Mainstreaming Agrobiodiversity in Sustainable Food Systems

Scientific Foundations for an Agrobiodiversity Index

5

Conserving agricultural biodiversity for use in sustainable food systems

M. Ehsan Dulloo, J.E.O. Rege, Marleni Ramirez, Adam G. Drucker, Stefano Padulosi, Nigel Maxted, Bhuwon Sthapit, Devendra Gauchan, Imke Thormann, Hannes Gaisberger, Nicolas Roux, Julie Sardos, Max Ruas, Mathieu Rouard

Conservation

KEY MESSAGES:

→ The many potential benefits of agricultural biodiversity to sustainable food systems are often not realized because of poor conservation, lack of information or restrictive policies.

→ Successful conservation takes an integrated approach that safeguards genetic diversity in places it has evolved, backs it up in *ex situ* facilities for posterity, and makes it readily accessible and available for use.

→ Only 12 crops and five animal species provide 75% of the world's food. Yet there are thousands of neglected animal and plant species, breeds and varieties with potential uses for humans, representing one of the most poorly utilized and underappreciated food resources we have. These species must be conserved and used.

Introduction

Earlier chapters illustrate how agricultural biodiversity is one vital component of healthy diverse diets and of sustainable farming systems that provide multiple benefits to people. For these benefits to be realized, agricultural biodiversity needs to be kept available. In other words, it needs to be conserved (1). In addition to supporting benefits today, conservation of agricultural biodiversity also keeps open options for unknown future needs.

Agricultural biodiversity is wide ranging and includes all species and their genetic diversity that are of relevance to agriculture, plus landscape diversity, microbiological diversity in the soil and the diversity of pollinators. For the purpose of the Agrobiodiversity Index, in this chapter we focus only on the diversity of animals and crops, as representative of the foundations of agriculture. Once the Agrobiodiversity Index is established, it will be possible to expand its focus to cover pollinators, fish, trees and even landscapes, as is necessary.

What diversity to conserve for sustainable food systems?

The globalization and homogenization of diets and farming systems are the greatest threats to agricultural biodiversity (2, 3). From the pool of 40 animal species and at least 5,538 plant species documented as human food (4), only 12 crops and five animal species now provide 75% of the world's food (5).

Yet the diversity conserved on and around farms continues to be remarkable. A study in Benin found that households grew and gathered 65 different plant species over a year – including crops and fruit trees, wild trees and bushes (6). Similarly, single home gardens around the world often harbour 20 to 50 different plants and several small livestock species (7). Many of these are highly nutritious (8–15), adapted to marginal farming conditions (16), resilient to climate change (15, 17), with potential for income generation (18, 19) and/or closely linked to cultural identity (20, 21). Most have never been formally improved and so, despite their local and potential value, are neglected by national conservation efforts ('neglected and underutilized species' or NUS) (21). This does not mean that they are neglected or underutilized by rural communities. Many farmers cultivate them widely for various reasons, especially in marginal areas. In the case of animal genetic resources, the 'NUS equivalents' are traditional breeds or strains that produce under usually very harsh production conditions and possess adaptive attributes such as disease resistance and heat or drought tolerance (22, 23). Conservation of neglected plant species and traditional breeds on farm, along with the vast traditional knowledge developed by users over generations, is of paramount importance for keeping diversity options for future generations and for maintaining the evolutionary potential of agricultural biodiversity.

Countries make strategic conservation decisions, focusing on biodiversity that is important to people's food and nutrition security and farming systems, highly threatened, globally valuable and unique, or a combination of these. For example, certain crops have great local importance because of the role they have in local cuisine and farming systems. In these cases, it is common for there to be wide diversity in those crops. For example, in Eastern Africa, there is wide banana diversity, which underpins a unique banana-based farming system and cuisine. Other times the conservation of a species is dependent on its use in local cuisine, such as the pungent leaves of *Garcinia cowa* (a relative of mangosteen) which are used as a traditional flavouring ingredient in Thailand (24).

Some countries are centres of diversity or centres of origin for certain crops and animals, which means that they harbour a greater diversity of these species than other countries. For example, there are over 1,483 varieties of Andean tuber species found in the Andean region of Peru. When species are endemic (i.e. native to a certain place), they tend also to have large populations of related species in the wild, 'crop wild relatives', which can be a valuable source of traits for breeding improved varieties. South Africa, for instance, is a significant centre of biodiversity, with more than 12,000 endemic plant species and many crop wild relatives, including sorghum, sweet potato and cowpea. While uncertainties still surround the exact domestication centres for some livestock species, the following geographic areas are important primary centres of origin and, therefore, centres of diversity of livestock species (25–28): the Andean chain of South America (llamas, alpacas, guinea pigs), Central America (turkeys, Muscovy ducks), Northeast Africa (cattle, donkeys), Southwest Asia including the Fertile Crescent (cattle, sheep, goats, pigs), the Indus valley region (cattle, goats, chickens, riverine buffaloes), Southeast Asia (chickens, Bali cattle), East China (pigs, chicken, swamp buffaloes), the Himalayan plateau (yaks) and North Asia (reindeer). Additionally, the southern part of the Arabian Peninsula is thought to be the region of origin of the dromedary, while the Bactrian camel is thought to have originated from the area that is now the Islamic Republic of Iran, and the horse from the Eurasian steppes.

The loss of agricultural biodiversity in our global food production systems, as well as associated cultural practices and knowledge, is an issue of increasing concern, particularly in centres of origin and diversity. The Convention on Biological Diversity Aichi Target 13 addresses this concern directly:

Zebu in Ankarafantsika National Park, Madagascar. Zebu are domesticated cattle, farmed throughout the tropics, which can withstand extreme heat.
Credit: Bioversity International/D.Hunter

By 2020, the genetic diversity of cultivated plants and farmed and domesticated animals and of wild relatives, including other socio-economically as well as culturally valuable species, is maintained, and strategies have been developed and implemented for minimizing genetic erosion and safeguarding their genetic diversity.

Maintaining genetic diversity is also addressed in Sustainable Development Goal target 2.5:

Maintain the genetic diversity of seeds, cultivated plants and farmed and domesticated animals and their related wild species, including through soundly managed and diversified seed and plant banks at the national, regional and international levels, and promote access to and fair and equitable sharing of benefits arising from the utilization of genetic resources and associated traditional knowledge, as internationally agreed.

Challenges in monitoring conservation status

It is notoriously difficult to measure the exact status of crop and animal genetic diversity. For animal genetic resources – where the greatest diversity content is within species (breeds and strains) – there is much better data at species level than at breed or strain level. The *State of the World´s Animal Genetic Resources for Food and Agriculture* (29) states that 62 livestock breeds became extinct between 2001 and 2007. In 2014, a total of 1,458 breeds (17% of all breeds including those that are extinct) were classified as being at risk, but more than half – 58% of breeds – were classified as being of unknown risk status (30). This latter classification is symptomatic of the data gaps in animal genetic resources. Indeed, a combination of challenges around availability of reliable data as well as a lack of a clear-cut definition of strain and breed distinctiveness in developing countries implies that conservation discourses and decisions on animal genetic resources are still based on incomplete information (31) and lesser known populations or strains in remote areas in developing countries continue to be lost (23). A close look at the list of extinct and at-risk breeds and strains of livestock, as well as their wild relatives, reveals that most of these have been identified in developed countries (where more reliable data are available) and only limited numbers have been reported in the developing world – a reflection of the data gap. The challenge is all the greater because the diversity is already quite limited – and a unit loss represents a significant part of the remaining diversity. Here the biggest cause of diversity loss is ill-conceived ‘development programmes’ which support cross-breeding and breed replacement, without paying due attention to the consequences (23).

Despite the fact that crop genetic resources have received much more attention and for far longer than animal genetic resources, the data situation is worse for crop genetic resources than for animal genetic resources: there is no global information of the extent of diversity of crop genetic resources on farm and *in situ* and the extent to which they are threatened, despite the existence of an information-sharing mechanism of the Food and Agriculture Organization of the UN (FAO) Global Plan of Action on Plant Genetic Resources for Food and Agriculture.[i] To monitor the status, we need first to measure the extent and trends of the diversity, and at present there are serious data gaps (such as number and distribution patterns of species, varieties and breeds, and their genetic diversity), which means that comprehensive and reliable numbers of species at risk of extinction and genetic erosion are difficult to determine (32, 33). One challenge is the vast richness of crop diversity to be conserved. Even if we consider only the 150–200 species of crops commercially cultivated, to identify, monitor and conserve all the variation therein is a daunting task, particularly since the diversity is not static but constantly evolving in response to human and natural pressures. A further complication is that at the genetic level not all differences are visible simply by looking at a plant, and not all differently named crops are in fact genetically different.

Partly as a result of these challenges, there are persisting gaps in available data for crop genetic resources. We lack the numbers of species at risk of extinction and genetic erosion remains difficult to determine (1, 33, 34). Some studies suggest that perhaps genetic erosion for some crops has not happened as much as was once thought, e.g. millets and sorghum in West Africa (35), wheat in France (36). Nonetheless, evidence exists that much crop genetic diversity in farmers' fields and in the wild is rapidly being eroded (33, 37).

Part of the loss of crop genetic resources in farmers' fields and their wild relatives has been offset by collecting and conservation away from the field in genebanks (known as *ex situ* conservation), where over 7 million samples are conserved in 1,750 genebanks worldwide (38). From a sustainable food system perspective, however, the diversity held in genebanks is only tip of the iceberg. Genebanks have largely focused on the conservation of major staple crops, while non-staple crops represent only 2% of materials stored and crop wild relatives are also poorly represented (39). Furthermore, even diversity held in *ex situ* facilities can face genetic erosion due to inadequate management practices as a result of insufficient support, lack of duly trained staff and frequently overwhelmed and underfunded conservation programmes.

How to conserve agricultural biodiversity for sustainable food systems

Genetic resources are ideally conserved within three broad interconnected realms:

- On farm in farmers' fields: managed by farmers on farm and thus allowing responses to natural and human selection
- In the wild: occurring in natural habitats, *in situ*, that are under selective forces of nature
- *Ex situ* collections: diversity that has been collected and conserved and managed in offsite facilities, e.g. genebanks.

While the concept of *ex situ* conservation is pretty clear, such is not the case for on-farm conservation and *in situ* conservation. Some authors prefer to use the term *in situ* conservation for conservation of all species that are "in their natural surroundings" (40), whether the surroundings be natural habitats or domesticated and cultivated contexts. Other authors prefer to use the term *in situ* conservation only for conservation of species purely under the forces of nature and the term on-farm conservation for species subject to selection both by nature and by farmers. In this chapter we take the latter approach, making a distinction between on-farm and *in situ* conservation, since they generally involve different players – agriculturalists in the first case and environmentalists in the second – and different approaches and methodologies (Box 5.1).

It is difficult to conserve animals anywhere apart from on farm, though strides are being made to conserve biological samples *ex situ* in tissue banks (31). Also, efforts have been limited so far to identify and protect key habitats for wild relatives of domesticated animals. For this reason, in this chapter, we discuss the conservation of animal genetic resources primarily only in the realm of on-farm conservation.

For crop genetic resources, these three realms – on-farm, *in situ* and *ex situ* – are all necessary, but none is sufficient on its own, as each serves different purposes and each has merits and limitations. Government strategies to conserve crop diversity are based on consideration of the purposes for conserving it, the biology of the species and an assessment of benefits and challenges (Figure 5.1).

Measures to safeguard the traditional knowledge associated with wild and cultivated crop and farm animal diversity are also important in order to keep alive best practices and cultures that support the sustainable use of the biological resources.

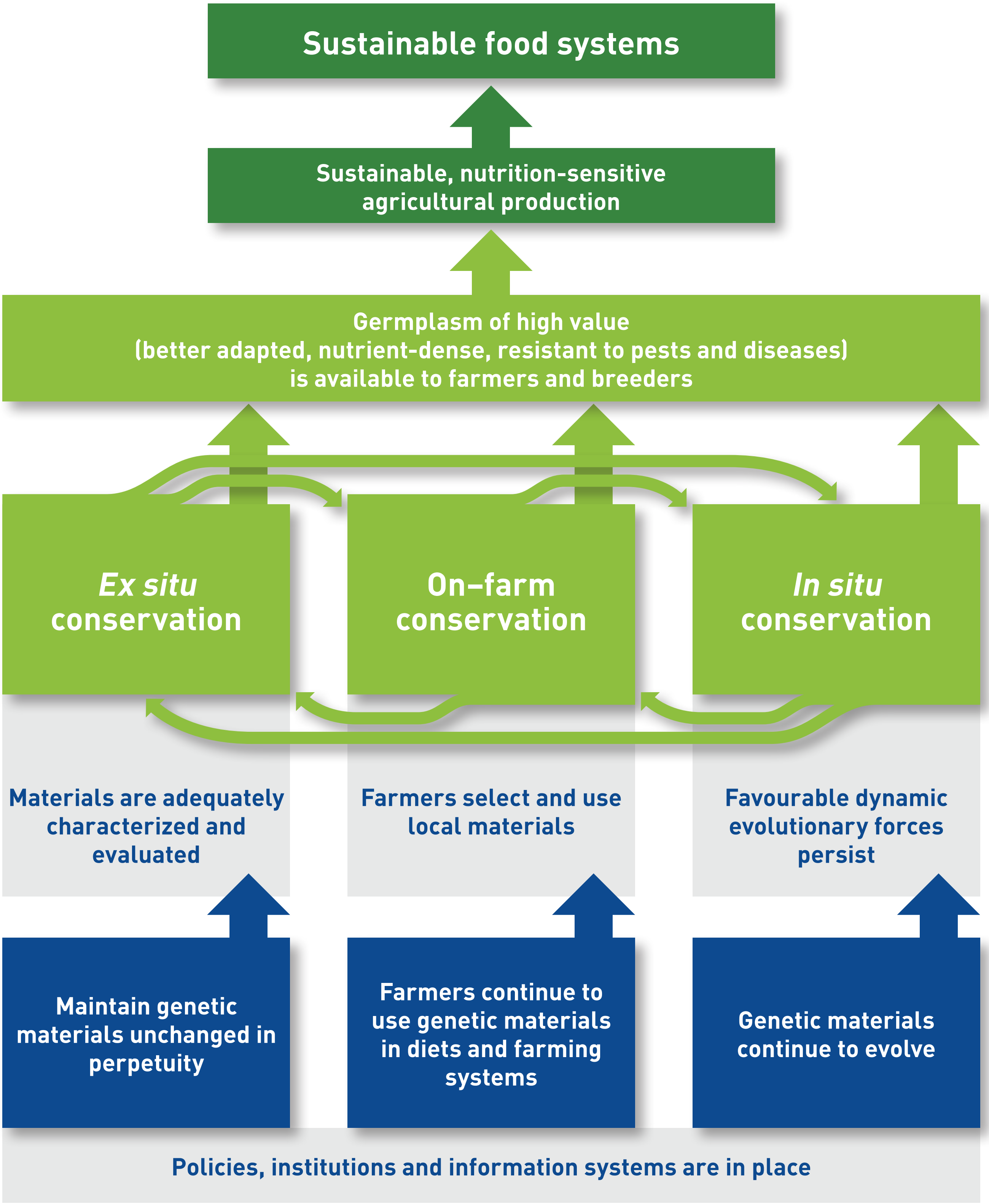
BOX 5.1 – Distinction between *ex situ*, on-farm and *in situ* conservation realms

***Ex situ* conservation**	***In situ* conservation in cultivated and wild habitats**	
Ex situ conservation is the conservation of components of biological diversity outside their natural habitats (40)	*In situ* conservation is the conservation of ecosystems and natural habitats and the maintenance and recovery of viable populations of species in their natural surroundings and, in the case of domesticated or cultivated species, in the surroundings where they have developed their distinctive properties (40)	
	On-farm conservation in agricultural production systems	***In situ* conservation in wild ecosystems and natural habitats**
	On-farm conservation is a dynamic form of crop and animal genetic diversity population management in farmers' fields, which allows the processes of evolution under natural and human selection to continue (41, 42)	*In situ* conservation is often used to refer to conservation of wild ecosystems and natural habitats and the maintenance and recovery of viable populations of species in their natural surroundings (40)

FIGURE 5.1 – The three realms needed for effective conservation of genetic resources

The grey boxes are starting conditions that must be in place for conservation to be effective. Dark blue are the aims of conservation, light green are the three realms and dark green are the higher goals.

The arrows between the realms show the features of an integrated conservation system – the interconnectedness between diversity held on farm, *in situ* and *ex situ*: diversity held *ex situ* is available to breeders and farmers and can be used to restore diversity on farm and *in situ*; gene flow from wild relatives to cultivated species on farm can increase resistance; and long-term conservation *ex situ* acts as a back up for on-farm and *in situ* biodiversity.



Our premise is that the conservation of agricultural biodiversity is fundamental to realize the goal of ensuring a healthy food system and other global challenges, such as stopping land degradation and climate change. Often the many potential benefits of agricultural biodiversity to sustainable food systems are not realized because they are poorly understood and valued. In other cases, it may be difficult to get access to resources, identify traits and promote their use. This may be the result of an inability to locate information or because the agricultural biodiversity itself is eroding.

In this chapter we describe the three complementary realms of a healthy conservation system, and outline evidence for how to identify intervention points to make conservation more effective. By 'healthy conservation system', we mean a well-functioning system where the species and genetic diversity and their agricultural and natural production systems are maintained. The chapter also reviews and proposes a set of indicators and metrics for tracking progress across these three realms that can be used by policymakers, investors and farmers to assess the conservation dimension of agricultural biodiversity in the Agrobiodiversity Index.

As well as understanding what works from a technical perspective in the three realms, there are also political, legal and institutional factors that influence the ability or willingness of farmers, organizations, governments and other entities to manage, conserve and provide access to agricultural biodiversity (43). Conservation may be non-functional if the enabling environment for conservation and use of genetic resources is not adequately addressed.

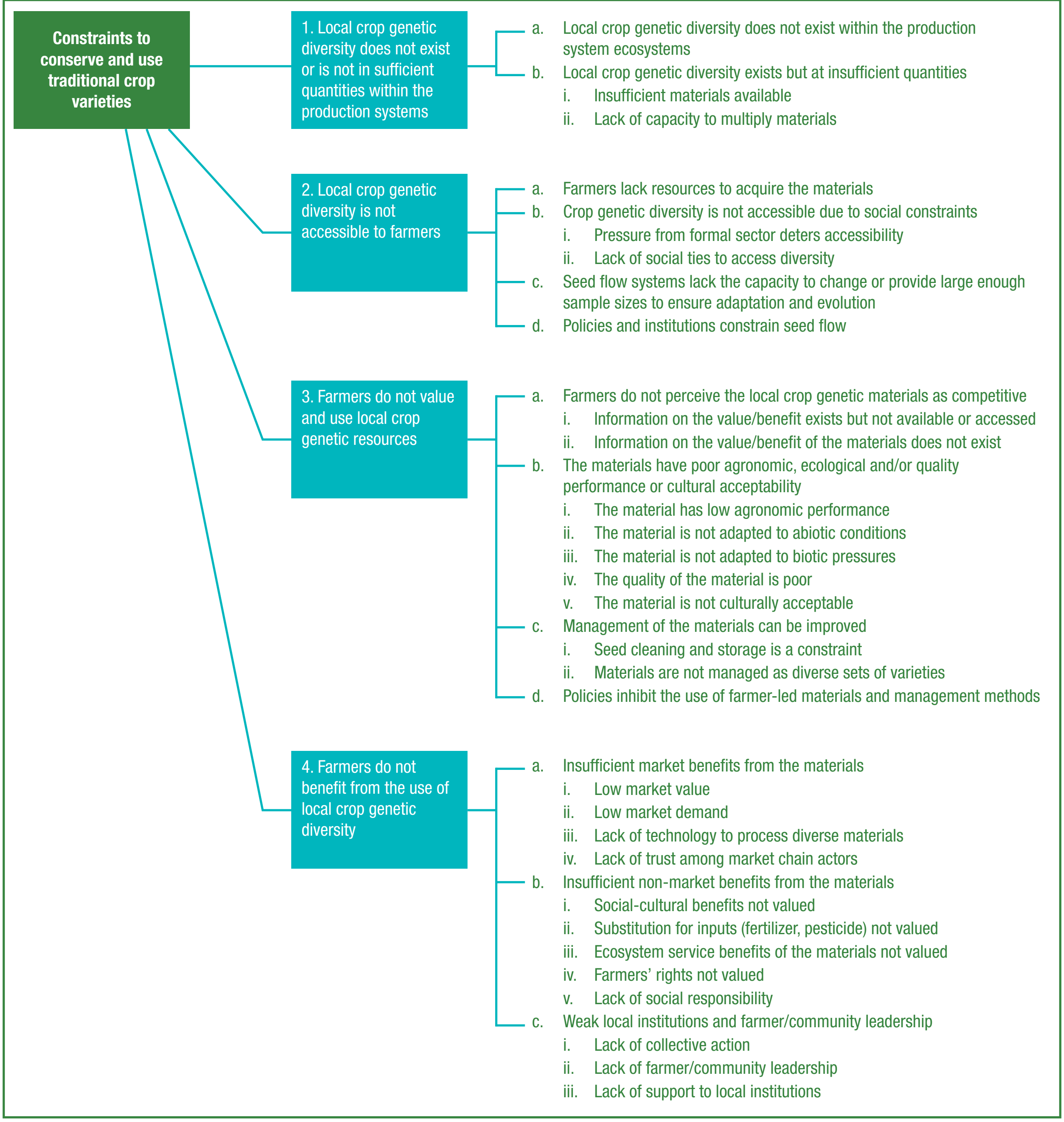
On-farm conservation

Where the main purpose of conservation is that communities should continue to benefit from the use of crop and animal biodiversity, one strategic approach is on-farm conservation. On-farm conservation is the result of networks of farmers doing different things over large areas – i.e. each engaged in their own livelihood and risk management strategies, and adapting crops to their own niche environments – with the unplanned end result across a region or country that a wide range of diversity is conserved (44). It is a highly dynamic form of crop and animal population management, which allows the processes of both natural and human selection to continue to act in the production system (41, 42, 45), thereby contributing to ecosystem services (such as soil quality, pest control and pollination, as described in Chapter 3) and the autonomy that farmers have over crop and animal genetic resources (46). An analysis of different conservation approaches for animal genetic resources concluded that the most rational strategy for conserving livestock breeds was to ensure that they remain a functioning part of the farm production system (47). Such processes help to maintain crop and animal evolution in farmers' fields, home gardens and landscapes (48). This conservation approach is valued for evolving new portfolios of adaptive traits and, therefore, enhancing farmers' capacity to cope with adversity, resulting from the consequences of socioeconomic and market forces and climate change (49). This conservation approach also covers aspects of genetic resources which cannot be protected in genebanks, such as local knowledge and ecosystem interactions (50–52) and, in fact, the processes that underpin this dynamic conservation of genetic diversity.

The second *State of the World's Plant Genetic Resources for Food and Agriculture* (38) report notes that over the last decade, promoting and supporting the conservation of genetic resources in farmers' fields, home gardens, orchards or other cultivated areas of high diversity, has become firmly established as a key component of crop conservation strategies, as methodologies and approaches have been scientifically documented and their effects monitored (1, 38).

A review of over 500 case studies documented "multiple ways of supporting the conservation and use of traditional crop varieties within the agricultural production system" (53). The review suggests an overall framework (a heuristic device) to help conservation and development workers and communities understand the preconditions that need to be in place for traditional crop varieties to be used and conserved in farming systems. It can be extended also to considerations of animal genetic resources. The heuristic framework categorizes into four groups issues faced by farmers which may increase or decrease their capacity and desire to continue to conserve and use crop or animal genetic resources on their farms (Figure 5.2). These include the existence in sufficient quantities of crop or animal genetic diversity in production systems, and the ability of farmers to benefit from the diversity, for instance through appropriate market and non-market incentives and institutions (53).

FIGURE 5.2 – Heuristic framework for identifying constraints and related actions to support the conservation and use of traditional crop varieties within agricultural production systems



Constraints to conserve and use traditional crop varieties

- 1. Local crop genetic diversity does not exist or is not in sufficient quantities within the production systems
    - a. Local crop genetic diversity does not exist within the production system ecosystems
    - b. Local crop genetic diversity exists but at insufficient quantities
        - i. Insufficient materials available
        - ii. Lack of capacity to multiply materials
- 2. Local crop genetic diversity is not accessible to farmers
    - a. Farmers lack resources to acquire the materials
    - b. Crop genetic diversity is not accessible due to social constraints
        - i. Pressure from formal sector deters accessibility
        - ii. Lack of social ties to access diversity
    - c. Seed flow systems lack the capacity to change or provide large enough sample sizes to ensure adaptation and evolution
    - d. Policies and institutions constrain seed flow
- 3. Farmers do not value and use local crop genetic resources
    - a. Farmers do not perceive the local crop genetic materials as competitive
        - i. Information on the value/benefit exists but not available or accessed
        - ii. Information on the value/benefit of the materials does not exist
    - b. The materials have poor agronomic, ecological and/or quality performance or cultural acceptability
        - i. The material has low agronomic performance
        - ii. The material is not adapted to abiotic conditions
        - iii. The material is not adapted to biotic pressures
        - iv. The quality of the material is poor
        - v. The material is not culturally acceptable
    - c. Management of the materials can be improved
        - i. Seed cleaning and storage is a constraint
        - ii. Materials are not managed as diverse sets of varieties
    - d. Policies inhibit the use of farmer-led materials and management methods
- 4. Farmers do not benefit from the use of local crop genetic diversity
    - a. Insufficient market benefits from the materials
        - i. Low market value
        - ii. Low market demand
        - iii. Lack of technology to process diverse materials
        - iv. Lack of trust among market chain actors
    - b. Insufficient non-market benefits from the materials
        - i. Social-cultural benefits not valued
        - ii. Substitution for inputs (fertilizer, pesticide) not valued
        - iii. Ecosystem service benefits of the materials not valued
        - iv. Farmers' rights not valued
        - v. Lack of social responsibility
    - c. Weak local institutions and farmer/community leadership
        - i. Lack of collective action
        - ii. Lack of farmer/community leadership
        - iii. Lack of support to local institutions

Source: (53) Copyright © 2011 © Devra I. Jarvis, Toby Hodgkin, Bhuwon R. Sthapit, Carlo Fadda, and Isabel López Noriega. Published with license by Taylor & Francis. Modified with permission.

Assessing the existence of sufficient quantities of crop or animal genetic diversity

Main concepts for assessing genetic diversity on farm

Three concepts of diversity are key to estimate the levels of animal and crop genetic diversity on farm. These are:

- Richness. How many different traditional varieties, breeds and species are being maintained?
- Evenness. How similar are the frequencies of the different variants? Low evenness indicates dominance by one or a few crop varieties or animal breeds.
- Divergence. This measure reflects the probability that any two randomly chosen households within the same community are growing different varieties.

In an analysis of varietal data on 27 crop species from five continents, measurements of richness, evenness and divergence showed that considerable crop genetic diversity continues to be maintained on farm, in the form of traditional crop varieties (44). The patterns of diversity give clues as to the farmers' strategies. Understanding these strategies can inform conservation actions. For example, in some cases, farmers' fields were dominated by a few varieties, with much of the variety richness held at low frequencies. This suggests that in these cases diversity may be being maintained in low quantities as an insurance to meet future environmental changes or social and economic needs (44). In other farms and communities, a more even distribution of varieties was found, indicating that farmers are selecting varieties to service a diversity of current needs and purposes (44). Understanding the diversity of strategies employed highlights the importance of a large number of small farms adopting distinctly diverse strategies as a major force that maintains crop genetic diversity on farm (44).

Sufficient diversity for different functions

Estimating the extent and distribution of diversity provides the information needed to determine whether there is sufficient diversity of a crop within a production system to meet the various needs of farming communities. Sufficient diversity is largely defined by farmers by the functions that the diversity serves them on farm, for example ecosystem services such as pest control or soil formation (Chapter 3) or provision of culturally preferred nutritious foods all year round for sale or consumption (Chapter 2). One important function is also managing uncertainty and risk, which requires wide genetic diversity availability in order to be able to adapt to new challenges such as climate change or prevalence of certain pests. Farmers in Mali, for example, in response to changing environmental conditions, were able to shift their production of sorghum to short-cycle varieties, thanks to the availability of and access to large enough population sizes of traditional sorghum varieties (cited in 53). An example of functional diversity is from research in the Yucatán in Mexico, where it was found that to cope with unpredictable rain and poor soils, farmers had quick maturing varieties (*Na'tel*) to avoid the drought period, and other varieties (*X-nuuk nal*) which were long maturing but drought resistant. In this way, the community could increase their chances of being able to eat maize whatever the weather (54).

'Sufficient diversity' may additionally be defined using prioritizing tools (55, 56) by those with an interest in conservation per se, i.e. not focusing so much on sufficient diversity for farmers' uses, but sufficient in the sense of covering the maximum breadth of genetic diversity safeguarded within a fixed conservation budget. It is possible to combine measures related to uniqueness, risk status and conservation cost in order to estimate optimum portfolios of diversity to conserve.

Where diversity is low, farmers may be able to source seeds and planting materials from public agricultural extension services, or purchase them in formal or informal markets. They can also be (re)introduced from other communities or from genebanks – possibly through intermediaries, since most genebanks are not easily accessible to local communities. A good example comes from a poorly known Andean grain, cañahua (*Chenopodium pallidicaule*), whose varieties had been lost by local communities near Puno in Peru. Loss occurred due to the replacement of cañahua cultivations with those of quinoa, a high cash earning crop in recent years. When the quinoa crop proved to be susceptible to unpredictable morning frost occurrences, 40 varieties of cañahua were brought back to communities from *ex situ* collections, thanks to previous collecting missions carried out by a national NGO (15). Owing to its cold resistant trait, the reintroduced cañahua varieties are helping farmers to better adapt to the new unpredictable morning frosts (Figure 5.3).

FIGURE 5.3 – Cold-tolerant cañahua (left and right) and susceptible quinoa (centre) crops following a heavy frost in Corisuyo (Puno, Peru)

Credit: Bioversity International/S.Padulosi

Other ways of reintroducing diversity are through seed exchange meetings with other communities, and through community seedbanks or nurseries for trees (see Box 5.2, 57).

BOX 5.2 – Community seedbanks

Community seedbanks are one approach in developing countries, particularly in South Asia and Africa, to conserve and manage agricultural biodiversity at the community level. Community seedbanks tend to be small-scale local institutions, which store seed on a short-term basis, serving individual communities or several communities in surrounding villages (58, 59). These community seedbanks are relatively inexpensive, usually employing simple, low-cost storage technologies. The people managing the seedbanks carry out deposit of seeds, replication, storage, distribution, germination quality testing and variety selection. Community seedbanks provide options for conservation and use of neglected and underutilized crops that are not commonly undertaken by national and international genebanks (59).

In Nepal, a total of 115 community seedbanks have been reported (60). Detailed data are available for 21 of these. These 21 community seedbanks were conserving 908 varieties of 62 crop species as of 2016. From 2011 to 2016, a total of 18,136 farmers gained access to the local and modern varieties conserved in these seedbanks (61). About 43% of poor and 45% of medium-income farmers have received seeds from these community seedbanks (60). In 2015, 10t of local varieties and approximately 125t of modern varieties and varieties bred through participatory methods were produced by these community seedbanks. Sixty percent of the seed produced is marketed by local seed retailers and local extension agents to meet local needs. Total income generated by seed sale for six seedbanks (US$34,635 in 2015) is used to safeguard local crop diversity and support the day-to-day management of community seedbanks. Nepal is now piloting access and benefit-sharing mechanisms at the community level through community seedbanks as a practical way of implementing farmers' rights (62).

Ensuring benefits to farmers from market and non-market incentives and institutions

Supporting internal incentives for conservation on farm

One successful way of engaging farmers so that they gain both biodiversity and livelihood benefits from their efforts is 'community biodiversity management' (23, 63–65) Community biodiversity management of crop and animal resources entails community-driven participatory approaches that empower farmers and communities to organize themselves and develop strategies so that they can manage their agricultural biodiversity in ways that improve their livelihoods.

The community biodiversity management approach integrates knowledge and practices with social systems, institutions and regulations that support conservation and development goals set by participating communities (23, 62, 63, 66). Production practices change as the farmer acquires new sets of scientific knowledge, skills and technologies, and blends them with traditional practices for further livelihood improvements. Communities can benefit in many ways: improved agronomic practices, commercialization of certain species or varieties, improved access to elite planting materials, or new networks leading to access to funding or expertise (66). For example, in France, a self-organized network of farmers and amateur gardeners started to collect local varieties of maize and other crops, describing their special traits, and promoting them in the network. From modest beginnings of just a handful of maize varieties that had almost disappeared from farmers' fields, in 2013 they reported over 100 maize varieties, more than 10 sunflower varieties, several varieties of soybean, buckwheat, moha (Hungarian grass), lupine, and a number of vegetable and fodder crops (67).

Participatory plant breeding, which empowers farmers to set breeding goals using local crop diversity, also demonstrates a successful method to provide benefits to farmers from their existing agricultural biodiversity (68). One example is that of making an aromatic rice landrace competitive by selection from 338 populations of a landrace called Jethobudho (69). Together with the local community, researchers improved milling recovery (by 5%), tolerance to being flattened by wind and rain, consistent and aromatic cooking quality, and resistance to diseases. Consumers are willing to pay a relatively high price because of its special cooking quality measured by grain expansion, taste and aroma, which are not available with other high quality types, such as Basmati. Once this variety was released, seed companies started marketing it in other parts of the country, which supported its conservation.

Also for animal diversity, participatory breeding approaches have proved successful in providing livelihood benefits which support conservation goals. For example, in Côte d'Ivoire from 1983 to 2000 a large community-based national sheep improvement programme was carried out for the local breed Djallonké. While the primary goal was to increase the benefits to smallholders by improving the performance of the breed, which is appreciated for its tolerance of tsetse-borne diseases, the activities also had the aim of improving conservation of the breed. The programme learned that the main factor for success was the desire on the part of the farmer to adopt new management techniques. Although not all farmers continued to breed Djallonké after government financial support was withdrawn, still numbers of sheep were greatly increased (from about 3,000 ewes in 1984 to well over 14,000 in 2000) and genetic analyses showed that the genetic values of the breed had been maintained, or even slightly improved, during the period (70).

Incentive mechanisms for conservation can also be indirect. One example is the establishment of community biodiversity management (CBM) funds that can be used at a local level to tie community conservation goals with individual microcredit. In this context, a CBM fund can be set up by linking ongoing savings and credit schemes for members to a community seedbank. Its operational modality is similar to other microfinance schemes (71). In Nepal, where this approach was developed (60, 72), seed money from an international project[ii] contributed to the establishment of the fund and matching funds were collected within the community. Every household within the village is eligible to apply for loans from the CBM fund, on condition that they abide by some local codes of conduct, such as multiplying seeds of rare varieties, or paying a locally determined interest rate in cash or in seeds (57, 64, 66). CBM funds have led to the cultivation of crop varieties that had been at risk of disappearing. They also support landscape level and wild biodiversity. For example, in a scheme in a town called Begnas in Nepal, loans for raising livestock were given, on condition that the receiver planted 30 saplings of local fodder tree species. In the area of Lake Rupa, loan conditions are that people take on the care of the local wetlands, which house wild rice, local fish, birds and white lotus (74).

From the traditional pollination of date palms in North Africa, to the many mixed cropping systems developed by farmers around the world to leverage ecosystem functions of different species, to the huge array of food recipes that characterize agricultural areas and 'terroir' identity, indigenous knowledge associated with crop genetic diversity plays a fundamental role in supporting the benefits that farmers obtain from diversity (73). Traditional cultivation, management and use practices need to be monitored and supported to prevent their erosion (74).

Creating external incentives for conservation on farm

Where the livelihood benefits of conserving biodiversity are not sufficient and smallholder farmers start to abandon certain species, breeds or varieties that may be prioritized from a public good conservation perspective, incentive schemes can be created to compensate farmers for conserving agricultural biodiversity on their farms. The importance of positive incentives for the conservation of biodiversity has been explicitly recognized by the Convention on Biological Diversity (Aichi Biodiversity Target 3).

Value chain development is one incentive mechanism that has gained increasing attention in recent years as a tool for harnessing the potential of agricultural market channels to promote the use of specific livestock breeds and neglected and underutilized crop species and varieties (examples include minor millets, Andean grains, African leafy vegetables, peach palm, cherimoya and mango, see 75) with consumers ultimately paying for the on-farm conservation of locally adapted genetic resources through mechanisms such as eco-labelling, certification or 'denomination of origin' schemes. Such support can generate enhanced private benefits for farmers through access to improved species and varieties, increased choices of input suppliers and product outlets, increased accessibility to credit, better management capacity, improved employment opportunities and associated income generation (76, 77). As an example, in Peru a private company (Kai Pacha Foods) is contracting a local community to produce 10ha worth of the *Chulpi* variety of quinoa in order to process it and market it as quinoa milk (78), which will likely support the conservation of this variety. However, value chain development has limitations as a conservation strategy and its impact on agricultural biodiversity conservation may be less than once assumed (79). The growth in sales of quinoa worldwide has not led to increased management of the wide genetic base of the crop; only 10–15 quinoa varieties (out of thousands) are found in national and international markets (Rabines, Ministry of Agriculture, Peru, personal communication, Sept 2014).

An alternative approach is to compensate farmers directly for conserving targeted agricultural biodiversity on their farms. Tested and proven concepts from 'payments for ecosystem services' (PES) schemes, where incentives to farmers are given to maintain ecosystem services that benefit wider society (e.g. maintaining wild biodiversity, forests or water quality), can be applied to agricultural biodiversity as Payments for Agrobiodiversity Conservation Services (PACS, see Box 5.3). Applied within an innovative prioritization framework and competitive tender context that allows for scarce conservation resources to be allocated in such a way as to maximize diversity and associated ecosystem services, incentives are offered at community level (e.g. women's or producers' groups). Such schemes are expected to support farmers to diversify their livelihood strategies to include not only agricultural production, wage labour and value chain development, but also provision of agricultural biodiversity conservation as a public good.

A PACS approach can also benefit farmers by strengthening their farmers' rights (62). The approach puts into practice the right to equitably participate in sharing benefits arising from the use of plant genetic resources for food and agriculture. Farmers define the conditions of their participation, so the approach can be tailored to benefit certain target groups, such as women farmers or certain ethnic groups.

BOX 5.3 – Payments for Agrobiodiversity Conservation Services (PACS)

PACS schemes have been tested since 2009 on plant genetic resources in Peru, Ecuador, Bolivia, India, Nepal and Guatemala; on animal genetic resources in Slovenia and on crop wild relatives in Zambia. They were recognized by the SIRGEALC (Latin American and Caribbean Genetic Resources International Symposium) in 2011 as an innovative tool that should be promoted in the region and with the International Treaty on Plant Genetic Resources for Food and Agriculture and Commission on Genetic Resources for Food and Agriculture. PACS schemes involve landscape-wide competitive tenders inviting communities to cultivate a priority portfolio of crop species and varieties and to name their conditions for doing so. Efficiency and social equity are the criteria used to select the communities which offer the best bids. At the end of the agricultural season, if cultivation has proceeded according to the contract, in-kind rewards – e.g. agricultural inputs and machinery, school building and materials – are given to the community groups. Participating groups define the conditions for their participation (i.e. which priority species or varieties to cultivate, what level of reward is needed and which women and men farmers will participate), and how to share the rewards amongst themselves and other community members.

By creating a low-risk environment for farmers to experiment in, farmers are able to explore whether the threatened crop species or varieties benefit their families sufficiently to keep cultivating them even in the absence of future incentives. Results from 2010/11 revealed that 30–50% of participating farmers had decided to do so.

The Peruvian Ministry of Environment (MINAM) has recognized the complementary role that PACS can play, in a programme called Euro Eco-Trade, which facilitates the value addition and export of organic products from selected native crops while seeking to ensure that the underlying genetic resource base is not degraded as a result. MINAM incorporated PACS approaches into its 2015 annual work plan with a view to promoting the adoption of this kind of incentive scheme at the national level.

Spades, wheelbarrows, cement and mattresses – some of the rewards requested by farming communities in Peru for cultivating priority conservation varieties of quinoa.
Credit: Bioversity International/A.Drucker

In situ conservation

When the purpose of conservation is the continued evolution of novel traits for breeding, conservation in the wild and on farm (i.e. *in situ*) is a strategic choice. *In situ* conservation refers to the maintenance and recovery of viable populations in their natural surroundings where they have evolved as a result of natural selection. Where the species and their genetic diversity are declining due to a number of threats, mostly as a result of human actions, *in situ* conservation involves the recovery of populations through active conservation actions or, in the case of whole ecosystems, it involves taking restoration measures. *In situ* conservation complements *ex situ* and on-farm conservation by preserving both the population and the evolutionary processes that enable the population to adapt by allowing them to evolve in their natural state or within their normal range (80). The term *in situ* conservation spans a diversity of approaches including ecosystem-based, species-based or genetic-based approaches (81). For each of these approaches, detailed methodologies and protocols have been developed (81, 82).

The wild relatives of crops and animals serve as a large repository of genetic diversity of value for crop and animal improvement, which can be used to strengthen the sustainability of food systems. They are potential sources of traits beneficial to crops and domesticated animals, such as pest or disease resistance, yield improvement, better taste or stability. For example, in the 1970s, the US maize crop was severely threatened by corn blight, which destroyed almost US$1,000 million worth of maize and reduced yields by as much as 50% in 1978 (83). The problem was resolved through the use of blight-resistant genes from wild varieties of Mexican maize (84). Breeders' use of crop wild relative diversity in improving food production has been estimated at an annual value of US$115–120 billion worldwide (85, 86). In the individual case of producing sweeter tomatoes for the US market, a single gene from the tomato wild relative *Solanum chmielewskii* increased sales by US$5–8 million per year (87).

For species to be able to adapt to changed conditions (climate change, for example), they need to have the largest and widest genepool possible, improving the likelihood that the population has the genetic material to be able to adapt to future conditions (88, 89). *In situ* conservation is a way to maintain the maximum level of genetic diversity within and among wild populations of targeted species. *In situ* methods have the additional benefit of being able to conserve multiple plant species, particularly species producing seeds which cannot be stored in genebanks because of the nature of their seeds (90).

The limitations of *in situ* conservation are that the materials are not easily accessible for use, and may be vulnerable to natural and human-made calamities and to other natural interferences such as invasive alien plants (90, 91) unless backed up in *ex situ* facilities. *In situ* conservation needs to be well designed with well-trained personnel, a legal framework and political will to ensure long-term success of the conservation sites (92).

The second *State of the World's Plant Genetic Resources for Food and Agriculture* report by the Commission on Genetic Resources for Food and Agriculture notes that, over the last decade, a large number of surveys and inventories have been carried out and that awareness of the importance and value of crop wild relatives and the need to conserve them *in situ* has increased (38). *In situ* conservation is reflected in the FAO Second Global Plan of Action for Plant Genetic Resources (priority activities 1–4) and Article 8 of the Convention on Biological Diversity. Article 5.1 section (f) of the International Treaty on Plant Genetic Resources for Food and Agriculture refers to the promotion of *in situ* conservation of crop wild relatives and wild plants for food production, including in protected areas, by supporting, among other actions, the efforts of indigenous and local communities.

For animal genetic resources, wild relatives are even more at risk of extinction than domestic animals: 44% of sheep and goats, 50% of pigs and 83% of cattle. More wild relatives of chicken are also at risk (25%) than bird species overall (93).

The key elements that need to be in place to make *in situ* conservation of agricultural biodiversity effective and sustainable are:

- Strategies and management plans or action plans for the *in situ* conservation and sustainable use of genetic resources
- Genetic reserves
- Conservation activities
- Policy and enabling environment
- Effective information systems.

Strategies and management plans

Resources are not unlimited and thus, when planning the conservation and management of crop wild relatives, an essential step is to prioritize sites and interventions for conservation. In order to optimize the use of resources, countries are encouraged to develop National Strategic Action Plans for the conservation and use of genetic resources.[iii] Governments are supported to review, develop or strengthen national strategies for the *in situ* conservation of crop wild relatives through protected area networks and the development of integrated approaches that link conservation of these resources to their sustainable use (94). A number of countries have elaborated national crop wild relative checklists, identifying thousands of species with potential value for future breeding efforts (Table 5.1).

TABLE 5.1 – National crop wild relative checklists, showing the number of species inventoried in various countries

Area, country or region	Number of species	Group of species considered if not a complete checklist	Source of information
Armenia	2,518		(95, 96)
Benin	266		(97)
China	24,499	This checklist includes crop wild relatives and crops, accounting for around 70% of the flora of China	(98)
Cyprus	1,613		(99)
England	1,471		(100)
Finland	1,905		(101)
Germany	2,874	Wild species for agriculture and nutrition	(102)
Guatemala	105	Crop wild relatives of 29 selected crops	(103)
India	ca. 5,000	Wild relatives of ca. 2,000 cultivated plant species	(104)
Ireland	208	Relating to key species as prioritized by the International Treaty on Plant Genetic Resources for Food and Agriculture, and species from under-recorded areas	(105)
Italy	10,773	Crop wild relative and wild harvested plant checklist	(106)
Mauritius	528		(107)
Netherlands	1,274	83% of the Dutch flora	(108)
Norway	2,538		(109)
Portugal	2,319		(110)
Rodrigues	142		(107)
Russia	1,629		(111)
South Africa	1,593	Food and fodder crops	(112)
Spain	930		(113)
Sri Lanka	410	Food crops	(114)
Switzerland	2,749	Includes ornamentals, socioeconomically important plants and plants listed for Switzerland in the Euro-Mediterranean catalogue of crop wild relatives)	(115, 116)
United States of America	2,495		(117)
Venezuela	228	48 priority crops	(118)
Zambia	572	59 crops prioritized by national stakeholders	(119)
South African Development Community	>1,900	Species related to human food and beverage crops, as well as non-food crops	(107)
Europe and Mediterranean	23,483		(115)

These checklists are a first essential step in developing a national strategy to protect priority crop wild relatives relevant to sustainable food systems (See Box 5.4 for an example).

BOX 5.4. – The value of crop wild relative checklists and national strategies

For many national programmes facing the responsibility of conserving national crop wild relative diversity, the problem is where to start and what to do. An established methodology sets out an approach that breaks down the activities into a series of steps (120) as illustrated for the UK.

1. *Checklist* – The UK flora contains approximately 4,800 taxa of which 2,109 crop wild relative taxa are found in the same genus as agricultural, horticultural, forestry, ornamental, medicinal and aromatic crops. These 44% of the UK flora constitute the crop wild relative checklist.
2. *Prioritization* – The checklist was too long a list for detailed conservation planning so was prioritized to include: (1) human food or animal forage and fodder crop wild relatives only, (2) native crop wild relatives, (3) economic value of the related crop, (4) degree of relatedness to the crop, (5) threat assessment, (6) national conservation designations.
3. *Inventory* – following prioritization, a UK inventory of 223 priority crop wild relatives formed the basis for the conservation planning.
4. *Ecogeographic and gap analysis* – An ecogeographic dataset for all available 223 priority inventory crop wild relative taxa was analyzed using: (1) richness analysis, (2) complementarity analysis and (3) incidence of priority crop wild relatives within protected areas to identify priority conservation actions both *in situ* (27 sites in priority order) and *ex situ* (77 crop wild relatives needed further collection).
5. *National crop wild relative strategy* – The priority *in situ* and *ex situ* conservation actions were reviewed by national stakeholders and a consolidated strategy was published by the responsible national agency that included priority actions and institutional responsibilities.
6. *Implementation* – Subsequent to the publication of the strategy, the first UK crop wild relative genetic reserve has been established on the Lizard Peninsular in Southwest England by Natural England. Natural England with the Royal Botanic Gardens Kew are collecting priority crop wild relatives for genebank conservation.

One point in developing and implementing the national crop wild relative strategy cannot be over-emphasized: that is the need to involve the widest stakeholder community in the process described above. Experience has shown it is only with the widest stakeholder community that there will be buy-in and implementation.

Source:Nigel Maxted/University of Birmingham using an example from (100)

Protected areas are generally seen as the cornerstone of *in situ* conservation (81, 82). Protected areas that have specifically been set aside for the conservation of genetic diversity of target species, are referred to as genetic reserves.[iv] The goal of genetic reserves is to conserve *in situ* the maximum range of genetic variation within the target species. This is achieved by locating, designating, managing and monitoring the diverse populations of the target species within specific natural habitats designated for active long-term *in situ* conservation (81, 82).

Sites are identified using established conceptual models (82). The designation of genetic reserves should be founded on appropriate national legislation that provides long-term site security, as well as financial support, which is fundamental. A second critical factor that needs to be carefully considered is the dependence of local people on the area that is to be designated as a genetic reserve (96). Local people need to be part of the management of the reserve through mechanisms like managed access to the reserve or to an alternative source of material, so that neither livelihoods nor the reserve are threatened (Box 5.5). Once designated as a genetic reserve site, the target species is actively monitored and managed to ensure the best chance of long-term survival of the target populations.

BOX 5.5 – Participatory assessment of use of wild plants by local communities in Armenia

The Erebuni State Reserve in Armenia contains 292 vascular plants of which 40 species are wild relatives of wheat, rye and barley. Given its close proximity to the city of Yerevan, there is a strong pressure on the wild plants, which are collected for food and medicinal purposes and sold in the city markets. As a result, many of these species have become threatened. In a project[v] on '*In situ* conservation of crop wild relatives through enhanced information and field application' a series of workshops and a survey were conducted with local communities to gather information on the collection, use and conservation status of a range of plants; to raise awareness among local communities about the benefits and importance of conserving these valuable resources; and to train local communities on the correct use of particular plant species. The participatory engagement with the local communities was vital for the long-term maintenance of wild plants in the Erebuni State Reserve.

Source: (96)

Wild chives (*Allium schoenoprasum*) growing in the Lizard crop wild relative genetic reserve.
Credit: H. Fielder

Conservation activities

Once a strategy and a management plan have been developed and the site identified for the establishment of a genetic reserve, precise conservation activities in the field are required to ensure the safe conservation of the targeted populations of the target species. Conservation activities will depend on the threats present at each site. If the site already has a healthy target species population, in terms of numbers and a stable structure of plants of different ages (seedlings, saplings, immature and mature individuals), the necessity for management intervention may be minimal or even confined to periodic monitoring to confirm a healthy population is being maintained (120). Often, however, due to the effects of human activities, like pollution, invasive species, land conversion and over exploitation, the ecosystems and habitats of crop wild relatives are degraded and fragmented and require activities for their restoration or rehabilitation (Box 5.6).

BOX 5.6 – Restoration of a crop wild relative-rich degraded forest in Mauritius

The island of Mauritius possesses a rich diversity of endemic plants, including wild relatives of important crops such as coffee. Over hundreds of years, as a consequence of human colonization, the native vegetation had become greatly threatened, largely as a result of deforestation, agriculture and the invasion of introduced species that had displaced native species (121). In the 1980s, a series of experimental areas, termed Conservation Management Areas, were established to develop managed plots in representative areas of native vegetation specifically with the aim of restoring the forest. The main intervention used was to weed out invasive species.

Ten to twelve years after the initial weeding, the forest had recovered so well that the structure was close to that described by early ecologists in the 1930s (122). Many of the native species including the endemic coffee wild relatives in the Conservation Management Areas are now naturally regenerating, an indication that *in situ* conservation efforts have paid off.

Source: (123)

Ex situ conservation

Ex situ conservation is literally the off-site conservation of species, populations and varieties. It is defined as the "conservation of components of biological diversity outside their natural habitats" (40). *Ex situ* conservation occurs when individuals of a species are maintained in artificial conditions outside the selection pressures of their natural habitat. *Ex situ* conservation is important at different levels. First, many natural habitats, including traditional agroecosystems, in which most cultivated diversity is grown, are threatened. In these cases, *ex situ* conservation is an efficient and quick means to prevent this often unique diversity from disappearing. Second, *ex situ* conservation greatly facilitates access to diversity for a wide range of uses, including direct use and research. Third, *ex situ* conservation can be a source of materials for various uses such as breeding materials for breeders or restoration of lost diversity in its natural habitat or on farm.

In the context of sustainable food systems, *ex situ* conservation can contribute to sustainable production systems and nutritious diets by providing breeding materials for uses such as saline-, pest- or drought-tolerance, or which need lower synthetic inputs, or have high nutrient content. *Ex situ* conservation can make varieties and species that already have those traits easily available.

In vitro evaluation at the International Potato Center (CIP) genebank.
Credit: CIP/C.Ynouye

Typically the choice of the type of conservation method depends on the biology of the species to be conserved and on the facilities available for storage. These include seedbanks (for seeds), field genebanks (for live plants), *in vitro* genebanks (for plant and animal tissues and cells), pollen banks, DNA banks and cryobanks for ultra-long preservation (124). Seedbanks, which consist of conserving dried seeds at low temperatures, are commonly used, as the samples stored can be easily handled, require low maintenance and frequently remain viable for decades (124). However, not all types of seeds can be conserved in seedbanks. Some species produce seeds that are sterile (like the cultivated banana), or produce seeds that cannot be dried and stored at low temperature (recalcitrant species, for example tropical fruits such as mangosteen, rambutan, mango and cacao) (90). Other species are clonally propagated because they are grown for their roots and tubers (e.g. yams, potato, cassava and aroids) or propagated to maintain specific gene combinations (e.g. vine, citrus species or banana). Conservation options for these crops are to grow them out in field genebanks or preserve them as tissue culture, embryo or cell suspensions grown in test tubes (*in vitro*). Field genebanks are easy to set up, but are space and time consuming, as they need to be regularly replanted, and are very vulnerable as the germplasm is exposed to changing climatic conditions, pest and diseases, floods and droughts. *In vitro* conservation is more secure at least for medium-term storage (125). Cryopreservation (i.e. the storage of tissue, embryo and cell-suspensions above or in liquid nitrogen) is preferable for longer-term storage, but requires highly specialized expertise and equipment.

Challenges to *ex situ* collections include securing long-term funding and local combinations of environmental hazards such as hurricanes, earthquakes or severe drought episodes, and political instability, including wars. Thus, the storage of duplicates of the conserved material at another genebank, preferably in another country and on a different continent, is foreseen as part of the standard *ex situ* storage of germplasm (91). In addition, and in response to these threats, in 2008, the Svalbard Global Seed Vault, was launched as an additional safety backup for national and international collections. Situated halfway between mainland Norway and the North Pole, the Svalbard Vault has the capacity to conserve 4.5 million different crop varieties under the form of seeds. It currently holds more than 860,000 seeds that represent more than 10,000 taxa and more than 5,000 species of crops and some of their wild relatives (126).

There are two forms of *ex situ* conservation of animal genetic resources: *ex situ in vivo* of animal herds or flocks maintained as conserved populations, mainly by public sector institutions across the world; and *ex situ in vitro* mainly in the form of semen banks and, to a very limited extent, embryos. FAO (127) identifies possible biological materials for consideration in *ex situ* programmes: semen, embryos, oocytes, somatic cells and DNA. Semen banks (held as the core of artificial insemination programmes) have been the major method of *ex situ* conservation of livestock species, especially in cattle – where semen technology has been in use for a long time. There have also been recent initiatives – mostly by research establishments – to put together banks of biological material or purified DNA (biobanks). However, because these cannot, for now at least, be mainstreamed into wide-scale breeding programmes, investments in biobanks remain limited.

Policies and enabling environment

For conservation of agricultural biodiversity to happen successfully and contribute to sustainable food systems, conservation actions need to be supported by appropriate policies, mechanisms and institutions. In this section, we seek to determine the policy and regulatory elements that enable progress by looking at cases where countries are showing progress in integrating conservation with use in sustainable food systems. The focus on a sustainable food system leads to a particular emphasis on local, native and/or traditional biodiversity and neglected and underutilized species. Getting the policies right involves action at many levels. The case study of Peru (Box 5.7) illustrates how changes in policies in different sectors and at different levels can combine to produce an enabling environment for agricultural biodiversity to be valued and conserved.

BOX 5.7 – Policies, civil society and business converge around agricultural biodiversity: Peru's journey

Peru, a megadiverse country,[vi] has made considerable progress regarding laws, strategies and action plans to conserve and sustainably use its biodiversity, including its native agricultural biodiversity.

Starting in the 2000s, there has been increased recognition by policymakers, researchers and entrepreneurs of the contributions of traditional farmers to agricultural biodiversity, and of genetic resources to food security and to the economy, given an increased demand for native crops and for benefits to the environment. The gastronomic renaissance of Peruvian food, where chefs and cooks celebrate native crops, has contributed to an improved societal perception about crop genetic resources and the smallholder farmers who grow them. The media has played an important role in the debate about climate change, adaptation, non-certified seeds and smallholder farmers. Businesses too have started to pay attention to biodiversity, for example with a 'Business and Biodiversity' initiative, led by large businesses, which aims for "productive conservation".

The government for its part is supporting various programmes: ValBio, which is a government grants programme to fund research projects to value native biodiversity (128); GENESPERU, a one-stop-shop platform to facilitate access to genetic resources and benefit sharing. The Ministry for Agriculture, in a departure from the priority focus on export crops, has indicated interest in smallholder farmers, approving regulations for the recognition of agrobiodiversity zones, and announcing the creation of the National Center for Genetic Resources of Agrobiodiversity. Peru appears poised to take advantage of its agricultural heritage for sustainable development.

Laws, regulations and institutions relevant for the conservation and sustainable use of agrobiodiversity in Peru 1986–2016 (Adapted from 129)

Norms	Year	Basic tenets
Promotion, production and consumption of agricultural food products from the Andes (Law 24520)	1986	Promotion of production and consumption of Andean native foodstuffs
Environmental & Natural Resources Code (Legislative Decree 613)	1990	Cultural diversity, natural patrimony and genetic diversity
Convention on Biological Diversity (CBD)	1993	*In situ / ex situ* conservation, agricultural biodiversity
National Commission on Biological Diversity	1993	Compliance with CBD at national level
National Council on the Environment (CONAM) created (Law 26410)	1994	Responsible for national environmental policy, focal point for CBD
Conservation of Biological Diversity (Law 26839)	1997	Species with cultural value, traditional knowledge, cultural patrimony
Regulations Law 26839	2001	Agrobiodiversity zones to protect indigenous culture, native crop species, allowing tourism
National Strategy of Biological Diversity	2001	*In situ* conservation, agricultural biodiversity
Protection of Collective Knowledge of Indigenous Peoples related to biological resources (Law 27811)	2002	Legal protection of collective knowledge associated with biodiversity – including agricultural biodiversity – by communities
CONAM National Programme of Agrobiodiversity created, which guides regional agricultural biodiversity agendas	2004	Sustainable use of agricultural biodiversity and components
National commission against Biopiracy (Law 28216)	2004	Biopiracy, protection of traditional knowledge, sovereignty
Native crops, landraces and wild relatives are national patrimony (Law 28477)	2005	Germplasm conservation, national patrimony, species of crops and landraces
General law about the environment (Law 28611)	2005	Biological diversity, genes, cultural diversity, benefit sharing, genetic resources, traditional knowledge, biotechnology, *in situ* conservation
Ministry of Environment (MINAM) created (Decree 1013)	2008	Responsible for national environmental policy
MINAM National Strategy on Biological Diversity and Action Plan to 2021 (NBSAP) (Decree 009)	2014	Includes actions on agricultural biodiversity, agroecosystems and genetic resources for food and agriculture
Ministry of Agriculture Regulation of agrobiodiversity zones	2016	Mechanisms and procedures for recognition of agrobiodiversity zones

Maize diversity in a community seedbank, Cuchumatanes highlands of Western Guatemala
Credit: Bioversity International/G.Galluzzi

Evidence from the case studies gathered suggests that some of the key mechanisms for an enabling environment are as follows:

Coordination between different ministries

National programmes that involve different sectors of government are a prerequisite for effective conservation and use of agricultural biodiversity to support sustainable food systems. An in-depth look at the expression of international agreements in national policies and practices indicates that, although most international agreements aim to have a positive influence on crop and animal genetic resource conservation and farmers' livelihoods, at national level policies tend to focus only on the non-agricultural parts of conservation, such as forests, wildlife and protected areas. This has negative consequences on the cultivation of traditional species, varieties and breeds. Efforts are more successful when different sectors of government (i.e. environment and agriculture) that normally do not work together are supported by policies to coordinate their work (38). For example, in Central American countries, complementary to a process of economic integration over the last decade, there has been a rapprochement between the environment and agriculture sectors that led to the joint formulation of a climate change agenda of work between the Council of Ministers of Agriculture and the Council of Ministers of Environment of Central America (130, 131), thus in one step favourably advancing interagency coordination within countries. The Council of Ministers of Agriculture belonging to the Central American Integration System (SICA from the Spanish acronym) has endorsed an action plan to conserve and use native plant genetic resources in adaptation to climate change, called the *Strategic Action Plan for the Conservation and Use of Plant Genetic Resources of Mesoamerica (SAPM)* (132).

Participatory planning

The development of national strategies and action plans, such as National Biodiversity Strategy and Action Plans (NBSAPs) and National Adaptation Programmes of Action (NAPAs, for climate change action) need to involve all relevant stakeholders, including those working on agricultural biodiversity, to ensure the involvement of stakeholders other than the state. Broad participatory planning processes used for the development of the *Strategic Action Plan for Mesoamerica*, involving stakeholders from six countries (132), resulted in immediate and concrete action. For example, in Guatemala, the National Institute of Agrarian Technology (INTA) planned collection missions to fill genebank gaps, and a community-based organization, the Association of Associations of the Cuchumatanes, Guatemala (ASOCUCH), used the Strategic Action Plan to design projects that implement its actions (133). In Honduras, a Commission on Genetic Resources was formally recognized. The implementation of NBSAP actions is, however, most effective if there are funding allocations by governments. For example, Peru's NBSAP is being systematically implemented by the Ministry of the Environment with sector funding: national experts are bringing together baseline inventories of priority crops, and incentive mechanisms for on-farm conservation are being pilot tested (75, 133).

Recognition and strengthening of conservation at local level

On-farm conservation, by its nature, takes place through actions by farmers and communities at a local level. Community-level initiatives such as participatory plant breeding and the development of community seedbanks have proven to be successful local solutions for the conservation and use of agricultural biodiversity in several countries, such as Nepal and India (58, 59). For example community seedbanks in Nepal have been recognized and registered by some local governments, and the government has started to provide some of them with technical and financial support. There are now more than 100 community seedbanks in Nepal with functions from pure conservation to commercial seed production (59). In addition, recognizing the outstanding efforts of custodian farmers – farmers who actively maintain, adapt and disseminate agricultural biodiversity and related knowledge, over time and space, at farm and community levels and are recognized by community members for it – is one way to strengthen their contribution. (Box 5.8).

BOX 5.8 – Bolivian and Indian custodian farmers recognized by their governments as contributing to *in situ* and on-farm conservation

The Bolivian government announced in 2014 that custodian farmers are important complementary contributors on farm to the *in situ* conservation of biodiversity, and are integral members of the Germplasm Banks Network and the construction of the National System of Genetic Resources. A manifesto of Gratitude to Agricultural Biodiversity Custodian Farmers was signed and presented highlighting the establishment of a network of custodian farmers.

Source: (134)

In India, the Protection of Plant Varieties and Farmer Rights Authority, after a competitive process conferred the award 'Plant Genome Saviour Community Award' to the Society for Conservation of Mango Diversity, an NGO, for safeguarding mango genetic resources of the Malihabad district *in situ* and on farm.

Source: (135)

Bolivian farmer in a quinoa field.
Credit: Bioversity International/E.Gotor

Social and cultural attitudes

Social and cultural attitudes can play a large role in creating an environment favourable for conserving agricultural biodiversity and using it sustainably. Public awareness about the benefits of biodiversity and people's roles as stewards are thus key (Box 5.9).

BOX 5.9 – Social and cultural attitudes favouring biodiversity

The Union for Ethical Biotrade (UEBT) has released its Biodiversity Barometer every year since 2008. UEBT surveys countries on their attitudes towards biodiversity – including biodiversity used for food and agriculture. Their most recent report reveals that overall attitudes towards biodiversity and knowledge about it have improved worldwide. However, there are differences between countries. In Peru, biodiversity is a term known by most people (94% of respondents) and the highest percentage of people interviewed gave the correct definition of biodiversity (72% of those surveyed) among the 16 countries surveyed. The study noted a close connection between the levels of biodiversity and people's awareness of it: high biodiversity in countries such as Brazil, Peru and Colombia, goes hand in hand with high biodiversity awareness and the ability to describe it. In Latin America, unlike in other parts of the world, biodiversity is recognized and a source of pride in the continent. Many respondents in Latin America (over 95%) say it is important to personally contribute to biodiversity conservation and express the willingness to pay more for biodiversity-based products. When illustrating what biodiversity means, many Brazilians, Colombians and Ecuadorians point to the Amazon. In Peru and Mexico, biodiversity appears also deeply associated with local cuisines, world famous for the variety of natural and traditional ingredients.

Source: (136)

Information system for conservation

An effective functioning system of conservation, management and use of agricultural biodiversity relies on information and knowledge, both new and traditional, about what diversity is available, where it is, threats to it, its conservation status, where it is conserved (*in situ*, on farm or *ex situ*), and what characteristics or traits it has. Availability of, and accessibility to, these kinds of information are vital to enable farmers, scientists and policymakers to take decisions on what agricultural biodiversity to conserve, manage and use, where and how. There has been much progress in documenting diversity of plant genetic resources held in *ex situ* collections in information systems at global and regional levels (e.g. GeneSys, EURISCO, GRIN-Global, FAO WIEWS, State of the World reports on plant genetic resources) (38). However, information systems at national and local level are underdeveloped and need to be strengthened. For on-farm and *in situ* crop genetic diversity, there are not even global or national level information systems, except for the reporting mechanism of the FAO, which monitors implementation of the Second Global Plan of Action on Plant Genetic Resources for Food and Agriculture.

For animal genetic resources, the Domestic Animal Diversity Information System (DAD-IS) developed by FAO is a globally accessible, dynamic, multilingual database of animal genetic resources. It aims to assist countries in the implementation of the Global Plan of Action for Animal Genetic Resources. DAD-IS provides the user with searchable databases of breed-related information and images, management tools, a library of references and links, and contact details of regional and national coordinators for the management of animal genetic resources. Currently, the database contains more than 14,000 national breed populations from 35 species and 181 countries. A number of countries have developed their own national databases or information systems for animal genetic resources. For example, Ireland has developed a national version of DAD-IS known as EFABIS, with the assistance of the FAO and Europe. India has developed an Information system on Animal Genetic Resources of India (AGRI-IS). With a focus primarily on Africa and Asia, the Domestic Animal Genetic Resources Information System (DAGRIS) is an information system developed by the international Livestock Research Institute (ILRI) to facilitate the compilation, organization and dissemination of information on the origin, distribution, diversity, present use and status of indigenous farm animal genetic resources from past and present research results in an efficient way. The State of the World Reports on animal genetic resources prepared by FAO (29, 31) provide comprehensive summaries and useful analyses of the status of global animal genetic resources, and help to focus global attention at high levels on critical conservation and use issues.

Metrics to measure conservation of crop and animal genetic diversity for sustainable food systems

Proposed indicators to assess on-farm conservation of genetic diversity

Crop genetic diversity

Monitoring genetic diversity of crops and breeds in production systems over time is a very challenging exercise. There is no internationally agreed set of indicators that satisfactorily measure the state of crop genetic diversity (32, 137). Most indicators draw on a DPSIR (driving forces–pressure–state–impact–response) framework,[vi] but mainly measure driving forces, pressures and responses rather than the state of genetic diversity per se (32). The most direct measure of genetic diversity is allelic diversity measured at the DNA level with molecular tools (138, 139). This is the most elemental level of biodiversity that drives the formation of new species and underpins other levels of biodiversity, including functional traits, species and ecosystems (32, 137). This metric is very robust and the methodology for measuring genetic diversity is getting better and more feasible with advances in genomics, but data on allelic diversity are still not readily available, are expensive and can only be done on a limited scale. Instead, trends in genetic diversity on farm can be assessed and monitored by different proxies such as area of coverage of traditional varieties (in hectares), richness of crop varieties, evenness of crop varieties, number of growers (44, 140, 141) and, for animals only, effective population size and population level estimate of inbreeding (142). However, even for these proxies, data at national level are patchy and there are no mechanisms in place for systematically collecting data.

The most up-to-date set of indicators for monitoring crop genetic diversity is that for monitoring the implementation of the Second Global Plan of Action for Plant Genetic Resources for Food and Agriculture, which has been endorsed by members of the Commission on Genetic Resources for Food and Agriculture (143). For on-farm conservation, the relevant indicators fall under priority area 2 ‘Supporting on-farm management and improvement of plant genetic resources for food and agriculture’ as follows:

- Number of farming communities involved in management and improvement activities for on-farm plant genetic resources for food and agriculture
- Percentage of cultivated land under farmers’ varieties/landraces in areas of high diversity and/or risk
- Number of farmers’ varieties/landraces delivered from national or local genebanks to farmers (either directly or through intermediaries).

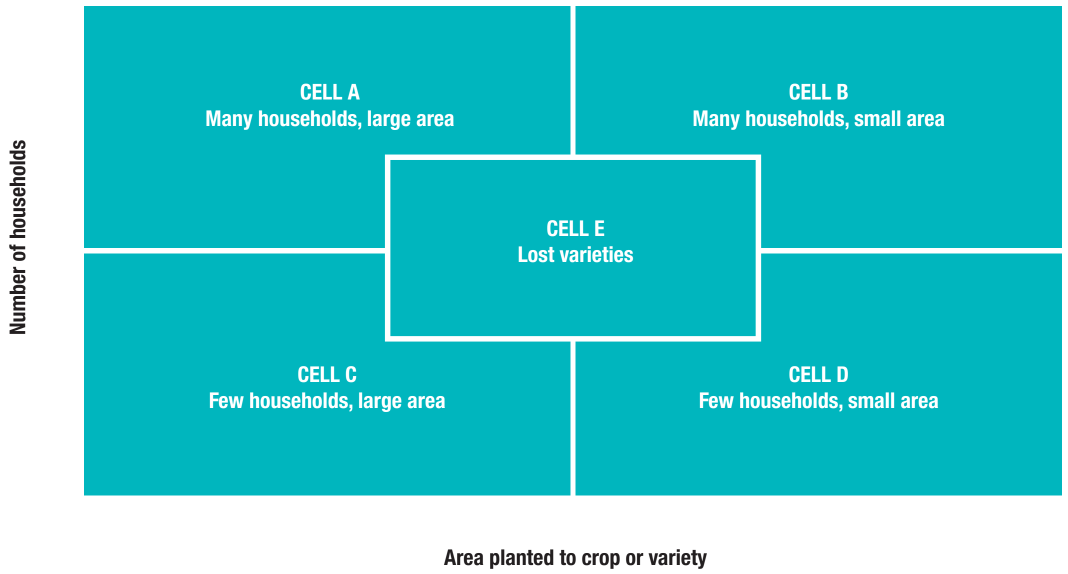
While the Global Plan of Action indicators are a proxy with global consensus, which are collected at national level following standard guidelines and reporting mechanisms developed by FAO (144), they have one major limitation: they do not give a precise measure of the status of crop genetic diversity on farm.

The ideal indicator to aspire to would be one which aggregates up from farm level, since knowledge of crop genetic diversity and how this is changing over time resides among local communities. There are proven socioeconomic research approaches that could be developed into a low-cost methodology for gathering data at this level, such as focus group discussions and seed fairs, where farmers can provide information on whether local diversity is increasing, decreasing or stable. A participatory bottom-up mechanism can support participatory documentation of local crops by communities and the flow of this information to the national level through the assistance of extension services and NGOs.

A community-level methodology named 4-cell analysis can be used to assess local diversity. The method was originally developed in Nepal and is based upon local assessment of richness (area planted to a crop or variety) and evenness (number of farmers growing the crop or variety) at the village level (145). The method is intuitive and has been widely adopted in many countries and contexts (6, 66, 146). A later development, 5-cell analysis, adds an extra cell in which lost varieties can be listed as a record of trends or with an eye to reintroduction (147) (Figure 5.4).

FIGURE 5.4 – Layout of the 5-cell analysis

Crops falling into cell D may be at risk. Those in call E may be recovered from neighbouring communities or genebanks.



With a system using the 5-cell analysis put in place at district or country level, a simple indicator to measure on-farm diversity could be:

- Trends (increasing, decreasing or unchanged) in: area, number of household growers or varietal diversity over the past five years.

Ideally, data originating from local communities would be consolidated by government agencies to provide a broader picture of crop diversity status. It must be stressed, however, that while this assessment and monitoring of diversity on farm represents an ideal decentralized mechanism, it would require financial resources for its mainstreaming (infrastructure and capacity building of community members) as well as careful procedures regarding the management and disclosure of sensitive information about varieties that some communities may not want to release to the general public.

If such data cannot be easily generated, useful proxies for crop genetic diversity on farm, based on data that are available in official national agricultural statistics, could include:

- Number of farmers’ varieties/landraces registered in the national seed board/registries
- Number of species cultivated at national level.

“Humanity’s collective knowledge of biodiversity and its use and management rests in cultural diversity; conversely, conserving biodiversity often helps strengthen cultural integrity and values” (148). Local languages spoken might therefore have potential to be a proxy for indigenous knowledge of biodiversity, as this is the mechanism by which knowledge is transferred from generation to generation. However, research on ways to monitor the status of indigenous knowledge related to agriculture is negligible. A monitoring system for assessing the status of indigenous knowledge could be developed using the 5-cell methodology.[viii]

Animal genetic diversity

The Global Plan of Action on Animal Genetic Resources (149), includes 23 strategic priorities for action grouped into four priority areas: characterization and monitoring; sustainable use and development; conservation; and policies, institutions and capacity-building. The main responsibility for implementing the Global Plan lies with national governments. Progress in the implementation of the Global Plan is monitored using two types of indicators. Process indicators are used to describe the extent to which the actions set out in the Global Plan have been implemented. Resource indicators are used to describe the state of animal genetic diversity itself and therefore the impact of the Global Plan. The indicators contribute to the measurement of progress towards Aichi Biodiversity Targets 13 (maintenance of genetic diversity), 7 (sustainable management of agriculture, aquaculture and forestry) and 4 (sustainable production and consumption). Information on the implementation of the Global Plan is obtained regularly from national governments, regional networks and international governmental and non-governmental organizations and the data are collected in the DAD-IS database described earlier.

FAO has led major efforts to develop and facilitate the application of tools and measures for quantifying and tracking animal genetic resources over time and space. The focus of this work has been on: (a) quantitative estimates of relationships among livestock breeds and strains; and (b) establishing risk status of breeds based on population figures and trends as well as herd/breeding structures (to incorporate effective population size). In 2004, FAO produced guidelines for development of national farm animal genetic resource management plans – measurement of domestic animal genetic diversity (MoDAD) (150), and the study of diversity in livestock populations using neutral markers is now widespread across the globe (151). FAO, ILRI and other international organizations have developed and tested tools for on-farm breed surveys, which have been adapted for use in many countries and provide the basis for risk status classifications and tracking of trends in breeds (152–155) (Box 5.10). In addition, FAO has been working to support countries to establish national breed inventories (by species). Many countries have established inventories, but the majority (63%) consider that their inventories are incomplete (31). Lack of human and financial resources are consistently reported as the major constraint to the conduct of surveys, establishment of inventories and implementation of effective programmes that support animal genetic resource management. More recently, FAO has developed guidelines for helping countries to design and implement integrated animal recording systems to support management and improvement (144).

The need for indicators for genetic diversity in animal genetic resources has come to prominence only relatively recently and only limited progress has been made, mainly in Europe. Lack of data has been the major challenge to the development of useful indicators. The risk status categories (see Box 5.10) of approximately 64% of reported breeds are available in the Domestic Animal Diversity Information System (29, 151), but a lack of regular updates of countries' breed population data means that trends cannot be described adequately at present (156). This presents a major constraint to tracking status of diversity. However, where risk statuses are available, one can use these, and we here propose the following candidate indicators:

- Proportion of breeds already at risk that slide a level or more down towards the 'critical' status
- Proportion of new breeds that enter 'at risk' classification (e.g. for a country) over a given time period.

BOX 5.10 – Risk status classification of livestock breeds

Extinct: a breed in which there are no breeding males or breeding females remaining. Genetic material that would allow recreation of the breed may, however, have been cryoconserved. In reality, extinction may be realized well before the loss of the last animal or genetic material.

Critical: a breed in which the total number of breeding females is less than or equal to 100 or the total number of breeding males is less than or equal to five; or the overall population size is less than or equal to 120 and decreasing and the percentage of females being bred to males of the same breed is below 80%; and which is not classified as extinct.

Critical-maintained: a breed that meets the criteria for inclusion in the critical category, but for which active conservation programmes are in place or populations are maintained by commercial companies or research institutions.

Endangered: a breed in which the total number of breeding females is greater than 100 and less than or equal to 1,000 or the total number of breeding males is less than or equal to 20 and greater than 5; or the overall population size is greater than 80 and less than 100 and increasing and the percentage of females being bred to males of the same breed is above 80%; or the overall population size is greater than 1,000 and less than or equal to 1,200 and decreasing and the percentage of females being bred to males of the same breed is below 80%; and which is not classified as extinct, critical or critical-maintained.

Endangered-maintained: a breed that meets the criteria for inclusion in the endangered category, but for which active conservation programmes are in place or populations are maintained by commercial companies or research institutions.

At risk: a breed classified as either critical, critical – maintained, endangered or endangered-maintained measurement.

Proposed indicators to assess *in situ* conservation of genetic diversity

The best set of indicators currently available for *in situ* conservation of genetic diversity are those under the FAO indicators for monitoring the implementation of the Second Global Plan of Action for plant genetic resources for food and agriculture (PGRFA) for *in situ* conservation, under priority activity 4: 'Promoting *in situ* conservation and management of crop wild relatives and wild food plants':

- Number of crop wild relatives and wild food plants *in situ* conservation and management actions with institutional support

- Percentage of national *in situ* conservation sites with management plans addressing crop wild relatives and wild food plants
- Number of crop wild relatives and wild food plants species actively conserved *in situ*.

However, as with on-farm conservation, these indicators do not assess the actual genetic diversity conserved *in situ*, but drivers of change and responses to change.

Here we propose a Crop Wild Relative Index as a single indicator to better document the effective status of *in situ* conservation of crop wild relatives. This indicator would measure the actual state (and not the responses) of crop relatives in the wild. The suggested index would be calculated by using existing data from the International Union for Conservation of Nature Red List Index for threatened species, which is the globally recognized index measuring trends in the extinction risk of sets of species (157). The index would not provide an exact indication of the status of genetic diversity, but would be a robust proxy.

As an illustration, we applied the Crop Wild Relative Index to three countries' crop wild relative threat assessments: Bolivia (158), Jordan (159), South Africa (Box 5.11) and a regional crop wild relative assessment for Europe (160) (Table 5.2), using a standard set of procedures (161). A case study on conservation of crop wild relatives in South Africa (Box 5.11) describes the process implemented in a project designed to inventory and characterize wild relatives of crops important for food security in the South African region.^{ix}

BOX 5.11 – Conservation status of crop wild relatives in South Africa

South Africa has a large and diverse flora, with approximately 20,500 indigenous species recorded and more than 8,000 species that have been introduced into the country. Many plant species in South Africa are used for a wide range of purposes, including food and beverages, medicines, perfumes and repellents, soap and cosmetics, poisons for hunting and fishing, dyes, fuel, weaving and building materials. As part of a project on '*In situ* conservation of crop wild relatives in three countries in the Southern African Development Community' (SADC CWR project for short), the South African National Biodiversity Institute, in collaboration with the Department of Agricultural Forestry and Fisheries and Agricultural Research Council, developed a checklist for South African crop wild relatives, which covered 420 crop genera of food (including beverages) and fodder crops, with a focus on the wild relatives of major global crops. 1,479 species were identified. Based on a set of criteria, including socioeconomic value, use potential for crop improvement, relative distribution and conservation status, 272 crop wild relatives were prioritized. Of these, 249 species had reliable information for Red List assessment using the IUCN Red List Categories (threats) and were assigned to one of five IUCN Red List categories as follows: critically endangered (25), endangered (26), vulnerable (16), nearly threatened (2) and least concern (180).

Source: (107)

Storage facilities and nurseries for traditional Andean grains, roots and tubers. Bolivia is home to roughly 20,000 species of plants and more than 2600 species of vertebrates. The National Protected Area System (NPAS) was established in 1997 with the objective to 'maintain representative samples of biogeographic provinces'. The NPAS contains more than 66 protected areas of national, departmental, municipal or private interest and accounts for more than 15%of the national territory.
Credit: Bioversity International/D.Hunter

TABLE 5.2 – Crop wild relative threat assessment in Bolivia, Jordan, South Africa and regional crop wild relative threat assessment in Europe

	Bolivia	**Jordan**	**South Africa**	**Europe**
Data source	(158)	(159)	(107)(Box 5.11)	(160)
IUCN Red List category (weight)				
Extinct (5)	0	0	0	0
Critically endangered (4)	7	19	25	19
Endangered (3)	22	54	26	25
Vulnerable (2)	16	33	16	22
Near threatened (1)	20	11	2	26
Least concern (0)	62	806	180	313
Total Threat Score (T) (total number of species x weight)	146	315	212	221
Maximum Threat Score (M) [total number of species x weight of maximum threat (5)]	635	4615	1245	2025
Crop Wild Relative Index [(M – T) / M]	0.7701	0.9317	0.8297	0.8909
0=all Extinct 1= all Least Concern				

Table 5.2 indicates that, of the countries and regions considered, Bolivia is the country where crop wild relatives are most at risk, and Jordan where they are of least concern. In order to monitor trends across years, the Crop Wild Relative Index would need to be calculated over regular periods of time, depending on species biology. Normally a period of five years is judged as acceptable. At this stage, only a few countries have started to assess the conservation threat of their crop wild relatives, but the numbers are growing (38), so this is a realistic indicator to develop in coming years.

Proposed indicators to assess *ex situ* conservation of genetic diversity

Compared to on-farm and *in situ* conservation, measuring the genetic diversity of *ex situ* collections is less challenging. Materials for assessing the diversity are readily accessible and, by and large, information about conserved material is readily available for large genebanks. With recent advances in genomics and greater accessibility to molecular tools, more and more genebanks are doing molecular characterization of their collections and this information will become more available in near future with initiatives like DivSeek (162), which aims to empower genebank managers, breeders, researchers and farmers to better characterize, disseminate and use plant genetic variation. While this initiative is being developed, proxies are needed to represent the diversity held in *ex situ* facilities that contributes to sustainable food systems.

The relevant FAO indicators under the Second Global Plan of Action for PGRFA for measuring the state of diversity in *ex situ* genebanks fall under priority activity 6 ‘Sustaining and expanding *ex situ* conservation of germplasm’ as well as one indicator under priority activity 7 ‘Regenerating and multiplying *ex situ* accessions’ as follows:[x]

- Number of species conserved *ex situ* under medium or long-term conditions
- Number of accessions conserved *ex situ* under medium or long-term conditions
- Percentage of *ex situ* accessions safely duplicated
- Percentage of *ex situ* accessions in need of regeneration.

If the aim is to measure the breadth of genetic diversity in collections, we would suggest, as an alternative indicator, an adaptation of the ‘Enrichment Index’.[xi] The Enrichment Index could be used at country level to measure the diversity within a portfolio of the main species identified as most important for local food systems. It can also be used to assess levels of neglected and underutilized species and crop wild relatives maintained in collections, applicable to both species and within-species levels. The Enrichment Index uses data readily available in genebanks and is very easy to calculate. It assesses the pool of accessions entering a given collection each year according to their uniqueness when compared to the accessions already present in the collection. Accessions in *ex situ* collections are always described by passport data (163), which contain information such as the species and country of origin. The uniqueness of each accession can be determined based on the plant family and the country of origin from which the accession was collected. These two pieces of information together give an idea of how different the new accession is from what is already in the collection.

An illustration of how the Enrichment Index works in practice is provided in Box 5.12.

BOX 5.12 – Application of the Enrichment Index to the world banana collection at the International Transit Center (ITC), Leuven, Belgium

The world *Musa* (banana and plantains) collection at the International Transit Center (ITC) genebank in Belgium contains approximately 1,500 accessions. We will use it as an example of a method to assess diversity in *ex situ* collections.

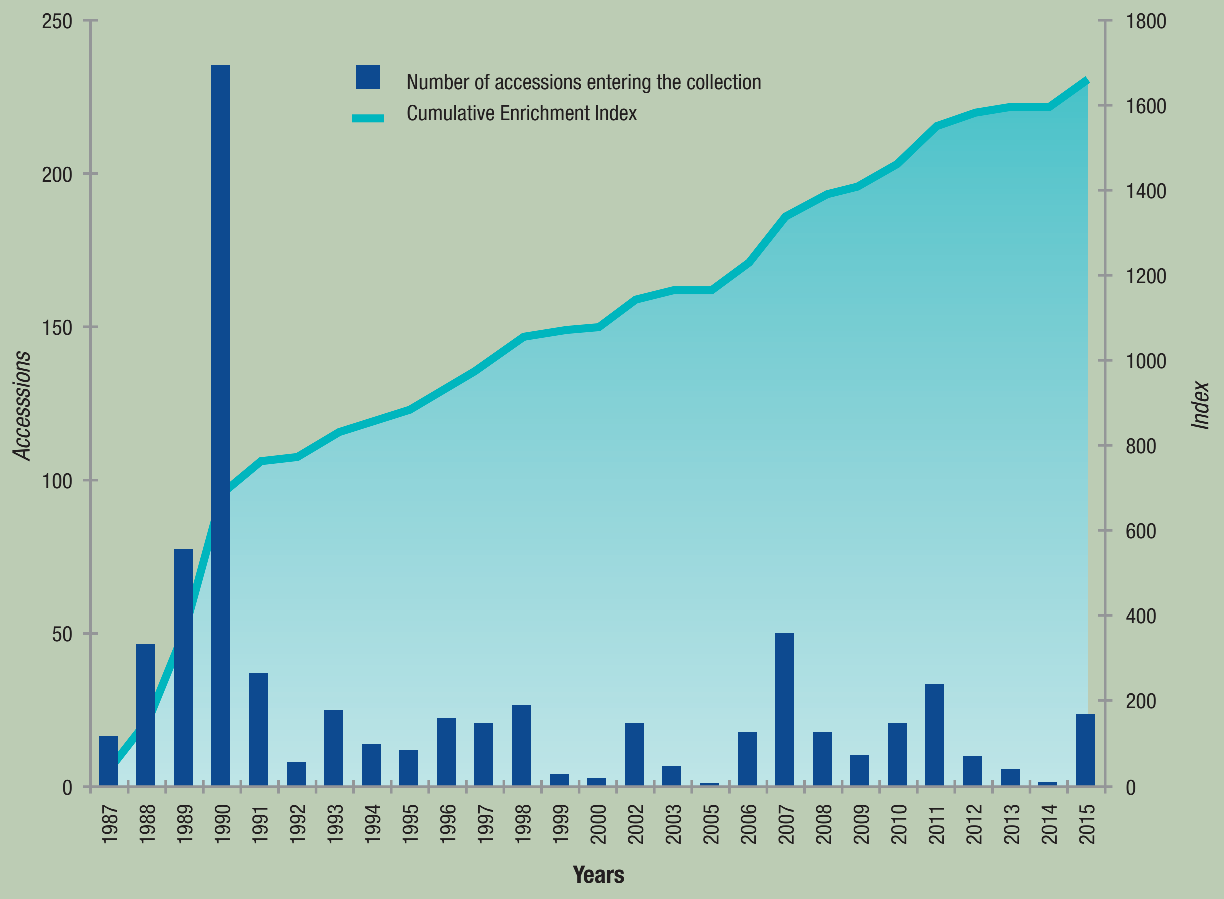
1. Select a valid dataset. We selected a dataset based on the completeness of the passport data fields: genus, species, country of origin and acquisition date. This took us from 1,501 to 769 accessions, representing 80% of the total species and 93.3% of the total countries.

2. Check for duplicates. We ran a duplication analysis over the valid dataset by searching for any accession sharing the exact same combination of values across the fields: genus, species, country of origin, latitude, longitude and acquisition date. From the 769 validated accessions we identified 152 duplicated records. Duplicated accessions should not be discarded, as they may contain useful information, but they receive a lower weighting.

3. Calculate the index. The increase of the Enrichment Index for the selected *Musa* accessions in ITC from 1987 till 2015 is represented together with the number of accessions that entered the collection each year. (Figure 5.5). Here the cumulative value in 2015 is 1,660. Applying the exact same methodology (taxonomic units, time units, etc.), this should be comparable between collections.

FIGURE 5.5 – Enrichment Index of the ITC collection between 1987 and 2015

An increase in the index represents the addition of accessions to *ex situ* collections. The steepness of the line indicates the diversity being incorporated into collections. A steeper line indicates that greater novelty is being added to collections with regard to both taxonomy and source country. A horizontal line indicates that no accessions are being added to collections. The steep increase from 1989 to 1990 corresponds to an important collecting mission in Papua New Guinea, when 215 accessions out of 236 entered the collection.



Banana accessions conserved at the world's largest banana genebank - the Bioversity International Musa Transit Centre in Leuven, Belgium.
Credit: Bioversity International/N.Capozio

Proposed indicators for policy and enabling environment

There are currently two global initiatives which collect data on the policy enabling environment for genetic resources. The first is the World Bank Group initiative 'Enabling the Business of Agriculture' (164) that collects yearly data from 62 countries on Environmental Sustainability, including on conservation of plant genetic resources. The second is the FAO Commission on Genetic Resources for Food and Agriculture which has established processes for collecting data to monitor the implementation and impact of the Global Plans of Action for both plant and animal genetic resources. The data are collected through the FAO WIEWS reporting system for plant genetic resources (165) and DAD-IS for animal genetic resources. Data are compiled and reported to the regular meetings of the Commission every two years.

Existing databases

Based on the analysis above of what is important for the conservation of genetic resources across the three realms of on-farm, *in situ* and *ex situ*, we propose to use these existing databases as a starting point for a scorecard observing the existence or not of key policies and practices that enable conservation of agricultural biodiversity. Further to these, we would add the annual Biodiversity Barometer, measuring social and cultural attitudes towards biodiversity.

Suggested candidate questions for crop and animal diversity in the scorecard could thus be as follows:

From Enabling the Business of Agriculture:

- Does your country have operating genebanks or collection systems for plant genetic resources?
- Has one of them been established by law or regulation as the national genebank or collection system for plant genetic resources?

- Are any of the following activities performed by the officially designated national genebank?
    - Collecting germplasm
    - Germplasm distribution
    - Viability testing
    - Characterization
    - Evaluation
    - Regeneration
    - Multiplication
    - DNA fingerprinting
- Are any of the data relating to these activities available in an online database?
- Does your country have policies, regulations or programmes that establish the following practices?
    - Community seedbanks
    - Diversity fairs
    - Participatory plant breeding
- Does your country have an inventory of crop wild relatives?
- Which of the following information is publicly available for each crop wild relative included in the list?
    - Geographical distribution
    - Conservation status (e.g. vulnerable, endangered or critically endangered)
    - Specific traits
    - Known uses including cultural values or practices associated with the crop wild relative
    - Others

From the FAO Global Plan of Action for plant genetic resources (priority areas in brackets):

- Does your country have national policies that promote development and commercialization of all varieties, primarily farmers' varieties/landraces and underutilized species? (PA11)
- Does your country have a national entity (agency, committee, etc.) functioning as a coordination mechanism for plant genetic resources for food and agriculture activities and/or strategies? (PA13)
- Does your country have a formally appointed national focal point or coordinator for plant genetic resources for food and agriculture? (PA13)
- Does your country have a governmental policy framework and strategies for plant genetic resources for food and agriculture conservation and use? (PA13)
- Does your country have a national information-sharing mechanism for plant genetic resources for food and agriculture? (PA13)
- Does your country have a national system to monitor and safeguard genetic diversity and minimize genetic erosion? (PA16)

From the FAO Global Plan of Action for animal genetic resources (priority areas in brackets):

- Does your country set and regularly review *in situ* conservation priorities and goals? (PA3)
- Does your country have an *in situ* conservation programme for breeds and populations that are at risk? (PA3)
- Does your country set and regularly review *ex situ* conservation priorities and goals? (PA3)
- Has your country established or strengthened fully functional National Focal Points for animal genetic resources? (PA4)
- Does your country have strong national coordination between the National Focal Point and stakeholders involved in animal genetic resources, such as the breeding industry, government agencies, civil society organizations and networks and advisory committees?
- Does your country promote coordination and synergy between the different authorities dealing with various aspects of planning, within and across ministries, as well as with other stakeholders, and ensure their participation in the process?

We suggest integrating the results of the Biodiversity Barometer into the resulting scorecard results, as a measure of social and cultural attitudes favouring biodiversity.

Conclusions

A sustainable food system is ultimately dependent on the availability of and access to a wide diversity of animals and crops, which represent the foundation of agriculture. Of particular importance are those species, varieties and breeds that are important to people's food and nutrition security and farming systems, and which are highly threatened, globally valuable, unique, or a combination of these. The three realms where the genetic diversity of plants and animals is conserved (on farm, *in situ* and *ex situ*) are regarded as complementary and any conservation strategy for agricultural biodiversity needs to consider these realms in a truly integrated system. Governments, companies and other stakeholders with an interest in conserving a wide genetic base for future agricultural challenges will need to take into account the scientific underpinnings that characterize the diversity across these three realms. The scientific evidence can suggest enabling policies and measures to establish simple monitoring systems, based on easy-to-measure or available indicators to better understand the status of agricultural biodiversity. A healthy conservation system will ensure that the raw materials necessary for sustaining our food system will always be available for agricultural improvements.

Diverse crops growing in a field as part of an on-farm conservation project in Ecuador.
Credit: Bioversity International/M.Bellon

Notes

[i] Global Plans of Action are negotiated by the Commission on Genetic Resources for Food and Agriculture, at the Food and Agricultural Organization (FAO) of the UN. They "seek to create an efficient system for the conservation and sustainable use of genetic resources for food and agriculture. Global Plans of Action are intended as comprehensive frameworks to guide and catalyze action at community, national, regional and international levels through better cooperation, coordination and planning and by strengthening capacities. They contain sets of recommendations and priority activities that respond to the needs and priorities identified in global assessments: the reports on the state of the world's genetic resources for food and agriculture." http://www.fao.org/nr/cgrfa/cgrfa-global/cgrfa-globplan/en/

[ii] This work was carried out under a large, multiyear, multicountry research project on 'Strengthening the scientific basis of *in situ* conservation of agrobiodiversity', which was started in 1997 in nine countries, with financial support from the governments of Canada, Germany, the Netherlands and Switzerland, led by Bioversity International (then called the International Plant Genetic Resources Institute, IPGRI).

[iii] The mechanism for the encouragement of countries is a joint notification by the secretariats of the Convention on Biological Diversity (CBD) with its Financial Mechanism – the Global Environment Facility (GEF), the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) and its Benefit Sharing Fund, the CGRFA and Bioversity International.

[iv] Genetic reserves are also known as genetic sanctuaries or gene management zones.

[v] This project, for the safe and effective conservation of crop wild relatives and their increased availability for crop improvement, was funded by the Global Environment Facility (GEF), 2004–2010, in Armenia, Bolivia, Madagascar, Sri Lanka and Uzbekistan. GEF Project ID: 1259. http://www.cropwildrelatives.org/

[vi] There are 17 megadiverse countries in the world. They are countries that harbour very high numbers of endemic species.

[vii] In the DPSIR framework there is a chain of causal links starting with 'driving forces' (economic sectors, human activities) through 'pressures' (emissions, waste) to 'states' (physical, chemical and biological) and 'impacts' on ecosystems, human health and functions, eventually leading to political 'responses' (prioritization, target setting, indicators).

[viii] As part of the CGIAR Research Program on Roots Tubers and Banana, a consortium of international agricultural centres – International Potato Center (CIP), Bioversity International, International Institute of Tropical Agriculture (IITA), and International Center for Tropical Agriculture (CIAT) – organized an international expert meeting on 'Development of Systematic Agrobiodiversity Monitoring Approaches' from 4 to 8 November 2013 in Huancayo, Peru. The aim of the meeting was to share state of the art methods and metrics for the systematic monitoring of *in situ* conserved diversity of crops and crop wild relatives in centres of origin and diversity, and to define a minimal core set of standard procedures to be shared among different organizations and countries. The report can be found at (166).

[ix] The project, on *in situ* conservation of crop wild relatives in three countries of the Southern African Development Community (SADC) region, was co-funded by the European Union and the Secretariat of the African, Caribbean and Pacific (ACP) group of States through the ACP-EU Co-operation Programme in Science and Technology (Grant: FED/2013/330-210).

[x] An accession is a "distinct, uniquely identifiable sample of seeds representing a cultivar, breeding line or a population, which is maintained in storage for conservation and use" (167).

[xi] The Enrichment Index has been Developed by FAO, IRD (Institut de Recherche pour le développement) and Bioversity International under the Biodiversity Indicators Partnership programme (168).

References

1. Dulloo ME, Hunter D, Borelli T (2010) *Ex situ* and *in situ* conservation of agricultural biodiversity: major advances and research needs. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca* 38(2):123–135.
2. IPES-Food (International Panel of Experts on Sustainable Food Systems) (2016) *From Uniformity To Diversity: A Paradigm Shift From Industrial Agriculture To Diversified Agroecological Systems.*
3. Global Panel on Agriculture and Food Systems for Nutrition (2016) *Food Systems and Diets: Facing the Challenges of the 21st Century* (Global Panel on Agriculture and Food Systems for Nutrition, London).
4. Royal Botanic Gardens Kew (2016) *The State of the World's Plants Report 2016* (Royal Botanic Gardens, London).
5. FAO (Food and Agriculture Organization) (2015) *The Second Report on the State of The World's Plant Genetic Resources for Food and Agriculture* (FAO, Rome).
6. Bellon MR, Ntandou-Bouzitou GD, Caracciolo F (2016) On-farm diversity and market participation are positively associated with dietary diversity of rural mothers in Southern Benin, West Africa. *PloS ONE* 11(9):e0162535.

7. Eyzaguirre PB, Linares OF eds. (2004) *Home Gardens and Agrobiodiversity* (Smithsonian Books, Washington DC).
8. Weinberger K, Swai I (2006) Consumption of traditional vegetables in Central and Northeastern Tanzania. *Ecology of Food and Nutrition* 45(2):87–103.
9. Bhardwaj R, Rai AK, Sureja AK, Singh D (2007) Nutritive value of indigenous vegetables of Arunachal Pradesh. In Proceedings 2nd Indian Horticulture Congress – *Opportunities and Linkages for Horticulture Research and Development*. (ICAR complex for NE region. 18–21 April 2007. Barapani).
10. Chadha ML, Oluoch MO (2007) Healthy diet gardening kit for better health and income. *ISHS Acta Horticulturae*, 752: 581–583.
11. Hawtin G (2007) Underutilized Plant Species Research and Development Activities – Review of issues and options. A report submitted to the chairs of the GFU Steering Committee and the ICUC Scientific Advisory Board.
12. Yang R, Hanson P, Lumpkin T (2007) Better health through horticulture—the World Vegetable Centre's approach to improved nutrition for the poor. *ISHS Acta Horticulturae* 744:71–78.
13. Erlund I et al. (2008) Favorable effects of berry consumption on platelet function, blood pressure, and HDL cholesterol. *The American Journal of Clinical Nutrition* 87(2):323–31.
14. Smith FI, Longvah T (2009) Mainstreaming the use of nutrient-rich underutilized plant food resources in diets can positively impact on family food and nutrition security—data from Northeast India and West Africa. *Acta Horticulturae* (806):375–384.
15. Padulosi S, Bhag Mal, King OI, Gotor E (2015) Minor millets as a central element for sustainably enhanced incomes, empowerment, and nutrition in rural India. *Sustainability* 7(7):8904–8933.
16. Sthapit BR, Rana R, Eyzaguirre PB, Jarvis DI (2008) The value of genetic diversity to resource-poor farmers in Nepal and Vietnam. *International Journal of Agricultural Sustainability* 6(2):148-166.
17. Kurukulasuriya P, Mendelsohn R (2008) A Ricardian analysis of the impact of climate change on African cropland. *African Journal of Agricultural and Resource Economics* 2(1):1–23.
18. Belcher B (2005) Forest product markets, forests and poverty reduction. *International Forestry Review* 7(2):82–89.
19. Gruère G, Nagarajan L, King OI (2009) The role of collective action in the marketing of underutilized plant species: Lessons from a case study on minor millets in South India. *Food Policy* 34(1):39–45.
20. Adoukonou-Sagbadja H, Dansi A, Vodouhè R, Akpagana K (2006) Indigenous knowledge and traditional conservation of fonio millet (*Digitaria exilis, Digitaria iburua*) in Togo. *Biodiversity and Conservation* 15(8):2379–2395.
21. Padulosi S, Hodgkin T, Williams JT, Haq N (2002) Underutilized crops: trends, challenges and opportunities in the 21st century. In *Managing Plant Genetic Diversity*, eds Engels J, Rao W, Brown A, Jackson MT (CABI, Wallingford), pp 323–338.
22. Thies E (2000) *Incentive Measures Appropriate to Enhance the Conservation and Sustainable Use of Agrobiodiversity* (GTZ, Eschborn).
23. Rege JEO (2001) Defining livestock breeds in the context of community-based management of farm animal genetic resources. *Community-Based Management of Animal Genetic Resources. Proceedings of the workshop held in Mbabane, Swaziland, 7–11 May 2001* (FAO, Rome), pp 27—35.
24. Changprasert S, Tongtao S, Noppornphan C, Somsri S (2016) Value addition of a local food using *Garcinia cowa* leaves through collective action and marketing by a women's group. In *Tropical Fruit Tree Diversity. Good Practices for In Situ and On-Farm Conservation*, eds Sthapit BR, Lamers HA. Rao R, Bailey AR (Routledge, London and New York).
25. Jianlin H, Jiexia Q, Zhenming M, Yaping Z, Wen W (1999) Three unique restriction fragment length polymorphisms of EcoRI, PvuII, and ScaI digested mitochondrial DNA of Bactrian camels (Camelus bactrianus ferus) in China. *Journal of Animal Science* 77(8):2315–6.
26. Hanotte O, et al. (2002) African pastoralism: genetic imprints of origins and migrations. *Science* 296(5566):336–339.
27. Bruford MW, Bradley DG, Luikart G (2003) DNA markers reveal the complexity of livestock domestication. *Nature Reviews Genetics* 4(11):900–910.
28. Hanotte O, Jianlin H (2005) Genetic characterization of livestock populations and its use in conservation decision-making. In *The Role of Biotechnology for the Characterization and Conservation of Crop, Forestry, Animal and Fishery Genetic Resources. International Workshop, Turin, Italy, 5-7 March 2005* (ILRI, Nairobi), pp 1–6.
29. FAO (Food and Agriculture Organization) (2007) *The State of the World's Animal Genetic Resources for Food and Agriculture* (FAO, Rome).
30. Scherf B, Baumung R (2015) Monitoring the Implementation of the Global Plan of Action for Animal Genetic Resources. *Biodiversity* 16(2-3):149–156.
31. FAO (Food and Agriculture Organization) (2015) *The Second Report on the State of the World's Animal Genetic Resources for Food and Agriculture* eds Scherf B, Pilling D (FAO, Rome).
32. Dulloo ME, Thormann I, Drucker AG (2016) What do we have to lose? Monitoring crop genetic diversity. In *Enhancing Crop Genepool Use: Capturing Wild Relative and Landrace Diversity for Crop Improvement*, eds Maxted N, Dulloo ME, Ford-Lloyd B V. (CABI, Wallingford), pp 421–435

33. Thormann I, Engels JMM (2015) Genetic diversity and erosion—A global perspective. *Genetic Diversity and Erosion in Plants: Indicators and Prevention*, Volume 1, eds Ahuja MR, Mohan Jain S (Springer International Publishing, Cham) pp 263–294.
34. Pilling D (2010) Threats to animal genetic resources for food and agriculture – approaches to recording, description, classification and analysis. *Animal Genetic Resources* 47:11–22.
35. Bezançon G, et al. (2009) Changes in the diversity and geographic distribution of cultivated millet (*Pennisetum glaucum* (L.) R. Br.) and sorghum (*Sorghum bicolor* (L.) Moench) varieties in Niger between 1976 and 2003. *Genetic Resources and Crop Evolution* 56(2):223–236.
36. Bonneuil C, et al. (2012) A new integrative indicator to assess crop genetic diversity. *Ecological Indicators* 23: 280-289.
37. Burke J, Burger J, Chapman MA (2007) Crop evolution: from genetics to genomics. *Current Opinion in Genetics & Development* 17(6):525–532.
38. FAO (Food and Agriculture Organization) (2010) *The Second Report on the State of the World's Plant Genetic Resources for Food and Agriculture* (FAO, Rome).
39. Castañeda-Álvarez NP, et al. (2016) Global conservation priorities for crop wild relatives. *Nature Plants* 2:16022.
40. CBD (Convention on Biological Diversity) (1992) *Article 2 Use of Terms* (CBD, Montreal).
41. Frankel OH, Hawkes JG (1975) Crop genetic resources for today and tomorrow. *International Biological Programme Synthesis Series (No 2)* (Cambridge University Press, Cambridge).
42. Bellon M (2009) Do we need crop landraces for the future? Realizing the global option value of *in situ* conservation. In *Agricultural Biodiversity and Economic Development* eds Kontoleon A, Pascual U, Smale M (Routledge, London), pp 51–59.
43. Frison EA, Cherfas J, Hodgkin T (2011) Agricultural biodiversity is essential for a sustainable improvement in food and nutrition security. *Sustainability* 3(12):238–253.
44. Jarvis DI, et al. (2008) A global perspective of the richness and evenness of traditional crop-variety diversity maintained by farming communities. *Proceedings of the National Academy of Sciences* 105(14):5326–5331.
45. Jarvis DI, Padoch C, Cooper HD eds. (2007) *Managing Biodiversity in Agricultural Ecosystems* (Bioversity International and Columbia University Press, New York).
46. Jarvis D, Hodgkin T (2000) Farmers decision making and genetic diversity: linking multidisciplinary research to implementation on farm. *Genes in the Field : On-Farm Conservation of Crop Diversity*, ed Brush SB (IPGRI, Rome), p 288.
47. Rege JEO (1999) The state of African cattle genetic resources I. Classification framework and identification of threatened and extinct breeds. *Animal Genetic Resources Information* 25:1–25.
48. Bellon MR, Gotor E, Caracciolo F (2015) Assessing the effectiveness of projects supporting on-farm conservation of native crops: evidence from the High Andes of South America. *World Development* 70:162–176.
49. Sthapit B, et al. (2012) Community based approach to on-farm conservation and sustainable use of agricultural biodiversity in Asia. *Indian Journal of Plant Genetic Resources* 25(1):97–110.
50. Oldfield ML, Alcorn JB (1987) Conservation of traditional agroecosystems. *Bioscience* 37(3):199–208.
51. Brush SB, Meng E (1998) Farmers' valuation and conservation of crop genetic resources. *Genetic Resources and Crop Evolution* 45(2):139–150.
52. Jarvis DI, et al. (2016) *Crop Genetic Diversity in the Field and on the Farm: Principles and applications in research practices* (Yale University Press, New Haven and London).
53. Jarvis DI, Hodgkin T, Sthapit BR, Fadda C, López Noriega I (2011) An heuristic framework for identifying multiple ways of supporting the conservation and use of traditional crop varieties within the agricultural production system. *Critical Reviews in Plant Sciences* 30(1-2):125–176.
54. Latournerie Moreno L, et al. (2006) Traditional maize storage methods of Mayan farmers in Yucatan, Mexico: implications for seed selection and crop diversity. *Biodiversity and Conservation* 15(5):1771–1795.
55. Weitzman M (1993) What to preserve? An application of diversity theory to crane conservation. *The Quarterly Journal of Economics* 108(1):157–183.
56. Samuel AF, Drucker AG, Andersen SB, Simianer H, van Zonneveld M (2013) Development of a cost-effective diversity-maximising decision-support tool for *in situ* crop genetic resources conservation: The case of cacao. *Ecological Economics* 96:155–164.
57. Vernooy R, Sthapit B, Galluzzi G, Shrestha P (2014) The multiple functions and services of community seedbanks. *Resources* 3:636–656.
58. Sthapit B (2013) Emerging theory and practice: community seed banks, seed system resilience and food security. In *Community Seed Banks in Nepal: Past, Present, Future. Proceedings of a National Workshop* eds. Shrestha P, Vernooy R, Chaudhary P (LI-BIRD/USC Canada Asia/Oxfam/The Development Fund/IFAD/Bioversity International, 14-15 June 2012, Pokhara).
59. Vernooy R, Sthrestha P, Sthapit B eds. (2015) *Community Seed Banks: Origins, Evolution and Prospects* (Routledge, London).
60. Shrestha P, Vernooy R, Chaudhary P (2013) *Community Seedbanks in Nepal: Past, Present, Future.* Proceedings of a National Workshop (LI-BIRD/USC Canada Asia/Oxfam/The Development Fund/IFAD/Bioversity International, 14-15 June 2012, Pokhara).
61. Shrestha P, Paudel H, Paudel S (2016) Community seedbank approach to strengthen local seed system and promote on-farm management of agricultural biodiversity in Nepal. *CBM Conference* (LI-BIRD, Pokhara).

62. Vernooy R, Clancy E (2016) Realizing Farmers' Rights Through Community-Based Agricultural Biodiversity Management. Policy Brief 8. (Bioversity International, Rome).

63. Shrestha P, Gezu G, Swain S, Lassaigne B, Subedi A, de Boef WS (2013) The community seedbank: a common driver for community biodiversity management. In *Community Biodiversity Management: Promoting Resilience and the Conservation of Plant Genetic Resources*, eds de Boef W, Subedi A, Peroni N, Thijssen M, O'Keeffe E (Routledge, Abingdon), pp 1–422.

64. Shrestha P, Sthapit S, Subedi A, Sthapit B (2013) Community biodiversity management fund: promoting conservation through livelihood development in Nepal. In *Community Biodiversity Management: Promoting Resilience and the Conservation of Plant Genetic Resources*, eds de Boef W, Subedi A, Peroni N, Thijssen M, O'Keeffe E (Routledge, Abingdon), pp 118–123.

65. Sthapit B, Lamers H, Rao R, Bailey A eds. (2016) *Tropical Fruit Tree Diversity. Good Practices for in Situ and on-Farm Conservation* (Routledge, Abingdon).

66. Sthapit B, Lamers H, Rao R, Bailey A (2016) Community biodiversity management as an approach for realizing on-farm management of agricultural biodiversity. *Tropical Fruit Tree Diversity: Good Practices for in Situ and on-Farm Conservation*, eds. Sthapit B, Lamers H, Rao R, Bailey A (Routledge, Abingdon).

67. Kendall J, Gras E (2013) The Maison de la Semence Paysanne and diversity platform. In *Community Biodiversity Management: Promoting Resilience and the Conservation of Plant Genetic Resources*, eds de Boef W, Subedi A, Peroni N, Thijssen M, O'Keeffe E (Routledge, Abingdon), pp 43–51.

68. Sthapit B, Joshi K, Witcombe J (1996) Farmer participatory crop improvement. III. Participatory plant breeding, a case study for rice in Nepal. *Experimental Agriculture* 32(04):479.

69. Gyawali S, et al. (2010) Participatory crop improvement and formal release of Jethobudho rice landrace in Nepal. *Euphytica* 1761(1):59—78.

70. Yapi-Gnaorè CV, Rege JEO, Oya A, Alemayehu N (1997) Analysis of an open nucleus breeding programme for Djallonkè sheep in the Ivory Coast. 2. Response to selection on body weights. *Animal Science* 64(02):301–307.

71. Shrestha P, Sthapit S (2014) Conservation by communities: The CBM approach. *LEISA India* 16(1).

72. Shrestha P, et al. (2013) *A Guide to Establishing a Community Biodiversity Management Fund for Enhancing Agricultural Biodiversity Conservation and Rural Livelihoods* (LI-BIRD, Pokhara).

73. FAO (Food and Agriculture Organization) (2005) *Building on Gender, Agrobiodiversity and Local Knowledge. A Training Manual* (FAO, Rome).

74. Genetic Resources Policy Committee (1999) *Enlarging the Basis of Food Security: Role of Underutilized Species, Proceedings of the International Consultation Organized by the Genetic Resources Policy Committee of the CGIAR at the M.S. Swaminiathan Research Foundation* (Genetic Resources Policy Committee, Chennai).

75. Drucker AG, Appels J (2015) Value chain development: a silver bullet for agrobiodiversity conservation and use? *Enhancing Crop Genepool Use: Capturing Wild Relative and Landrace Diversity for Crop Improvement*, eds Maxted N, Dulloo E, Floyd-Lloyd B (CABI, Wallingford), pp 362–373.

76. Eaton C, Shepherd A (2001) *Contract farming. Partnerships for growth*, Bulletin 145 (FAO, Rome).

77. UNIDO (United Nations Industrial Development Organization) (2011) *Pro-poor Value Chain Development: 25 Guiding Questions for Designing and Implementing Agroindustry Projects* (UNIDO, Vienna).

78. Wankel A, Hethcote L (2017) Estrategias de emprendimiento social para la conservación de la agrobiodiversidad de la quinua: leche de quinua de Kai Pacha. Presentation at VI World Quinoa Congress, 21-24 March 2017, Puno, Peru. Abstract available from http://congresomundialquinua.com/descargas/publicaciones/Eje-D-Aspectos.pdf

79. Narloch U, Drucker AG, Pascual U (2011) Payments for agrobiodiversity conservation services for sustained on-farm utilization of plant and animal genetic resources. *Ecological Economics* 70(11):1837–1845.

80. Press NA (1993) *In situ* conservation of genetic resources. In *Managing Global Genetic Resources: Agricultural Crop Issues and Policies* (National Academic Press, Washington DC).

81. Heywood V, Dulloo M (2005) *In Situ Conservation of Wild Plant Species: A Critical Global Review of Good Practices.* Technical Bulletin No 11 (IPGRI, Rome).

82. Maxted N, Ford-Lloyd B, Hawkes J (1997) *Plant Genetic Conservation: The In Situ Approach* (Chapman & Hall, London).

83. FAO (Food and Agriculture Organization) (2005) *Harvesting Nature's Diversity* (FAO, Rome).

84. Prance G (1997) The conservation of botanical diversity. *Plant Genetic Conservation*, eds Maxted N, Ford-Lloyd B, Hawkes J (Springer Netherlands, Dordrecht), pp 3–14.

85. Pimentel D, et al. (1997) Economic and Environmental Benefits of Biodiversity. *BioScience* 47(11):747–757.

86. PwC (Pricewaterhouse Cooper) (2013) *Crop Wild Relatives: A Valuable Resource for Crop Development* (PwC, London).

87. Iltis H (1988) Serendipity in the exploration of biodiversity. What good are weedy tomatoes? In *Biodiversity* eds. Wilson EO, Peter FM (National Academy Press, Washington DC), pp 98–105.

88. Shaw RG, Shaw FH (2014) Quantitative genetic study of the adaptive process. *Heredity* 112(1):13–20.

89. Clegg MT (1990) Molecular diversity in plant populations. In *Plant Population Genetics, Breeding, and Genetic Resources*, eds Brown AHD, Clegg MT, Kahler AL, Weir BS (Sinauer Associates Inc, Massachusetts), pp 98—115.
90. Dulloo ME, et al. (1998) Complementary conservation strategies for the genus *Coffea*: A case study of Mascarene *Coffea* species. *Genetic Resources and Crop Evolution* 45(6):565–579.
91. Engels JMM, Visser L (2003) *A Guide to Effective Management of Germplasm Collections* (IPGRI Handbooks for Genebanks No. 6 (IPGRI, Rome).
92. Maxted N, et al. (2016) Joining up the dots: a systematic perspective of crop wild relative conservation and use. *Enhancing Crop Genepool Use: Capturing Wild Relative and Landrace Diversity for Crop Improvement*, eds Maxted N, Dulloo ME, Ford-Lloyd B (CABI, Wallingford), pp 87–124.
93. McGowan PJK (2010) Conservation status of wild relatives of animals used for food. *Animal Genetic Resources* 47:115–118.
94. CBD (Convention on Biological Diversity) (2015) Strengthening the *in situ* conservation of Plant Genetic Resources for Food and Agriculture through Incorporation of Crop Wild Relatives under Areas Important for Biodiversity in Protected Area Networks and other Effective area-based Conservation Measures. Notification: SCBD/SAM/DC/DCo/84808 dated 3 Aug 2015. Available at https://www.cbd.int/kb/record/notification/2364?RecordType=notification&Subject=GSPC [Accessed 1 Jun 2017].
95. Gabrielian E, Zohary D (2004) Wild relatives of food crops native to Armenia and Nakhichevan. *Flora Mediterranea* 14:5–80.
96. Hunter D, Heywood V eds. (2011) *Crop Wild Relatives - A Manual of In Situ Conservation* (Earthscan, London).
97. Idohou R, et al. (2013) National inventory and prioritization of crop wild relatives: case study for Benin. *Genetic Resources and Crop Evolution* 60(4):1337–1352.
98. Kell S, et al. (2015) China's crop wild relatives: Diversity for agriculture and food security. *Agriculture, Ecosystems & Environment* 209:138–154.
99. Phillips J, Kyratzis A, Christoudoulou C, Kell S, Maxted N (2014) Development of a national crop wild relative conservation strategy for Cyprus. *Genetic Resources and Crop Evolution* 61(4):817–827.
100. Fielder H, et al. (2015) Enhancing the conservation of crop wild relatives in England. *PLoS ONE* 10(6):e0130804.
101. Fitzgerald H (2013) *The National Crop Wild Relative Strategy Report For Finland*, MTT Report 121 (Natural Resources Institute Finland, Helsinki), p 95.
102. PGRDEU (Plant Genetic Resources in Germany) List of Plant Genetic Resources in Germany. Available at https://pgrdeu.genres.de/information/themenlisten?lang=en.
103. Azurdia C, Williams KA, Van Demme V, Jarvis A, Casta O (2011) *Atlas of Guatemalan Crop Wild Relatives* [Bioversity International, International Center for Tropical Agriculture (CIAT), and the University of San Carlos in Gautemala (FAUSAC)].
104. Pradheep K, Bhandari DC, Bansal (2014) *Wild Relatives Of Cultivated Plants In India* (Indian Council of Agricultural Research, New Delhi).
105. National Biodiversity Data Centre (2017) National database - Biodiversity Ireland. Available at: http://www.biodiversityireland.ie/projects/genetic-resources/crop-wild-relatives/national-database/.
106. Landucci F, et al. (2014) A prioritized inventory of crop wild relatives and wild harvested plants of Italy. *Crop Science* 54(4):1628.
107. SADC Crop Wild Relatives (2016) Project Results. Available at: http://www.cropwildrelatives.org/sadc-cwr-project/.
108. Hoekstra R, Veller MGP van, Odé B (2008) Crop wild relatives in the Netherlands: actors and protection measures. In *Crop Wild Relative Conservation and Use* (CABI, Wallingford), pp 165–177.
109. Phillips J, Asdal Å, Magos Brehm J, Rasmussen M, Maxted N (2016), *In situ* and *ex situ* diversity analysis of priority crop wild relatives in Norway. *Diversity and Distributions* 22:1112 -1126.
110. Magos Brehm J, Maxted N, Ford-Lloyd BV, Martins-Loução MA (2008) National inventories of crop wild relatives and wild harvested plants: case-study for Portugal. *Genetic Resources and Crop Evolution* 55:779–796.
111. Smekalova T (2007) National crop wild relative in situ conservation strategy for Russia. In *Crop Wild Relative Conservation and Use*, eds Maxted N, Ford-Lloyd B, Kell S, Iriondo J, Dulloo ME, Turok J (CABI, Wallingford), pp 143–151.
112. SANBI (South African National Biodiversity Institute), ARC (Agricultural Research Council), DAFF (Department of Agriculture Forestry and Fisheries) (2017) CWR checklist and priority taxa of South Africa. *SADC Crop Wild Relatives Project Dataverse*. Available at: https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/LJWKBN.
113. PGR Secure (2016) Studies for the development of the National Strategy for CWR conservation Spain. *Universidad Rey Juan Carlos*. Available at: http://pgrsecurespain.weebly.com/.
114. Plant Genetic Resources in SAARC Countries: Their Conservation and Management, SAARC Agricultural Information Centre, Dhaka, Bangladesh. [Cited in 96].
115. Kell SP, Knupffer H, Jury SL, Ford-Lloyd BV, Maxted N (2007) Crops and wild relatives of the euro-mediterranean region: making and using a conservation catalogue. In *Crop Wild Relative Conservation and Use*, eds Maxted N, Ford-Lloyd B, Kell S, Iriondo J, Dulloo ME, Turok J (CABI, Wallingford), pp 69–109.

116. BLW (Bundesamt für Landwirtschaft) (n.d.) Crop Wild Relative Inventar. Available at: https://www.bdn.ch/cwr/inventory/.

117. Khoury CK, et al. (2013) An inventory of crop wild relatives of the United States. *Crop Science* 53(4):1496.

118. Berlingeri C, Crespo MB (2012) Inventory of related wild species of priority crops in Venezuela. *Genetic Resources and Crop Evolution* 59(5):655–681.

119. Ng'Uni D, Munkombwe G (2017) CWR checklist and priority CWR of Zambia. *SADC Crop Wild Relatives Project Dataverse.* Available at: https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/8YXCFR.

120. Iriondo J, Maxted N, Dulloo ME eds. (2008) *Conserving Plant Genetic Diversity in Protected Areas* (CABI, Wallingford).

121. Dulloo M, Jones C, Stahm W, Mungroo Y (1996) Ecological restoration of native plant and animal communities in Mauritius, Indian Ocean. In *The Role of Restoration in Ecosystem Management*, eds Pearson D, Klimas C (Society for Ecological Restoration, Washington DC), pp 83–91.

122. Vaughan RE, Wiehe PO (1941) Studies on the vegetation of Mauritius: III. The Structure and development of the upland climax forest. *The Journal of Ecology* 29(1):127.

123. Dulloo ME, Kell S, Jones C, Boudjelas S, Sunders A (2002) Impact and control of invasive alien species on small islands. *The International Forestry Review* 4(4):277–285.

124. Dulloo ME, Thormann I (2012) Lesson 1–What is conservation and sustainable use? *Conservation and Sustainable Use under the International Treaty* (International Treaty on Plant Genetic Resources for Food and Agriculture, Rome).

125. Dulloo ME, et al. (2009) Cost efficiency of cryopreservation as a long-term conservation method for coffee genetic resources. *Crop Science* 49(6):2123–2138.

126. Crop Trust (2015) *Securing Crop Diversity for Sustainable Development* (Crop Trust, Bonn).

127. FAO (Food and Agriculture Organization) (2012) *Cryoconservation of Animal Genetic Resources* (FAO Animal Production and Health Guildelines No. 12, Rome).

128. CONCYTEC (Consejo Nacional de Ciencia, Tecnología e Innovación Tecnológica) (2016). Available at: https://portal.concytec.gob.pe/.

129. Ruiz M (2016) Una Introducción al Marco Político, Institucional y Normativo sobre la Retribución por Servicios de Conservación de la Agrobiodiversidad en el Perú (Ministerio del Ambiente, Lima).

130. SICA (Sistema de la Integracion Centroamericana) (2008) *Estrategia Regional Agroambiental y de Salud* (SICA, San Salvador).

131. SICA (Sistema de la Integracion Centroamericana) (2010) *Estrategia Regional de Cambio Climatico* (SICA, San Salvador).

132. Bioversity International (2014) Strategic action plan to strengthen conservation and use of Mesoamerican plant genetic resources in adapting agriculture to climate change (SAPM) 2014-2024 (Bioversity International. Cali).

133. MINAM (2015) *Estrategia Nacional de Diversidad al 2021. Plan de Accion 2014-2018* (MINAM, Peru).

134. Bioversity International (2014) Bolivia leads the way in recognizing farmers as custodians of biodiversity. Available at: http://www.bioversityinternational.org/news/detail/bolivia-leads-the-way-in-recognizing-farmers-as-custodians-of-biodiversity/.

135. ICAR-Central (Central Institute for Subtropical Horticulture) (2008) Plant genome saviour community award. Available at: http://cish.res.in/event_page.php?a=Plant Genome Savior Community Award.

136. (UEBT) Union For Ethical Biotrade (2016) *UEBT Biodiversity Barometer*, 2009-2016 (UEBT, The Netherlands).

137. Bruford MW, Davies N, Dulloo ME, Faith DP, Walters M (2017) Monitoring changes in genetic diversity. In *The GEO Handbook on Biodiversity Observation Networks* eds. Walters M et al. (Springer International Publishing, Cham), pp 107–128.

138. Pereira HM, et al. (2013) Essential biodiversity variables. *Science* 339(6117):277–278.

139. Hoban et al (2014) Comparative evaluation of potential indicators and temporal sampling protocols for monitoring genetic erosion. *Evolutionary Applications* 7:985–998.

140. Last L, et al. (2014) Indicators for the on-farm assessment of crop cultivar and livestock breed diversity: a survey-based participatory approach. *Biodiversity and Conservation* 23:3051–3071.

141. Drucker A, Nguyen N (2013) *Reviewed and Proposed Indicators for Agrobiodiversity Conservation Services (unpublished report)* (Bioversity International, Rome).

142. FAO (Food and Agriculture Organization) (2000) *The State of Food and Agriculture: Lessons from the past 50 years* (FAO, Rome).

143. FAO (Food and Agriculture Organization) (2013) *Fourteenth Regular Session of the Commission on Genetic Resources for Food and Agriculture* (FAO, Rome).

144. FAO (Food and Agriculture Organization) (2016) *Development of Integrated Multipurpose Animal Recording Systems* (FAO, Rome).

145. Shrestha P, Subedi A, Sthapit S, Rijal D, Gupta S (2006) Community seed bank: reliable and effective option for agricultural biodiversity conservation. *Good Practices: On Farm Management of Agricultural Biodiversity in Nepal*, eds Sthapit B, Shrestha P, Upadhyay M (NARC, LI-BIRD, IPGRI, IDRC, Nepal).

146. Faridah Aini M, et al. (2017) Evaluating the usefulness and ease of use of participatory tools for forestry and livelihoods research in Sarawak, Malaysia. *Forests, Trees and Livelihoods* 26(1):29–46.

147. Padulosi S, Dulloo ME (2012) Towards a viable system for monitoring agrobiodiversity on-farm: a proposed new approach for Red Listing of cultivated plant species. In On-farm conservation of neglected and underutilized species: status, trends and novel approaches to cope with climate change, Proceedings of the International Conference Friedrichsdorf, Frankfurt, 14-16 June, 2011 eds. Padulosi S, Bergamini N, Lawrence T. pp. 171-199 (Bioversity International, Rome).

148. World Resources Institute, The World Conservation Union, UNEP (United Nations Environment Programme) (1992) *Global Biodiversity Strategy: Policymakers Guide* (WRI Publications, Baltimore).

149. FAO (Food and Agriculture Organization) (2007) *The Global Plan of Action for Animal genetic Resources and the Interlaken Declaration* (FAO, Rome).

150. FAO (Food and Agriculture Organization) (2004) *Secondary Guidelines for Development of National Farm Animal Genetic Resources Management Plans: Measurement of Domestic Animal Genetic Diversity* (MODAD) *Recommended Microsatellite Markers* (FAO, Rome).

151. FAO (Food and Agriculture Organization) (2011) Molecular Genetic Characterization of Animal Genetic Resources. FAO Animal Production and Health Guidelines No.9 (FAO, Rome).

152. FAO (Food and Agriculture Organization) (2011) Surveying and Monitoring of Animal Genetic Resources No. 7 (FAO, Rome).

153. Rowlands J, et al. (2003) A report to FAO on The design, execution and analysis of livestock breed surveys - a case study in Zimbabwe (ILRI, Nairobi).

154. MIRBSE (Monitoring Institute for Rare Breeds and Seeds in Europe) (2003) Agricultural genetic resources in the Alps. *Bristol-Schriftenreihe* 11:117.

155. Ayalew W, van Dorland A, Rowlands J (2004) *Design, Execution and Analysis of the Livestock Breed Survey in Oromiya Regional State, Ethiopia* (ILRI, Nairobi).

156. Martyniuk E, Pilling D, Scherf B (2010) Indicators: Do we have effective tools to measure trends in genetic diversity of domesticated animals? *Animal Genetic Resources* 47:31–43.

157. Butchart SHM, et al. (2007) Improvements to the Red List Index. *PLoS ONE* 2(1):e140.

158. Mora A (2009) *Red Book of Crop Wild Relatives of Bolivia* [VMABCC (Vice Ministry for Environment, Biodiversity and Climate Change), Bolivia].

159. Magos-Brehm J, et al. (2016) Crop wild relatives: a priority in Jordan? Developing a national strategy for the conservation of plant diversity in Jordan using a participatory approach. In *Enhancing Crop Genepool Use: Capturing Wild Relative and Landrace Diversity for Crop Improvement*, eds Maxted N, Dulloo ME, Ford-Lloyd B (CABI, Wallingford), pp 172–188.

160. Bilz M, Kell SP, Maxted N, Lansdown RV (2011) *European Red List of Vascular Plants* (Publications Office of the European Union, Luxemburg).

161. Kell S, Maxted N, Bilz M (2012) European CWR threat assessment: knowledge gained and lessons learnt: Towards the establishment of genetic reserves for crop wild relatives and landraces in Europe. In *Agricultural Biodiversity Conservation: Securing the Diversity of Crop Wild Relatives and Landraces*, eds Maxted N, et al. (CABI, Wallingford), pp 218–242.

162. DivSeek (2016) Mission and Goals — Diversity Seek. Available at: http://www.divseek.org/mission-and-goalsv1.

163. FAO (Food and Agriculture Organization), IPGRI (International Plant Genetic Resources Institute) (2001) *FAO/IPGRI Multi-Crop Passport Descriptors* (FAO, Rome).

164. The World Bank Group (2017) Enabling the Business of Agriculture. Available at: http://eba.worldbank.org/data/exploretopics/additional-indicators.

165. FAO (Food and Agriculture Organization) (2017) *Status of Implementation of Second Global Plan of Action for Plant Genetic Resources for Food and Agriculture* (FAO, Rome).

166. CIP (International Potato Center) (2013) First High-Level Meeting for monitoring agrobiodiversity. Available at: http://cipotato.org/press-room/blog/first-high-level-meeting-for-monitoring-agrobiodiversity.

167. FAO (Food and Agriculture Organization) (2016) Food and Agriculture Organization Glossary. Available at: http://www.fao.org/wiews/glossary/en/.

168. FAO (Food and Agriculture Organization), IRD (Institut de Recherche pour le Développement), Bioversity International (2017) Biodiversity Indicators Partnership. Available at: https://www.bipindicators.net/.

Farmer with one of her goats, Nepal.
Credit: IWMI/N.Palmer