakos, 1964). The Institute presently has a live gene bank that includes 15 Hungarian and 15 foreign carp strains (Bakos *et al.*, 2006). Intense research on cross-breeding has led to the development of three top productive hybrids for different conditions in fish farms and natural waters (Bakos and Gorda, 1995).

In aquaculture, the domestication of species and the development of breeds suited for aquaculture are of high importance because they allow for a more efficient utilization of resources. In farm crops and in livestock, the process of selecting valuable traits has been going on for centuries. In the aquaculture sector, however, this process is in its infancy, and selective breeding programmes remain highly dependent on inputs from wild genetic resources.

In the case of animal genetic resources, *ex situ* conservation usually involves *in vitro* cryoconservation of gametes or embryos in a gene bank. Cryoconservation can be supported by *ex situ – in vivo* conservation. This involves the conservation of a limited number of live animals in a small breeding herd or a zoo. Under these conditions, animals are kept outside their original production environment and their ability to adapt to changing conditions is impaired. *Ex situ* conservation is a cost-intensive process. In most developing countries, it cannot be undertaken without international support (FAO, 2007).

Integrating *in situ* and *ex situ* conservation

For specific genetic resources, some conservation systems may be more effective than others. However, a complementary conservation strategy that uses a combination of *ex situ* and *in situ* techniques is most likely to safeguard genetic diversity. In this conservation strategy, the establishment of on-farm conservation programmes and protected areas is complemented by genebanks and other *ex situ* conservation systems.

Over the last decade, a number of initiatives at national and international levels have succeeded in promoting on-farm management in farmers' fields. They have also identified specific sites and priority activities suited for the *in situ* conservation of crop wild relatives where these wild resources are at risk. One of the operational systems that support such initiatives is the Benefit Sharing Fund of the International Treaty on Plant Genetic Resources for Food and Agriculture, which was established as a direct international response to the challenges of climate change and food security. The Treaty's Multilateral System ensures access to the wide range of plant genetic diversity needed to respond to the ecological and socio-economic challenges faced by agriculture. In Peru for example, farming communities have established a potato park, where potato genetic diversity is protected *in situ* by local indigenous people. These communities have benefited from seed exchange and the *ex situ* conservation of many varieties that had disappeared from farmers' fields (see Box 6.9).

Box 6.9
Potato park in Peru

Peru's potato park, a unique 12 000 hectare reserve high in the Andes, near Cusco, was established to conserve the region's potato biodiversity, a task that has become increasingly difficult as warming climates have altered the growing patterns of some of the area's local varieties. The reserve is home to six indigenous Quechua communities whose 8 000 residents own the land and control access to local resources, but manage their communal lands jointly for their collective benefit. The communal activities are spearheaded by an organization known as the "guardian of native potatoes", the Papa Arariwa Collective.


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In the potato park, which is located within a microcenter of origin for potatoes, a typical family farm grows 20 to 80 varieties. Most of these varieties are grown for local consumption or regional barter. As the climate becomes warmer, local potato farmers have begun experimenting with different varieties at higher altitudes where temperatures are lower. The farmers are using many varieties that had disappeared from their fields but that had been conserved in the gene bank of the International Potato Center. The Benefit-sharing Fund of the International Treaty on Plant Genetic Resources for Food and Agriculture is working with the local farmers to repatriate varieties from the genebank into their fields. More than 1 345 varieties can be found in the Potato Park: 779 were collected locally; 410 were repatriated from the International Potato Center; and 157 were received through seed exchanges. The fact that these varieties were disease-free helped increase yields. The popularity of the older potato varieties increased thanks to marketing efforts and the increased attention these varieties received. The conservation of these potato varieties through in situ utilization will provide invaluable support to local communities in adapting to climate change.

Source: Farmers' Rights, 2013

Many plant and animal species found in wild ecosystems are valuable for food and agriculture, or play an important cultural role in local societies. They can provide a safety net when food is scarce. Moreover, they are increasingly being marketed locally and internationally, which provides an important contribution to local household incomes. Integrating *in situ* and *ex situ* conservation techniques is an effective strategy for the conservation of wild relatives and species harvested from the wild. While *in situ* conservation is generally the strategy of choice for these species, this should be backed up by *ex situ* programmes, which can greatly facilitate their use.

6.3 Concluding remarks

The genetic diversity of living species is a precious and irreplaceable resource that humankind needs to continue valuing, conserving and using. Genetic resources for food and agriculture safeguard agricultural production and provide options for coping with climate change (e.g. seeds with higher yields, better quality, earlier maturity, better adaptation and higher resistance to diseases, insects, and environmental stress). Domesticated species, breeds and varieties and their wild relatives will be the main source of genetic resources for adaptation to climate change. *In situ* and *ex situ* conservation and sustainable use of genetic resources for food and agriculture and their wild relatives will be critical for the development of climate-smart agriculture. With the interdependence of countries increasing, the transfer of genetic resources and the knowledge related to their use needs to be supported through effective cooperation between countries. The fair and equitable sharing of benefits arising from the use of genetic resources also needs to be properly addressed.

Notes

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Acronyms

CO_2	carbon dioxide
CH_4	methane
GIAHS	Globally Important Agricultural Heritage Systems
IPCC	Intergovernmental Panel on Climate Change
N_2O	nitrous oxide

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