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Crop Wild Relative Population Management Guidelines

2021

Cover photo: Demographic monitoring of *Aegilops geniculata* Roth in the CWR genetic reserve of the Biosphere Reserve of Sierra del Rincón in Madrid (Spain) (A. Molina).

Illustrations: C. Álvarez-Muñiz

These guidelines are a product of the Farmer's Pride project – 'Networking, partnerships and tools to enhance *in situu* conservation of European plant genetic resources' (http://www.farmerspride.eu).

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Executive Summary

The aim of this work is to provide protected area managers, conservation practitioners, farmers, policy developers and any other professionals or volunteers responsible for the conservation of crop wild relatives (CWR) populations, some practical guidelines on how to manage the target CWR populations and the genetic reserves where they are being conserved.

In chapters 1 and 2, the guidelines provide an introduction to the subject and an accessible tour to all the elements that one should consider for the design and the implementation of a management plan, including the definition of the management unit, the location, delimitation and characterisation of target CWR populations, habitat characterisation, population threat assessment, management objectives, management interventions, workplans, monitoring schemes and adaptive management. In addition, other complementary aspects of management of great relevance are also discussed including institutional support and participation of stakeholders, communication strategy, management of information, implementation of national, regional and international policies, and procedures to ensure and regulate access and use of CWR.

In chapters 3 and 4, the guidelines contemplate the different situations in which a CWR genetic reserve can be established and provide specific management tips to take into account when considering their placement within protected areas, in public land outside protected areas, in farmlands and other types of private property. When the genetic reserves are located within protected areas, specific consideration is given to the incorporation of genetic reserve management into protected areas management plans. This must be carried out taking into account the multiple objectives and conditioning factors that operate at the protected areas level. Therefore, the different potential conflicts with other biological components and human interests must be addressed. When the genetic reserves are planned to be located outside protected areas, the different habitats and land cover units amenable for genetic reserves must be assessed. Furthermore, in this case, land stewardship and other types of agreements with public and private landowners take a special relevance. In both cases, within and outside protected areas, the composition of the management team and the budget and economic conditioning factors are addressed.

Chapter 5 provides a specific framework to tackle the challenge of climate change based on an adaptive management approach. Moreover, it delivers a set of management techniques that can be applied to mitigate the effects of climate change based on conservation translocations, habitat management and enhancement of evolutionary resilience.

The essential coordination with CWR *ex situ* conservation activities and use are detailed in chapter 6. After presenting the challenge of providing breeders with greater access to the full breadth of CWR diversity, this chapter details the necessary coordination that must be implemented between *in situ* and *ex situ* conservation and provides a model for how *in situ* and *ex situ* CWR conservation, and utilization might be better integrated. Furthermore, it describes the particular challenges associated to the *ex situ* conservation of CWR in terms of germination and seed dormancy breaking protocols, and to seed regeneration.

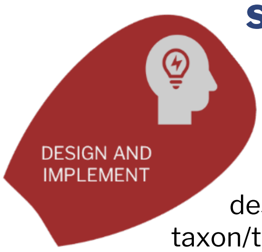
These guidelines close with a final chapter dedicated to outline the essence of CWR genetic reserve management. The fact is that CWR genetic reserve management is likely to be quite simple and straightforward, since the target CWR populations will, in most cases, be healthy, viable and resilient, and not subject to great threats. Thus, the concept of minimum standards is presented and applied to i) the design and implementation and ii) the management of CWR genetic reserves. The summary of procedures presented in the next section provides a simplified review of the different aspects to consider in the management of CWR.

The guidelines are complemented with a set of appendices that provide a glossary of terms, sample data sheets for target population documentation and threat assessment, and standard descriptors for the documentation of *in situ* CWR conservation.

Summary of procedures

Step 1: Include all the different stakeholders into the process (section 1.3)

The conservation of CWR *in situ* requires close cooperation between a wide diversity of stakeholders — policy and decision makers, scientists, protected area managers, landowners, local communities, including farmers and community leaders, among others — with different expertise in various fields of science, politics, economy, sociology and culture. It is critical to the success of the conservation to get the collaboration of all key stakeholders from the start in the different steps of the process.



Step 2: Design and implement a management plan (sections 2.1 - 2.10)

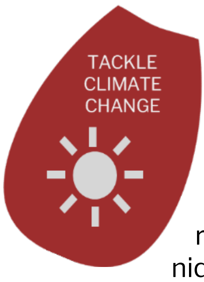
Once a genetic reserve for the targeted CWR has been delineated, a management plan for the genetic reserve must be prepared. The management plan should contain: i) site description, with definition of the management units; ii) target taxon/taxa description, including location and characterisation of target CWR populations; iii) habitat characterisation, describing the physical characteristics in terms of topography, geology, soil and climate, and the co-occurring plant species, pollinators, herbivores, seed dispersers, pests and diseases, as well as the existing and potential threats; iv) management objectives focused on maintaining the viability of target CWR populations; v) prescriptions aimed at human interactions, physical environment, biotic interactions and target CWR populations; vi) work plan, containing specific tasks and a timeframe for their implementation, required resources, assumptions made, outcomes, role and responsibilities of personnel and budget and vii) monitoring and evaluation plans to detect changes in the physical and biotic components of the habitat and in population size and genetic diversity of target CWR populations that may affect their viability as well as to determine and assess the outcomes of management actions.

Step 3: Integrate the complementary aspects into the management plan (sections 2.11 - 2.15)

Some additional aspects that need to be addressed involve i) getting institutional support, ii) developing an efficient communication strategy, iii) building an accurate information system to register management (actions, decisions) and monitoring data, iv) reviewing and implementing national, regional and international policies, and v) facilitating links to an appropriate back-up genebank to ensure access and use of the conserved CWR.

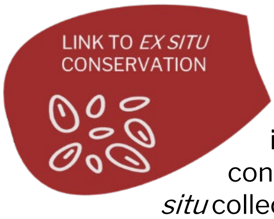
Step 4: Adapt the management to the land context (sections 3 and 4)

CWR conservation inside and outside protected areas are both important and necessary, but they require different attention to specific management aspects involving the establishment of management teams, budget considerations and potential conflicts that are likely to rise. When genetic reserves are established in protected areas, the management plan of the protected area must be adapted to ensure active conservation of the CWR populations. This involves identifying the prioritized CWR present in the protected area, indicating the specific interventions that they require and incorporating their monitoring into the protected area monitoring systems. Potential conflicts with other biological components and human interests must be discussed and resolved. Outside protected areas, the different habitats and land cover units amenable for genetic reserves must be previously assessed. In this case, land stewardship and conservation agreements should be deployed. Community support and incentives should be sought to promote long-term population maintenance.



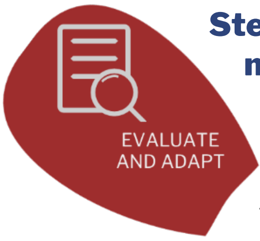
Step 5: Tackle climate change (section 5)

If a target CWR population in a genetic reserve is vulnerable to the effects of climate change, the adaptive approach of the climate-smart conservation cycle should be implemented in an iterative process aiming at reducing the uncertainty over time, via regular and continuous monitoring. Several management techniques, including conservation translocations, habitat management and enhancement of evolutionary resilience, can be applied to mitigate the effects of climate change.



Step 6: Link to ex situ conservation and use (section 6)

A fully integrated approach to CWR conservation and use is required that links in nature diversity to *in situ* and *ex situ* conservation and then makes it available for use. Back-up *ex situ* collections should be established with the aim of resettlement in the case of natural disasters eroding CWR *in situ* populations and as the existing means of accessing conserved germplasm for other germplasm users. The target CWR populations should be sampled at regular intervals for complementary *ex situ* conservation and to ensure sufficient sample size available to meet user demands.



Step 7: Evaluate and adapt periodically the management plan (section 7)

The management plan of the genetic reserve should be periodically evaluated and adapted. Additionally, the set of minimum management standards should always be tentatively implemented.

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Acronyms and abbreviations

CBD: Convention on Biological Diversity

CLC: Corine land cover.

CGIAR: Consultative Group on International Agricultural Research.

CGRFA: Commission on Genetic Resources for Food and Agriculture (within FAO).

CWR: Crop Wild Relative.

CWRSG: Crop Wild Relative Specialist Group (established by IUCN).

ECPGR: European Cooperative Programme for Crop Genetic Resources Networks.

FAO: Food and Agriculture Organization of the United Nations.

GIAHS: Globally Important Agricultural Heritage Systems (within FAO).

GIS: Geographic information systems.

GPS: Geographic positioning systems.

GR: Genetic reserve.

GRIN: United States Genetic Resources Information Network.

ITPGRFA: International Treaty for Plant Genetic Resources for Food and Agriculture.

IUCN: International Union for the Conservation of Nature and Natural Resources.

MAB: Man and Biosphere Programme of UNESCO.

MLS: Multi-Lateral System of ITPGRFA.

NGO: Non-governmental organization.

OECMs: Other effective area-based conservation measures.

PA: Protected area.

PGR: Plant genetic resources.

PGRFA: Plant genetic resources for food and agriculture.

PoWPA: Programme of Work on Protected Areas.

PVS: Participatory varietal selection.

SDG: Sustainable Development Goals.

SMTA: Standard Material Transfer Agreement.

SNP: Single nucleotide polymorphism.

SSC: Species Survival Commission of IUCN.

1 Introduction

Dulloo, M.E., Ralli, P., Iriondo, J.M., Magos Brehm, J., Maxted, N.

1.1 Purpose, objectives and scope

The aim of these guidelines is to provide **site / CWR managers** (protected areas managers, field technicians, private owners) with a **clear understanding and best practices** of how to manage, document, and secure CWR populations as well as make them available to diverse user stakeholders.

These guidelines are a product of the project "Networking, partnerships and tools to enhance *in situ* conservation of European plant genetic resources", Farmer's Pride in short, which is funded under European Union's Horizon 2020 Research and Innovation Programme on Societal Challenge 2 Food security, sustainable agriculture and forestry, marine and maritime and inland water research, under the specific call SFS-04. The principal aim of the project is to build an integrated multi-actor network of sites and stakeholders to sustain PGR *in situ* conservation that complements *ex situ* activities and enhances utilization of plant genetic resources for food and agriculture (PGRFA) as a means of underpinning agriculture, food and nutritional security in Europe.

One of the key objectives of Farmer's Pride is to enhance the population management and best practices for *in situ* conservation of Crop Wild Relatives (CWR). With this objective in mind, the present guidelines have been developed to provide a clear understanding to the site managers (protected areas managers, field technicians, private owners) (see section 1.3 below) of how the population level diversity of CWR species might be most effectively managed, documented, secured and made available to diverse user stakeholders. The scope is to expand the capacities of site managers to manage the wild populations of CWR in a more dynamic and participatory way. It is meant to serve as a "How to do" *in situ* population management of CWR (Figure 1).

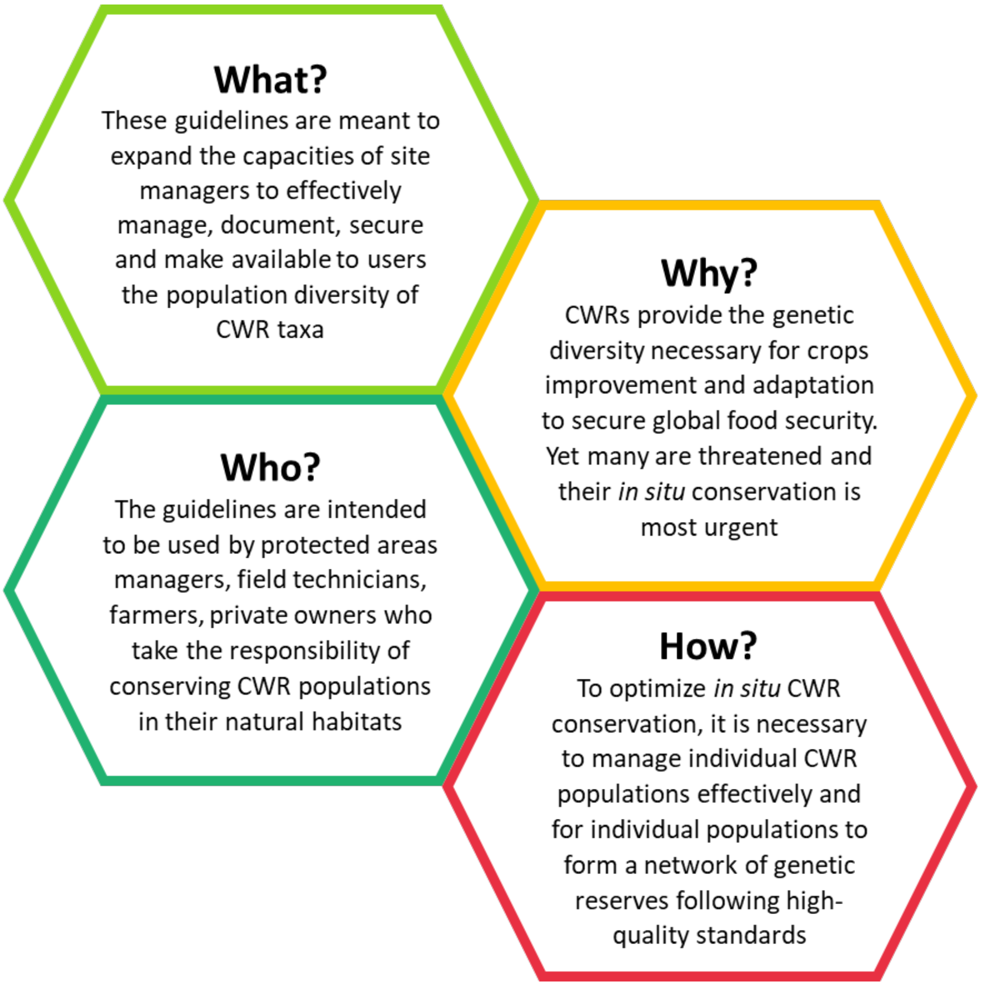


Figure 1. Purpose of the Crop Wild Relative Population Management Guidelines.

1.2 Background

- Crop wild relatives are wild species that are closely related to crops and can provide important traits for the benefit of agriculture.
- The importance of CWR has been recognised by many global policy instruments – Convention on Biological Diversity, Sustainable Development Goals, International Treaty on Plant Genetic Resources, FAO second Global Plan of Action etc.
- CWR are poorly conserved *ex situ* and *in situ* and often threatened in their natural habitats. This may occur even in protected areas due to lack of awareness of CWR value by site managers.
- The *in situ* conservation of CWR can be improved through the establishment of a network of genetic reserves that enable the preservation of the full range of existing genetic diversity.

Crop wild relatives (CWR) are wild plant species that are closely related to crops and include their wild progenitors (Maxted *et al.*, 2006). They provide the raw material for variety improvement. They are the sources of resistant traits to fight against pests and diseases and adaptive traits to mitigate climate risks as well as to improve nutrition, flavour, colour, texture and handling qualities (Hajjar and Hodgkin, 2007). CWR thus represent a large pool of genetic diversity for use in breeding programmes and their use has accelerated over the past decades as new advanced methods of plant breeding and technologies have facilitated their use (Dempewolf *et al.*, 2017). CWR are gaining more and more importance especially as new challenges due to climate change, land degradation, soil impoverishment, pest and disease epidemics and genetic erosion are negatively affecting the way we produce food in sustainable ways (Dulloo and Maxted, 2019). Their importance is now being recognized by many global policy instruments like The Convention on Biological Diversity (CBD, 2010a) (Aichi Target 13 and the following Post2020 biodiversity targets), the Global Strategy for Plant Conservation (Target 9), Article 5.1 of the International Treaty on PGRFA (FAO, 2009) and Priority Action 4 of the FAO Second Global Plan of Action (FAO, 2012). The Sustainable Development Goals (SDGs) Goal 2 (Zero Hunger) target 2.5 (SDG, 2016) also refer to the need of maintaining genetic diversity contained in related wild species of cultivated plants and animals, while SDG 15 (Life on Land), target 15.6 points to the promotion of fair and equitable sharing of the benefits arising from the utilization of genetic resources (including CWR) and promote appropriate access to such resources, as internationally agreed.

Despite this recognition, CWR species are poorly conserved in wild or man-made areas and disturbed habitats (*in situ*) both within and outside protected areas (Maxted *et al.*, 2012), as well as in *ex situ* collections (gene banks) (Castañeda-Álvarez *et al.*, 2016). Their conservation *in situ* is particularly important because of their dynamic development and continuous evolution that allows them to adapt to climate change and other environmental changes. Furthermore, the small number of existing *in situ* reserves do not always meet the required management standards to maintain CWR populations and their genetic diversity in the long-term (Iriondo *et al.*, 2012). At the European level, the red list assessment of priority vascular CWR taxa has shown that 467 out of 1826 species are identified as threatened with extinction (Bilz *et al.*, 2011; Kell *et al.*, 2012). It is thus imperative that *in situ* conservation is undertaken to safeguard the wild populations of priority CWR.

To effectively conserve the genetic diversity of target CWR species, it is necessary to establish individual genetic reserves, which together would ideally form a network of sites that would represent the range of genetic diversity within the species, as one single site will not be enough to fully conserve the desired extent of diversity (Iriondo *et al.*, 2008). A good example of a CWR genetic reserve network is the "Network of Genetic Reserves for Wild Celery Species (*Apium* and *Helosciadium*)"[1], which has been established in an eight step procedure (see Bönisch and Frese, 2020), and which is part of the German Network of Genetic Reserves (Thormann, 2020). Management guidelines are required to help site managers ensure that the wild populations as a whole are being maintained at high quality standards and made available to diverse users.

[1] https://netzwerk-wildsellerie.julius-kuehn.de/index.php?menuid=48

1.3 Major actors involved in managing CWR populations

- The *in situ* conservation of CWR requires **close cooperation between a wide diversity of stakeholders, including the local community,** with different expertise in the various fields of science, politics, economy, sociology and culture.
- It is critical to get the collaboration of key stakeholders in planning and overseeing the effective implementation of management and monitoring interventions and the promotion of use strategies.

The conservation of CWR, from the selection of priority species to field implementation to sustainable use, requires a wide degree of interdisciplinary cooperation (Maxted *et al.*, 1997a). That is because biodiversity conservation itself is a strategic process of setting priorities and goals (Hunter and Heywood, 2011) with a high degree of complexity (Box 1). Therefore, it is conceivable that the responsibility of CWR conservation and management is shared by multiple stakeholders – people, groups or organizations that may be involved in or affected by conservation activities. It is also widely recognized that conservation goals cannot be achieved in isolation by any one of them. Since CWR genetic diversity is primarily conserved *in situ* in protected areas, sustainability of conservation relies not only on solid conservation science, but also on the long-term commitment and actions of the entire stakeholder community. Thus, stakeholders need to continuously collaborate in planning and overseeing effective implementation of conservation, monitoring management interventions effectiveness and promotion of use strategies (Magos Brehm *et al.*, 2017).

Box 1. Reasons of complexity of CWR conservation.

- The forces that affect biodiversity are of diverse nature, fall into different scientific disciplines and present a complex network of interactions.
- Conservation is organized at different levels (local, national or regional).
- Conservation actions are financed in a variety of ways.
- A wide range of conservation actions, based on solid scientific evidence, must be addressed.
- Conservation actions for CWR populations must be compatible with other conservation objectives that may be present in the area.

Sources: Maxted *et al.* 2010, Hunter and Heywood 2011, Jaisankar *et al.* 2018, Maxted *et al.* 2020.

Considering the complexity of CWR conservation, the range of potential stakeholders is extensive, and they often belong to various fields of science, politics, economy, society and culture (Box 2). Stakeholders may have different interests in protected areas and CWR conservation and their impact may vary considerably. Conversely, conservation activities may also have positive or inadvertent negative impact on stakeholders (Mannetti *et al.*, 2019). Thus, early identification of stakeholders and consideration of diverse needs, viewpoints and concerns will allow for better development of conservation and environmental planning initiatives (Vogler *et al.*, 2017). Stakeholder participation is important for establishing trust, identifying partnership opportunities, strengthening an advocacy base for conservation, and/or averting and managing conflicts before they threaten the stability of activities (USAID, 2005). It should be emphasized that conservation success relies more on the increased trust between stakeholders than on increased stakeholder involvement alone (Young *et al.*, 2013).

Box 2. Potential stakeholders in CWR conservation.

Policy and decision makers

- Political leaders and senior policy-makers
- Senior biodiversity, environment and agriculture decision-makers
- Heads of relevant organizations and institutes
- National and local policy planners
- Landowners of private and public natural areas

Academia and research organization

- Universities and other educational institutes
- Research centres
- Scientists and researchers
- University lecturers and postgraduate students

Environment sector

- Protected area managers
- Project management staff
- Field technicians
- Landowners of private and public natural areas
- Community and indigenous leaders and groups

Agriculture sector and industries

- Farmers/livestock holders
- Landowners of agricultural lands
- Breeding research institutes
- Breeders companies
- PGR centres
- Agricultural unions
- Community and indigenous leaders and groups
- Local small entrepreneurs
- Business and industry

Tourism sector

- Tourism facilities
- Consumers/tourists/hunters
- Landowners of private and public natural areas

Others

- Media
- Non-Governmental Organizations (NGOs)
- Investors/insurance companies
- Information analysts and managers
- Consumer organizations
- Training specialists
- Extension and outreach specialists

Sources: Vassilev 2008, Hunter and Heywood 2011, Vogler *et al.* 2017, Mannetti *et al.* 2019, Maxted *et al.* 2020.

While it is both impossible and not strategic to attempt to involve all relevant stakeholders in all aspects of conservation planning, it is important to have a plan for knowing who, when and how to engage them (USAID, 2005). The range of potential contributions or roles of a stakeholder is very extensive (Box 3, Figure 2) and a stakeholder may contribute in different ways and involvement at different stages of a conservation project.

Box 3. Potential contributions of stakeholders in CWR conservation.

- funding
- planning, decision making, guidance and oversight
- development of national action plans
- conservation prioritization
- data and other related information collection
- plant material collection
- adoption and development of management plans
- education and public awareness
- *ex situ* conservation of CWR
- consultation
- technical advice
- participatory conservation
- dissemination of learned lessons
- use of CWR or other resources from Protected Areas
- progress monitoring
- on-going activities for additional funding

Sources: USAID 2005, Hunter and Heywood 2011.

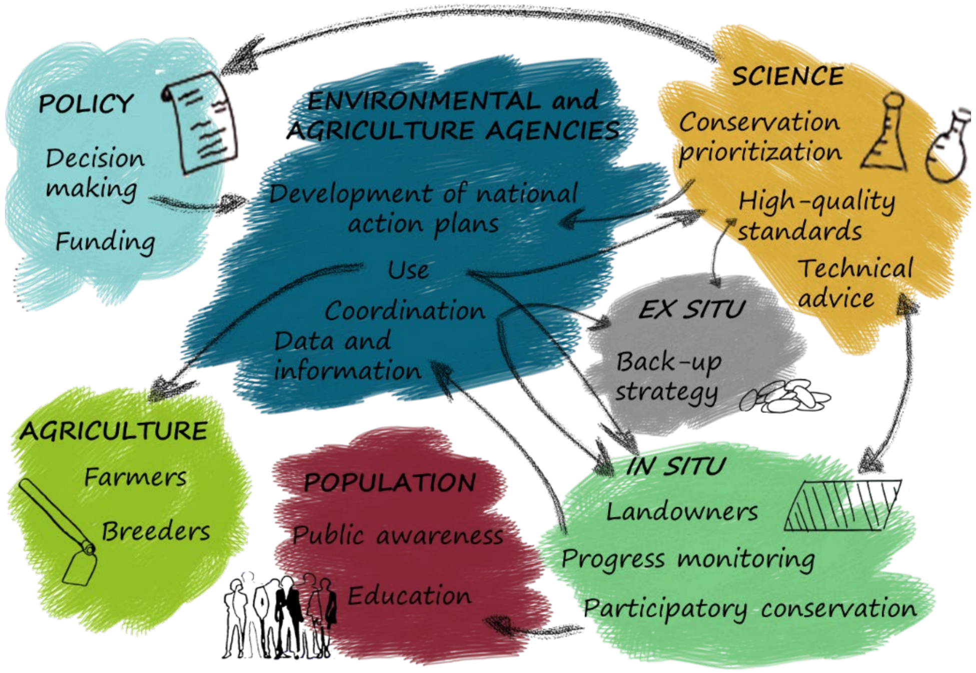


Figure 2. Potential stakeholders that interact in CWR conservation.

2 Design and implementation of the management plan

Iriondo, J.M., Dulloo, M.E., Álvarez-Muñiz, C., Maxted, N., Ralli, P., Ĉivić, K., Bissessur, P., Mroz, W., Magos Brehm, J., Frese, L., Hosking, J.B., Rasmussen, M.

2.1 Elements of a genetic reserve management plan

The **main elements of a genetic reserve management plan** are site description, target taxa description, habitat characterisation, conservation objectives, prescriptions, workplan and resources, monitoring and evaluation.

Once a genetic reserve for the targeted CWR has been delineated, a management plan for the genetic reserve must be prepared. A management plan is a planning tool that contains a set of prescriptions and interventions to meet the objectives of the genetic reserve (Maxted *et al.* 1997b; Heywood and Dulloo, 2005; Maxted *et al.*, 2008a).

There is no single and correct way to prepare a management plan. It depends on the context under which the genetic reserve has been established, but in general, it should ideally contain the following:

i. **Site description** of the genetic reserve in terms of its geographic location, size, status tenure, ownership and agreements with landowner(s), access, legislation and/or policy measures establishing the genetic reserve (section 2.2). The description should also include the effects of local human population (both within reserve and around it), land use and land tenure (and history of both), cultural significance, public interest (including educational and recreational potential), bibliography and register of scientific research.

ii. **Target taxon / taxa description** of the genetic reserve including general and site specific information. The general taxon description may include taxonomy (classification, delimitation, description, iconography, identification aids), wider distribution, habitat preferences, phenology, breeding system, means of reproduction (sexual or vegetative) and regeneration ecology, genotypic and phenotypic variation, local name(s) and uses. On the other hand, the site specific taxon description may include details of the taxa included regarding spatial distribution in the site, abundance, minimum viable population size, and genetic structure and diversity within the site (section 2.3), autecology within the reserve with microhabitat preference, associated fauna and flora (particularly pollinators and dispersal agents), and specific threats to population(s) (section 2.5).

iii. **Habitat characterisation** of the site, describing its physical and biotic components including topographic, geological, edaphic, climatic and hydrologic information as well as species composition, naturalness, recorded history, including description of the vegetation, flora, fauna of the site, focusing on the species that directly interact with the target taxa (keystone species, pollinators, seed dispersers, herbivores, symbionts, predators, diseases, etc.) (section 2.4).

iv. Management **objectives** of the genetic reserve including a rational for the management objective and operational objectives of the reserve (section 2.6).

v. **Prescriptions** including a description of the interventions (tasks) to be carried out, what methodology to be used, who is responsible for intervention and how they will be managed (section 2.7). This element should also consider the risks associated to the prescribed management.

vi. Detailed **work plan** including responsibility for executing tasks, time frame for execution of the tasks and the **resources** needed, i.e., a clear description of how the genetic reserve will be funded; what human resources and operational funds are available and needed (section 2.8).

vii. **Monitoring and evaluation plan** – description of how monitoring of the CWR population(s) and progress are done including clear indicators and frequency of monitoring (sections 2.9 and 2.10).

The management plan of a genetic reserve must be a living document and should be reviewed and updated periodically (at least every 5 years once the reserve is firmly established) depending on progress made, changes in staff and funding (section 2.10).

2.2 Definition of the management unit

The **management unit** of a genetic reserve is defined as the operational unit where the management interventions and monitoring plans are applied to sustain CWR populations.

The criteria to structure the genetic reserve into one or several management units should be based on the homogeneity of management interventions and monitoring techniques applicable to a given set of targeted populations or subpopulations. If the genetic reserve is established to conserve a single population of a targeted CWR, the management unit will, in principle, address a single population and its relationship with the biotic and abiotic environment (Figure 3A). Ideally, the management unit will be delineated to include all individuals of the population, *i.e.* all those that actually interbreed and constitute a reproductively coherent unit that is locally adapted (Kleinschmit *et al.*, 2004). If the population is large and widespread, and structured in different subpopulations that are spatially apart from each other, each subpopulation can be considered as a management unit (Figure 3B). In the case of genetic reserves that contain multiple co-occurring targeted CWR populations, the plant community that hosts the targeted populations can be used as the management unit (Figure 3C). On the contrary, if the populations of the different targeted CWR are geographically apart from each other, occupying different microhabitats, the management of the genetic reserve can be structured in various management units (Figure 3D).

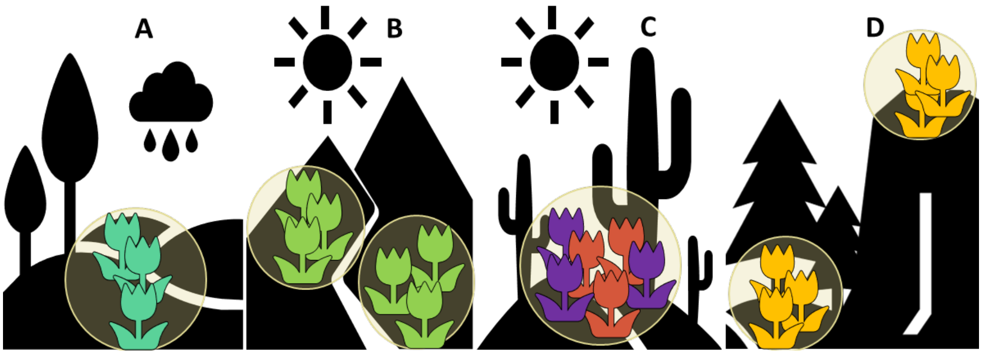


Figure 3. The management unit of a genetic reserve. It can be A) a single CWR population, B) a spatially differentiated subpopulation in a widespread CWR population, C) a plant community that hosts several CWR populations, D) a subpopulation associated to a particular microhabitat.

2.3 Location and characterisation of target CWR populations

Key steps in **locating and characterising** target CWR populations include:

- Decide on the location of the genetic reserve(s) either through bottom-up initiative involving local stakeholders or through the application of conservation planning tools (diversity and complementarity analyses) top down to identify a network of the most important sites for priority CWR.
- Define the geographic limits of the genetic reserve, then identify and document the target CWR populations within the genetic reserve.
- Carry out a population census (number of reproductive individuals) of the target CWR.
- Deposit herbarium specimens of the target CWR in public herbaria and/or analyse their DNA, to verify their taxonomic identification.

A genetic reserve can be established based upon a bottom-up initiative in which the managers of a particular site (for example protected area, farm, private land) decide to conserve a population of a targeted CWR, or a set of populations belonging to different priority CWR, that occur at their site. Alternatively, the development of a national strategy for the conservation of CWR may be able to identify, through diversity and complementarity analyses, a network of sites that can provide efficient *in situ* conservation for a set of priority CWR[2]. The suitability of these sites as genetic reserves can later be explored. In any case, once the decision to establish a genetic reserve in a given location is made, the geographic limits of the genetic reserve and main characteristics of the targeted CWR populations must be properly determined.

It is paramount that target CWR taxa are be properly identified and documented. Therefore, herbarium specimens should be collected and deposited in two well-established public herbaria so their identification can be confirmed. Complementarily or alternatively, documentation may also be achieved through

[2] http://www.cropwildrelatives.org/conservation-toolkit

sampling and conserving DNA for reference analysis. This will allow the verification of the taxonomic identification by expert botanists and the possibility to review the characteristics of the plants and update the taxon assignation, should any revision occur in the corresponding taxonomic group.

2.3.1 Georeferencing and delimitation of CWR populations

The genetic reserve will include the whole area covered by the targeted CWR populations and a buffer area to protect their habitat. The determination of the area covered by each targeted CWR population is quite straightforward (Figure 4). The best time to do it is during the flowering season, when plants are easier to find. The process involves marking the flowering individuals that occur at the perimeter of the target plant population with flag stakes or any other marking material. It is advisable to walk beyond the perceived limits to make sure that the population does not continue further away. Ideally, additional subpopulations should be searched around the perimeter of the currently known population occupancy area. When the limits of the population have been marked with the flags, an additional buffer zone can be added to protect the population and associated biota (for example, pollinators and seed dispersers). The geographic coordinates of the resulting perimeter can then be obtained using a GPS tracker. The higher the accuracy of the GPS tracker, the better. When no GPS trackers are available, the geographic coordinates can be obtained using topographic applications in a smartphone (e.g., Mobile Topographer[3]). When accurate sub-metric GPS trackers are not available, the accuracy of the delimitation of the area of occupancy can be improved by marking the boundaries with permanent survey marking stakes. Georeferencing may need periodic updating because the limits of the population may change through time.

When the genetic reserve comprises various populations of several targeted CWR, the same process can be followed to obtain the area covered by each population. Then these areas can be overlapped to obtain their sum.

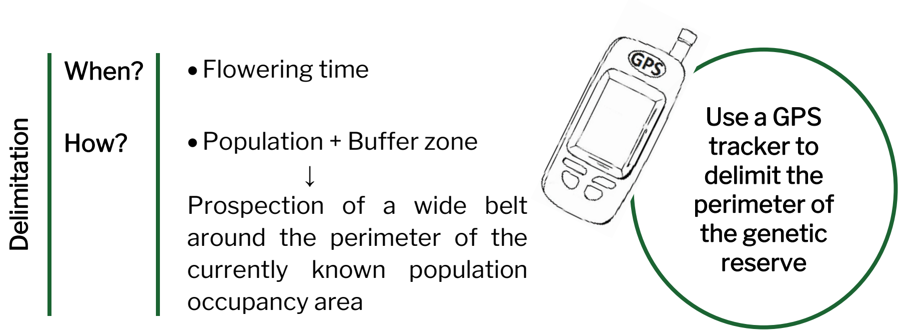


Figure 4. Delimitation of CWR populations.

2.3.2 Population census

Determining the population size is an essential component of the characterisation of CWR populations because population size is a good indicator of the conservation status of the population as well as its genetic diversity and availability of propagating material for use in plant breeding.

To carry out a population census, the first step is to have a clear idea of the definition of an individual plant. This will not be a problem in plants that form a single

[3] http://applicality.com/mobile-topographer/

main shoot from their roots but can be confusing for vegetatively propagated adjacent plants when several shoots, from their underground rhizome, tuber or bulb, are intermingled and emerge from the soil (Figure 5). In these cases, the best approach, after some careful study of the architecture of the plant, is to define an individual plant as a set of shoots (ramets) that grows together at less than a threshold distance from each other. This will not have to be measured for each plant once the surveyors get their eye in. Carrying out multiple observer sampling trials to determine the rates of observer recording variation and acting to reduce the error will help obtain a more accurate census. The idea is to adopt a pragmatic approach that will be systematically followed through the management of the population.

The objective of the census is to determine the number of reproductive (or mature) individuals of the population. Therefore, the census should be carried out at peak flowering time. All flowering or fruiting individuals will be considered as potentially reproductive individuals. Other individuals without flowers or fruits, but with evidences of having flowered before or likely to flower later in the season should also be included.

Figure 5. Definition of an individual plant. Lady's slipper (*Cypripedium calceolus* L.) is a typical rhizomatous plant with different shoots stemming from a single rhizome. In this case, the shoots that grow below a certain distance from each other are considered to belong to a single individual (Photo from: Mg-K (GFDL) – own work, CC BY-SA 3.0[4]).

When the number of reproductive individuals is manageable, the best way to proceed is to count all individuals one by one (direct census). For instance, a team composed of two or three persons can easily count directly a population of 3000 individuals in a few hours. For larger population sizes, it is better to replace direct census by an estimation of population size through sampling (Figure 5).

[4] https://commons.wikimedia.org/w/index.php?curid=44950

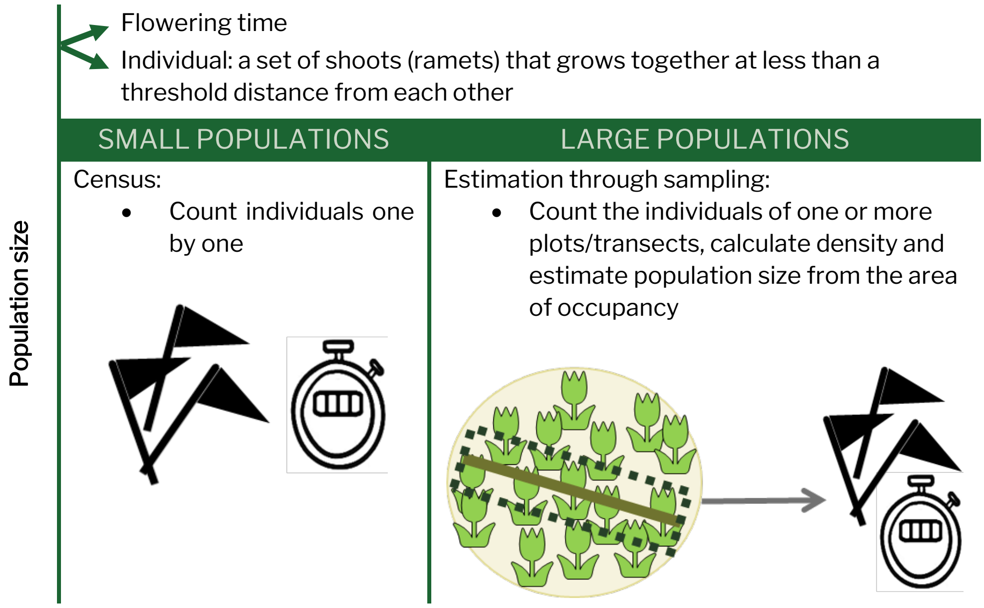


Figure 6. Determination of CWR population size.

a) Direct population census

- Recommended material: flag stakes and tally click counters.
- The population must be carefully scanned. All reproductive plants must be marked using flag stakes. Then, the individuals can be counted as the flag stakes are removed.
- Tally click counters can be used to help with the procedure. It is essential to follow this procedure systematically.
- Counting the individuals without previous marking leads to error either by omission or double counting.
- The information should be documented in an appropriate data sheet (Table 1; Appendix 2 Table S1).

Table 1. Sample data sheet to document population size, along with definition of population, individual, georeferencing, and information on herbarium specimens obtained at the population.

Direct population census		
Taxon: *Lupinus angustifolius* L.	**Date:** 15/04/2020	
Population: "La Garranchosa"	**GPS coordinates:** 38.325735, -6.433799	
Threshold distance between populations: 1 km	**Definition of individual**: each plant has a single shoot emerging from the ground	
Name of data collector: John Smith		
Direct census		
Mature individuals: 1428	**Vegetative individuals**: 245	**Seedlings:** none
Herbarium specimen: MA-01-00773726	**Observations** : Photograph no. LA024 habitat	

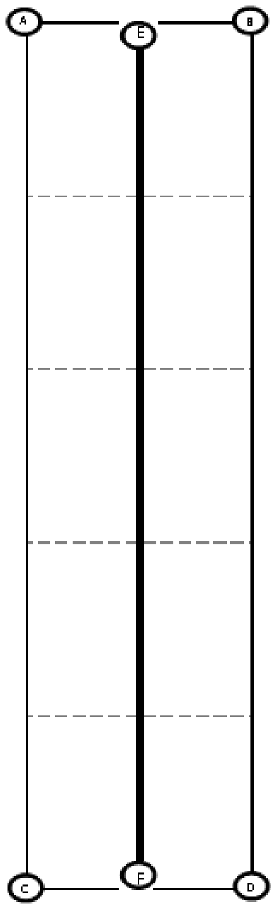
b) *Population size estimation through sampling*

Recommended material: flag stakes, measuring tapes, strings and steel pegs to delimit transects or plots and tally click counters.

There are many ways of estimating the population size through sampling, but we will just detail the simplest approach:

- It implies setting a transect that crosses the population through the widest dimension. This is done by attaching a string to a steel peg in one end of the population and extending it to the opposite end of the population where it is attached to another steel peg. Additional steel pegs can be used in between to keep the string in place.
- Once the transect is established, the census team can sweep a stretch along the sides of the string and mark with flag stakes all reproductive individuals found up to a threshold distance from the string.
- This threshold distance will depend on the type of plant (e.g., 1-2 m for herbaceous plants, 3-5 m for small shrubs, 5-10 (20) m for large shrubs).
- Alternatively, a rectangular plot can be delimited by connecting the four corners marked with a steel peg with a string. Then, all reproductive individuals within can be counted.
- In all cases, the endpoints of the transect or the four corners of the plot should be georeferenced, so the transect of the plot can be set up again in the future for monitoring purposes (Table 2).

Table 2. Sample data sheet to document population size in a plot/transect, along with definition of population, individual, georeferencing, and information on herbarium specimens obtained at the population.

Estimation of population size: Plot/transect data	
Taxon: *Lupinus angustifolius* L.	**Date**: 15/04/2020
Population: "La Garranchosa"	**GPS coordinates**: 38.325735, -6.433799
Threshold distance between populations: 1 km	**Definition of individual**: each plant has a single shoot emerging from the ground
Name of data collector: John Smith	
Plot/Transect number: 1	**Plot/transect coordinates:**
	**A**: 38.325785, -6.433809
	B: 38.325785, -6.433789
	C: 38.325685, -6.438099
	D: 38.325685, -6.433789
	E:
	F:
Mature individuals: 1428 **Vegetative individuals**: 245 Seedlings: none	
Herbarium specimen: MA-01-00773726	**Observations:** Photograph no. LA024 habitat

The number of reproductive individuals counted in the transect or plot divided by the transect/plot area will give an estimate of the population density. Total population size can then be estimated by multiplying population density by the area covered by the population (see section 2.1). This area is obtained by calculating the area of the minimum polygon that encompasses all individuals of the population. If the population occurs in a heterogeneous habitat with great differences in plant density, one or more rectangular plots can be established in each type of habitat, and specific estimates of density can be obtained for each of them. Total population size will then be established by the sum of the products of multiplying the density in each habitat by the occupancy area of the population in each habitat (Table 3; Appendix 2 Table S3). Some additional easy-to-apply approaches for obtaining demographic information of plant populations can be found in Iriondo *et al*., 2008; Elzinga *et al*., 2009; Iriondo, 2011 (in Spanish[5]).

Table 3. Sample data sheet to estimate population size in a population from information obtained from data gathered at one or several plot/transects, along with definition of population, individual, georeferencing, and information on herbarium specimens obtained at the population.

Estimation of population size: Population results						
Taxon: *Lupinus angustifolius* (L.)			**Date**: 15/04/2020			
Population: "La Garranchosa"			**GPS coordinates**: 38.325735, -6.433799			
Threshold distance between populations: 1 km			**Definition of individual**: each plant has a single shoot emerging from the ground			
Name of data collector: John Smith						
Plot/ Transect No.	**Plot/ Transect area (m²)**	**No. mature individuals recorded**	**Density (ind/m²)**	**Occupancy area (m²)**	**Estimated population size**	**Observations**
1	20	27	1.35	2500	3375	Habitat 1
2	20	36	1.80	3300	5940	Habitat 2
					9315	Total pop
Herbarium specimen: MA-01-00773726				**Observations:** Photograph no. LA024 habitat		

[5] https://www.miteco.gob.es/es/biodiversidad/temas/inventarios-nacionales/manualdemetodologiaafa_tcm30-99748.pdf

2.4 Habitat characterisation

Habitat characterisation is important because it provides information on the environmental factors that are conditioning the presence of target CWR populations and help to define the CWR niche. To pursue this task:

- Describe the habitat type, including its conservation status, vegetation types and ecological processes, using standardised EUNIS habitat classification developed by EEA or Annex 1 natural habitat types of the Habitats Directive for NATURA 2000 sites.
- Describe the abiotic physical characteristics in terms of topography, geology, soil and climate.
- Describe the biotic component present in the genetic reserve including co-occurring plant species, pollinators, herbivores, seed dispersers, pests and diseases.

Habitat characterisation is an essential component of the genetic reserve management plan as it will describe the environmental factors that are conditioning the presence of the target CWR populations. These limiting environmental factors are in great part responsible for the different type of evolutionary adaptations that the populations may have experienced and that could potentially be transferred to the related crops. The description of the habitat type where the genetic reserve is found should follow the standardized EUNIS habitat classification developed by the European Environment Agency (EEA)[6]. In case of Natura 2000 sites, this description should be directly linked to the list of Habitats Directive Annex I natural habitat types with clear distinction of priority habitat types (listed in Natura 2000 standard data forms and existing management plans) (European Council, 1992; European Comission, 2013). The description should also refer to the existing data on habitats conservation status and results of habitat assessments. Additional information on vegetation types according to regional approaches would be also very useful (e.g. Braun-Blanquet plant communities). The description should focus on these habitats which are hosting the most important CWR populations within the site. It should also refer to the most important ecological processes that might affect the effective protection of CWR, such as secondary succession, change in species composition or results of change in water regime, including human intervention, such as changes in land use.

2.4.1 Physical characterisation (soil, geology, climate, hydrology)

This characterisation addresses the abiotic conditions that are present in the genetic reserve. Ideally, they should include topographic, geologic, edaphic and climatic information. This type of information is extremely valuable for understanding the conditions in which the CWR populations are growing and evolving. It also provides very useful hints on adapted traits that may be found within the populations. General information on topographic, geologic and edaphic traits can be obtained directly from the site. This can be complemented with information derived from the geographical coordinates of the site. Thus, Table 4 and Appendix 2 provide global sources of topographic, bioclimatic and edaphic information that can be obtained from the geographical coordinates of the genetic reserve. Alternatively, this information can be obtained at the national level

[6] https://www.eea.europa.eu/data-and-maps/data/eunis-habitat-classification#tab-european-data

from relevant institutes in countries where extensive physical mapping has been undertaken. The quality of this information can be greatly improved if the managers can obtain direct data from their own or nearby weather stations and conduct soil analyses from soil samples from the site.

Many CWR populations are dependent on maintenance or restoration of wetlands or, more generally, on preservation of appropriate water conditions. Therefore, in such cases, the hydrological features and their impact on these species should be described and analysed (with use of spatiotemporal modelling if available). This should take into account, where appropriate, effects from human interference, such as water use, pumping stations or nearby draining.

Table 4. Sources of topographic, bioclimatic and edaphic information that can be obtained from the geographical coordinates of the genetic reserve.

Source	Variable
Digital Elevation Models (DEM) of the Shuttle Radar Topography Mission (Jarvis *et al.*, 2008).	Topographic; elevation, northness, eastness and slope of the site
WorldClim2[7] (Fick and Hijmans, 2017)	Bioclimatic (1970-2000); a set of bioclimatic variables corresponding to the 1970-2000 period
CHELSA database[8] (Karger *et al.*, 2017)	Bioclimatic (1979-2013)
Harmonized World Soil Database[9] (HWS Database, 2012)	Edaphic variables corresponding to the given geographic coordinates

2.4.2 Characterisation of biotic components

The characterisation of the biotic conditions present at the genetic reserve mainly includes the presence of other plant species that co-occur with the target CWR populations. The identification of the plants should be carried out using botanical keys of local or national floras, ideally with the participation of a local botanist. The list of co-occurring plant species should outline the dominant species of the community. This is very important in view of possible competition of CWR species with native expansive species (as a result of secondary succession connected with changes in management regime) or expansion of alien invasive species. Considering the risk of hybridization with other taxa (e.g. crops), the data about closely related species and crop varieties occurring in the site and its surroundings should also be included. If this information is already available through previous studies, a verification of existing data should be carried out.

[7] https://rmets.onlinelibrary.wiley.com/doi/abs/10.1002/joc.5086

[8] http://chelsa-climate.org/

[9] http://webarchive.iiasa.ac.at/ Research/ LUC/ External-World-soil-database/HTML/

The characterisation should also include information on other components of the biotic community, especially those that may interact with the target CWR populations such as parasites, herbivores, pollinators, seed dispersers and plant diseases. This can provide critical information about the potential of the population to contain resistance to pests and diseases of special value. Appendix 2 Table S5 provides a sample data sheet where this information can be gathered.

2.5 Population threat assessment

It is important to review the **risks and external factors that could potentially threaten the CWR population**, in particular, its **chance to adapt to effects of climate change, as well as its natural and cultural values**. The following steps can be pursued:

- Use the IUCN Threats Classification Scheme to identify key threats to the population under assessment.
- Record the timing, scope, and severity of the threats.
- Design and implement a risk assessment in which different risks associated with CWR population management are identified and dealt with (see Box 4).

Ideally, we would wish that all target populations were not threatened at the time of establishment of the genetic reserve, that is, they should have population sizes (see section 2.3.2) that warrant population stability in demographic terms and genetic diversities that do not compromise the resilience of the population due to processes leading to genetic erosion. Nevertheless, it is not always the case and it is important to review the risks and external factors that could potentially threaten the evolutionary potential of the population, in particular its probability to adapt to the effects of climate change (see section 5), as well as its natural and cultural values. The International Union for Conservation of Nature (IUCN) Threats Classification Scheme (version 3.2) (see Appendix 3) can be used to gather information on threat assessment of target CWR populations in the genetic reserve. For each threat, IUCN recommends that the timing of the threat (i.e. past, ongoing or future), its scope (i.e. the proportion of the total population affected) and severity (i.e. the overall declines caused by the threat) is recorded. Guarino (1995) provides a useful approach to measure the risk of genetic erosion.

On the other hand, there is a risk that management actions, either deliberately or inadvertently, will affect the natural resources of the area and/or some social and economic aspects of local people. This is especially relevant when the CWR genetic reserve is located within a protected area. Frequently, the initial reasons for creating a protected area are subjective or poorly understood and badly communicated. Unless the management plan can document the inherent natural and cultural values, incompatible usage may continue, making it difficult to ensure its conservation into the future (Thomas and Middleton, 2003). Therefore, it is advisable to design and implement a risk assessment in which the different risks associated to the CWR population management are identified and dealt with. The basic model for risk assessment involves the steps indicated in Box 4 (Gardner and Davidson, 2011).

Box 4. Basic model for risk assessment of CWR management (Gardner and Davidson, 2011).

Step 1. Identification of the problem	Determine if there is a potential threat and define the objectives and scope, providing the foundation for the risk assessment.
Step 2. Identification of the adverse effects	Evaluation of the likely extent of adverse change or impact on the genetic reserve and associated biotic community and ecosystem.
Step 3. Identification of the extent of the problem	Estimation of the likely extent of the problem on the genetic reserve of concern by using information gathered about its behaviour and extent of occurrence elsewhere. For instance, in the case of potential genetic pollution through gene flow from a nearby crop culture, it might include detailed information on the size and location of the crop culture, pollination and dispersal systems, and abundance of compatible pollination vectors and/or dispersal agents. While field surveys most likely represent the ideal approach, use of historical records, simulation modelling, and field and/or laboratory experimental studies all represent alternative or complementary methods of characterising the extent of the problem.
Step 4. Identification of the risk	Integration of the results from the assessment of the potential effects with those from the assessment of the likely extent of the problem, in order to estimate the level of adverse ecological change on the genetic reserve.
Step 5. Risk management and reduction	Final decision-making process that uses the information obtained from the assessment described above and attempts to minimize the risks without compromising other societal, community or environmental values. Risk management not only considers the result of the risk assessment, but it also integrates political, social, economic, and engineering/ technical factors, and the respective benefits and limitations of each risk-reducing action. It is a multidisciplinary task requiring communication between site managers and experts in relevant disciplines.
Step 6. Monitoring	Monitoring is the last step in the risk assessment process and should be undertaken to verify the effectiveness of the risk management decisions. It should incorporate components that function as a reliable early warning system, detecting the failure or poor performance of risk management decisions prior to serious environmental harm occurring. The risk assessment will be of little value if effective monitoring is not undertaken. The underlying concept of early warning indicators is that effects can be detected, which are in fact, precursors to actual environmental impacts. As such, early warning indicators can be defined as ‘the measurable biological, physical or chemical responses to a particular stress, preceding the occurrence of potentially significant adverse effects on the system of interest’. For example, the presence of natural pollinators in the target CWR population carrying pollen of a nearby cross-compatible crop could be an early warning indicator of genetic pollution.

2.6 Management objectives

Overall objective of a genetic reserve is to maintain the viability of target CWR population(s) at the site, conserving its breadth of genetic diversity and fostering its use. For this to happen a few key specific management goals must be attained. These include:

- Maintain optimal abiotic and biotic environmental conditions for CWR survival and reproduction.
- Minimize the risks of genetic erosion and genetic pollution to the CWR.
- Minimize human threats to genetic diversity of the CWR.
- Support actions that sustain genetic diversity in target CWR populations.
- Ensure access to CWR populations for back-up in *ex situ* collection for research and use in breeding programmes.
- Ensure availability and access to conserved CWR material to local communities and other users.

The overall objective of the genetic reserve management plan is to maintain the viability of the target CWR population or populations occurring at the site. This involves, among other factors, the maintenance of the optimal abiotic and biotic environmental conditions for the survival and reproduction of their individuals. In general terms, the approach is very similar to the one followed for the conservation of rare and threatened plant species, where the focus is both on the conservation of their natural habitats and the protection of their genetic diversity. However, CWR conservation might need to involve additional specific goals to maintain and facilitate the use of genetic diversity such as (Iriondo and De Hond, 2008):

1. Minimize the risk of genetic erosion from demographic fluctuations, environmental variation and catastrophes.
2. Minimize the risk of genetic pollution from the cultivated crop to the CWR population as has often be noted in genetic studies (e.g. *Oryza rufipogon* Griff. from Thailand - Akimoto *et al*., 1999).
3. Minimize human threats to genetic diversity.
4. Support actions that promote genetic diversity in target populations (provided they do not affect viability in a negative way).
5. Ensure access to populations for research.
6. Ensure access to backup *ex situ* population sample for use in breeding and research.
7. Ensure availability and access to material of target populations that are exploited and/or cultivated by local communities.

2.7 Management interventions

Depending on the nature and impacts of the threats to CWR populations, **management interventions** may involve actions aimed at mitigating adverse human interactions, and changes to the physical environment, biotic interactions and target CWR population(s) to enhance their self-sustainability (see Figure 7).

Different potential or existing threats may compromise the viability of target CWR populations in the genetic reserve. Once the threats are identified and scored at the time the genetic reserve is established or because of a periodical monitoring survey, proper management interventions must be implemented to minimize them and/or mitigate their effects. The expected results of the intervention should be defined from the beginning, as well as how they would be measured. Depending on the nature and impacts of the threat, the interventions may be directed at different levels (Figure 7), focusing on the:

- human interaction
- physical environment
- biotic interactions
- target CWR populations

It should be noted that the interventions directed to respond to a particular threat may have unexpected consequences on other essential aspects affecting population viability. For instance, the fencing of a CWR population to protect it from herbivores may negatively affect its survival by promoting ecological succession and enhancing competition between the target CWR population and accompanying flora. Therefore, management interventions should be designed and implemented carefully, taking into consideration all possible direct and indirect effects. Potential management interventions related to threats associated to climate change are presented in chapter 5 ‘Management to address climate change’.

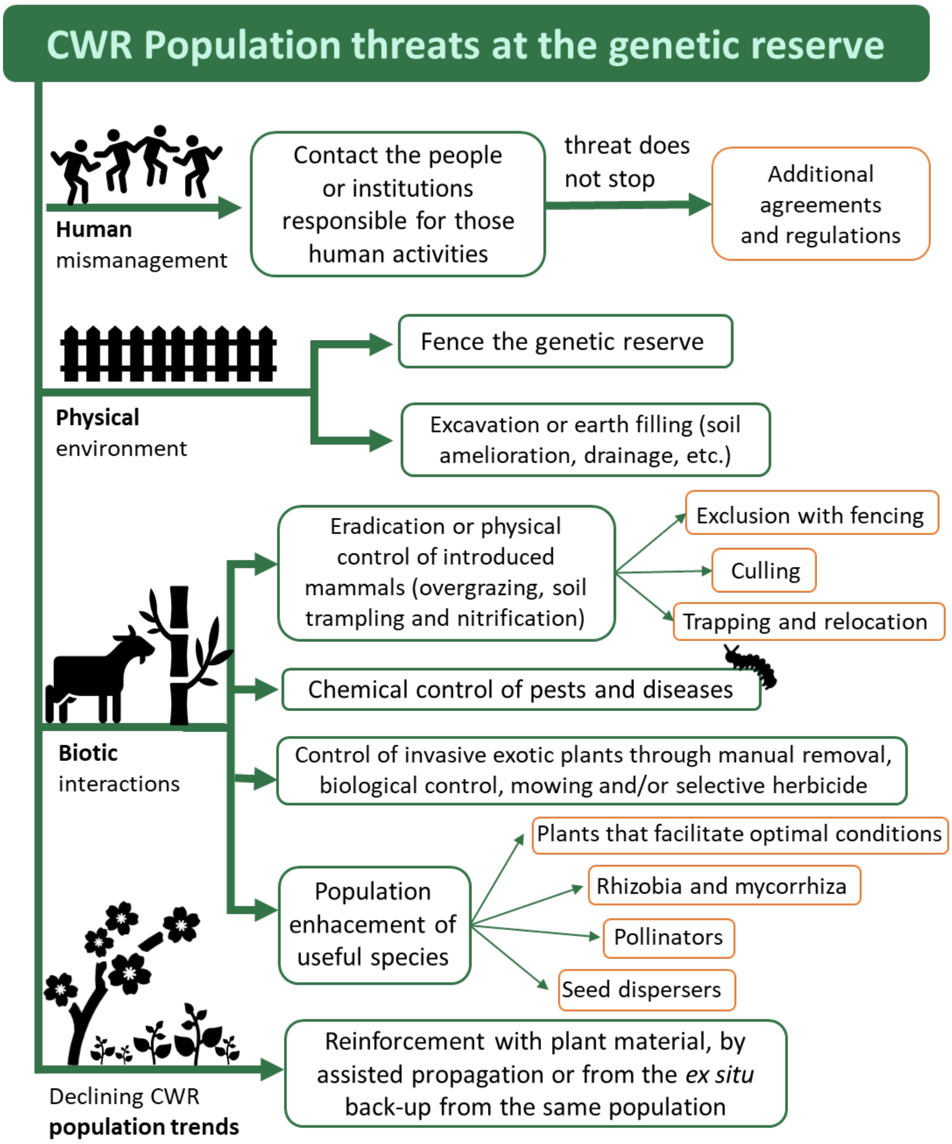


Figure 7. Management interventions to address existing threats.

See chapter 5 'Management to address climate change' for additional management interventions concerning climate change.

2.7.1 Human interactions

Most threats are likely to be caused as a result of human mismanagement of the habitat, as a result of residential, infrastructural and commercial development, agriculture and forestry, energy production and mining, transportation, hunting and collecting, accidental introductions and recreational activities. Abandonment of land, elimination or reduction of grazing in grasslands, and overgrowth are also other relevant causes for loss of CWR biodiversity resulting from human mismanagement. Where such threats occur, the protected area manager or the owners of the site must adopt measures to limit these activities by interacting with the people responsible for these threats. A specific action plan should be developed and be included in the management plan of the site. Measures can include activities such as meetings with local authorities and community leaders to explain the value of the sites to be protected and to implement agreements on how to limit the impacts on the site, and awareness campaigns to educate local people. Often, these threats may appear as a result of lack of knowledge about the existence of the genetic reserve in the surroundings or about the potential impact of their activities on it and simply getting in contact with the responsible people may eliminate the threat. In some cases, additional agreements and/or regulations may be needed to prevent it recurring. However, when significant damage has been caused on the target CWR populations or their habitats, additional interventions will be needed (see below).

2.7.2 Physical environment

Management interventions affecting the physical environment should only be attempted when severe damage has been caused to the habitat (e.g. habitat loss, fire, chemical pollution, flooding, etc.). Interventions may involve the excavation or earth filling to change the topography of the site to control or prevent soil erosion, for soil amelioration, retention of soil moisture, and/or drainage improvement. They may be needed as a result of habitat alteration due to the incidence of large fires in the area, logging and wood harvesting, intensification of agriculture and housing and commercial development in the surroundings. It should be carried out by experts in habitat restoration bearing in mind the needs and limitations of the target CWR species. Although highly impacting at their implementation they can be essential for a long-term improvement of the habitat.

A much simpler intervention of the physical environment involves fencing the genetic reserve to prevent access to humans (e.g. in recreational areas with large human visitation rate) or to cattle (see below). However, the former may be undesirable and the latter may end up being harmful for the CWR populations, so this type of intervention should be used with caution (Shands, 1991).

2.7.3 Biotic interactions

The biotic community other than humans can have a profound influence (both positive and negative) on the target CWR populations we are trying to protect. They may include beneficial species such as pollinators and seed dispersers which are important biotic component for the survival and regeneration of the target CWR species; or they can be other plants or animal species that are competing with or predating on the target species, as well as pest and diseases. Management interventions will depend very much on the type of habitat and biotic components that are playing out at the site. Some common measures may include:

a) Eradication or control of introduced mammals which may cause overgrazing, soil trampling, seed predation and nitrification. Techniques include trapping and relocation, exclusion with fencing and culling.

b) Chemical and/or biological control of pests and diseases.

c) Control of invasive exotic plants through manual removal, biological control, mowing and/or selective herbicide applications.

d) Population enhancement of useful species, such as pollinators and seed dispersers, either directly or through the creation of appropriate nesting sites, or microhabitats, or plant species that act as facilitators for the target species providing optimal shading conditions or protecting from wind or extreme temperatures.

e) Control of genetic pollution from crops, by excluding, within a buffer area around the genetic reserve, the cultivation of crops that can potentially cross with the target CWR populations conserved at the genetic reserve.

As previously mentioned the opportunity of implementing any of these measures should be carefully assessed, taking into account all potential direct and indirect effects. For instance, the use of pesticides has been identified with a dramatic decrease in insect species diversity and mass, and, therefore, their use within protected areas and in fields around protected areas is under intense debate.

2.7.4 Target CWR populations

Management interventions on the target CWR populations should only be applied in extreme situations where, for some reason (e.g. habitat destruction, pests, diseases, fire, etc.), population size has decreased dramatically, and population trends are declining. As much as possible, the regeneration of target CWR populations should be enhanced *in situ*. This can be done by applying some of the measures discussed above in section 2.5. If these measures are not sufficient, the population can be reinforced, and threats minimized. This may simply consist of collecting seeds or other propagules from plants of the target populations and dispersing them in the same population. If seed recruitment or early life stages of the plants are very vulnerable at the natural site, seeds can be germinated elsewhere, and plantlets transferred back to the natural site at the most appropriate time. Since we are interested in conserving the genetic diversity of the target population, reinforcement with plant material from other populations should not be considered. It is highly advisable to collect a representative sample of seeds of the target CWR populations and to conserve them *ex situ* in collaborating gene banks (see section 6.2). This collection should be repeated at appropriate intervals to record and store any changes in the genetic diversity present. These seed accessions would be of great value to perform a reinforcement intervention when needed. These types of operations are highly complex and should be carefully prepared following the indications and suggestions provided in specialized literature (Guerrant *et al.*, 2004; Hunter and Heywood, 2011; IUCN/SSC, 2013). If the genetic reserve is subject to threats which will take a long time to reduce, *quasi-in situ* conservation approaches (Volis and Blecher, 2010) may also be considered. Plant propagules obtained from the target population are then translocated and established in nearby-areas with similar habitat conditions, where they can be further propagated to provide locally-adapted plant material to be later used in the reinforcement of the original population.

2.8 Workplan and financial, technical and human resources

A **workplan** is needed to plan and coordinate the steps that are required to implement the management interventions. The workplan should contain:

- A review process to decide what interventions are necessary.
- Specific tasks and a timeframe for their implementation.
- Resources required to implement the tasks (materials, equipment, personnel etc.).
- Assumptions made.
- Means of monitoring short and long-term outcomes.
- Role and responsibilities of personnel.

In order to ensure that the genetic reserve, once established, is protected and managed in a way that warrants its effective conservation in the long run, proper conservation measures need to be implemented. The implementation process includes the concrete steps that are taken to turn the management plan into the actions that help accomplish the objectives. The workplan is used to define the implementation strategy. Typically, it outlines the timeframe for the execution of the tasks, resources, assumptions, short and long-term outcomes, roles and responsibilities, and budget.

The generation of the timeframe for the execution of the tasks initially involves the listing of the task order and predicting the duration of this task. It should cover the full period of the management plan. This information can then be used to generate a Gantt chart. A Gantt chart is a graphical bar chart that can be used as a project timeline. As the management plan moves from implementation to execution, a Gantt chart can help track individual task progress, see relationships among tasks, and identify critical or at-risk tasks. Along with the definition of the time frame it is vital to conduct a proper assignment of roles and responsibilities of personnel to each task. To be able to achieve the objectives through the execution of the planned tasks, adequate financial, technical and human resources are needed, or the genetic reserve will be at risk of being ineffective. The necessary resources will largely depend on the management strategies that are needed for a certain site, some of which include:

- Funding conservation actions: To determine the financial and technical resources required for funding the conservation actions, the above-mentioned work plan, also identifying costs of each task and possible funding sources must be prepared. In the view of keeping this plan SMART (Specific, Measurable, Achievable Realistic and Timely), it should not over stretch the resources that are available. In addition, before the start of each financial year a detailed cost programme should be prepared by the site manager which should be based upon the resource allocation received, i.e. how much money and human resources s/he can ‘spend’ on various activities. The datasheet in Table 5 may be helpful to identify and estimate the required resources. These can be translated into costs using the handbooks or other available tools in the country that provide the costs for the different work units (e.g. tractor hours, labourer hours, etc.). The preparation of this programme will immediately highlight shortfalls in resources and allow the manager to decide about which planned activities will not be possible to achieve in that year. For the projects and actions that, from the very start, are known not to be covered by the available resources, fundraising should be one of the activities foreseen by the management plan. The funding challenges cannot be underestimated, and adequate attention should be given to this.

- Adequate skilled and competent staffing: The costed work plan will also help to identify the staff with the right competencies and what training is needed for putting an effective management in place. A reserve without at least a minimum of surveillance, even if no immediate conservation actions are required, is not very likely to fulfil its purpose. Who will provide the necessary staff will depend on the governance model of the genetic reserve in question. In some cases, this will be the staff of a governmentally designated reserve, but it can also be the staff of an NGO which has some kind of stewardship agreement for the land or is supporting the local landowners in managing their land (e.g. Land Stewardship agreements).
- In all cases, some resources will be required for basic monitoring and communication and establishment of good relations with the stakeholders in and around the reserve.

Table 5. Sample sheet of work plan that could be the basis for estimating the required resources.

Action	Who should implement it	Time frame for implementation	Time assignment	Resources/means required	Additional involvement
Meeting with local farmers	Director of the genetic reserve	1-30 September	2 hours	Meeting room at town hall	Town Mayor
Weeding of invasive plants	Foreman	First week of March-April-May	3 work days	Weeding tools, bags, cart	Two other laborers

2.9 Monitoring

What is plant population monitoring and why it is important to monitor CWR populations?

Monitoring of plant populations involves the systematic **collection of data over time** to ascertain the extent of compliance with a predetermined standard or the degree of deviation from an expected norm (Hellawell, 1991). The monitoring of CWR populations and the habitats in which they occur has different specific objectives: i) to detect changes in the physical and biotic components of the habitat that may affect qualitatively and/or quantitatively the target CWR populations, ii) to assess trends in population size and structure and to detect changes that may indicate demographically unstable populations and to provide data for modelling population trends, iii) to assess trends in population genetic diversity, and iv) to determine the outcomes of management actions on populations and to guide management decisions (Iriondo *et al.*, 2008).

CWR populations require regular monitoring to evaluate any short, medium and long-term changes which may contribute to demographic loss, genetic erosion, hybridization or even species extinction (de Carvalho *et al.*, 2016; Iriondo *et al.*, 2008; Maxted *et al.*, 1997a). Specific parameters (see below) should be measured over regular intervals for monitoring the status of wild populations of CWR to inform the management interventions and provide feedback to the conservation strategies and plans. Monitoring can also provide supporting evidence to justify maintaining or modifying current management practices. When possible, it would be desirable to involve local stakeholders in monitoring tasks to keep them attached to the project through time and because it can be the most cost-effective option.

In all cases, an efficient monitoring method should be:

- reliable (will not lead to false conclusions).
- powerful (sensitive enough to detect changes).
- robust (measurement techniques provide data that are independent of the technique used).

Furthermore, a monitoring programme should be able to distinguish between the significant biological changes that negatively impact target population survival and normal seasonal and annual variations that need not trigger changes in management.

The periodicity of monitoring will strongly rely on plant longevity, the human and economic resources available to the genetic reserve manager and the type of variables under consideration. Thus, biotic variables regarding the target CWR and interacting species are more dynamic and it may be interesting to monitor them more frequently. On the other hand, some abiotic variables, such as temperature and moisture, can be regularly monitored with automatic sensors at a very low cost. Further, monitoring when a genetic reserve is first established may be more frequent than when the appropriate management is more clearly understood depending on the climatic, land use and other changes experienced ate the individual conservation sites.

Periodic collection of demographic data is perhaps the most commonly used method for monitoring plant populations. Monitoring using ecological data identifies changes in the physical environment that shape the target CWR population and that affect the dynamics and composition of the living communities with which it is associated. Overall, a combined approach, using demographic, ecological and anthropogenic parameters, is desirable. In this way, the target species is monitored directly, but also the biotic and abiotic conditions and the human activities that might contribute to changes in population dynamics are examined and taken into account. Genetic diversity monitoring programmes may also be carried out. However, given that this type of monitoring requires staff with specific skills, specialized equipment and/or higher financial resources, it may be less likely to implement unless there is a need to answer a specific question that requires such data.

The purpose of monitoring is to detect the changes that deviate from the natural fluctuations and that may indicate a risk for the target CWR population. Natural fluctuations in many of the identified levels of monitoring are common and should be previously known. Because monitoring is expensive and time consuming, the specific objectives that are aimed with this task should be clearly identified before implementation. Table 6 provides an account of monitoring parameters that may be considered to detect change at different levels, when deemed appropriate provides additional advice regarding data collection and documentation systems.

Box 5. Data collection and documentation systems for monitoring and sequential sampling.

- Once the monitoring design has been finalized, monitoring data should be collected at the frequency determined in the design stage and analysed to detect significant biological changes that may negatively impact the target population.
- Data collection methods need to be consistent across all target CWR populations and at each monitoring event. If monitoring of different populations of the same species is being carried out, it is extremely important that the same procedures are followed, to allow for reliable comparisons.
- Monitoring methods must be clearly explained so that measurements in successive monitoring events are taken in exactly the same manner. Thus, a consistent and comprehensive monitoring documentation system that clearly describes the monitoring methodology is of utmost importance.
- Monitoring data should be clearly recorded using field data forms, portable computers or personal digital assistants (PDAs). Iriondo *et al.* (2008) recommends filling the field forms with as much information as possible before going out into the field and use predefined codes to avoid repetitive writing and to reduce mistakes. Collected data are then generally transferred to a spreadsheet or statistical software for subsequent data analysis.
- After each monitoring cycle, the data collected need to be properly analysed using appropriate statistical tests specified in the monitoring design. In this way, any problems regarding the monitoring design or the status of a population can be identified and addressed in a timely manner.

Source: Maxted *et al.*, 2016.

Table 6. Monitoring parameters for different levels of monitoring that may be considered in the design of the monitoring process. See Iriondo *et al.* (2008) for more details on each parameter.

LEVEL OF MONITORING	PARAMETERS	EXPLANATION	OBJECTIVES
Physical environment	• Temperature, precipitation, solar radiation, wind, cloud cover, atmospheric pressure, humidity • Soil moisture, texture, pH, nutrients, salinity, redox potential, cation exchange capacity	Environmental conditions of the habitat where the plant occurs	To identify changes in the physical conditions that characterise target CWR populations

LEVEL OF MONITORING	PARAMETERS	EXPLANATION	OBJECTIVES
Biotic interactions	• Density, dominance, frequency, cover and importance value of all taxa that occur in the community • Density and frequency of pollinators, seed dispersers, predators and parasites • Identification of pathogens and intensity of pathogen infection	• Density: Number of individuals/area sampled • Dominance: Total basal area or aerial coverage values/area sampled • Frequency: Number of plots in which a species occurs/total number of plots sampled • Importance value: Relative density + relative dominance + relative frequency	To identify relevant changes in the communities that occur in the habitat of the target CWR populations, including changes in ownership, occupation and land use.
Natural and anthropogenic disturbance	• Natural (fire, flooding, slope movement, wind damage, extreme temperatures, trampling, erosion) • Human-induced disturbance (mining, logging, livestock grazing, recreation, road construction or maintenance, weed control)	Threats to the populations of the target species. See the IUCN's Threats Classification Scheme in Appendix 1	• To identify changes in the physical conditions that characterise CWR and their associated communities. • To account for human influence on the status of CWR populations
Demographic	Population size	Total number of individuals in a population	• To assess viability of populations using: • Population trends • Extinction risk • Population viability analysis (PVA) • To identify demographic factors that are most relevant to population viability
	Population density	Number of individuals per unit area	
	Population frequency	% of plots occupied by the target species within the sampled area	
	Population cover	% of plot area that falls within the vertical projection of the plants of the target species	
	Population structure	Size, stage or age of individuals	
	Survival rate	Proportion of individuals recorded in a first census that are still alive at the second census (usually for each class in structured populations)	
	Growth rate	Probability that a surviving individual moves from one size (or stage) class to any of the others	
	Fertility rate	Average number of offspring that individuals in each class produce from one census to the next	
	Spatial structure	Spatial distribution of each individual	

LEVEL OF MONITORING	PARAMETERS	EXPLANATION	OBJECTIVES
Genetic	Effective population size (*Ne*)	The size of a hypothetical population that would lose genetic diversity at the same rate as the population under study	• To evaluate the genetic diversity within populations and trends/changes therein over time • To understand the dynamics of populations • To recognize the causes behind the reduction of fitness of a population • To determine the level of inbreeding of the target population • To determine what to do if a protected population has suffered a severe decline in population size
	Genetic diversity, inbreeding, gene flow and population structure (*F* statistics)	Both genetic 'richness' (the total number of genotypes or alleles regardless of frequency) and 'evenness' (the frequencies of different alleles or genotypes) can be measures of genetic diversity; Nei's expected heterozygosity is also a measure of genetic diversity. Inbreeding is determined through F_{IS}, and gene flow and population structure through F_{ST}, and clustering analysis.	
	Minimum viable population	The minimum size of a population needed to maintain genetic variation, avoid inbreeding depression and retain evolutionary potential	

2.9.1 Physical environment

Parameters like climatic conditions (temperature, rainfall, humidity), topography, soil nutrient content need regular monitoring to assess their impact on the population dynamics. A periodic assessment of these variables can be useful to identify any changes in the physical environment of the species, such as land-use or stochastic events, that lead to contraction of the population or population increase. There are temperature and moisture sensors in the market (e.g. i-buttons[10]) that can be placed in the genetic reserve to easily and inexpensively obtain a daily record of these variables for the site. A pluviometer to record rainfall is also an economic device that will allow the monitoring of rainfall. In all these cases, suitable equipment to store the logging of data must be taken into account. Another possibility is to gain access to data from nearby weather stations. Monitoring of soil nutrients will require periodic sampling and chemical analysis by a competent laboratory and the need and periodicity of such tests will have to be assessed by the genetic reserve manager. Other variables that are not likely to change, such as topography, soil structure and texture do not require periodic monitoring. The data sheet included in Appendix 2 Table S4 for the characterisation of the abiotic components of the genetic reserve can also be used in the implementation of the monitoring of the physical environment.

2.9.2 Biotic interactions

Most CWR species rely on pollinators and seed dispersers to maintain the gene flow within and between populations. Presence of flower visitors and seed dispersers, their relative abundance and frequency of visits, as well as phenology

[10] https://www.ibuttonlink.com/collections/ibuttons

of target species should be regularly assessed. In a similar way, the presence of pests and pathogens in the target CWR, and changes in the frequency and composition of the plant community should be regularly monitored. All this information is of utmost importance to be able to associate changes in population size or genetic diversity with possible underlying causes. This information will be very useful for the management of the target CWR populations. The periodicity of the monitoring of biotic interactions will depend on the conservation status of the target CWR population. For healthy CWR populations with stable demographic trends, one monitoring event every six years may suffice, while endangered CWR populations may need surveys on biotic interactions every year. The sample data sheet in Appendix 2 Table S5 formulated to gather information on the biotic components of the genetic reserve can also be used to periodically monitor the biotic interactions.

2.9.3 Anthropogenic factors

Threat assessment of the CWR populations (section 2.5) should be integrated in the monitoring program to identify the levels of endangerment of the different species and to assess the effectiveness of conservation measures in place. Accidental introductions of alien invasive species, deforestation or active logging of habitats, pollution, climate change and other human-induced disturbances should be monitored to determine their impacts on the population size and interactions at the local scale (appendix 1). The periodicity of the threat assessments will depend on the degree of human intervention in the area where the genetic reserve is located, and changes in ownership, occupation, management and land use. Accordingly, it may vary from yearly assessments to one every six years.

2.9.4 Demographic monitoring of target CWR populations

Monitoring of plant populations implies a systematic collection of data over time to detect changes in population size, age/size structure, trends and estimate extinction risk, and, thus, to assess population viability. The monitoring of CWR populations may indicate demographically unstable populations, and hence, more need for specific conservation measures. Assessment of population structure and size may include the stratified sampling of number of seedlings, juveniles and adults while population trends can be assessed through data collection of survival, growth and fertility of concerned plants in the target CWR population. The simplest way of conducting the demographic monitoring is by implementing periodically the same procedures established initially to characterise population size and structure (section 2.3.2). There are several ways of developing a population viability analysis for the target population. Morris and Doak (2002) provide a good account and procedure details about them.

2.9.5 Genetic monitoring of target CWR populations

Analysis and assessment of the genetic diversity within CWR populations is a crucial step to understand the dynamics of the populations and their adaptive potential. Genetic monitoring is important to give insight into the following:

- understanding of genetic diversity in the populations
- the degree of inbreeding in the target population
- the effective size of the population
- population structure for a target CWR species
- the rate of gene flow
- the minimum viable population
- allelic diversity for a particular gene responsible for a given phenotype

Neutral markers, such as microsatellites or more recently SNPs corresponding to non-transcriptional regions of the genome are the most appropriate for genetic diversity, inbreeding, population structure and gene flow estimations, whereas the determination of allelic diversity for particular genes will ideally involve the complete sequencing of that gene. The economic resources available and the collaboration with research laboratories with genetic or genomic capacities will determine the extent of the genetic studies in the genetic reserve. Ideally, in addition to an initial screening of the genetic diversity of the population it would be advisable to repeat the genetic characterisation periodically to monitor the genetic dynamics of the population. The periodicity of the genetic survey will greatly depend on the life history characteristics of the target species. Thus, long-lived species with high generation times will require fewer surveys. On the contrary, for annual species, it would be advisable to conduct a genetic monitoring every six years (Goldringer *et al.*, 2006).

2.10 Adaptive management

It is common that actions do not always go as planned and circumstances change all the time. Consequently, there is a need to adapt the management strategy/plan to such changes which are often unpredictable and uncertain. **Adaptive management** is thus a process by which a system is managed, and the managers learn as they go, 'learning by doing', helping to resolve critical uncertainties.

The adaptive management cycle identifies five steps: assess, plan, implement, analyse and adapt, and share (Figure 8).

While structured decision-making can help to identify the first-choice actions, there may remain uncertainty or disagreement as to the best course of action in implementation. A common approach to handling such uncertainty during implementation is through adaptive management. Adaptive management is a process by which a system is managed and the managers learn as they go: 'learning while doing' (Holling, 1978). The issue is to decide between a set of alternative actions or strategies.

An adaptive management approach can help to resolve critical uncertainties around aspects such as:

- How might species respond to different climate change scenarios?
- How might species respond to different conservation interventions or actions?
- How are conservation alternatives traded off in combination with their costs and in combination with their values to different stakeholders, while always striving to meet the objectives?

In active adaptive management, managers assess the likely outcome of, and learn from, each of a range of alternative strategies, and choose the one most likely to achieve their objectives overall (McDonald-Madden *et al.*, 2011). By assessing the likelihood of each of the set of strategies in advance of implementation, the manager has a set of hypotheses for implementing the desired change. When the first-choice strategy has been applied and tested, the outcomes can be assessed against this hypothesis. If the outcomes have not been as expected, then there are alternative hypotheses and strategies available to be tested. The considered next best strategy is applied, tested and learnt from. Through this iterative approach, active adaptive management will identify the most effective conservation measures, and maximum learning will have taken place. McDonald-Madden *et al.* (2011) demonstrate the application of active adaptive management with respect to the optimal timing for relocating species faced with the negative effects of climate change.

One of the main initiatives of implementation of adaptive management in nature conservation is the *Open Standards for the Practice of Conservation* (OS), developed within the frame of Conservation Measures Partnership (CMP[11]) which is a worldwide joint venture of 25 conservation organizations. This initiative considers five steps in the adaptive management cycle that are summarised in Figure 8.

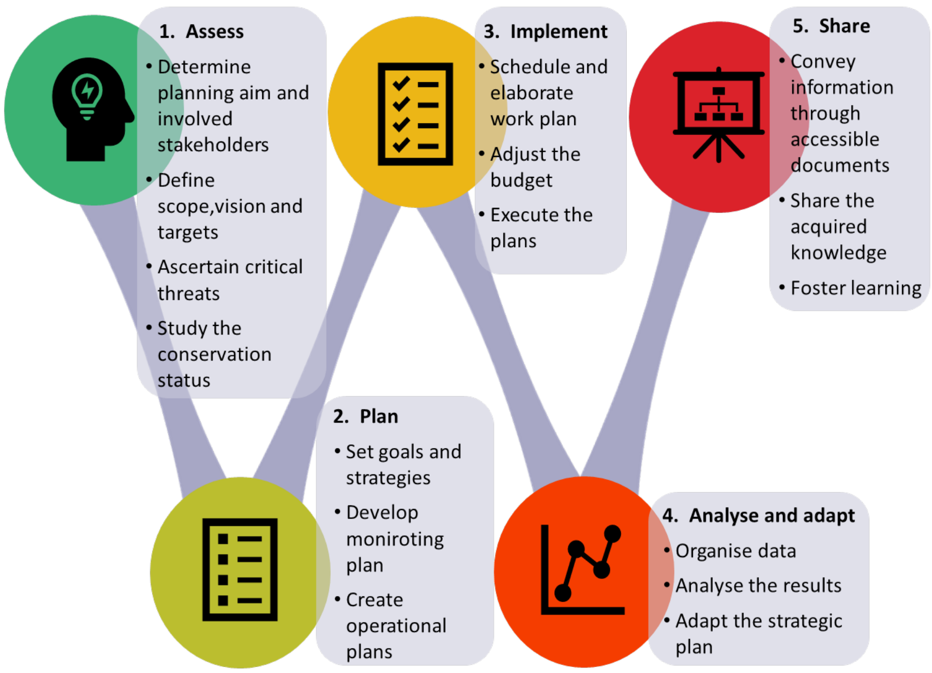


Figure 8. Five steps of the adaptive management cycle (Conservation Measures Partnerships, 2020).

2.11 Institutional support and participation of stakeholders

It is important that the development of the management plan of genetic reserve and its implementation is done in a participatory way involving relevant **stakeholders** right from the start. The manager should ensure that the final management plan for the reserve is discussed and agreed with the stakeholders and implemented with their support.

Some of the main stakeholders include managers, politicians, resource planners and owners, farmers, local communities, scientists, breeders and visitors (Figure 9).

The management of the genetic reserve should be participatory, with sufficient involvement of relevant stakeholders into the decision-making process and

[11] https://www.conservationmeasures.org/

planning, but equally, whenever possible, into the implementation of the management actions. This is particularly important where there are close interactions with local communities or specific stakeholders (see section 2.5). Whoever in the end is responsible for the management of a reserve (e.g. a nature conservation organization, protected area management authority, public authority or scientific institution), they should make sure that the final management plan should be accepted and 'owned' by all relevant stakeholders.

There are many reasons why stakeholders need to be at the heart of management plan preparation. A major challenge in CWR conservation is the cross-sectorial nature of the work. This means that alignment between environment sector, agriculture sector and other relevant sectors is necessary. Since the main difficulties are experienced at the level of responsible authorities and their institutions, there is a need to formally anchor mutual understandings and expectations. On the other hands, other stakeholders may live within the genetic reserve or close by. They are often taxpayers, visitors or supporters. Their businesses might benefit from ecosystem goods and services the area provides and their activities may be required to maintain features or influence them otherwise. They are also potentially the cause of pressures and depletion of natural resources, but they might also be a part of future generations for whom opportunities for personal fulfilment are needed. In practice, often, managing a genetic reserve is mainly about managing people. When considering who are the stakeholders that should be involved, it is useful to think about who the users of a management plan of the genetic reserve are (Box 2, Figure 9).

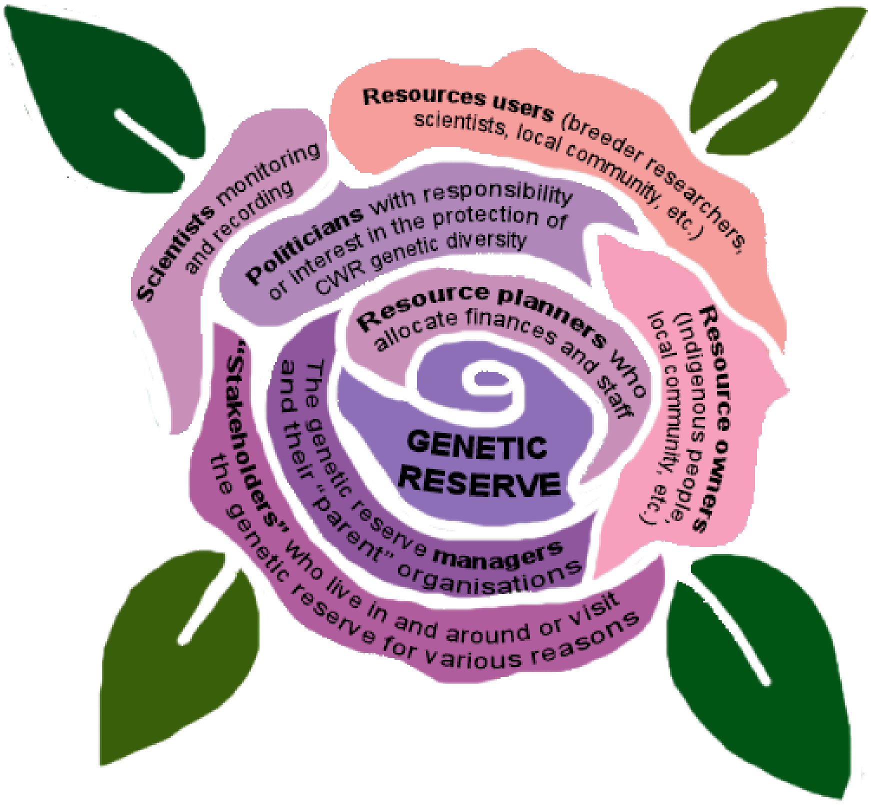


Figure 9. Potential stakeholders participating in a genetic reserve.

Of course, the exact spectrum of stakeholders that need to be engaged will depend also on the size of the reserve. A very small locality within a single farm will require much less stakeholder groups to be involved than a larger area, although this still might be broader than just a single site manager / farmer. To be able to better decide on the stakeholders that need to be involved, it is useful to do a stakeholder analysis based on their impact, attitudes, level of interest, influence and power. A very useful source of information on how to develop a management plan in a participatory way and how to involve the relevant stakeholders is in the Eurosite's 'Management Planning for Protected Areas – a guide for practitioners and their bosses' (Idle and Bines, 2004).

In addition to the institutional support provided at the local level, genetic reserve managers can rely on the technical and scientific support that can be provided by regional and global groups of experts. At the European scale, the ECPGR Wild Species Conservation in Genetic Reserves Working Group[12] is a working group of experts from 35 European countries dedicated to the improvement of knowledge and methodologies concerning the conservation and use of CWR. In the last 20 years the group has been highly active in promoting CWR conservation at the different European instances and have carried out several research projects funded by European institutions. Furthermore, they developed a concept document for *in situ* conservation of crop wild relatives of Europe[13] that was endorsed by the ECPGR Steering Committee.

The IUCN Crop Wild Relative Specialist Group (CWRSG[14]) is an international expert group established by IUCN to promote the conservation and sustainable use of CWR diversity. CWRSG has four primary objectives:

a) Develop effective strategies for gathering, documenting and disseminating baseline information on crop wild relatives.

b) Promote the conservation and use of crop wild relatives.

c) Provide advice, expertise and access to appropriate contacts to enhance the actions of individuals or organizations working on the conservation and use of crop wild relatives.

d) Increase awareness of the importance to agriculture and the environment of crop wild relatives among governments, institutions, decision-makers and the general public.

Therefore, the CWRSG provides a coordinated network of experts in the field of CWR conservation and use and aims to open the necessary communication channels to share information and experiences and encourage a more strategic approach to CWR conservation (and through conservation, a link to enhanced utilization).

[12] https://www.ecpgr.cgiar.org/working-groups/wild-species-conservation

[13] https://www.ecpgr.cgiar.org/fileadmin/templates/ecpgr.org/upload/WG_UPLOADS_PHASE_IX/WILD_SPECIES/Concept_for_in__situ_conservation_of_CWR_in_Europe.pdf

[14] http://www.cwrsg.org

2.12 Communication strategy

A genetic reserve should develop a **communication strategy** to plan on what and how it will communicate to different types of stakeholders. Key steps include:

a) Identify key stakeholders with whom you wish to communicate.
b) Define type of materials/information relevant to each stakeholder.
c) Decide how data will be collected and documented and by whom.
d) Decide how data will be managed.
e) Decide how data/information will be made accessible.
f) Decide on format and media for dissemination.
g) Develop a costed communication plan.

It is important to be able to communicate information on the CWR populations contained in the genetic reserve to different types of stakeholders. These stakeholders can range from staff of the protected areas and owners of genetic reserve (if private), natural resources and agricultural scientists including breeding researchers, extension officers, policy makers responsible for nature, environment, forestry and agriculture sectors, media and public in general. The interests of each of these stakeholders differ in specific aspects and thus communication materials should be geared towards each of them in different ways. Each will require different types and different media. A genetic reserve should develop a communication strategy and plan on what and how it will communicate to the different types of stakeholders. It should be noted that science and plant breeding are by far the most important users of crop wild relatives, and, therefore, should be especially taken into account in respect to communication. The key steps that could be followed to prepare a communication strategy and plan are summarized in Figure 10.

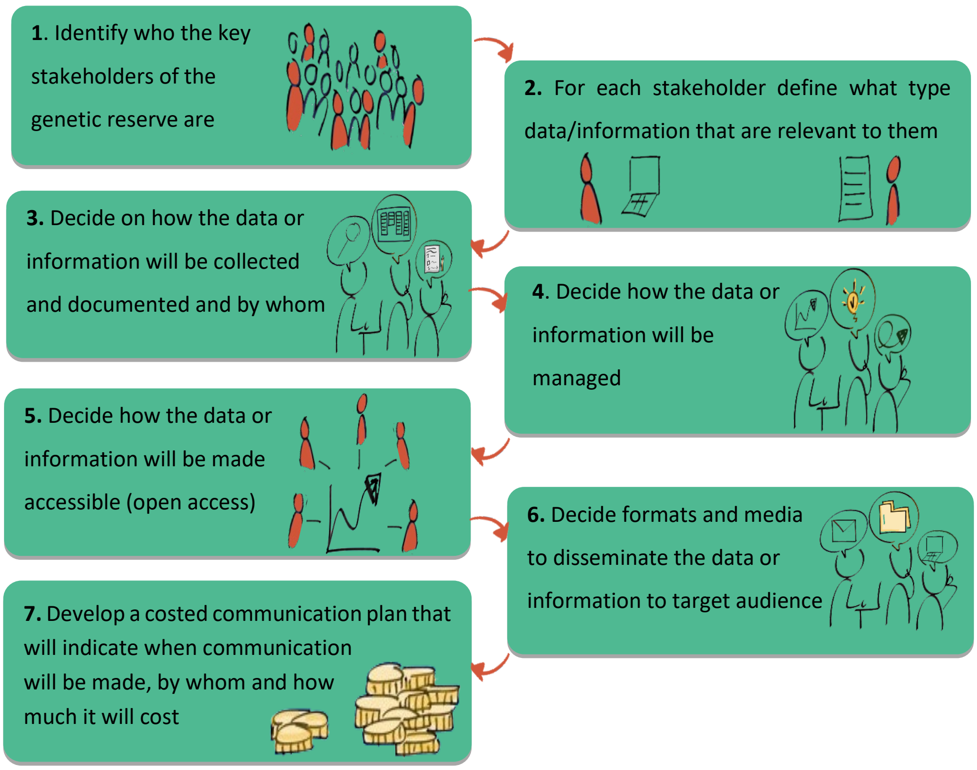


Figure 10. Steps in the preparation of a communication strategy and plan.

2.13 Management of information: Registry of actions, decisions and biological data

The development of an effective management plan should be based on accurate **information/datasets** about the target CWR populations and the reserves in which they occur. This will determine the management objectives. Thus, consistent data collation, documentation, management, availability, and access are required. Key information/data required include, inter alia:

- Taxonomic occurrences within the site.
- Ecogeographical information including biotic and abiotic conditions for the site.
- Demographic data of the target population(s).
- Generic and local threats and status.
- Conservation status.
- Genetic information/data.
- Time series data on demographic and genetic changes.
- Legislations.

It is widely acknowledged within the plant genetic resources conservation and user community that one major factor hindering effective conservation and use of plant genetic resources diversity is the lack of easy access to data and obstacles to information exchange, due to the many different approaches and incompatible systems for managing data (FAO, 2010).

If we are to effectively conserve and use the genetic resources contained in CWR populations conserved *in situ*, then consistent data collation and management is required. This process would ideally involve taxonomic occurrences within the site, ecogeographical information including a characterisation of the biotic and abiotic conditions present at the site, threats and conservation status of the populations, phenotypic and genetic characterisation of the populations, as well as time-series data regarding demographic and genetic changes in the target populations.

2.13.1 Collection of baseline information

A CWR genetic reserve should be established based on an initial data set, which is used to determine the management objectives. As planning processes usually require the gathering of additional data before some management options can be evaluated and selected, baseline data collection can almost always be informed to a considerable extent by the management objectives for the genetic reserve (Thomas and Middleton, 2003).

The stages involved at this stage are:

i) To gather available background information and carry out a field survey to collect or confirm the information about the site, the target CWR population, the biotic and abiotic factors and the human component as indicated in sections 2.2, 2.3, 2.4, 2.5, 2.6 and 2.7.

ii) To document it in the form of a description of the genetic reserve, which could be called ‘State of the Genetic Reserve’ report.

In its scope, the description should refer to the characteristics of the genetic reserve itself, external factors which affect the genetic reserve and factors which may become significant in the future. It should explain how things are changing, as well as their current impacts. It is important that the description identifies uses and activities both within and near the area that may impair or adversely affect the genetic reserve's values and resources. In addition to collecting site-related information, it is necessary to identify and understand the relevant government legislation affecting the planning of the site. Applicable legislation may exist at all tiers of government and it should be closely considered to ensure compliance. Beside nature conservation laws, many others may affect the genetic reserve, for example, legislation affecting water supply, cultural heritage, fishing, hunting, telecommunications, roads and electricity infrastructure.

To collect the information in a consistent and systematic way, data is often codified when it is entered in conservation databases. In this case, it is important to adopt standard codes wherever possible to facilitate data transfer between databases. Maxted *et al.* (2020) list some advantages of adopting standards in biodiversity information, which:

a) reduces any problem of text synonyms.

b) provides greater consistencies.

c) permits automatic checks for data integrity.

d) allows comparison of results and quicker data searching.

To consistently document key characteristics for *in situ* conservation of CWR, internationally agreed descriptor lists are needed. The secretariat of the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) has recently published a globally agreed list of descriptors for *in situ* Crop Wild Relatives documentation (Appendix 4, Alercia *et al.*, 2020). It builds upon the Core Descriptors for *In situ* Conservation of CWR v.1 published by Bioversity International, on recent experiences conducted by (ITPGRFA) of FAO and its Global Information System (GLIS) and Digital Object Identifiers (DOIs) (GCP/GLO/685/GER), as well as on international projects such as the Horizon 2020 Farmer's Pride[15].

2.13.2 Registry of actions, decisions and biological data

Once the CWR genetic reserve is established and properly characterised and described, a great amount of data is generated through the conservation and management activities. The management of data associated with *in situ* conservation is referred to as documentation (Painting *et al.*, 1993). Genetic reserve managers should document all actions and decisions that are taken daily to conserve the target populations. Furthermore, field population data obtained in the monitoring of a conserved population should be analysed to identify the effectiveness of management practices in place (Iriondo *et al.*, 2008) and is often restricted to time series, demographic estimates of population size, density, frequency and cover. More exceptionally, some form of periodic genetic diversity monitoring takes place. Globally there are so few active, long-term *in situ* CWR conservation activities that field CWR population data management has yet to be formalized, though consideration has been given to what such monitoring may involve and how such time series data might be stored and manipulated (Iriondo *et al.*, 2008). While an effective data management system exists for handling and managing *ex situ* conservation facilities, such as GRIN-Global, there are no parallel conservation management systems currently available for *in situ* conservation of CWR. However, the first steps are now being taken to

[15] http://www.farmerspride.eu/

develop it in the context of the Farmer's Pride project and also the CGIAR Root, Tuber and Banana research programme[16]. Both national authorities and global plant genetic resources databases must make the necessary adaptations to be able to properly host the data from CWR genetic reserves.

2.13.3 Data types

Some of the types of useful plant genetic diversity data for *in situ* conservation are summarized in Table 7.

Table 7. Types of plant genetic diversity data (Maxted *et al.*, 2020).

Historical, passport and ecogeographic data	Description of the taxonomic, geographical areas where the species is located, the population characteristics, the local biotic and abiotic factors and the institution where it is maintained.
Characterisation or observational data	Characters that are highly heritable, can be seen easily by eye and are expressed in all environments (e.g. flower colour; number of fruits per inflorescence). These are used to describe the diversity within the genetic resources themselves and they are measured or recorded directly from observation. They are descriptive and may assist in the maintenance and use of the genetic material. For example, a specimen may have white flower petals, multiple leaflets per leaf or be perennial.
Preliminary evaluation or experimental data	Agronomic traits of interest for a particular crop that are susceptible to environmental differences. Such an evaluation is carried out in experimental fields located at different sites. A preliminary evaluation of a limited number of agronomic traits thought desirable by users of the particular crop may be achieved at the genetic reserve. It will essentially involve the collection of phenological data, including the timing of flowering and fruiting and vegetative stages.
Management or curatorial data	Essential data that facilitate the maintenance of the population. They include information associated with the management interventions affecting the target population being conserved, and time-series data that help the conservationist identify trends in population size.

[16] https://www.rtb.cgiar.org

2.14 Implementation of national, regional and international policies

The management plan should include a **review of relevant policies** that govern the conservation and use of biodiversity including plant genetic resources, and particularly support measures applicable for CWR populations. These should consider not only policies existing **at national, regional, and international levels**, but also those operating **at local and sub-national levels** (see Figure 11).

The management plan should contain a review of the national, regional and international policies in the country where the genetic reserve is located. Often a country also has local authorities at different levels (states, provinces, counties, municipalities, district councils etc.) which may have their own policies and legal frameworks. These policies should also be considered in the review. It is important that managers of the genetic reserves become cognizant about the policy instruments, such as those described below to be able to design and effectively manage their reserves. It may also help in getting support from local authorities, national, regional or global programmes and in getting recognition of the work they are doing. In this part of the management plan, the policy framework in the country at subnational, national, regional and global levels that are relevant for the conservation and sustainable use of CWR should be described (Figure 11).

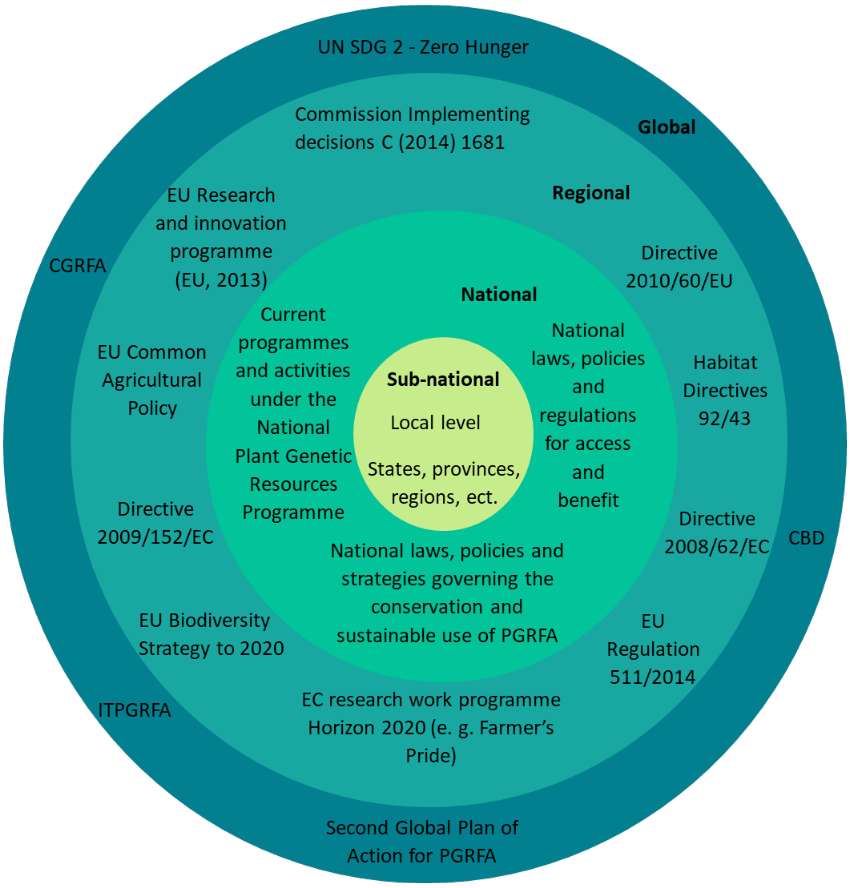


Figure 11. Sub-national, national, regional and global policy frameworks that affect a CWR management plan in the context of the European Union.

2.14.1 Sub-national policy framework

Depending on the administrative organization of each country, the importance of the policies at the sub-national level will greatly vary. In general, two different levels can be found:

- Local level, including regulations concerning the management and use of parks, streets, and public land in rural areas.
- Subnational public administration entities immediately below the country level corresponding to NUTS level 2[17] including states, provinces, regions, government regions and autonomous communities etc. depending on the country. In many countries, like Germany or Spain, these entities are competent to enact legislation concerning agriculture and environment, and, therefore, the policy framework may include subnational laws, policies and strategies regarding these areas as well as more specific ones governing the conservation and sustainable use of PGRFA.

2.14.2 National policy framework

Each country has developed its own policy instruments relating to the conservation and use of plant genetic resources. In general, these include:

- Existing national policy framework, including development plans, poverty reduction strategies, climate change adaptation plans, agricultural and environmental policies.
- Existing national laws, policies and strategies governing the conservation and sustainable use of PGRFA, including sector-specific strategies and national programmes.
- National laws, policies and regulations for access and benefit sharing of genetic resources.
- Current programmes and activities under the National Plant Genetic Resources Programme.

2.14.3 Regional policy framework

Regional agreements and/or treaties to which the country is a party should be mentioned as well as regional, sub-regional and bilateral programmes and networks of which the country is a member. For example, in Europe, some of the key policy instruments include:

- EU Biodiversity Strategy to 2020.
- Habitats Directive 92/43.
- EU Common Agricultural Policy (CAP).
- The community programme on the conservation, characterisation, evaluation and use of genetic resources in agriculture, based on Council Regulation (EC) 870/2004 replaced by EU Research and innovation programme (EU, 2013).
- EC research work programmes.
- EU Regulation 511/2014 (EU ABS Regulation).

[17] https://en.wikipedia.org/wiki/Nomenclature_of_Territorial_Units_for_Statistics

2.14.4 Global policy framework

This includes the international agreements and/or treaties to which the country is a party. In brief, these include:

- Convention on Biological Diversity (CBD) adopted in 1992. In 2010, CBD COP adopted a Strategic Plan for Biodiversity 2011–2020 with its associated Aichi Targets, which is a ten-year framework for action. These targets are currently being revised for the period 2021-2030. The Nagoya Protocol to the CBD, which came into force into 2014, creates specific obligations for users of genetic resources relating to the fair and equitable sharing of the benefits arising out of the utilization.
- International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA), legally binding instrument entered in force in June 2004 with its objectives being in harmony with those of the CBD.
- FAO's Commission on Genetic Resources for Food and Agriculture (CGRFA), which adopted in 2013 three targets for PGRFA, the first of which by 2020, an increasing proportion of genetic diversity of cultivated plants and their wild relatives as well as wild food plant species are maintained *in situ*, on farm and *ex situ* in a complementary manner.
- Second Global Plan of Action for PGRFA adopted by the FAO council in November 2011 provides 18 Priority activities to be implemented by member states, of which the first four activities (1-4) relates to the *in situ* conservation and management.
- UN Sustainable Development Goals (SDG) 2 - Zero Hunger: SDG goal 2 highlights the need of eradicating extreme poverty and hunger and its target 2.5 aims to maintain the genetic diversity of seeds, cultivated plants and farmed and domesticated animals and their related wild species, by 2020. SDG 15 – Life on Land: highlights the need to halt biodiversity loss.

In 2015, the Secretariats of the CBD, International Treaty on PGRFA, CGRFA along with Bioversity International notified their respective Contracting Parties, together with the national focal points of the CBD Programme of Work on Protected Areas (PoWPA), of the need to strengthen *in situ* conservation of plant genetic resources through the incorporation of active CWR conservation in protected area networks, and link *in situ* conservation to sustainable use (Notification SCBD/SAM/DC/DCo/84808 dated 3 August 2015).

2.15 Procedures to ensure and regulate access and use of CWR

The **access and benefit sharing** arising from the use of CWR species, governed by the **Nagoya Protocol and International Treaty on PGRFA**, are critical to meeting the global goals of food and nutritional security and need to be facilitated so that the fair and equitable sharing of benefits that CWR provide may be realized.

Managers of genetic reserves should have a basic understanding of these policies. They should discuss how they will be applied when samples from the genetic reserve are backed-up *ex situ* and made available to users under standard access and benefit sharing by the genebank on behalf of the genetic reserve. Details should be clearly described in the management plan of the genetic reserve and the communication strategy.

The access and use of CWR species are critical to meeting the global goals of food and nutritional security and need to be facilitated so that the benefits that CWR provide may be realized. As mentioned above, the Nagoya Protocol to the CBD, which came into force into 2014, and the relevant EU Regulation (511/2014), have created specific obligations for users of genetic resources relating to the fair and equitable sharing of the benefits arising out of the utilization. Access and benefit sharing to some CWR species of crops are governed by the International Treaty on Plant Genetic Resources for Food and Agriculture, which establishes a multilateral system of access and benefit sharing (article 10). The Treaty, through its article 12, requires that contracting parties facilitate access to plant genetic resources for food and agriculture under the multilateral system as defined in article 11. This includes PGRFA that are listed under Annex 1 (which includes specific CWRs) of the Treaty and that are under the management and control of the contracting party and in the public domain.

Many countries have already developed their own procedures for ensuring access and use of plant genetic resources for food and agriculture and wild plants, (both including CWR species). There is overlap between the Nagoya protocol, which applies to wild species, and the ITPGRFA, which is applicable to most crops (and their wild relatives). Where this happens, ITPGRFA takes precedence and it is the procedures of the Treaty that need to be followed. For CWR taxa not included in Annex 1 of the multilateral system of the ITPGRFA, the Nagoya protocol applies unless the contracting party has decided otherwise (Figure 12).

In this context, the resource owners within the genetic reserve are crucial and should be fully recognized. For instance, the landowners will normally also be the owners of the plants growing on the land, especially if they are wild plants. Unless the ownership and use of all CWR plants growing in the wild has been nationalized by the law of their 'resident' country, the international treaties do not change the normal rule that they (and their plant material components, etc.) are likely to be owned by the landowner on whose land they are growing.

Managers of genetic reserves should ideally become familiar with the procedures of access and benefit sharing of both Nagoya Protocol and the ITPGRFA established in their country, and ensure that the access and use to CWR in their reserve are facilitated while respecting the legal procedures in place. Depending on the nature of the genetic resource (i.e., seeds vs clonal material) and the particularities of each country, users may have an easier access to *in situ* genetic resources from the backup placed in their partner *ex situ* gene banks. In this way, the gene banks, who are familiar with ITPGRFA or Nagoya protocol procedures, can facilitate user accesses (Maxted *et al.*, 2020) (see chapter 6).

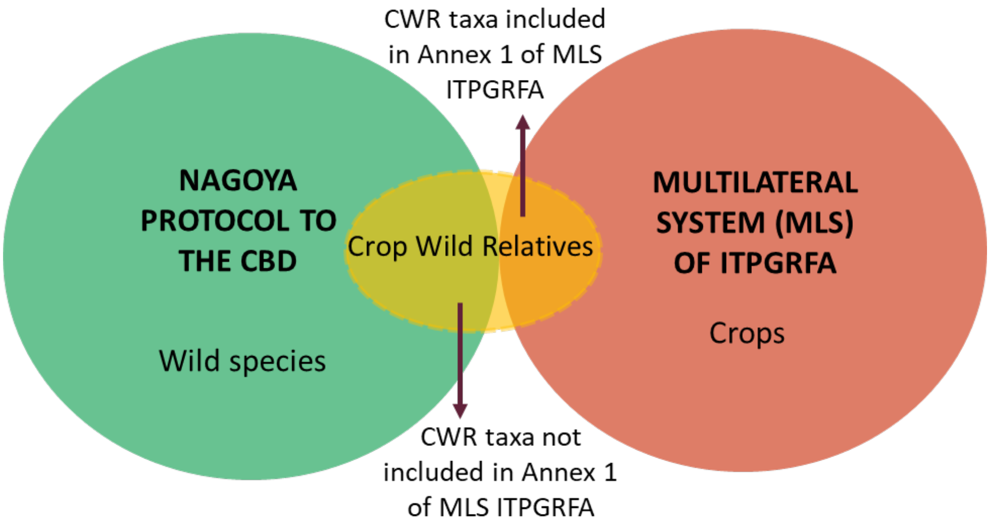


Figure 12. Regulations for the access and use of CWR.

Locally the materials held in the reserve may have traditionally been used in construction, craft, adornment or food. This form of traditional utilisation of the reserve by local people should be encouraged, providing it is sustainable and not deleterious to the target taxon or taxa, as it is essential to have local support for conservation actions if the reserve is to be sustainable in the medium to long-term (Maxted *et al.*, 2020).

3 Integration of CWR conservation with protected area management

Maxted, N., Mroz, W., Ĉivić, K., Iriondo, J.M., Álvarez-Muñiz, C., Alves, J., Bönisch, M., Dudley, N., Dulloo, M.E., Fitzgerald, H., Hosking, J.B., Magos Brehm, J., Rasmussen, M., and Weibull, J.

3.1 Background

Most existing protected areas contain multiple CWR populations of interest, however, they are **conserved passively** and their perdurance is uncertain. The goal of explicitly conserving genetic diversity is still to be recognized widely by the protected area community. The **consensus on the need to conserve CWR diversity is increasing**, but still, in the few sites where CWR are actively conserved *in situ,* they are generally not managed in the most appropriate manner to maximize the conservation of the genetic diversity.

A protected area (PA) is "a clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long term conservation of nature with associated ecosystem services and cultural values" (Dudley, 2008) and IUCN recognizes seven Protected Area Categories based on the PA management objectives which enable international standardization (Dudley, 2008). PAs are also often classified according to national criteria, depending on governance structure and whether they are managed by public administrations, private entities or local communities, among others (Stolton *et al*., 2006). The concept of a PA, where the goal is explicitly genetic diversity conservation, rather than species or habitat presence or absence is still to be recognized by the formal international PA community, although mini reserves for crop wild relatives or land races are mentioned explicitly in Dudley (2008). The closest existing category to a genetic reserve (GR) is IUCN Category IV Habitat/Species Management Area (Dudley, 2008). In this absence and for this manual the following definition is applied: "genetic reserve conservation as the location, management and monitoring of genetic diversity in natural wild populations within defined areas designated for active, long-term conservation" (Maxted *et al*., 1997a). The distinction between GR conservation and other forms of PA conservation is twofold (a) the focus on maximising the conservation of the target taxon, and (b) the maintenance of evolution of this diversity, rather than the species *per se* or the entire ecosystem in which the species is/are found.

In addition to the network of PAs that each country has, there are several other international networks that aim to conserve biodiversity *in situ*, which currently passively conserve CWR diversity and could in the future play a more active role in *in situ* CWR conservation. Box 6 lists and provides a brief description of the most relevant ones with their links with CWR conservation.

Box 6. International networks dedicated to *in situ* conservation of nature.

European Natura 2000
https://ec.europa.eu/environment/nature/natura2000/ index_en.htm

It is the largest coordinated network of PAs in the world. It stretches across 27 EU countries and over 18% of EU's land and almost 6% of its marine territory. The network was created within the framework of the Habitats Directive in 1992 (Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora). It consists of two types of sites:

a. Special Areas of Conservation (SACs) – created under the Habitats Directive.

b. Special Protection Areas (SPAs) – created much earlier, before Natura 2000 network establishment–under the Birds Directive from 1979 and amended in 2009 (Directive 2009/147/EC of the European Parliament and of the Council of 30 November 2009 on the conservation of wild birds).

Concerning CWR *in situ* conservation, it may be expedient to focus on SACs because they are most strongly associated with the type of management required by CWR GRs. SACs are delimited according to Habitats Directive Annex III and they are designed to protect natural habitats of Community interest listed in Habitats Directive Annex I, as well as animal and plant species of Community interest listed in Habitats Directive Annex II. However, Annex IV lists animal and plant species of Community interest in need of strict protection. Some Annex II and Annex IV plants species are CWR, moreover several Annex I natural habitats, especially non-forest ones, are important CWR habitats.

A study conducted by the Farmer's Pride project (www.farmerspride.eu) identified 863 European priority CWR taxa found that 519 taxa occur within the limits of Natura 2000 network. 17 of them are included under Annexes II and IV, and 84 are characteristic species of some of the natural habitats protected by Annex I. 83 of the 233 habitat types included in Annex I have one or more CWR taxa amongst their characteristic species (Rubio Teso *et al.*, 2020). Therefore, each SAC is likely to contain multiple CWR taxa and GRs could be established by amending the management plan to ensure active CWR population management.

EMERALD Network https://www.coe.int/en/web/bern-convention/emerald-network

The Emerald Network is an ecological network made up of Areas of Special Conservation Interest (ASCI). Its implementation was launched by the Council of Europe as part of its work under the Bern Convention (Recommendation No. 16 (1989) of the standing committee on areas of special conservation interest). However, the conservation of ASCI is looser and not bound by strict and binding legal regulations as are Natura 2000 sites. However, the EMERALD network site management plans are still amendable to more actively support CWR *in situ* conservation. Seven countries, Andorra, Belarus, Georgia, the Republic of Moldova, Norway, Switzerland, Ukraine and UK, have officially adopted Emerald sites on their territories. Moreover, there is also a list of officially nominated candidate sites from Albania, Armenia, Azerbaijan, Bosnia and Herzegovina, Montenegro, North Macedonia, Russian Federation and Serbia. In the case of EU, which is also a Contracting Party to the Bern Convention, Natura 2000 sites are considered as the contribution from the EU member States to the Emerald Network. The strictly protected flora species under Bern Convention are listed in its Appendix I. Some of them can also be considered CWR. CWR species can also be found in Resolution No. 6 (1998) listing the species requiring specific habitat conservation measures. The endangered habitat types are listed in the Revised Annex I of Resolution 4 (1996) of the Bern Convention on endangered natural habitats types using the EUNIS habitat classification (year of revision 2010).

UNESCO Man and Biosphere Programme (MAB): http://www.unesco.org/new/en/natural-sciences/environment/ecological-sciences/man-and-biosphere-programme/

The MAB Programme is an Inter-governmental Scientific Programme aiming to set a scientific basis for the improvement of the relationships between people and their environment globally. Launched in the early 1970s, it provides interdisciplinary research and capacity building targeting the ecological, social and economic dimensions of biodiversity loss and the reduction of this loss. The World Network now comprises 701 biosphere reserves in 124 countries, including 21 trans-boundary sites. They seek to reconcile conservation of biological and cultural diversity and economic and social development through partnerships between people and nature. Biosphere reserves are thus globally considered as sites of excellence where new and optimal practices to manage nature and human activities are tested and demonstrated. Following designation, biosphere reserves remain under national sovereign jurisdiction, yet they share their experience and ideas nationally, regionally, and internationally within the World Network of Biosphere Reserves. Given their compromise with biodiversity conservation and economic and social development, they are appropriate settings for *in situ* CWR conservation.

UNESCO World Heritage Sites (WHS): http://whc.unesco.org/en/list/

The Convention concerning the Protection of World Cultural and Natural Heritage, commonly abbreviated to World Heritage Convention, was adopted by UNESCO on 16 November 1972 and has subsequently been ratified by 193 states. The WHC brings together the concepts of nature conservation, the preservation of cultural properties and the balance between the two. It sets out the duties of States Parties in identifying potential sites and their role in protecting and preserving them, as well as defining the kind of natural or cultural sites to be included in the World Heritage List. Sites must be of "outstanding universal value" and meet at least one of the ten defined selection cultural and natural criteria.

FAO Globally Important Agricultural Heritage Systems (GIAHS):
http://www.fao.org/giahs/en/

GIAHS, a FAO initiative, are the sole international site-based conservation network that have a focus on agrobiodiversity, although not actual PAs. GIAHS aim to promote public understanding, awareness and recognition of Agricultural Heritage systems. They also aim to safeguard the social, cultural, economic and environmental goods and services associated with agrobiodiversity and support family farmers, smallholders, indigenous people and local communities working with this diversity. GIAHS sites are selected based on their provision of local food security, high levels of agricultural biodiversity and associated biological diversity.

Internationally, there has been an increasing consensus of the need to conserve CWR diversity in the era of growing ecosystem instability and climate change (Engels and Thormann, 2020). However, despite significant progress in global *ex situ* seed collection of priority CWR (Dempewolf *et al.*, 2014), the *ex situ* coverage is far from systematic. Castañeda-Álvarez *et al.* (2016) conclude that globally 70% of targeted CWR taxa are identified as high priority for further collecting and over 95% are insufficiently genetically represented in genebanks, while in terms of *in situ* CWR conservation the situation is significantly less developed (Iriondo *et al.*, 2012; Maxted *et al.*, 2017). There is currently no over-arching global network or clearing-house mechanism specifically devoted to the conservation and use of CWR, which is unnecessarily limiting CWR diversity availability to diversity users (Maxted *et al.*, 2016).

It should also be noted that the goal of genetic conservation is not only to maximise the genetic diversity conserved (Maxted *et al.*, 2020), but also to ensure diversity is particularly conserved from CWR populations occurring in extreme or marginal habitats. Within the context of rapid climate change, the value of CWR diversity from populations in extreme habitats is expected to be greater because they are likely to have evolved adaptions to those extreme habitats that are likely to prove particularly interesting in crop adaptation and likely not to have evolved in their centres of diversity where the pressures for adaption will be different. This is a clear argument when setting up a regional or even global network of *in situ* sites to deliberately include less taxonomically diverse but marginal sites which may contain the rarer alleles required for breeding programmes (Maxted *et al.*, 2020).

The majority of the world's PAs contain multiple CWR populations, however, in most cases the PAs were established to conserve threatened habitats and species, not agrobiodiversity or specifically CWR (see Box 6). In these PAs, CWR with populations within their boundaries are conserved so-called passively, meaning that the CWR populations are not actively managed and individual populations may decline or go extinct without the site managers being aware of the loss. Further, if the PA manager does not appreciate the value of CWR, they may deliberately reduce or destroy CWR populations if they believe that the notified habitats and species are at risk by these 'weedy' species presence.

Where CWR have historically been actively conserved it is often fortuitous, because they also happen to be charismatic or threatened taxa, and so are prioritized for this reason and not because of their importance as CWR (Maxted *et al.*, 1997c). Even in the few sites where CWR are actively conserved *in situ* (Table 8), the sites are generally not managed in the most appropriate manner to maximize the conservation of the genetic diversity contained within CWR populations. Commonly, these sites do not meet the set of quality standards for CWR GRs proposed by Iriondo *et al.* (2012) and their designation has been *ad hoc* and opportunistic rather than guided by scientific objective.

Table 8. Examples of CWR actively conserved *in situ* (Álvarez-Muñiz *et al.*, 2021).

CWR	Protected Area	Country	References
Teosinte (*Zea diploperennis.* Iltis *et al.*)	MAB Sierra de Manantlán Biosphere Reserve	Mexico	Sánchez-Velásquez (1991)
Wild emmer wheat (*Triticum turgidum* L. subsp. *dicoccoides* (Körn. Ex Asch. and Graebn.) Thell.)	Ammiad, Galilee	Israel	Anikster *et al.* (1997); Safriel *et al.* (1997)
Wild coffee (*Coffea mauritiana* Lam., *C. macrocarpa* A.Rich, *C. myrtifolia* (A.Rich. ex DC) Leroy)	Black River Gorges National Park	Mauritius	Dulloo *et al.* (1998)

CWR	Protected Area	Country	References
Wild wheats (*Triticum turgidum* L. subsp. *dicoccoides* (Körn. Ex Asch. and Graebn.) Thell., *T. monococcum* L., *Ae. Tauschii* Coss., *Ae. Speltoides* Tausch.)	Ceylanpinar	Turkey	Karagöz (1998)
Medicago L. spp., *Vicia* L. spp., *Trifolium* L. spp., *Lathyrus* L. spp., *Lens* Mill. spp., *Triticum* L. spp., *Avena* L. spp., *Hordeum* L. spp., *Aegilops* L. spp., *Allium* L. spp., *Amygdalus* L. spp., *Prunus* L. spp., *Pyrus* L. spp., *Pistacia* L. spp. and *Olea* L. spp.	Abu Taha, Sale-Rsheida, Ajloun, Wadi Sair	Lebanon, Syria, Jordan, Palestinian Territories	Al-Atawneh *et al.* (2007)
Wild wheats (*Triticum monococcum* L. subsp. *aegilopoides* (link) Thell., *T. urartu* Tumanian ex Gandilyan, *T. timopheevii* Zhuk.) Zhuk.)	Erebuni	Armenia	Avagyan (2008)
Wild beet (*Beta patula* Aiton)	Desertas Is.	Portugal	Pinheiro De Carvalho *et al.* (2011)
Allium schoenoprasum L., *Allium ursinum* L., *Asparagus officinalis* L. subsp. *prostrates* (Dumort.) Corbière, *Beta vulgaris* L. subsp. *maritima* (L.) Arcang., *Daucus carota* L. subsp. *gummifer* (Syme) Hook. F., *Raphanus raphanistrum L., Trifolium occidentale* D.E.Coombe. and *Trifolium repens* L.	Lizard Peninsula CWR Reserve	United Kingdom	Department for Environment Food and Rural Affairs (2011)
Wild barley and wheat (*Secale strictum* (C.Presl) C.Presl), celery *(Apium graveolens* L.), grass pea (*Lathyrus* L. spp.), etc.	Majella National Park	Italy	Martino, L., Cecco, V., Santo, M. and Manzi, A. 2019 (Pers. Comm.)

CWR	Protected Area	Country	References
Celery (*Apium graveolens* L. ssp. *graveolens*, *Helosciadium repens (Jacq.) W.D.J.Koch* and *H. inundatum W.D.J.Koch*)	Sülldorf, Saxony-Anhalt; Lake Hohennau, Brandenburg; Großer Schwerin, Mecklenburg-Pomerania; Nature Reserve Venne, North Rhine-Westphalia; Nature protection-area, Celle, Lower Saxon	Germany	Frese (2019)
Aegilops geniculate Roth, *Daucus carota* L., *Hypericum perforatum* L., *Lathyrus aphaca* L., *Linum bienne* Mill., *Lupinus angustifolius* L., *Lupinus hispanicus* Boiss. and Reut., *Ornithopus compressus* L., *Papaver rhoeas* L., *Trifolium angustifolium* L., *Trifolium campestre* Schreb., *Trifolium pratense* L., *Trifolium strictum* L., *Salvia verbenaca* L.,	*Sierra del Rincón* Biosphere Reserve	Spain	Molina, A., 2019 (Pers. Comm.) Community of Madrid 2019

3.2 Incorporation of genetic reserve management into protected areas plans

Genetic reserves should be established, when possible, in existing protected areas —since they are already associated to long-term conservation, the site management is relatively easy to amend and does not imply expenses of acquiring land—. The **management plan of the protected area should be adapted** accordingly to ensure active conservation of the CWR resource. In most cases, the adaptation will be simple:

- Identify the prioritized CWR that are present in the protected area.
- Indicate specific management interventions that the target CWR require.
- Incorporate their monitoring into the site monitoring systems.
- Link the *in situ* conserved CWR taxa to *ex situ* conservation and utilization.

Creating new PAs each time new conservation priorities are established would be prohibitively expensive and resource wasteful, especially if that process involves expropriating the land on which the reserve was to be established. Therefore, where possible, GRs should be established in existing PAs and their management should be incorporated into the overall conservation management programme of the site. This is preferable because:

a) these sites already have an associated long-term conservation ethos and are less prone to hasty management changes associated with private land or roadside where conservation value and sustainability is not normally a consideration.

b) it is relatively easy to amend the existing site management to facilitate genetic conservation of wild plant species.

c) it means that creating novel conservation sites can be avoided so circumventing the possibly prohibitive cost of acquiring previously non-conservation managed land (Maxted *et al.*, 2008b).

This in part assumes that each PA has a management plan that exists, is periodically updated, and is implemented, which is certainly in line with best conservation practice but not always the case.

The establishment of the GR does mean that in the existing PA the management plan of the PA should be adapted accordingly to ensure active conservation of the CWR resource. To achieve this, it is necessary to persuade the authorities governing the PA that the target taxon is worthy of conservation. In several European countries, PA management plans must be legally approved and published before being implemented. The incorporation of a GR in a PA may have substantial implications that require amendments and/or renewal of existing management plans that subsequently have to be legally approved. However, genetic diversity conservation may not need to be carried out across the entire PA, and effective management linked to the GRs could be targeted in selected zone(s). In any case, depending on the precise location of the GR, the establishment of the GR may affect: a) the zoning of the PA or zoning plans; b) sectorial plans (i.e. visitor management); c) conservation plans of specific emblematic species; d) site management plans (i.e., of a specific visitor attraction).

In practice the amendment of the PA management plans is usually modest, simply stating that CWR are present in the PA and their conservation is considered a priority, what CWR taxa are present, the specific management interventions they require, incorporating their monitoring into the site monitoring systems, and the procedure to link the conserved CWR taxa to *ex situ* utilization. The additional management interventions are likely to be minimal, given the site was initially selected because it hosted vibrant CWR population so the current management must be suitable. However, if genomic analysis of within PA CWR population variation and comparison with external existing *in situ* conserved CWR populations is envisaged, then the resource requirement will be increased. Although routine genomic analysis is not required, use of demographic data as a proxy for genetic diversity is adequate in the short term, with periodic genomic analysis being repeated once every 20-25 years for annual taxa. PAs are normally revised periodically but if this is done irregularly then the establishment of the GR could be added as an additional annex to the management plan and incorporated fully next time the whole document is revised (Maxted *et al.*, 2020).

Existing PAs are likely to have been established initially to conserve a rare or threatened taxon (commonly a megafauna) or habitat not the CWR populations, therefore, there is the possibility that the management interventions required to maintain the rare or threatened taxon or priority habitat may be in conflict with the requirement to maintain the CWR populations. Again, such management conflict seems unlikely given the PA was selected because it already hosted vibrant CWR populations and a priori conflict was not noted. But if, when establishing the GR, potential conflict became apparent, then possibly some form of compromise could instigate, such as applying diverse management regimes in different sectors of the PA (Maxted *et al.*, 2020). Taking into account that in many countries protected areas may fall partially or entirely in private land, any management for the implementation of a genetic reserve should also be discussed with the landowners and appropriate measures conducted accordingly.

3.3 Management team

The responsibility of managing the genetic reserve will depend on the human resources availability of the protected area:

- When the existing capacity of the protected area management staff is sufficient, **the protected area** should designate a **person responsible for the management of the genetic reserve** within existing staff and to ensure appropriate CWR conservation training and resources.
- When protected areas do not have their own staff, **a participatory model of governance with one leading body** should be established, comprised by all the authorities, stakeholders, governmental offices and organizations involved.

Considering that the optimal and cost-effective approach is to integrate the management of GRs and PAs, the first-choice solution is to check whether existing capacity of PA management staff is sufficient to undertake the measures indicated in GR management plans. In the PAs with well-established organizational structure and sufficiently resourced with appropriately trained staffed, including botanists though no prior knowledge of CWR is necessary, such integration would be the easiest. In such cases it might be enough to designate a person responsible for the GR within existing staff and to ensure appropriate CWR conservation training and resources (additional budget or equipment) are available, although these are not foreseen to be extensive.

The situation would be different in PAs without their own staff and administration. The management responsibilities are often shared by local and regional nature conservation authorities together with local stakeholders, self-governmental offices and organizations. In such cases a participatory model of governance with one leading body seems to be the best solution. Such a structure could be built on the basis of local partnerships, in the line with the following examples: Yorkshire Peat Partnership[18], Lancashire Peat Partnership[19] and Cumbria Local Nature Partnership[20]. Realistically, it would be preferable if one person from the management team was given responsibility for overseeing the genetic reserve management and the kind of skills most beneficial to them would be:

- CWR and conservation of plant genetic resources
- plant ecology and conservation
- vegetation dynamics

[18] https://www.yppartnership.org.uk

[19] https://www.forestofbowland.com/Lancashire-Peat-Partnership

[20] https://www.cumbriawildlifetrust.org.uk/about/what-we-do/groups-and-partnerships

- animal ecology (with important impact on CWR populations, pollinators and seed dispersers)
- habitat management (e.g. farming, forestry, hydrology)
- local spatial (GIS) planning and management
- project administration and fundraising
- communication, dissemination and public participation
- regional and local nature conservation planning
- good contact to regulating and administrative levels of conservation, environment and agriculture

It is also highly recommended for local managing bodies to strengthen regional and international cooperation by developing thematic networks focused on CWR or even particular groups of CWR (cereal, legumes, vegetables, fruit trees, etc.) aiming at sharing experience on conservation measures and improve the flow of data on distribution, diversity and threats to CWR species. A good example of such an approach is the Wild Celery Network in Germany[21].

3.4 Budget and economic considerations

Protected area managers may have difficulties in using general management funds to cope with direct costs associated to conservation of CWR. Some of the operating costs of the genetic reserve may be assumed by the **dedication of staff and volunteers** already working for the protected area without additional costs. Additionally, **direct funding may be obtained from independent sources** related to plant genetic resources conservation or stewardship schemes for priority target species. In any case, the protected area manager may be forced to make some decisions about competing proposals for different conservation actions involving CWR genetic reserve operation or not. In those cases, **the cost and the conservation benefit** of all possible conservation actions should be assessed to choose the **most effective option**.

PAs operate with an annual budget to cover such costs as staff for monitoring, any equipment, etc., that is provided by the administration to attain the goals specified in the PA management plan. In some countries the budget is not devolved to individual PA but stay centrally as an amount nominally available to meet individual PA expenditure, even including staffing with a pool of staff working across multiple PA sites. As CWR *in situ* conservation has thus far rarely been enacted, PA managers may have difficulties in using general management funds to cope with direct costs associated to the implementation and operation of the CWR in an individual GR. These difficulties may be averted in two different ways:

a) Some of the operating costs of a CWR GR may not involve monetary resources. For instance, the need to periodically demographic monitoring and surveying of the target CWR populations may be assumed by partial dedication of wildlife rangers or citizen scientists that are already contracted by the PA and conduct similar activities with other threatened emblematic plant or animal species that occur in the PA.

[21] https://netzwerk-wildsellerie.julius-kuehn.de/index.php?menuid=48

b) Direct monetary costs needed to operate the GRs may be obtained through other resources, independent from the general budget provided by the public administration. Resources may be obtained from the public administration (but from the department in charge of PGRFA conservation in the Ministry of Agriculture), or from other local, national or international sources associated to rural development or PGRFA conservation, public or private calls to fund specific conservation projects, NGO mediated projects, etc.

In any case, it is highly likely that the PA manager will be forced to make some decisions about competing proposals for different conservation actions involving CWR GR operation or not, or between alternative solutions for a particular GR management goal. For instance, in many situations, more than one conservation action will have the potential to give a positive conservation outcome (such as an increase in population size, or reduction in extinction risk). In such cases, it is necessary to compare both the cost and the conservation benefit of all possible conservation actions and the most effective option chosen (Figure 13).

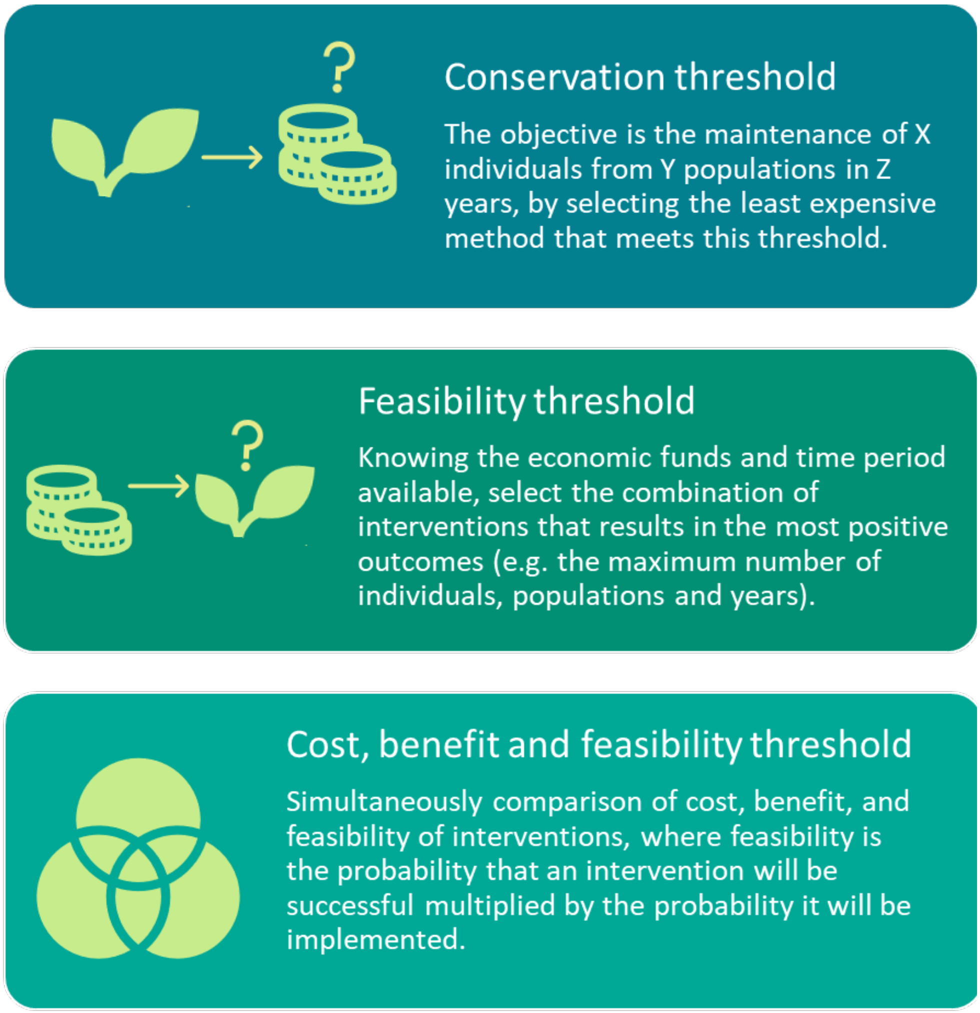


Figure 13. Different situations and methods that can be found when managing the funds for the conservation action. Adapted from (Carwardine *et al.*, 2012).

A simple approach is to first set the conservation threshold (e.g., the maintenance of *X* individuals from *Y* populations in *Z* years) and select the least expensive method that meets this threshold. Another simple approach is to set a feasibility threshold (e.g., there are *X* euros to spend in *Y* years), so select the combination of interventions that cost less than this amount and results in the most positive outcome (e.g., the largest individual populations and absolute number of populations, increase in the size of the most important population, where such assessment is possible). More sophisticated methods simultaneously consider the cost, the benefit and the feasibility of the action, where feasibility is the probability that the action will be successful multiplied by the probability that the interventions will be taken up (Carwardine *et al.*, 2012). It is important to consider uncertainties both in the cost of each conservation interventions, and in the conservation benefit that is anticipated.

3.5 Search for synergies for an effective use of resources

The integration of CWR conservation with protected area management significantly reduces the costs of genetic reserve operation. Some specific costs of GR on the research and planning level than cannot be assumed by existing resources can be obtained from **other available resources** (protected areas management plans and documentation, information on Natura 2000 and EMERALD sites, national biodiversity mapping and monitoring schemes, Important Plant Areas documentation, etc.). In any case, the management needs of the genetic reserve will largely be concordant with **standard habitat conservation and restoration measures that are already undertaken** in the protected area.

The overall approach – to integrate CWR conservation with PAs management is a good way to minimize the costs of GR operation. However, there are specific costs that cannot be covered easily from existing resources. They refer mainly to specific consultancy needed to establish and create GR plans, including knowledge about ecological requirements of target CWR species, their distribution within the PA, demographic monitoring, or the genetic structure of the CWR populations. On the research and planning level different resources are available, that may be used as a background in the first stage of planning, such as:

- PAs management plans and documentation
- information on Natura 2000 and EMERALD sites
- national biodiversity mapping schemes
- national biodiversity monitoring schemes
- Important Plant Areas documentation
- forest management plans
- nature conservation projects (such as: LIFE Programme, Interreg)
- research projects (e.g. EC Life projects)
- local spatial planning plans
- citizen science biodiversity projects
- agri-environmental schemes documentation

On the other hand, as stressed above, PAs selected to contain GR will have been selected because of their healthy CWR population, so will largely be concordant with standard habitat conservation and restoration measures that are already undertaken in the PA – e.g., extensive late mowing, removal of shrub, removal of invasive species, extensive grazing by appropriate grazers, water retention, sustainable agricultural and forest management.

3.6 Potential conflicts with other biological components and human interests

Different conservation target species may have distinct conservation needs and, in some cases, the optimal measures for one may have adverse for another. CWR populations occurring in open habitats may become threatened by competition from plant species that dominate after successional changes in the management regime or migrating birds that arrive when CWR are seeding. Therefore, one of the most important tasks in the planning process is to **understand and prioritise the conservation interventions** or mosaic of different conservation interventions across the protected area. Conservation management is often a compromise between the desirable and the expedient.

One of the main ecological processes observed in PAs in Europe is that without extensive management regimes there is inevitable decline in the quality of open habitats. These pre-climax habitats are generally grasslands and pastures connected that require grazing and mowing interventions to stop succession to the final climax vegetation. When these activities are abandoned, ecological succession takes place and the open habitats disappear becoming encroached with shrubs and trees. In most cases CWR populations occurring in open habitats and may become threatened by competition from more competitive plant species that dominate after successional changes in the management regime (Jarvis *et al.*, 2015). This is a common situation in PAs with the strictest conservation regime, such as national parks and nature reserves. Therefore, in PAs management plans, active conservation measures are often included to maintain plant diversity of pre-climax non-forest ecosystems. The details of these management interventions include the intensity of grazing, ways of scrub removal or mowing (e.g., height), seasonality of actions, periodicity, etc., can vary depending on the different potential conservation targets (plant or animal species). Different conservation target species may have distinct conservation needs and, in some cases, the optimal measures for one may have adverse for another. Therefore, one of the most important tasks in the planning process is to understand and prioritise the conservation interventions or mosaic of different conservation interventions across the PA (Hurford, 2006). This may inevitably lead to situations where CWR populations may be subjected to interventions suitable for a more emblematic and threatened species – conservation management is often a compromise between the desirable and the expedient (Maxted *et al.*, 2020).

4 CWR management outside protected areas

Mroz, W., Álvarez-Muñiz, C., Iriondo, J.M., Alves, J., Bönisch, M., Dudley, N., Hosking, J.B., Ralli, P., Rasmussen, M., Weibull, J. , Maxted, N.

Historically PAs were often designated to conserve charismatic mega-fauna or aesthetically pleasing habitats, or even simply because the area had limited exploitation value; therefore, and perhaps surprisingly, there is not always a match between PAs and high intrinsic levels of biodiversity (Maxted *et al.*, 2020). In general, areas with high levels of biodiversity are also areas suitable for agro-silvicultural or some other form of commercial exploitation. In such high biodiversity locations where PA designation is competing with agro-silvicultural utilisation the designation of PA is less common than in less biodiverse rich sites given protection; also, high biodiversity rich sites when designated tend be smaller for the same reason. This combined with the fact that many CWR are often found growing in anthropogenic, disturbed habitats (Jain, 1975; Jarvis *et al.*, 2015) means that CWR hotspots do not always project perfectly onto existing PA networks, therefore, *in situ* CWR sites may need to be established outside of existing PA networks (see for example Magos Brehm *et al.*, in prep.).

The requirement for extra-PA site based *in situ* conservation for CWR taxa was first highlighted by Al-Atawneh *et al.* (2007), when trying to implement area-based conservation in West Asia and found that many intensively cultivated areas contain significant CWR diversity at their margins in field edges, habitat patches or roadsides and not within existing PAs (Al-Atawneh *et al.*, 2007). Extra-PA *in situ* conservation sites were established in the Beqaa Valley in Lebanon and around Hebron area of Palestine on roadsides around the edges of industrially cultivated cereal cropping, there are globally significant populations of rare CWR found along the roadside, and in Jabal Al-Druze in Syria where very rare wheat, barley, lentil, pea and bean CWR are common in modern apple orchards. In fact, Al-Atawneh *et al.* (2007) noted that in Palestine, *Pyrus syriaca* Boiss. is only found as scattered trees and never as continuous populations, and so is primarily conserved outside of the existing protected area network.

Maxted *et al.*, (2008a) attempted to review extra-PA *in situ* conservation site management but were unable to locate many examples, exception for local management agreements made between conservationists and local landowners over micro-reserves site management in the Valencia region of Spain (see Laguna, 1999; Serra *et al.*, 2004). Maxted *et al.* (2008a) concluded, as with the establishment of genetic reserves within existing PAs, extra-PA *in situ* conservation sites CWR conservation would only be likely to be established where there were healthy existing CWR populations. Therefore, the key to management would be to maintaining the existing site management, making no substantial or sudden site management changes that might negative impact the CWR populations, as Laguna had already shown with local management agreements with local landowners in the Valencia region. In recent years, several governments have responded by providing incentives or even financial subsidies to maintain such systems, at least partially to secure continued cultivation and through cultivation to maintain the wild and CWR species that thrive in such anthropogenic habitats. Recently, for example the new England Agriculture Act (2020) explicitly call on the government to “The Secretary of State may give financial assistance for or in connection with any one or more of the following purposes— … i) conserving plants grown or used in carrying on an agricultural, horticultural or forestry activity, their wild relatives or genetic resources relating to any such plant”, and similar wording is believed to be being incorporating in the new EU Common Agriculture Policy. The provision of government incentives is linked to some form of guarantee from the landowner to ensure that wild and CWR species thrive, so again a management agreement including a conservation prescription is required.

It can be argued that the provision of long-term grants to landowners is unlikely to be a practical option in many developing countries where CWR diversity is largely located but where resources are more limited (Maxted *et al.*, 2008a). However, Wainwright *et al.* (2019) investigated payments for agrobiodiversity conservation services in Zambia, where landowners would be subsidised to manage CWR populations in and around their crops. Thirty CWR were identified and in 26 communities and competitive tender bid offers were used to determine the on-farm cost of conserving CWR, specifically in field margins/borders. The conservation costs ranging from US$ 23 to 91 per ha per year in regions of high CWR presence. The study concluded that competitive tendering, coupled with CWR data can be used to improve the efficiency of extra-PA *in situ* CWR conservation.

A broad definition of extra-PA *in situ* conservation is discussed by Maxted *et al.* (2016) and more explicitly formulated by Maxted *et al.* (2020): "the location, management and monitoring of genetic diversity of natural wild populations in informal *in situ* conservation sites". However, outside of the specifically CWR context, IUCN-WCPA Task Force on OECMs (2019) also point out that Aichi Biodiversity Target 11 calls for increased area-based conservation action composed of "systems of protected areas" and "other effective area-based conservation measures (OECMs)". This effectively recognises the *status quo*, that "some areas outside the recognised protected area networks also result in the effective *in situ* conservation of biodiversity". These are (mainly) places that provide effective conservation by accident because of other management objectives ("ancillary conservation") or as a secondary objective. As such a location is primarily managed as an orchard, roadside or cropped field margin but coincidentally provides a suitable habitat for the CWR or other wild plant species, which thrives providing the primary management does not change. Changing management may or may not threaten the secondary target taxa, but the likelihood is that the impact of any change and its impact on the target CWR or other wild species would not be recognized as these populations are not being actively monitored. Therefore, to ensure long-term conservation the best outcome would be to retain the original management that is known to benefit the secondary target populations. Furthermore, conservation agreements would need to be established between the conservation agency and the landowner.

IUCN-WCPA Task Force on OECMs (2019) refers to OECMs as mainly places that provide effective conservation by accident, as a result of other management objectives ("ancillary conservation") or as a secondary objective. IUCN-WCPA Task Force on OECMs (2019) provide guidance on the definition and characteristics of OECMs including (a) the fact that area is not part of an existing PA, (b) the area is governed and managed, (c) the areas is capable of providing positive *in situ* conservation outcomes, and (d) the area is part of a 'healthy' functioning ecosystem. Based on these criteria, IUCN-WCPA Task Force on OECMs (2019) provide a screening tool that identifies if a site can be regarded as an OECM and how conservation from OECM might be monitored and reported; it also includes a list of area types that are unlikely to meet the criteria and specifically states "*Small, semi-natural areas within an intensively-managed landscape with limited biodiversity conservation value, such as municipal parks, formal/domestic gardens, arboreta, field margins, roadside verges, hedgerows, narrow shoreline or watercourse setbacks, firebreaks, recreational beaches, marinas and golf courses*". Unfortunately, these are exactly the kind of sites favoured by many CWR taxa, which means practically although there are close similarities between extra-PA *in situ* conservation sites and OECMs, they are not identical. OECMs are more tightly defined and extra-PA *in situ* conservation site definition is deliberately kept flexible and informal to allow broader application but sharing the goal of long-term active *in situ* conservation working closely with local communities. Some governments are starting to question the economic value of formal PA-based conservation and therefore it seems likely that application of extra-PA *in situ* conservation and OECMs is likely to grow; potentially both could be important tools for CWR conservation.

Sites outside PAs that aim at conserving CWR diversity *in situ* can be located using the same ecogeographic and gap analyses methods used for PAs, where CWR hotspots co-exist with existing land management regimes that are amenable for long-term target CWR maintenance. Such sites are often associated with weedy roadsides, field margins, orchards and even fields managed using traditional agro-silvicultural practices (Jarvis *et al.*, 2015). It is necessary to reach agreement with the landowner / manager to retain existing management practices that have led to the selection of the land so to retain the target taxon population diversity (Maxted *et al.*, 2008a). In these sites the conservationist would rarely directly manage the site, but may influence site management providing incentives to sustain current site management and therefore the CWR populations. Periodic monitoring would be required to ensure genetic diversity maintenance and avoid the loss of target populations. It should also be recognized that in several cases the landowner / manager partners in the conservation agreement may not be environmental and agricultural stakeholders, but stakeholders from the culture/museum sector. The approach in these cases may change, putting more emphasis of communication the history of the CWR species and the rationale behind conservation, to gain interest for and ownership to development of conservation.

4.1 Habitats and land cover units amenable for extra-PA in situ conservation

The **diversity of different habitat types and land cover classes that might be populated by CWR is relatively high**. However, many CWR are associated with marginal and transitional patches of habitats scattered in agricultural landscape, particularly in margins between arable or urbanized lands.

The diversity of different habitat types (identified using the EUNIS or Natura 2000 classification) and land cover classes (identified using the Corine Land Cover classification) that might be populated by CWR is relatively high (see Table 9 and Table 10). Corine land cover (CLC) classes associated to habitats important for CWR diversity are often located outside existing PAs (Table 9). This is because the occurrence of many CWR can be associated to marginal and transitional patches of habitats scattered in agricultural landscape, particularly in margins between arable or urbanized lands (Jarvis *et al.*, 2015). Such plant communities have unclear syn-taxonomic position and therefore are often overlooked in habitat mapping surveys. Nevertheless, they can be one of the most important areas of biodiversity outside PAs, including, but not limited to, CWR species, as they are also particularly important for bird, bat and insect conservation.

Table 9. Corine land cover (CLC) classes[22] associated to habitats important for CWR diversity outside protected areas.

CLC code	CLC class label	Examples of CWR species
122	Road and rail networks and associated land	*Daucus carota, Lupinus angustifolius, Avena sterilis, Cichorium intybus, Brassica nigra, Vicia* spp., *Medicago* spp.
141	Green urban areas	*Trifolium* spp., *Medicago* spp.
211	Non-irrigated arable land	*Avena sterilis, Lolium rigidum*
222	Fruit trees and berry plantations	*Allium roseum, Hordeum murinum, Medicago* spp., *Poa annua, Rubus* spp.
231	Pastures	*Aegilops neglecta, Bromus* spp., *Cynodon dactylon, Dactylis glomerata, Festuca* spp., *Lolium perenne, Medicago spp., Poa pratensis, Trifolium* spp., *Vicia* spp.
242	Complex cultivation patterns	*Daucus carota, Lupinus angustifolius, Avena sterilis, Cichorium intybus, Brassica nigra, Vicia* spp., *Medicago* spp.
243	Land principally occupied by agriculture, with significant areas of natural vegetation	*Daucus carota, Lupinus angustifolius, Avena sterilis, Cichorium intybus, Brassica nigra, Vicia* spp., *Medicago* spp.
244	Agro-forestry areas	*Medicago* spp., *Pistacia terebinthus, Trifolium* spp.
311	Broad-leaved forest	*Corylus avellana, Fragaria* spp., *Prunus* spp., *Rubus* spp., Vaccinium spp.
312	Coniferous forest	*Fragaria vesca, Rubus saxatilis*
313	Mixed forest	*Corylus avellana, Prunus padus, Vitis sylvestris*
321	Natural grasslands	*Agrostis spp., Allium spp., Astragalus spp., Bromus* spp., *Festuca* spp., *Medicago* spp., *Trifolium* spp.
322	Moors and heathland	*Hordeum maritimum, Trifolium michelianum, Vaccinium* spp.
323	Sclerophyllous vegetation	*Olea europaea, Pistacia lentiscus*
324	Transitional woodland-shrub	*Pistacia lentiscus, P. terebinthus*
411	Inland marshes	*Cynodon dactylon, Hordeum maritimum*
412	Peat bogs	*Vaccinium vitis-idaea, Vaccinium myrtillus*
421	Salt marshes	*Beta vulgaris* subsp. *maritima, Limonium* spp.

[22] https://land.copernicus.eu/pan-european/corine-land-cover

Table 10. Examples of natural habitat types listed in Habitats Directive Annex 1 which host important populations of CWR outside of protected areas.

Notation	Label	Examples of CWR species
1330	Atlantic salt meadows (*Glauco-Puccinellietalia maritimae*)	*Agrostis stolonifera, Beta vulgaris* subsp. *maririma, Festuca rubra*
1410	Mediterranean salt meadows (*Juncetalia maritimi*)	*Hordeum bulbosum, H. maritimum, Trifolium michelianum*
2330	Inland dunes with open *Corynephorus* and *Agrostis* grasslands	*Agrostis capillaris, A. gigantea, A. stolonifera*
2340	Pannonic inland dunes	*Cynodon dactylon*
3220	Alpine rivers and the herbaceous vegetation along their banks	*Agrostis gigantea*
5130	*Juniperus communis* formations on heaths or calcareous grasslands	*Prunus spinosa*
6120	Xeric sand calcareous grasslands	*Allium schoenoprasum, Astragalus arenarius*
6210	Semi-natural dry grasslands and scrubland facies on calcareous substrates (*Festuco-Brometalia*) (important orchid sites)	*Medicago falcata*
6230	Species-rich *Nardus* grasslands, on siliceous substrates in mountain areas (and submountain areas in Continental Europe)	*Festuca ovina*
62C0	Ponto-Sarmatic steppes	*Agropyron cristatum, Elytrigia intermedia*
6410	Molinia meadows on calcareous, peaty or clayey-silt-laden soils (*Molinion caeruleae*)	*Lotus pedunculatus*
6440	Alluvial meadows of river valleys of the *Cnidion dubii*	*Allium tuberosum*
6510	Lowland hay meadows (*Alopecurus pratensis, Sanguisorba officinalis*)	*Alopecurus pratensis, Arrhenatherum elatius, Daucus carota, Linum bienne, Trisetum flavescens*
6520	Mountain hay meadows	*Trisetum flavescens*

4.2 Land stewardship and other agreements with public and private landowners

A **custody agreement** is a voluntary mechanism —formally written and legally binding— between a landowner or manager and custodian to agree on how to conserve and manage a site.

CWR management on public and private land may take place in the form of land stewardship. Land stewardship is a set of strategies and tools that aim at involving owners and land users in conservation and makes good use of natural, cultural and landscape resources. Agreements and mechanisms for ongoing collaboration between owners, custodians and other public and private actors are therefore made (Basora Rock and Sabaté I Rotés, 2006) and an example of such an agreement used for wild celery genetic reserves in Germany is available on the website of the wild celery network[23] (Basora Rock and Sabaté I Rotés, 2006).

A custody agreement is a voluntary or more formal mechanism between a landowner or manager and custodian to agree on how to conserve and manage a site. The agreement should not just be verbal but formally written and legally binding (Basora Rock and Sabaté I Rotés, 2006). Custodians are public or private non-profit organizations or individuals actively involved in conservation. In the case of *in situ* CWR conservation, the custodians may be technical staff of the public administration that operate at the local level, such as forest or wildlife rangers or a conservation organization (Box 7). In cases where the owner is very actively involved with the management of the land, such as with farmers, the management can directly be performed by the owner / farmer. Involvement of private landowners in conservation activities and development of land stewardships is also supported by international initiatives such as the International Land Conservation Network[24] and the Eurosite–European Land Conservation Network Box 8[25].

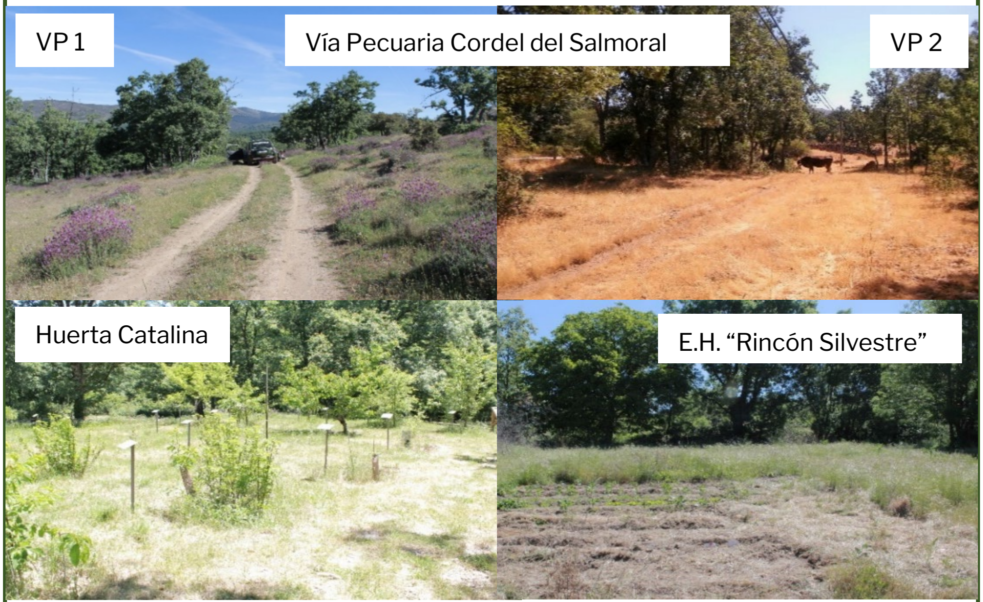
[23] https://netzwerk-wildsellerie.julius-kuehn.de/index.php?menuid=28

[24] www.landconservationnetwork.org

[25] www.eurosite.org, www.elcn.eu

Box 7. Public and private land stewardships for CWR *in situ* conservation in the Biosphere Reserve of Sierra del Rincón.

In 2019, the Biosphere Reserve of Sierra del Rincón (http://www.sierradelrincon.org/) promoted the establishment of three GRs for the *in situ* conservation of CWR through a collaboration agreement with the Rey Juan Carlos University (URJC) and the Technical University of Madrid (UPM) and with funding from the Autonomous Community of Madrid. The analysis of the botanical inventory of the Biosphere Reserve and field prospection provided the basis for the selection of the three sites. The first one is located in private land at the "Rincón Silvestre Herbal School" (https://rinconsilvestre.net/), where the owner grows medicinal herbs and also maintains part of the property untouched with natural vegetation. The second one, "Huerta Catalina", is also found in a private property but managed by Biosphere Reserve of Sierra del Rincón, where they grow traditional fruit varieties. Finally, the third GR, "Vía Pecuaria Cordel del Salmoral" is located on public land, a traditional livestock trail that is managed by the Autonomous Community of Madrid. As a whole, the three GRs contain populations of 30 CWR species. The first two GRs hold a verbal custody agreement that allows wildlife rangers and university researchers to monitor and manage the populations, whereas in the third one there is a written consent.



Photographs by A. Molina (2019).

Box 8. Eurosite

Eurosite (eurosite.org) is a network of natural site managers bringing together non-governmental as well as governmental organisations, and individuals committed to a common vision of a Europe where nature is cared for, protected, restored and valued by all. It provides practitioners with opportunities to network and exchange experience on practical nature management. One of the main aims of the network is to initialize and support local cooperation by facilitating twinning agreements between local partners and involvement of land stewardships in nature conservation. Eurosite is coordinating several working groups focused on economics and ecosystem services, wetlands and climate change, management planning and peatland restoration and management. One of the useful, open tools available online on Eurosite website is the Management Toolkit (mpg.eurosite.org). This online portal provides support for individuals and organisations involved in managing PAs. It offers solutions to issues that impact the protection and management of PAs by providing links to additional information and to examples of best practice. Eurosite collaborates closely with the European Land Conservation Network (http://www.elcn.eu) and, in the near future, these two Pan-European networks will be fully integrated to strengthen their common efforts to support landowners and site managers in site management.

4.3 CWR management on private land/farmers

Active *in situ* conservation of CWR populations can take place on private land located outside of PAs. Two factors to consider are **community support and incentives**. Local community support is required for the CWR conservation to be successful in the development and implementation of GR. In the context of the common agricultural policy (CAP) in the European Union or national legislation in non-EU countries, some incentive actions that are currently being put into practice could be used to promote *in situ* CWR conservation in farmlands.

Active *in situ* conservation of CWR populations can take place on private land located outside of PAs as long as the custodians and owners collaborate together and are conscious of the relevance of this action and strongly supportive. In many cases, the property will be farmland and home gardens owned by farmers. Low-input, traditional farming, organic farming, farmers in marginal agro-environments or open-air museums, properties owned and managed by the church, and properties of certain historic significance, e.g., manors and castle sites, are normally the production systems that are most suitable to implement CWR conservation. Alternatively, the property may be used for hunting or military purposes, so the site may not be subject to any other type of exploitation at all, which facilitates the thriving of natural plant populations.

Two factors to consider when establishing extra *in situ* CWR conservation sites on private land are community support and incentives. Local community support is required for the CWR conservation to be successful. To help ensure the support of local communities they should be involved in the development and implementation of specific CWR action plans whenever possible (Maxted *et al.*, 2020). If provision of government incentives is used, it should be linked to some form of guarantee from the landowner to ensure that the CWR plant diversity thrives. The custody agreement should then include a conservation prescription to ensure that CWR are appropriately managed and that the local community's role in conserving a CWR is recognized (see introductory section above and the local agreements reached as a result of community bids to conserve CWR taxa).

Further, personal experience of explaining the value of CWR to individual farmers in the UK has resulted in immediate offers of support for active CWR conservation on their land, because they appreciate the direct link between CWR diversity conservation and the future of global agriculture in the face of climate change (Maxted pers. comm.).

In the context of the common agricultural policy (CAP) in Europe, there are some incentive actions that are currently being put into practice that could be used to promote extra *in situ* CWR conservation in farmlands. Agri-environment measures[26] are a key element for the integration of future environmental concerns into the CAP, though the precise details have yet to be agreed. They are likely to include farm designed to encourage farmers to protect and enhance the environment on their farmland by paying them for the provision of environmental services. Farmers commit themselves, for a minimum period of five years, to adopt environmentally friendly farming techniques that go beyond legal obligations. In return, farmers receive payments that provide compensation for additional costs and income foregone resulting from applying those environmentally friendly farming practices in line with the stipulations of agri-environment contracts. Agri-environment payments encourage farmers to adopt agricultural activities or levels of production intensity that deliver positive environmental outcomes, while not being necessarily the first choice from the point of view of profitability. Examples of commitments covered by national/regional agri-environmental schemes are shown in Figure 14. At present CWR conservation is not specifically supported using these schemes, but lobbying is underway to ensure the revised CAP stewardship schemes does actively support farmers / land managers for sustaining CWR populations on their land (Maxted pers. comm.).

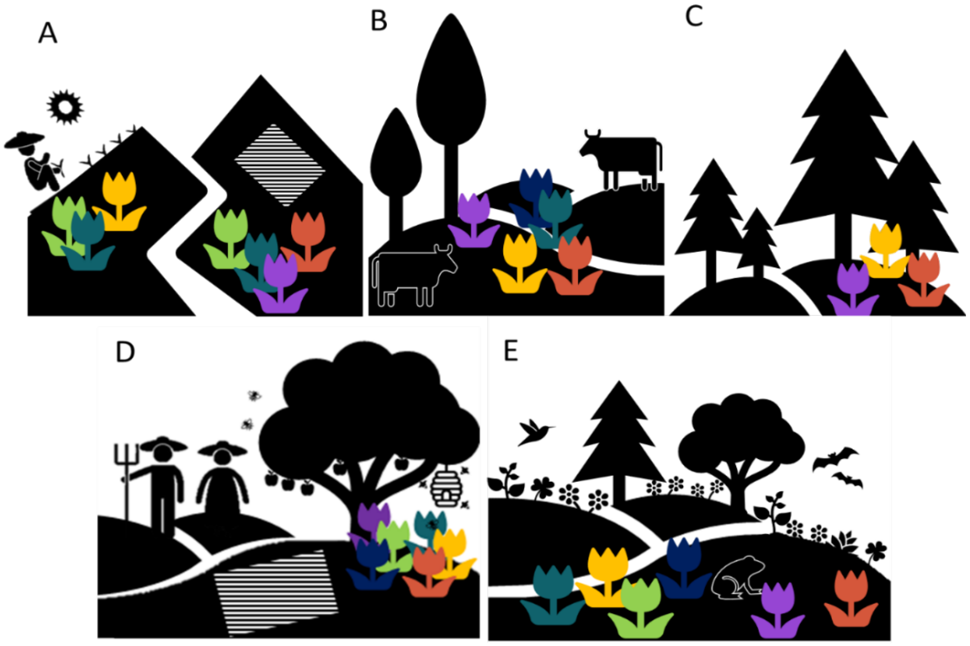


Figure 14. Examples of agri-environmental schemes in private land. A) environmentally favourable extensification of farming, B) management of low-intensity pasture systems, C) preservation of landscape and historical features such as hedgerows, ditches and woods, D) integrated farm management and organic

[26]https://ec.europa.eu/info/food-farming-fisheries/sustainability/environmental-sustainability/cap-and-environment_en

agriculture, E) conservation of high-value habitats and their associated biodiversity specifically including CWR populations.

Agri-environment measures may be designed at the national, regional, or local levels so that they can be adapted to particular farming systems and specific environmental conditions. This makes agri-environment a targeted tool for achieving environmental goals. Agri-environment measures are co-financed by EU countries. Since 1992, the application of agri-environment programmes has been compulsory for EU countries in the framework of their rural development programmes, whereas they remain optional for farmers. Through rural development programmes, EU expenditure on agri-environment measures is expected to total 25 billion EURO over the course of the 2014-2020 period. As already mentioned above similar initiatives are underway outside the EU, such for example, Environmental Land Management Scheme (ELMS) in England "public money is being used for public goods" by UK DEFRA.

A point that should also be stressed is the practicalities of working with farmer, landowners or the general public is that they should not scared off from collaboration by excessive bureaucracy. Farmer and other landowners may have the positives of incentives, even payments for prescribed environmental land management, but even they are more likely to become involved if the administration is simple and employs low-cost administrative tools to carry out such collaboration on long term. Minor private entities, small farms, private museums, etc. do either not have or have little interest in acquiring the administrative capacity to carry out annual reporting, applications for annual funding, etc, which an overly bureaucratic public conservation system may require. Therefore, some kind of simple system, preferably automatic, if possible, and definitely involving low time consumption, must be developed.

4.4 Management team

It is highly recommended to consider a **general system approach to management of CWR outside PAs that operates at a larger scale** (e.g., county, province or regional level). The general competencies of team members could be enriched with experts in land stewardships, collective payments, agri-environmental schemes and more generally in citizen stakeholder involvement and civil society participation.

Organization of complementary CWR conservation and creation of extra-PA *in situ* conservation is quite a challenge. There are no existing management structures, the understanding of conservation aims among landowners may be relatively low, and available financial support is currently scattered in different funds that are scarcely available for individual landowners. Additionally, single CWR populations may be smaller than those within PAs due to habitat fragmentation. Therefore, it is highly recommended to consider a general system approach to management of CWR outside PAs that operates at a larger scale (e.g., county, province or regional level). The general competencies of team members are the same as in the case of PAs but, in this case, the team could be enriched with experts in land stewardships, collective payments, agri-environmental schemes and more generally in stakeholder involvement and citizen participation (Box 9).

Box 9. A citizen science initiative to identify population occurrences of crop wild relatives.

Biosphere reserves are UNESCO recognized sites for understanding and managing changes and interactions between social and ecological systems, including conflict prevention and management of biodiversity. They are composed of a) core areas, comprising a strictly protected zone that contributes to the conservation of landscapes, ecosystems, species and genetic variation, b) buffer zones, which surround the core area, and are used for activities compatible with sound ecological practices, and c) transition areas where communities foster socio-culturally and ecologically sustainable economic and human activities. The Biosphere Reserve of Sierra del Rincón, located 90 km north of Madrid, in collaboration with two Universities of Madrid, launched in 2019 a citizen science initiative using the iNaturalist platform to engage citizens in the identification of natural populations of crop wild relatives occurring within its limits. The link to this project can be found at: https://www.inaturalist.org/projects/parientes-silvestres-de-los-cultivos-de-la-rb-sierra-del-rincon. Similar CWR awareness raising initiatives can easily be put forward by other stakeholders managing GRs, regardless of whether they are found inside or outside PAs.

Often CWR populations are selected for active conservation because they are healthy, threat free populations. Hence, in many cases, the only required management intervention is monitoring surveys to check population status and trends and react in case of land use change and/or any accidental abrupt environmental change (Maxted *et al.*, 2008a; 2020). In these cases, no other specific conservation measures are needed, and the management team can be reduced to a regional coordinator (or coordination body) and a monitoring team, possibly associated with a NGO, but if more extensive monitoring is required then a private company or public administration may need to undertake the task. Such a team should have a flexibility to create *ad hoc* working groups to respond to emerging local threats to CWR diversity (Figure 15). It is also especially important to include tasks focused on knowledge dissemination, networking between landowners, joint search of funding opportunities, sharing best management practices and regional CWR inventories. This management cooperation might be more effective when the created networks are devoted to conservation of particular groups of species, characterised with similar ecological and management requirements, as for example the Wild Celery Network in Germany[27]). Here a coordination unit researches celery species, collects and shares information and connects local stakeholders as a foundation for conservation. In particular, research on genetic diversity by the coordination unit can significantly complement and inform the conservation organizations undertaking by the field-based conservation team (Frese *et al.*, 2018; Herden *et al.*, 2020). Such an approach makes it much easier to develop a common management strategy, to share experiences between landowners and, last but not least, to secure appropriate funding. Additional useful information about various aspects of planning and management in nature conservation can be found in online Eurosite Management Toolkit[28].

[27] https://netzwerk-wildsellerie.julius-kuehn.de/

[28] mpg.eurosite.org

Figure 15. Management groups involved at the Genetic Reserve.

4.5 Budget and economic considerations

In most cases the **costs involved** will be related to carrying out periodic **monitoring** surveys, networking connected with CWR **knowledge sharing**, and actively **promoting genetic resource use**. It is important to keep financial flexibility to be able to react quickly to new threats and land use change. **Collective payments** may play a crucial role at extra-PA CWR conservation, such as collective approaches to agri-environmental schemes through community-based or conditional collective contracts.

The starting point is to ask the question whether the existing management regime is adequate for CWR conservation. If we observe a viable CWR population with no signs of decline, there is no need for more active conservation intervention of the target taxon populations or to undertake measures that further restrict existing land use. The only costs involved would be related to carrying out periodic monitoring surveys, networking connected with CWR knowledge sharing, and actively promoting genetic resource use from the conserved population. It might be also important to keep financial flexibility of networks or stewardships to be able to react quickly to new threats and land use change.

On the other hand, if it is proved that the existing management regime is not appropriate for the conservation of the CWR population, yet the population is still prioritised for active conservation, a population of a rare taxon or know to contain rare and threatened allelic variation, then more active conservation must be carried out. Semi-natural habitats, such as grassland and pastures, which often host CWR populations, cannot be maintained without extensive management, i.e., grazing or mowing (Maxted *et al.*, 2020). The abandonment of these traditional practices, which is often observed in the least accessible regions (e.g. distant mountain glades) or areas of de-population where the younger generation move away due to weak economic incentives, lack of jobs or a desire for less physical and more economically value work causes succession. There is an increase in scrub and tree undergrowth and dispersal of expansive species and a decrease in overall plant diversity. In this case, the conservation of CWR plants would be focused on the implementation of active conservation measures – removal of scrub and controlled grazing and mowing. Such practices in many cases can be subsidized within existing funds such as agri-environmental schemes of habitat restoration projects (e.g., within the LIFE programme or other EU funds). However, the existing level of payments may not be sufficient, especially in the case of remote locations and the need of manual intervention. In such cases, it is especially important to support landowners in the search of additional funds and preparation of targeted projects with better funding level, adjusted to local conditions. The farmer / landowner is recommended to seek assistance from local farmer or landowner associations, government extension agencies, regional authorities, or national parks and conservation agencies as to what support may be available to them to support CWR population maintenance.

Finally, in some regions we can still observe intensification of agricultural production or urbanization, neglecting the need of conservation of associated valuable habitats. Maintenance of CWR diversity is then dependent on coordinated advocacy at all levels – from local to international. Moreover, alternative development strategies should be sought and supported. In the case of agricultural production, these can be realized by general support to low-input, agro-ecological and organic farming approaches. The improvement of citizen awareness and watchdog activities can also be crucial in this process.

It should be also highlighted that it is difficult to justify the conservation of every hedgerow, road bank or small CWR population. In terms of genetic conservation, the goal is maximum conservation of genetic diversity found in the crop gene pool not the conservation of every CWR population. If a CWR taxon is already adequately conserved using both conservation strategies and a range of conservation techniques it can be argued, it would be wasteful of resources for more active conservation measures to be applied. However, it can be argued that for these common CWR taxa that are unthreatened and well conserved a landscape scale might be applied, which targets payments and benefits on the whole farm or groups of farms as an additional payment for best practices in maintenance of marginal habitats in general. Any kind of collective payments may play a crucial role to solve it, such as collective approaches to agri-environmental schemes. For this purpose there are two broad categories of contracts (Kuhfuss *et al.*, 2015):

a) Contracts signed with a group of farmers and involving a collective payment and the entire community acts as required to provide the public goods benefit, so called **community-based contracts**.

b) Individual contracts with a payment condition linked to the behaviour or environmental results of a pre-defined group, in the CWR context payment made for maintaining specific CWR taxa / populations in particular locations, so called **conditional collective contracts** where compliance is easily assessed and only evidence of compliance triggers payment.

4.6 Specific risks and problems

The **lack of CWR awareness**, the **gap of knowledge** of CWR population in extra-PAs, the **lack of cooperation** between landowners and stewardship schemes and the **limited experience in collective approaches** could turn into risks for the CWR conservation. Therefore, such sites are always going to be more vulnerable to miss-management and designating proportionally more sites per CWR would be prudent.

Most of the objectives and management practices in extra-PA *in situ* CWR conservation are the same as those found in PAs, although they will generally be more connected to biodiversity in agricultural and urban landscapes and importantly the landowner / local community have a much stronger voice in conservation implementation. As a result of this, the issues that deserve special attention are depicted in Figure 16.

Figure 16. Issues that deserve special attention.

5 In situ management to address climate change

Magos Brehm, J., Maxted, N., Iriondo, J.M., Álvarez-Muñiz, C., Hosking, J.B., Rasmussen, M.

Climate change has already observed negative impacts on natural systems, at scales from genes to populations, species, communities and ecosystems, and further change is predicted for the foreseeable future, causing considerable disturbance to regional and seasonal patterns of precipitation and increase of frequency and intensity of extreme climate events (IPPC, 2019). Studies have reported range shifts towards the poles or upwards in altitude with gradually earlier spring events, loss, expansion, relocation and fragmentation of habitats, disruption of biotic interactions, and changes in distribution, abundance, phenology and physiology of a wide range of species (e.g. Hughes, 2003; Parmesan and Yohe, 2003; Lenoir and Svenning, 2015). While acknowledging that CWR diversity is under threat from climate change (e.g. Aguirre-Gutiérrez *et al.*, 2017; Phillips *et al.*, 2017), CWR themselves also offer a critical means of mitigating the predicted impact of changes in climate on crops (Magos Brehm *et al.*, 2017).

Plant populations may be able to adapt to changing conditions either via: migration to favourable conditions (e.g. Schiffers *et al.*, 2013), short term responses to environmental changes based on their phenotypic plasticity (e.g. Franks *et al.*, 2013), and longer term adaptive evolutionary responses that may result in allelic and associated phenotypic changes (e.g. Savolainen *et al.*, 2013) (Figure 17). Those populations that are unable to respond to changes in climate are increasingly at risk of reduced fitness and of extinction (Aitken *et al.*, 2008) unless we interfere. Phenotypic plasticity and migration permit more immediate responses to environmental changes but, in the long term, an adaptive evolutionary response (or evolutionary rescue) (O'Connor *et al.*, 2012; Schiffers *et al.*, 2013) may be needed in order to avoid or limit the negative consequences of maladaptation under changed environmental conditions (Hamilton and Miller, 2015). Maladaptation to changing climates not only decreases species' productivity and health but also aggravates the decline of small populations (Aitken *et al.*, 2008; O'Connor *et al.*, 2012).

It is therefore essential to incorporate climate change considerations into species conservation planning and ensure that planning is climate-smart (Maxted *et al.*, 2013; Stein and Moser, 2014; Maxted *et al.*, 2015a)(Figure 17). For *in situ* conservation this may mean accommodating predicted plant distribution range shifts when selecting new areas for active conservation (as highlighted by Aguirre-Gutiérrez *et al.*, 2017; Maxted *et al.*, 2013), upgrading the current, highly static protected area system to incorporate both current and future projected distributions (Midgley *et al.*, 2002) or selecting areas where species persistence is unlikely to be negatively affected (Magos Brehm *et al.*, in prep.; Maxted *et al.*, 2013). For *ex situ* conservation, it may mean prioritizing for urgent collection those populations that are likely to be negatively affected by climate change and/or those at the edge of species distributions to capture the genetic diversity that is under threat (Magos Brehm *et al.*, in prep.; Maxted *et al.*, 2013) and to regularly collect CWR germplasm from key sites to assess changes and their causes over time.

What if a target CWR population in a genetic reserve is vulnerable to mid- or long-term effects of climate change? How can we design and implement a climate-smart management plan? What management strategies can be adopted? Ideally populations will migrate to favourable conditions, or populations will show short-term resilience via phenotypic plasticity or longer term adaptive evolutionary responses. However, if these are not viable options, then yes, the CWR may go extinct but hopefully the conservation strategy designed initially would be sufficiently robust to ensure that 'all the conservation eggs were not placed in the same basket'. This means that, although the number of populations of each CWR taxon that should be designated for conservation may vary (for example between self-pollinated and cross-pollinated taxa), and whenever genetic information is lacking, populations that occur in diverse ecogeographic conditions should be targeted. Therefore, the loss of any one population will not jeopardize on-going *in situ* conservation and if one population is lost another can be nominated to replace that population in the network (Maxted *et al.*, 2013).

5.1 Climate-smart conservation cycle

A framework for climate-smart conservation refers to an **adaptive management approach**, i.e. managing the reserve in a structured and iterative process aiming at reducing the uncertainty over time via regular and continued monitoring (Araújo, 2009., see also section 2.10).

Stein and Moser (2014) suggested a framework for climate-smart conservation with the following seven individual steps (left side of Figure 17):

I. **Define planning purpose and scope.** It includes defining the purpose for developing a plan for adaptation to climate change, clarifying existing conservation goals, identifying conservation targets, geographic scope, time frame, key stakeholders, and available resources.

II. **Assess climate impacts and vulnerability of target species/populations to climate change.** It generally considers three components: i) exposure, which measures the impact of a change in climate in target species/population/system, ii) sensitivity, which measures whether and how the species/population/system is likely to be affected by or responsive to particular changes in climatic variables and/or related factors, and iii) adaptive capacity, which refers to the species/population/ system's ability to accommodate or cope with the change (both intrinsic and extrinsic characteristics associated with the conservation target, as well as relevant institutional factors), including epigenetics (i.e. the study of how environment changes affect the way genes work without affecting the DNA sequence, (Waddington, 1968).

III. **Revise conservation goals and objectives**. This generally comprises a re-evaluation of the "what" (conservation target), "why" (intended outcomes or desired condition), "where" (geographic scope), and "when" (time frame). This also implies a revision of the budg*et al*located for conservation actions.

IV. **Identify possible adaptation options**. It implies considerations on how those species/population/system' vulnerabilities may be reduced. These actions may include conservation translocations, habitat management and enhancement of evolutionary resilience (Figure 17 and sub-section 5.2).

V. **Evaluate and select adaptation actions**. The various management adaptation actions should be evaluated and finally selected. Evaluation of actions can be selected following four criteria: i) conservation goals, i.e., whether the action helps achieve agreed-upon conservation goals and objectives, ii) other goals and values, i.e. whether the action helps achieve social, cultural and/or economic goals and objectives, or provide benefits to other sectors, iii) feasibility, whether the action is practical and realistic, and (iv) climate-smart considerations, whether the action follows the principles of climate-smart conservation. Management actions should typically be planned for periods up to 20 to 50 years, depending on the speed with which ecosystem changes are predicted (Araújo, 2009).

VI. Implement priority adaptation actions. The selected management action(s) need(s) actual implementation.

VII. Track action effectiveness and ecological responses. Through continued monitoring it is possible to ensure that management actions are being successful as well as help discern when and where changes in tactics may be needed, i.e. in case any shift in species population structure, fitness and/or distribution takes place.

It should be highlighted that the unpredictability or instability of conservation costs derived from climate change challenges is likely to increase the need for additional funding the revision of the conservation program and its corresponding budget is essential.

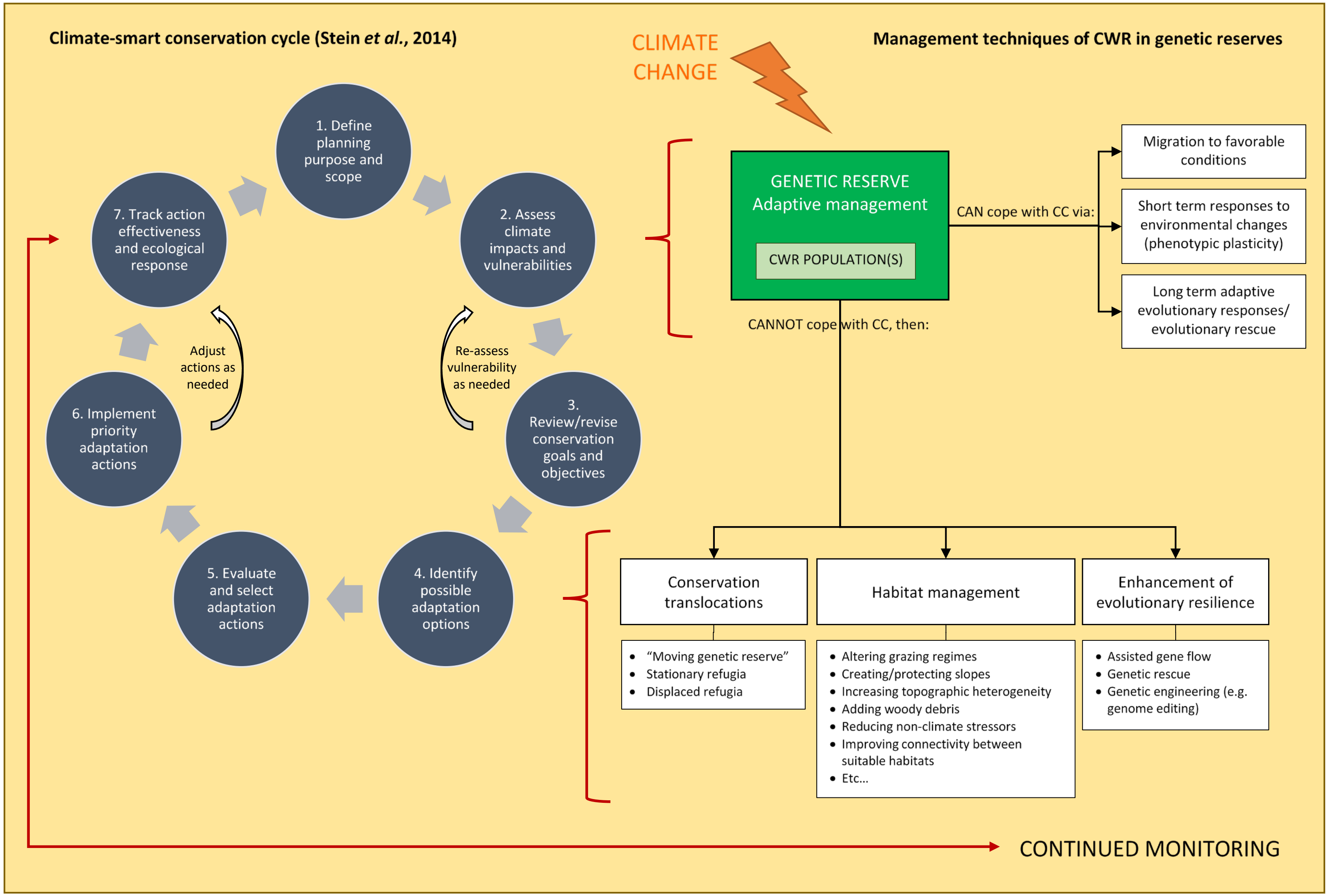


Figure 17. Management techniques to address the effects of climate change on CWR in genetic reserves.

5.2 Management techniques of CWR in genetic reserves

Conservation translocation is the intentional movement and release of a living organism where the primary objective is a conservation benefit: this will usually comprise improving the conservation status of the focal species locally or globally, and/or restoring natural ecosystem functions or processes" (IUCN/SSC, 2013).

Habitat management aims at maintaining and improving the habitats where natural processes no longer create suitable conditions for the target species (Ausden, 2008).

Enhancement of evolutionary resilience refers to artificially increase "the ability of populations to persist in their current state and to undergo evolutionary adaptation in response to changing environmental conditions" (Gunderson, 2000; Thrush *et al.*, 2009), recognizing that ongoing evolutionary change is one of the dynamic processes that generate and maintain biodiversity patterns and processes (Sgro *et al.*, 2011).

5.2.1 Conservation translocations

Translocation may involve releases either within or outside the species' native range. A particular modality of conservation translocations that may be suitable for CWR *in situ* conservation is *circa situ* or quasi *in situ* conservation (Volis and Blecher, 2010). This approach generally involves five steps: i) ecogeographic survey and analysis, ii) *ex situ* sampling of ecogeographically diverse populations, iii) planting of samples in ecogeographically matching sites and *in situ* maintenance, (iv) record life-history traits and abiotic/biotic effects on population demography, and v) reintroduction of plants or seed to the source location (Volis and Blecher, 2010).

Translocation can take place to sites (or genetic reserves) that are suitable for the target CWR species and that are expected to escape to changes in climate (stationary refugia) or to suitable sites after they have been displaced by climate change from their original location (displaced refugia) (Araújo, 2009). Displaced refugia occur typically at the edge of species distribution areas and their identification can be inferred with bioclimate envelope models (e.g. Bakkenes *et al.*, 2006; Harrison *et al.*, 2006; Huntley *et al.*, 1995; Thuiller *et al.*, 2005). Like stationary refugia, these can be found on mountain ranges, in deep valleys or other areas with steep climate gradients that are expected to maintain certain types of climate despite becoming regionally restricted due to climate change (Araújo, 2009). When the target population occurs in a genetic reserve located in a protected area that contains a steep elevational gradient, it may be possible to plan an upward "moving genetic reserve" along the elevational gradient, where seed dispersal could be assisted through well-planned translocations. Nevertheless, it should be evaluated whether microclimate, soil, water availability, etc remain suitable for that population.

However, is translocation suitable for routine CWR conservation? Important criticisms to this technique include: i) it does not take into account the other biotic and abiotic factors at the source location (moving a population may also require moving other species alongside the target species to the new host environment and this may require significant resources over many years and would not always succeed), ii) the negative impact of the translocated population into the existing species community at the host site acting like pseudo-invasive species outcompeting local species in their niches, and iii) the high costs of purchasing land if the populations is to be translocated into private land (Maxted *et al.*, 2020). Therefore, although a theoretical option, it is impractical for many CWR taxa. Its applicability might be justified, however, if it represents a close wild relative (i.e., GP1B, see 'genepool' in Appendix 1) or a taxon restricted to a single natural population that is highly threatened. One such unique example is the case of *Lathyrus belinensis* (Rowe and Maxted, 2019).

Guidelines on how to assess the feasibility, plan, design, manage and monitor a translocation can be found in the IUCN/SSC *Guidelines for Reintroductions and Other Conservation Translocations* (UICN/SCC, 2013).

5.2.2 Habitat management

It is possible to improve the quality of the habitat and promote actions to facilitate the use of areas that may become more suitable in a context of climate change by manipulating their habitats. It can potentially be used to offset the adverse impacts on plant diversity of changes in temperature, water availability and sea-level rise (Greenwood *et al.*, 2015).

Habitat management measures depend on the extent and the actual change in climate and on the ecological requirements of the target species. It is very important to have a clear diagnosis of which environmental factor is responsible for the maladaptation of the CWR population to the site, and whether it is feasible to do something to mitigate the impact of this factor to improve current conditions. A careful study and planning of which technique is more appropriate to benefit the target species and to not interfere negatively with the remaining species is required.

Evidence of success of habitat interventions is generally indirect and only very few studies provide empirical tests of the long-term effectiveness of these interventions. These interventions may have a high risk of failure, may also produce unexpected outcomes (Greenwood *et al.*, 2015) and may be very expensive.

A wide range of techniques can be used (see for example Ausden 2008 and Greenwood *et al.* 2015):

- **Altering grazing regimes**. For instance, a common case is that climate change promotes the shrub encroachment of grasslands that often contain interesting CWR taxa. In some cases, shrub encroachment can be contained with proper management of cattle or wild herbivore populations. On the other hand, reduced grazing may reduce diversity, particularly in areas with productive soils and high rainfall. There is a risk of failure, however, as grazing can have both positive and negative impacts (Greenwood *et al.*, 2015).
- **Creating/protecting slopes**. Creation of slopes exposed to cool winds may protect species that can then grow in less long-term warming areas (e.g. Ashcroft *et al.*, 2009; Bennie *et al.*, 2008).
- **Increasing topographic heterogeneity**. Persistence of plant species threatened by climate change is generally higher in areas with high topographic heterogeneity (Suggitt *et al.*, 2014). By creating raised and lowered areas, the range of available niches is expected to increase, and thereby helping some species establish (e.g. (Doherty and Zedler, 2015; Varty and Zedler, 2008).
- **Adding woody debris**. A measure that stabilises soil temperature and reduces moisture loss, leading to increasing overall survival of plants (e.g. Haskell *et al.*, 2012). Applied blindly, however, it may reduce the area of optimal microclimate.

- **Reducing non-climate stressors.** By minimizing the impacts from other sources of stress (e.g. pollution, invasive species, etc) we are helping the species to be fit and withstand the impacts of climate change (Wilkening *et al.*, 2019).
- **Improving connectivity between suitable habitats**. Species dispersal is likely to be the most important mechanism of the species to cope with changes in climate. Habitat fragmentation and/or modification can hinder this process. Therefore, connectivity between suitable habitats within the genetic reserve or between genetic reserves, that allow species to track climate changes through dispersal may be recommended (Araújo, 2009).

5.2.3 Conservation and enhancement of evolutionary resilience

The prerequisites for a population to keep its identify and integrity under environmental changes have been recognised by Gregorius (2001) and are: "i) intactness (operability) of the mechanisms of the genetic system, ii) recognition of the mechanisms' external conditions for operation (operational conditions), and iii) availability of genetic variation for alteration of these mechanisms". Presumably, these are the three main factors that should be considered when planning for the enhancement of evolutionary resilience.

Enhancement of evolutionary resilience techniques can be carried out at different scales (single population, multiple populations of one species, multiple populations of multiple species, etc) depending on our management goals and what the impact of climate change is on the target population/taxon (see Sgrò *et al.*, 2011). Management goals may include: i) increase population size and overall genetic variation, ii) maintain adaptive potential in target genes/traits, iii) identify species with little adaptive potential (i.e. low diversity in key ecological traits), (iv) identify and protect evolutionary refugia, v) increase connectedness and gene flow across environmental gradients, vi) increase adaptability to future environments by translocation (Sgro *et al.*, 2011). Enhancement of evolutionary resilience may only be viable if climate change is affecting a CWR population that contains a really important trait, as it is not feasible to be applied to a large number of CWR populations and/or taxa.

Enhancement of evolutionary resilience techniques include:

- **Assisted gene flow**. This refers to the introduction of genotypes/individuals that are pre-adapted to new local climates or the increase of the frequency of these genotypes in the existing and affected populations, i.e. within the native species' range. It helps to increase the recipient's fitness, its mean survival rate, fecundity, local population size and adaptive capacity of that population. As temperature increases, genes that confer adaptation to warm temperatures are favoured by selection hence increasing their frequency within the population. In practice, the gene flow between populations that are affected by the same climatic conditions as those now experienced by the target population (e.g., southern populations), and those within the genetic reserve that is being managed, may confer the local population greater evolutionary resilience. Problems associated with this technique include: outbreeding depression, disruption of local adaptation to other environmental factors, or loss of original local lineages (Byrne *et al.*, 2011; Edmands, 2007; Weeks *et al.*, 2011). On the other hand, as the target populations are kept in the species native range, ecological risks are lower and relatively predictable (Aitken and Whitlock, 2013). More information can be found in Aitken and Whitlock (2013) Broadhurst *et al.* (2008), Kelly and Phillips (2015), Kreyling *et al.* (2011), Sgrò *et al.* (2011), Weeks *et al.* (2011).

- **Genetic rescue**. This is an approach used for restoring genetic diversity specifically in small, isolated and frequently inbred populations (hence, low fitness) (Mussmann *et al.*, 2017; Whiteley *et al.*, 2015). It differs from assisted gene flow and from targeted gene flow by the fact that any individual from elsewhere can be translocated and the increase in genetic variation can go in any direction (Kelly and Phillips, 2015).
- **Genetic engineering techniques**. These involve the alteration of the genetic structure of an organism by either removing or introducing specific genes (but preventing undesirable genes) from a different organism within or between species (McCoy, 2019). Genome editing is one technique in which DNA is inserted, deleted, modified or replaced in a specific site of the genome of a living organism (see, for example Kamburova *et al.*, 2017 for a review). Within this context, genetic engineering would aim at increasing the population's fitness. However, this may result in the development of weedy populations, amongst other unforeseeable ecological consequences (Barrett *et al.*, 2019).

Again, it should be stressed that these techniques are theoretically possible, but are they practical given the necessary resource investment? It may be more conservation resource efficient to ensure that enough populations for each CWR taxon are designated to complement each other in diverse ecogeographic zones and replace any lost populations by nominated replacement populations (Maxted *et al.*, 2013). However, where such replacement is not possible, applying options such as those above are the only choice available. Additionally, up-to-date back-up *ex situ* gene bank populations is essential (see section 6).

6 Linking CWR in nature to in situ and ex situ conservation to use

Díez, M.J., Iriondo, J.M., Álvarez-Muñiz, C., Hosking, J.B., Rasmussen, M., van Hintum, T., Weibull, J., Maxted, N.

6.1 The CWR status quo

Breeders are increasingly **requesting greater access to the full breadth of CWR diversity** to meet the growing challenge of climate smart varietal development. However, breeders only access conserved diversity of CWR populations that have been sampled and conserved *ex situ* in gene banks. A fully integrated approach to CWR conservation and use is required that links in nature diversity to *in situ* and *ex situ* conservation and then links through to increased breeders use of the full breadth of CWR diversity.

It is increasingly recognized that breeders are requesting greater access to the full breadth of CWR diversity to meet the growing challenge of climate smart varietal development (Maxted and Kell, 2009; Heywood, 2013; McCouch *et al.*, 2013; IPCC (Intergovernmental Panel on Climate Change), 2014; Lusty *et al.*, 2014). Maxted and Kell (2009) reviewed literature citations for CWR use and found a doubling of CWR usage between 1970 and 2000, while Lusty *et al.* (2014) reported that, in the decade from 1996 to 2006, CWR accounted for 27% of the samples supplied by the CGIAR centres. Practically it is recognized that breeders only access conserved diversity, and, for CWR, that amounts to CWR populations that have been sampled and conserved *ex situ* in gene banks (Maxted *et al.*, 2020).

However, CWR diversity is vast, widely threatened and poorly conserved. It is estimated that using the broad generic definition of CWR there are between 50,000 and 60,000 CWR taxa globally (Maxted and Kell, 2009). To enable conservation actions to be focused on those CWR taxa most likely to be used by breeders, Vincent *et al.* (2013) prioritized these taxa on the basis of (a) belonging to the primary or secondary gene pools of major crops, (b) being threatened with extinction or (c) having known useful adaptive traits, giving a priority global list of 1,667 CWR taxa. As an illustration of the threat facing CWR diversity, Kell *et al.* (2012) undertook IUCN Red List Assessment for 572 European CWR species and found that at least 11.5% of the species are threatened and one species (*Allium jubatum* J.F. Macbr.) is Regionally Extinct. On the other hand, Castañeda-Álvarez *et al.* (2016) reviewed *ex situ* gene bank holdings of 1,076 taxa related to 81 crops and found that 29.1% had no accessions in gene banks and 23.9% were represented by fewer than ten accessions per taxon, while >70% of the taxa were identified as high priority for further collecting. Maxted *et al.* (2016) reviewed CWR *in situ* conservation and found, although many CWR are passively conserved in existing PAs, only a handful of genetic reserves had been established globally where CWR can be actively conserved *in situ* and many of these do not the recommended minimum standard for *in situ* conservation set by Iriondo *et al.* (2012).

Even with the recent collection of 3,447 seed accessions of 237 CWR taxa from 21 countries and increasing CWR *ex situ* conservation (Dempewolf *et al.*, 2014), it is unrealistic to believe an *ex situ* approach alone will meet breeders demand for diversity. Increasing threat in nature to CWR diversity and addressing breeders needs means that a fully complementary and integrated approach to CWR conservation and use is required that links in nature diversity to *in situ* and *ex situ* conservation and then links through to increased breeders use of the full breadth of CWR diversity.

6.2 Linking in situ to ex situ conservation

There are currently **no established links between *in situ* conservation of CWR and their utilization**. *Ex situ* conservation is regarded as a complement to *in situ* measures. Therefore, in this context, back-up *ex situ* collections should be established with the aim of resettlement in the case of natural disasters eroding the wild relatives in their habitats or for other germplasm uses. However, for PGRFA conservation, *ex situ* conservation is more than just a back-up, *ex situ* conservation is the existing means of accessing conserved germplasm.

Some recent studies have shown that there are currently no established links between *in situ* conservation of CWR and their utilization (Maxted *et al.*, 2015a, 2017; Valdani Vicari and Associati *et al.*, 2015, 2016). Without such links, *in situ* conservation of these taxa would necessarily be of low[er] priority for CWR conservation. Improving these links have not been a priority for either the *in situ* conservation or CWR user communities. The current culture among many *in situ* PA managers is one of an entirely conservation focus and any form of exploitation of the conserved resource is often seen as detrimental to the conservation ethos of the PA. Also, PA managers do not have experience of receiving requests for germplasm, processing such a request and supplying germplasm with the appropriate SMTA to the end user. While at first this linkage may appear of limited practical importance to researchers and breeders, if they can have access to the germplasm they request, it does have long term implications for them, as it necessarily restricts the overall breadth of diversity that is available to them. The lack of an effective *in situ* conservation to utilization link for CWR taxa does undoubtedly restrict CWR usage and perhaps this is only now becoming apparent as users calls for greater CWR diversity availability are being made (McCouch *et al.*, 2013; Maxted and Kell, 2009).

From a sole conservation perspective (CBD, 1992), *ex situ* conservation is regarded as a complement to *in situ* measures. Therefore, in this context, back-up *ex situ* collections should be established with the aim of resettlement in the case of natural disasters eroding the wild relatives in their habitats. However, for PGRFA conservation, *ex situ* conservation is more than just a backup, *ex situ* conservation is the existing means of accessing conserved germplasm. Historically it was thought that germplasm might also be obtained directly from *in situ* conservation sites (Maxted *et al.*, 1997a), but experience has shown this is not practical. PA managers have no experience of using SMTAs and use of their conserved material remains for many of them a foreign concept (Maxted and Palmé, 2015; Maxted *et al.*, 2020). Furthermore, providing access from *ex situ* collected samples is more efficient in terms of cost and timeliness, and as the standard access route, should further enhance potential user application.

Meeting the growing user requirement for greater breadth of genetic diversity to sustain cultivar production within changing cultivation ecosystems (IPCC (Intergovernmental Panel on Climate Change), 2014; McCouch *et al.*, 2013) means germplasm users demand for diversity can only be met from the broader range of diversity found in nature and *in situ* conservation, as well as *ex situ* conservation, and that all three sources of diversity must improve links facilitating resource access to utilization. While Aguirre-Gutiérrez *et al.* (2017) concluded, following SDM climate modelling, that the current range of protected areas would not guarantee long-term CWR conservation in Europe, (Maxted *et al.*, 2017) indicated that the required range of diversity could not be met by the current sample of diversity held *ex situ* alone. Therefore, both *in situ* and *ex situ* genetic conservation need to 'up their games' to meet this growing challenge to supply the diversity users require (Maxted *et al.*, 2020). In this context, concern has been raised over the potential additional and significant financial and technical burden that would be placed on gene banks if they were required to incorporate *in situ* back-up samples into their *ex situ* collection and make them available to users (Valdani Vicari and Associati *et al.*, 2016). In response to this, Maxted and Palmé (2015) suggested a potential model for how *in situ* and *ex situ* CWR conservation, and utilization might be better integrated. This original model has later been enhanced by further discussion with stakeholders (Figure 18). They also suggested that with the increasing responsibility for *in situ* conservation and use, gene banks should be more correctly referred to as plant genetic resource centres (PGRC) to reflect the significant extension of their role beyond conventional gene banking.

The model distinguishes four options for *in situ* to *ex situ* conservation integration. From the simplest to the most complex: (a) **Demand and supply mediated by the PGRC** – involves the user requesting a CWR population sample from an *in situ* conservation site, the sample collected by the PGRC or GR staff and, once documented and packaged, sent to the user; (b) **Black box safety backup** – involves the sample being collected by PGRC or GR staff, then sent to the PGRC for processing and conservation in a virtual 'black box' within the PGRC, where the samples would only be available to the original donor; (c) ***In situ* backup** – involves the sample being collected by PGRC or GR staff, then sent to the PGRC for processing and conservation, but when regeneration was required, rather than regenerate the existing sample, a fresh sample would be taken from the *in situ* population; and (d) **Long-term *ex situ* conservation** – involves the sample being collected by PGRC or GR staff, then sent to the PGRC for processing and conservation, and then incorporated into the PGRC as a normal *ex situ* collection that happened to have been collected as backup sample from an *in situ* conservation site.

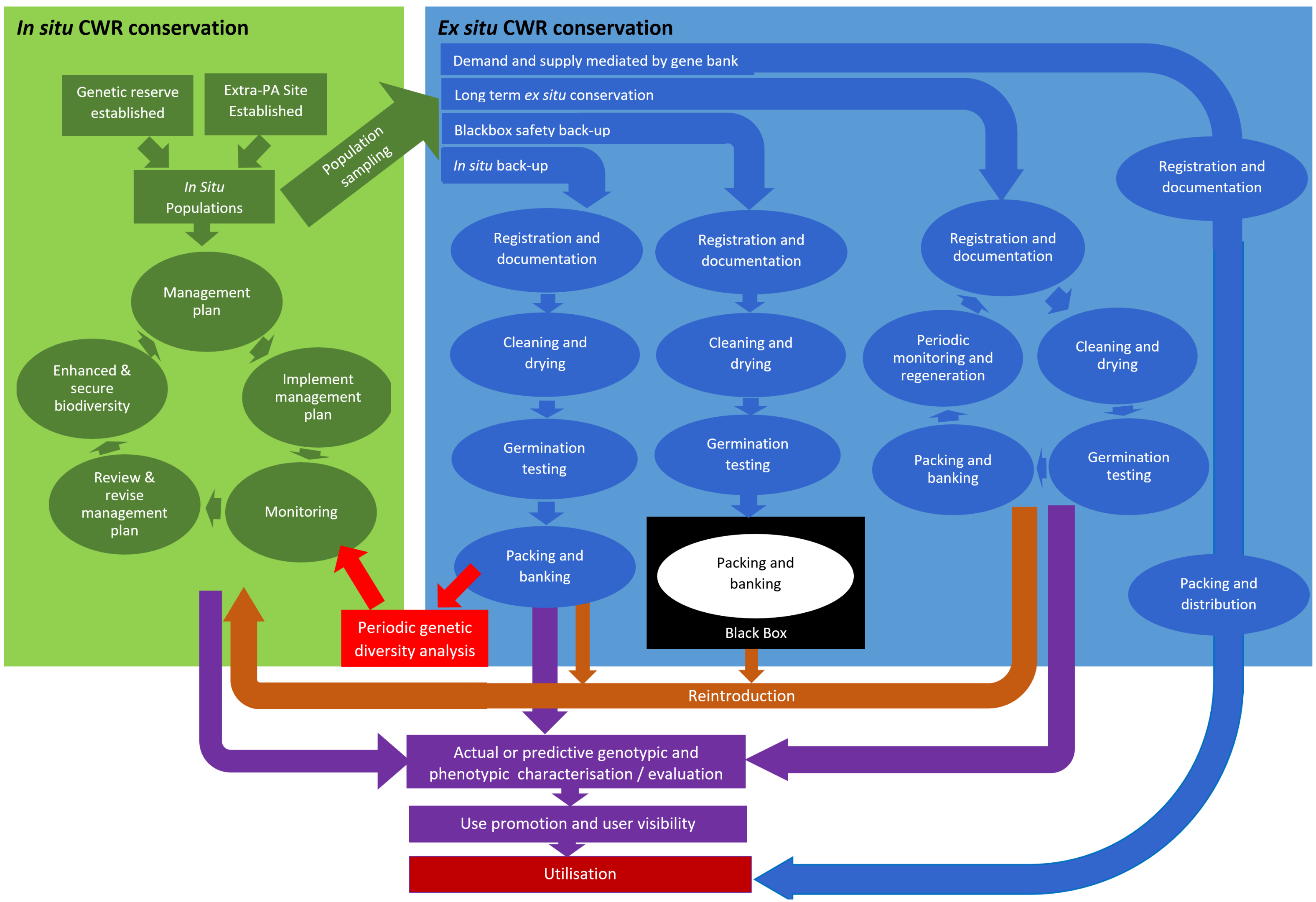


Figure 18. Four approaches to *in situ* to *ex situ* conservation integration (Maxted, In Prep.).

The advantage of demand and supply *in situ* to *ex situ* linkage is that it is the least work for the PGRC and additional *in situ* samples are only collected when they are known to be required, but it does imply a delay in provision of the sample as the PGRC or GR staff could only collect the sample when seed was available. While black box samples would not undergo routine PGRC monitored procedures, such as regeneration, they would not be available to the user community. Such an approach would significantly reduce the potential cost of *in situ* back-up where resources were limiting but would not assist in making the *in situ* resource available to the user community. The *in situ* backup option would pass through normal registration and documentation, cleaning and drying, germination testing and then seeds would be packed and banked, but the sample would not be regenerated (so reducing maintenance costs). Regeneration would be replaced by fresh sampling of the *in situ* conserved population, and here samples could be made available to potential users. As the *in situ* back-up was distributed to users further samples could be supplied by the *in situ* maintainer. The *in situ* back-up recorded in the PGRC's documentation system would be flagged to the user community and those wishing to obtain an *in situ* sample could then contact the PGRC to supply a sample. The fourth option has the advantage that it would be treated as any normal additional sample being added to the PGRC, but here it would simply be noted that the sample represented an *in situ* conserved population. This option would be the most expensive for the PGRC to implement and if *in situ* conservation were to be implemented in a truly complementary manner to *ex situ* it would add significantly to PGRC recurrent expenditure. The added advantage of each these options is that the GR manager interest preserving their control over samples taken *ex situ* would be guaranteed by the ABS legal agreement signed between the GR manager and the plant genetic resource centre.

So, each *in situ* to *ex situ* conservation linkage option has its advantages and disadvantages, and the option chosen may depend on the stakeholder community making the choice. For example, the plant genetic resource centre staff may prefer option (a) demand and supply mediated by the PGRC because it is the option that is least resource intensive for them to implement, while the *in situ* conservationist may prefer option (c) *in situ* backup, which is more resource intensive for the plant genetic resource centre but maximises the potential use of the *in situ* conserved resource. However, we have yet to see in practice which option is favoured, or even whether a combination of options is applied within a single country or *in situ* network.

To help individual GR conservation managers ensure the most appropriate outcome for them when deciding the *in situ* to *ex situ* conservation linkage options Figure 19 shows the different steps to be addressed when implementing an *ex situ* collection of CWR.

It must be stressed that all germplasm that is transferred away from a wild population should be transferred legally with the relevant technical documentation and in accordance with the international and national regulations such as phytosanitary/quarantine laws, ITPGRFA or CBD access regulations, and national laws for genetic resources access (FAO, 2014). Most notably there are requirements under the ITPGRFA or CBD Nagoya protocol to use a Standard Material Transfer Agreement (SMTA) or Material Transfer Agreements (MTA) when transferring material from *in situ* to *ex situ* conservation[29]. Although the requirement under the ITPGRFA only applies to taxa specifically listed in Annex 1 that are under the management and control of the Contracting Parties and in the public domain, there is a general consensus on using the SMTA for the exchange of materials,

[29] http://www.fao.org/3/a-bc083e.pdf

even for PRGFA species not included in the so-called Annex I. The national application of these rules will be determined by whether the country has signed the Nagoya Protocol and/or the ITPGRFA.

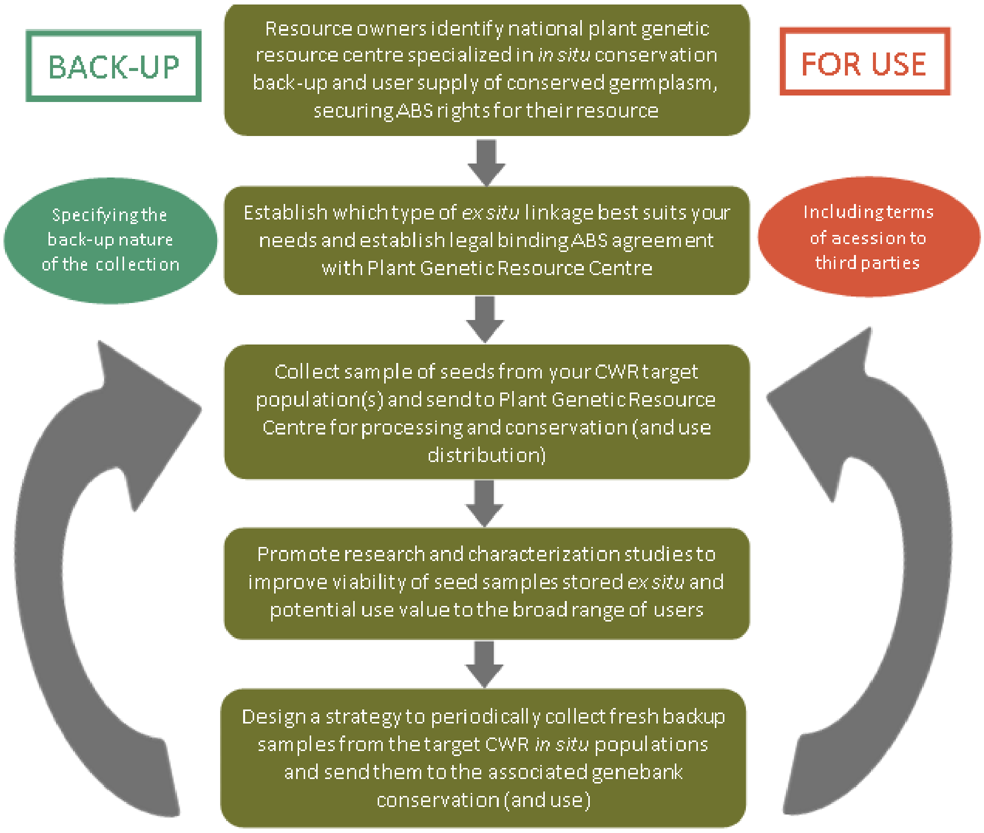


Figure 19. Tips for CWR *in situ* conservation managers when developing *ex situ* duplication linkage.

One of the main justifications for the relatively recent introduced CBD and ITPGRFA legislation was the desire to improve plant genetic resource availability and to clearly establish resource ownership, so increased utilization was linked to "*the fair and equitable sharing of the benefits arising out of the utilization of genetic resources*" (CBD, 1992). Whichever model for *in situ* – *ex situ* – use linkage is favoured, it is important that the original resource owner is fully recognized. The landowners will normally also be the owners of the plants growing on the land, especially if they are wild plants. This implies that the landowners also own all parts of the plants – including all their tissues and germplasm, etc. Therefore, it is essential for the CWR plant material owners to be able to agree the terms of any change of such ownership and/or receive a fair and reasonable share of any benefits derived from the commercial utilization of their plant material. Whatever arrangements are put in place, they must be open and transparent, so that CWR plant owners are not deterred from positive engagement with CWR plant conservation both *in situ* and *ex situ*. Such issues should be clearly addressed in the MTA signed by the *in situ* site owner, the PGRC and the end user.

As well as the global legally binding requirement, there may also be national legislation that requires action when transferring seed or samples *ex situ* and material should always be transferred in compliance with phytosanitary requirements (FAO, 2014). The genebank where the deposit is to lodged may require a specific form of phytosanitary certificate, other additional declarations, certificate of donation, certificate of no commercial value and import permit and other documents, especially if the sample is moving between countries. More detailed information can be found at ISTA website[30].

6.3 Ex situ conservation for use

Many CWR have yet to be successfully curated. Drying protocols are still unknown for many species, the predominant allogamy of many CWR taxa requires accession isolation during regeneration, and seed longevity and the means of dormancy breaking are uncertain yet.

Three of the four options for *in situ* to *ex situ* conservation integration require active curation of the *in situ* sampled accessions by the PGRC. Although few PGRCs have experience of CWR curation, many CWR have yet to be successfully processed. Drying protocols are unknown for many species, the predominant allogamy of many CWR taxa requires accession isolation during regeneration, and seed longevity and the means of dormancy breaking are uncertain. As a consequence, necessary seed regeneration is delayed or rarely accomplished, leading to insufficient quantities of viable seeds to meet users' needs and decline in genetic diversity within accessions. All of which means material of CWR is seldom made available, or even published as available, in the webpages of the PGRCs, which in turn significantly limits their utilization. *In situ* to *ex situ* conservation integration requires fresh research, including all aspects related to the reproductive biology, longevity, conservation, and ecological aspects, to solve these problems to improve access to the material available in *ex situ* conservation.

CWR regeneration is complicated and often species specific, but necessary to provide enough seeds for users. The out-breeding system, flower asynchrony and seed shattering of many crop wild relatives hinder their regeneration in PGRCs. Thus, once the breeding system of the target CWR is known, some other complementary aspects should be addressed, such as, the pollination method (insect or wind), impact of environmental conditions on pollination success, isolation needs between accessions to avoid pollen contamination, adequate maturity state of seeds for collecting, etc. An alternative option is provided by *in situ* backup, described above, which involves *ex situ* conservation but avoids expensive and complex regeneration by periodic replenishment of back-up *in situ* germplasm samples to the PGRC. For some orthodox seeds, if the seeds are harvested at the right time and properly dried and frozen, they can maintain their viability over 50 years. Thus, the periodicity of harvesting will depend on the seed longevity behaviour of the species and the conditions of seed processing and storage.

As well as conserving samples of CWR population, it may be just as important to conserve back-cross populations with the associated crop with known adaptive traits, which avoid the problems of linkage drag associated with direct use of CWR germplasm. This is illustrated by the work of (Pickering *et al.*, 2004) on barley breeding. Although it might be argued that this action goes beyond 'normal' conservation activities, it would undoubtedly promote CWR usage. Furthermore, ideally it would be advisable to store replicates of the *ex situ* samples in three geographically-separated locations as insurance against loss of gene

[30] https://www.seedtest.org

bank facilities (and their contents) due to natural or human-induced catastrophes (e.g. wars, earthquakes, flooding, etc.).

Last, but not least, it is essential to make available all existing information on the conserved CWR accession to users, including all relevant data about the species provenance. For this purpose, it is important to implement an efficient procedure to transfer the information available by the CWR GR manager to the PGRCs and holder institutions. The latter, in turn, should establish databases publicly and easily accessible over the Internet.

7 Minimum standards and concluding remarks

Iriondo, J.M., Maxted, N., Magos Brehm, J., Dulloo, M.E.

The information provided in these guidelines covers a wide array of themes regarding the management of CWR populations. Reading these guidelines from the beginning to the end, the protected area manager, the farmer, the NGO volunteer or the local public administrator interested in becoming a CWR genetic reserve manager might wrongly end up concluding that managing a CWR genetic reserve is too complex and laborious. However, the fact is that, in most cases, CWR genetic reserve management is quite simple and straightforward. A CWR genetic reserve may be created as a result of a top-down approach, where a particular site is identified as a valuable component of a national, regional or international network for the *in situ* conservation of CWR, or as a result of a bottom-up approach where the managers of a particular protected area or land property, are conscious of the relevant CWR populations that occur at their site and want to provide them an appropriate conservation regime (Maxted *et al.*, 2015b). As a result of this, and the various property and management regimes that may underlie a CWR genetic reserve, the human and economic resources available for genetic reserve management may greatly vary. Given this context, we can ask, what are the minimum standards that a CWR genetic reserve should follow in order to warrant a proper *in situ* conservation of their target CWR populations?

In October 2019, a workshop was held in the island of Santorini (Greece) as part of the Farmer's Pride project[31] to discuss the development and establishment of the European Network of Plant Genetic Resources. In this workshop, a working group was set to discuss standards and procedures for CWR sites/populations. The aim was to get a consensus concerning the minimum standards that would be required for an *in situ* CWR genetic reserve to join the European Network and provide a meaningful contribution to the conservation of CWR.

The term 'minimum standards' has been applied to genetic reserves to refer both to aspects related to the design and implementation of the reserve and to the management practices (Iriondo *et al.*, 2012; Maxted *et al.*, 2015b). For the purpose of these management guidelines it is convenient to differentiate one from the other.

7.1 Minimum standards: design and implementation of CWR genetic reserves

Minimum standards regarding design and implementation of CWR genetic reserves detail the requisites concerning the nature of target CWR taxa and populations, and the location of the site, as well as the delimitation of its boundaries. Regarding the nature of target CWR taxa, the working group indicated that species that are already included in national CWR inventories and surveys and in the European CWR priority list should receive priority. Furthermore, CWR that are used for food and agriculture and species that are collected for food should be prioritized. Similarly, threatened species that are listed in red data books should be given priority, but also species that are not threatened but contain specific traits, i.e. taxa that contain distinct genetic diversity. Maxted *et al.* (2015b) also

[31] www.farmerspride.eu

request that the target taxa contain distinct and complementary genetic diversity or ecogeographic diversity as a proxy for genetic diversity, or specific traits of interest that enhance the overall value of the network. Furthermore, the taxa should be native at that location, or if introduced, should have occurred at that location for sufficient generations to be significantly distinct from the founder source material. Concerning the target CWR populations, Iriondo *et al.* (2012) indicate that population size ideally should be large enough to sustain the populations in the long term. Moreover, Maxted *et al.* (2015b) recommend that they are not specifically threatened, or if initially threatened, they are actively managed to remove the threat, so there is a good chance of long-term survival. Potential threats from site development or climate change should have been modelled and found negligible at the site in the foreseeable (≥50 years) future. Finally, with regard to the location and delimitation of boundaries, Iriondo *et al.* (2012) recommend that the location is selected following a rigorous scientific process and found in a protected area or less formal but recognized sites. The working group stressed that the network should not only rely on protected areas but genetic reserves could also be established in less formal areas, and that the inclusion of sites should consider different ecogeographic areas with specific adaptations. The group also considered that boundaries should be defined based on the area of occupancy, taking into account population diversity and the geography, and that stakeholders should be consulted in defining the boundaries of the sites.

7.2 Minimum standards: management of CWR genetic reserves

Minimum standards concerning the management of CWR genetic reserves deal with the contents provided in these guidelines. Taking into account previous existing information (Iriondo *et al.*, 2012; Maxted *et al.*, 2015b) and the considerations made in the working group discussion, the minimum management practices that should be implemented in all CWR genetic reserves are outlined in Table 11.

Table 11. Minimum management standards that should be applied in all CWR genetic reserves.

Management practice	Further detail in CWR population management guidelines
Actively and sustainably managed as a long-term *in situ* conservation resource through the design and implementation of a management plan	section 1
Herbarium specimens of the target CWR obtained and deposited in two public herbaria	section 2.3
Georeferencing and demographic survey of target CWR populations	section 2.3
Basic characterisation of abiotic and biotic conditions	section 2.4
Monitoring plan implemented	section 2.9
Local community involved in site management	section 2.11

Agreement signed between land owner of site outside protected areas and public administration to ensure the protection of target CWR	section 4.2
Sampled at regular intervals for complementary *ex situ* conservation	section 6.3
Material and information accessible from a known national *ex situ* facility as part of the Multilateral System (MLS)	sections 2.15 and 6.2

Some additional specific points made by the working group concerning the management practices were:

a) the CWR sites should have a management plan that is recognised by national and sub-national authorities.

b) demographic data should be monitored, but it should not be used as an absolute requirement because it is not always possible to do it.

c) local community involvement, although important, should not be considered compulsory, where applicable and appropriate.

d) regularly collecting samples to transfer to *ex situ* collections should not threaten wild populations.

e) for populations that are used by local communities there should be clear rules on the use of the genetic material to avoid overexploitation.

7.3 Concluding remarks

To conclude let us come back to and allay the fears of our concerned protected area manager, the farmer, the NGO volunteer or the local public administrator interested in becoming a CWR genetic reserve manager. Many genetic reserves will almost be self-selecting in the sense that they will contain healthy, abundant CWR populations. Therefore, in those cases, the site management will be simple, just a matter of keeping doing what it has already been done, which is not too onerous even for the busiest potential manager. Many of the conflicts and difficulties addressed in these guidelines will only concern certain specific situations.

The relevance of conserving CWR *in situ* and using them as a source of genetic diversity for crops is enormous for current and future generations. In the last two decades the scientific community has developed a wealth of knowledge concerning the conservation and use of CWR as plant genetic resources. Further, it is worthy to note that the community of people across the globe managing CWR populations is growing fast and that it is an approachable group willing to provide help and advice when asked. It is, thus, time to cheer up and get started with the *in situ* conservation of CWR in genetic reserves. It is also time for local, national and international administrations to contribute by rewarding successful participation in CWR conservation both *in situ* and *ex situ* – e.g. by providing agri-environment payments, stewardship support, gene banking incentives and grants, capital and revenue tax reliefs, etc. When climate change and food security are becoming increasing topics of general conversational concern, doing something to address these issues will ensure we tried to do our bit.

8 Further readings

Dulloo, M. E. (Ed.), (2021). *Plant Genetic Resources: A Review of Current Research and Future Needs*. Burleigh Dodds Science Publishing, Cambridge, UK (ISBN: 978 1 78676 451 5).

Elzinga, C. L., Salzer, D. W., Willoughby, J. W., and Gibbs, J. P. (Eds.), (2009). *Monitoring Plant and Animal Populations: a Handbook for Field Biologist*. Blackwell Science, Malden, USA.

Heywood, V. H., and Dulloo, M. E. (2005). *In situ* conservation of wild plant species: a critical global review of best practices. *Technical Bulletin IPGRI* (Vol. 11). International Plant Genetic Resources Institute. https://www.bioversityinternational.org/fileadmin/user_upload/online_library/publications/pdfs/1092.pdf.

Hunter D. and Heywood V.H. (Eds.), (2011). *Crop Wild Relatives. A Manual of In Situ Conservation*. Earthscan, London, Washington DC.

Iriondo, J. M., Maxted, N., Kell, S., Ford-Lloyd, B. V, Lara-Romero, C., Labokas, J., and Magos Brehm, J. (2012). Quality standards for genetic reserve conservation of crop wild relatives. In N. Maxted, M. E. Dulloo, B. V. Ford-Lloyd, L. Frese, J. M. Iriondo, and M. A. A. Pinheiro de Carvalho (Eds.), *Agrobiodiversity Conservation: Securing the Diversity of Crop Wild Relatives and Landraces* (pp. 72–77). CAB International, Wallingford. https://doi.org/10.1079/9781845938512.0072.

Iriondo, J. M., Maxted, N., and Dulloo, M. E. (Eds.), (2008) *Conserving Plant Genetic Diversity in Protected Areas*. CAB International, Wallingford.

IUCN/SCC (2013). *Guidelines for Reintroductions and Other Conservation Translocations. Version 1.0.* (p. 57). IUCN Species Survival Commission, Gland, Switzerland.

IUCN-WCPA Task Force on OECMs (2019). Recognising and reporting other effective area-based conservation measures. Gland, Switzerland: IUCN.

Magos Brehm, J., Kell, S., Thormann, I., Gaisberger, H., Dulloo, M.E. and Maxted, N. (2017). Interactive Toolkit for Crop Wild Relative Conservation Planning version 1.0. University of Birmingham, Birmingham, UK and Bioversity International, Rome, Italy. Available at: www.cropwildrelatives.org/conservation-toolkit/.

Maxted, N., Ford-Lloyd, B.V., Kell, S.P., Iriondo, J. M., Dulloo, E. and Turok, J. (Eds.), (2008). *Crop Wild Relative Conservation and Use.* CAB International, Wallingford.

Maxted N., Hunter D., and Ortiz-Ríos R. (Eds.), (2020). *Plant Genetic Conservation*. Cambridge University Press, Cambridge. https://doi.org/10.1017/9781139024297.

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References

Aguirre-Gutiérrez, J., van Treuren, R., Hoekstra, R., and van Hintum, T. (2017). Crop wild relatives range shifts and conservation in Europe under climate change. *Diversity and Distributions*, *23*(7), 739–750. https://doi.org/10.1111/ddi.12573.

Aitken, S. N., and Whitlock, M. (2013). Assisted Gene Flow to Facilitate Local Adaptation to Climate Change. *Annual Review of Ecology, Evolution, and Systematics*, *44*(1), 367–388. https://doi.org/10.1146/annurev-ecolsys-110512-135747.

Aitken, S. N., Yeaman, S., Holliday, J., Wang, T., and Curtis-McLane, S. (2008). Adaptation, migration or extirpation: climate change outcomes for tree populations. *Evolutionary Applications*, *1*(1), 95–111. https://doi.org/10.1111/j.1752-4571.2007.00013.x.

Akimoto, M., Shimamoto, Y., and Morishima, H. (1999). The extinction of genetic resources of Asian wild rice, Oryza rufipogon Griff.: A case study in Thailand. *Genetic Resources and Crop Evolution*, *46*(4), 419–425. https://doi.org/10.1023/A:1008622405001.

Al-Atawneh, N., Amri, A., Assi, R., and Maxted, N. (2007). Management plans for promoting *in situ* conservation of local agrobiodiversity in the west Asia centre of plant diversity. In N. Maxted, B. Ford-Lloyd, S. Kell, M. Dulloo, and J. Turok (Eds.), *Crop Wild Relative Conservation and Use* (pp. 340–363). CAB International, Wallingford. https://doi.org/10.1079/9781845930998.0340.

Alercia, A., López, F., Marsella, M., and Cerutti, A. L. (2020). *Descriptors for Crop Wild Relatives conserved under in situ conditions (CWRI v.1)*. International Treaty on Plant Genetic Resources for Food and Agriculture, FAO, 11 p. Rome, Italy. Available at: http://www.fao.org/3/cb0681en/cb0681en.pdf.

Álvarez-Muñiz, C., Magos Brehm, J., Ralli, P., Palmé, A., Dulloo, M.E., Maxted, N., Negri, V., Löwenhardt, H., Aykas, L., Kell, S., Rubio Teso, M.L. and Iriondo, J.M. (2021). Crop Wild Relative Network Showcases - Analysis and Best Practices. *Farmer's Pride: Networking, partnerships and tools to enhance in situ conservation of European plant genetic resources*. Available at: https://more.bham.ac.uk/farmerspride/wp-content/uploads/sites/19/2021/04/D1.5_CWR_network_showcases.pdf.

Anikster, Y., Feldman, M., and Horovitz, A. (1997). The Ammiad experiment. In N. Maxted, B. V. Ford-Lloyd, and J. G. Hawkes (Eds.), *Plant Genetic Conservation* (pp. 239–253). Chapman and Hall, London. https://doi.org/10.1007/978-94-009-1437-7_15.

Araújo, M.B. (2009). Protected areas and climate change in Europe. In: *Convention on the Conservation of European Wildlife and Natural Habitats*. Council of Europe Strasbourg, p. 28.

Ashcroft, M. B., Chisholm, L. A., and French, K. O. (2009). Climate change at the landscape scale: Predicting fine-grained spatial heterogeneity in warming and potential refugia for vegetation. *Global Change Biology*, *15*(3), 656–667. https://doi.org/10.1111/j.1365-2486.2008.01762.x

Ausden, M. (Ed.), (2008). *Habitat Management for Conservation: A Handbook of Techniques*. Oxford University Press, Oxford.

Avagyan, A. (2008). Assessment of Biodiversity Priority Capacity Building

Needs and Establishment of Clearing House Mechanism in Armenia View project. In N. Maxted, B. Ford-Lloyd, S. P. Kell, J. M. Iriondo, M. E. Dulloo, and J. Turok (Eds.), *Crop wild relative conservation and use* (pp. 58–68). CAB International, Wallingford.

Bakkenes, M., Eickhout, B., and Alkemade, R. (2006). Impacts of different climate stabilisation scenarios on plant species in Europe. *Global Environmental Change*, *16*(1), 19–28. https://doi.org/10.1016/j.gloenvcha.2005.11.001

Barrett, L., Legros, M., Kumaran, N., Glassop, D., Raghu, S., and Gardiner, D. (2019). Gene drives in plants: opportunities and challenges for weed control and engineered resilience. *Proceedings of the Royal Society B*, *286*(1911).

Basora Rock, X., and Sabaté I Rotés, X. (2006). *Custodia of the territory in the practice. Manual of introduction to a new participatory strategy of conservation of the nature and the landscape.* Departamento de Medio Ambiente y Vivienda; Fundació Territoi i Paisatge; Universitat de Vic. Generalitat de Cataluña.

Bennie, J., Huntley, B., Wiltshire, A., Hill, M., and Baxter, R. (2008). Slope, aspect and climate: Spatially explicit and implicit models of topographic microclimate in chalk grassland. *Ecological Modelling*, *216*(1), 47–59. https://doi.org/10.1016/j.ecolmodel.2008.04.010.

Bilz, M., Kell, S. P., Maxted, N., and Lansdown, R. V. (2011). European Red List of Vascular Plants. In *Publications Office of European Union*. Publication Office of the European Union, Luxembourg. https://doi.org/10.2779/8515.

Bönisch, M., and Frese, L. (2020). Designation of genetic reserves for wild celery species in Germany. *Crop Wild Relative Newsletter*, *12*, 4–7.

Broadhurst, L., Lowe, A., Coates, D., Cunningham, S., McDonald, M., Vesk, P., and Yates, C. (2008). Seed supply for broadscale restoration: Maximizing evolutionary potential. *Evolutionary Applications*, *1*(4), 587–597. https://doi.org/10.1111/j.1752-4571.2008.00045.x.

Byrne, M., Stone, L., and Millar, M. (2011). Assessing genetic risk in revegetation. In *Journal of Applied Ecology* 48(6), pp. 1365–1373). https://doi.org/10.1111/j.1365-2664.2011.02045.x.

Carwardine, J., O'Connor, T., Legge, S., Mackey, B., Possingham, H., and Martin, T. (2012). Prioritizing threat management for biodiversity conservation. *Conservation Letters*, *5*(3), 196–204. https://doi.org/10.1111/j.1755-263X.2012.00228.x.

Castañeda-Álvarez, N. P., Khoury, C. K., Achicanoy, H. A., Bernau, V., Dempewolf, H., Eastwood, R. J., Guarino, L., Harker, R. H., Jarvis, A., Maxted, N., Müller, J., Ramirez-Villegas, J., Sosa, C. C., Struik, P. C., Vincent, H., and Toll, J. (2016). Global conservation priorities for crop wild relatives. *Nature Plants*, *2*(4). https://doi.org/10.1038/NPLANTS.2016.22.

CBD. (1992). *Convention on Biological Diversity*. Secretariat of the Convention on Biological Diversity, Montreal, pp 34.

CBD. (2010a). *The strategic plan for biodiversity 2011–2020 and the Aichi biodiversity targets, decision X/2*. Convention on Biological Diversity, Montreal.

CBD. (2010b). *The strategic plan for biodiversity 2011–2020 and the Aichi biodiversity targets. COP Decision V/5, appendix*. Convention on Biological Diversity, Montreal.

Community of Madrid. (2019). La Comunidad identifica 173 especies silvestres de cultivo en la Reserva de la Biosfera Sierra del Rincón. *Press Release*. https://www.comunidad.madrid/notas-prensa/2019/12/05/comunidad-identifica-173-especies-silvestres-cultivo-reserva-biosfera-sierra-rincon.

Conservation Measures Partnerships. (2020). *Open Standards for the Practice of Conservation, Version 4.0* (p. 81). Conservation Standards. Avaliable at: https://conservationstandards.org/wpcontent/uploads/sites/3/2020/10/CMP-Open-Standards-for-the-Practice-of-Conservation-v4.0.pdf.

Dempewolf, H., Eastwood, R. J., Guarino, L., Khoury, C. K., Müller, J., and Toll, J. (2014). Adapting Agriculture to Climate Change: A Global Initiative to Collect, Conserve, and Use Crop Wild Relatives. *Agroecology and Sustainable Food Systems* 38(4), pp. 369–377). https://doi.org/10.1080/21683565.2013.870629.

Dempewolf, H., Baute, G., Anderson, J., Kilian, B., Smith, C., and Guarino, L. (2017). Past and future use of wild relatives in crop breeding. *Crop Science* 57(3), pp. 1070–1082). https://doi.org/10.2135/cropsci2016.10.0885.

Department for Environment Food and Rural Affairs DEFRA. (2011). *Biodiversity 2020 : A strategy for England's wildlife and ecosystem services*. https://www.cbd.int/doc/world/gb/gb-nbsap-v3-p1-en.pdf.

Doherty, J., and Zedler, J. (2015). Increasing substrate heterogeneity as a bet-hedging strategy for restoring wetland vegetation. *Restoration Ecology*, *23*(1), 15–25. https://doi.org/10.1111/rec.12154.

Dudley, N. (Ed.), (2008). Guidelines for Applying Protected Area Management Categories. In *Guidelines for applying protected area management categories*. Best Practice Protected Area Guidelines Series No. 21, Gland.

Dulloo, M. E., Guarino, L., Engelmann, F., and Maxted, N. (1998). Complementary conservation strategies for the genus Coffea with special reference to the Mascarene Islands. *Genetic Resources and Crop Evolution*, *45*, 565–579.

Dulloo, M. E., and Maxted, N. (2019). Special issue: Plant Genetic Resources conservation and utilization-crop wild relatives. *Plant Genetic Resources: Characterisation and Utilisation*, *17*(2), 101–102. https://doi.org/10.1017/S1479262118000606.

Edmands, S. (2007). Between a rock and a hard place: Evaluating the relative risks of inbreeding and outbreeding for conservation and management. *Molecular Ecology* , *16*(3), pp. 463–475. https://doi.org/10.1111/j.1365-294X.2006.03148.x.

Elzinga, C. L., Salzer, D. W., Willoughby, J. W., and Gibbs, J. P. (Eds.), (2009). *Monitoring Plant and Animal Populations: a Handbook for Field Biologist*. Blackwell Science, Malden, USA.

Engels, J., and Thormann, I. (2020). Main challenges and actions needed to improve conservation and sustainable use of our crop wild relatives. *Plants*, *9*(8), 1–26. https://doi.org/10.3390/plants9080968

England Agriculture Act. (2020). *England Agriculture Act*. UK Parliament, London, UK.

European Comission (2013). *Interpretation manual of European Union habitats* (p. 146). DG Environment. https://ec.europa.eu/environment/nature/legislation/habitatsdirective/docs/Int_Manual_EU28.pdf

European Council. (1992). *Council Directive 92/43/EEC of 21 May 1992 1992 on the conservation of natural habitats and of wild fauna and flora*. https://eurlex.europa.eu/legal-content/EN/TXT/?uri=CELEX:31992L0043

FAO. (2009). *International Treaty on Plant Genetic Resources for Food and Agriculture*. Food and Agriculture Organization of the United Nations, Rome, Italy. Available at: http://www.fao.org/3/i0510e/i0510e.pdf.

FAO. (2010). *Second report on the State of the World's Plant Genetic Resources for Food and Agriculture*. Food and Agriculture Organization of the United Nations, Rome, Italy. Available at: http://www.fao.org/agriculture/seed/sow2/en/.

FAO. (2012). *The Second Global Plan of Action for the Conservation and Sustainable Utilization of Plant Genetic Resources for Food and Agriculture*. Food and Agriculture Organization of the United Nations, Rome, Italy. Available at: http://www.fao.org/3/i2624e/i2624e00.pdf.

FAO. (2014). *Genebank Standards for Plant Genetic Resources for Food and Agriculture*. Food and Agriculture Organization of the United Nations, Rome, Italy. Available at: http://www.fao.org/3/i3704e/i3704e.pdf.

Fick, S. E., and Hijmans, R. J. (2017). WorldClim 2: new 1-km spatial resolution climate surfaces for global land areas. *International Journal of Climatology*, *37*(12), 4302–4315. https://doi.org/10.1002/joc.5086.

Frankham, R., Ballou, J., Eldridge, M. D. B., Lacy, R. C., Ralls, K., Dudash, M. R., and Fenster, C. B. (2011). Predicting the Probability of Outbreeding Depression. *Conservation Biology*, *25*(3), 465–475. https://doi.org/10.1111/j.1523-1739.2011.01662.x.

Franks, S., Weber, J., and Aitken, S. N. (2013). Evolutionary and plastic responses to climate change in terrestrial plant populations. *Evolutionary Applications*, *7*(1), 123–139. https://doi.org/10.1111/eva.12112.

Frese, L. (2019). *Designation of the first five crop wild relative genetic reserves in Germany and Europe* (p. 2). Available at: http://www.ecpgr.cgiar.org/fileadmin/templates/ecpgr.org/upload/PHASE_X/WORKING_GROUPS/Wild_species/Designation_genetic_reserves_Germany_final_with_photo_v2.pdf.

Frese, L., Bönisch, M., Nachtigall, M., and Schirmak, U. (2018). Patterns of genetic diversity and implications for *in situ* conservation of wild celery (Apium graveolens L. ssp. graveolens). *Agriculture*, *8*(9), 129. https://doi.org/10.3390/agriculture8090129.

Gardner, R. C., and Davidson, N. C. (2011). The Ramsar Convention. In LePage B. (Ed.), *Wetlands* (pp. 189–203). Springer Netherlands, Dordrecht. https://doi.org/10.1007/978-94-007-0551-7_11.

Goldringer, I., Prouin, C., Rousset, M., Galic, N., and Bonnin, I. (2006). Rapid differentiation of experimental populations of wheat for heading time in response to local climatic conditions. *Annals of Botany*, *98*(4), 805–817. https://doi.org/10.1093/aob/mcl160.

Greenwood, O., Mossman, H., Suggitt, A., Curtis, R. J., and Maclean, I. (2015). Using *in situ* management to conserve biodiversity under climate change. *Journal of Applied Ecology* 53(3), pp. 885–894). https://doi.org/10.1111/1365-2664.12602.

Gregorius, H. (2001). Sustainable treatment of resources: The genetic basis. In G. Müller-Starck and R. Schubert (Eds.), *Genetic Response of Forest Systems to Changing Environmental Conditions. Forestry. Sciences Book Series, vol. 70* (pp. 203–222). Springer, New York. https://doi.org/10.1007/978-94-015-9839-2_17.

Guarino, L. (1995). Assessing the threat of genetic erosion. In L. Guarino, V. Ramanatha Rao, R. Reid, K. Eatwell, G. Goodman, E. Keeble, A. Meredith, and J. Hedley (Eds.), *Collecting Plant Diversity: Technical Guidelines* (pp. 67–74). CAB International, Wallingford.

Guerrant, E. O., Havens, K., and Maunder, M. (Eds.), (2004). *Ex situ plant conservation: supporting species survival in the wild*. Society for ecological restoration Island press, Washington, Covelo and London.

Gunderson, L. (2000). Ecological resilience - In theory and application. *Annual Review of Ecology and Systematics*, *31*, 425–439. https://doi.org/10.1146/annurev.ecolsys.31.1.425.

Hajjar, R., and Hodgkin, T. (2007). The use of wild relatives in crop improvement: A survey of developments over the last 20 years. In *Euphytica* 156(1–2), pp. 1–13). https://doi.org/10.1007/s10681-007-9363-0.

Hamilton, J. A., and Miller, J. M. (2015). Adaptive introgression as a resource for management and genetic conservation in a changing climate. *Conservation Biology*, *13*(1), 33–41. https://doi.org/10.1111/cobi.12574.

Harlan, J., and Wet, J. (1971). Toward a rational classification of cultivated plants. *Taxon*, *20*, 509–517.

Harrison, P., Berry, P., Butt, N., and New, M. (2006). Modelling climate change impacts on species' distributions at the European scale: Implications for conservation policy. *Environmental Science and Policy*, *9*(2), 116–128. https://doi.org/10.1016/j.envsci.2005.11.003.

Haskell, D., Flaspohler, D., Webster, C., and Meyer, M. (2012). Variation in soil temperature, moisture, and plant growth with the addition of downed woody material on lakeshore restoration sites. *Restoration Ecology*, *20*(1), 113–121. https://doi.org/10.1111/j.1526-100X.2010.00730.x.

Hellawell, J. (1991). Development of a rationale for monitoring. In B. Goldsmith (Ed.), *Monitoring for Conservation and Ecology*. Springer, New York. https://doi.org/10.1007/978-94-011-3086-8_1.

Herden, T., Bönisch, M., and Friesen, N. (2020). Genetic diversity of *Helosciadium repens* (Jacq.) W.D.J. Koch (Apiaceae) in Germany, a Crop Wild Relative of celery. *Ecology and Evolution*, *10*(2), 875–890. https://doi.org/10.1002/ece3.5947.

Heywood, V. H. (2013). Overview of agricultural biodiversity and its contribution to nutrition and health. In J. Franzo and D. Hunter (Eds.), *Diversifying Food and Diets: Using Agricultural Biodiversity to Improve Nutrition and Health* (pp. 35–67). Earthscan, London, Washington DC. https://doi.org/10.4324/9780203127261

Heywood, V. H., and Dulloo, M. E. (2005). *In situ* conservation of wild plant species: a critical global review of best practices. *Technical Bulletin IPGRI* (Vol. 11). International Plant Genetic Resources Institute. https://www.bioversityinternational.org/fileadmin/user_upload/online_libary/publications/pdfs/1092.pdf.

Holling, C. (1978). *Adaptive environmental assessment and management*. Blackburn Press, New Jersey, USA.

Hughes, L. (2003). Climate change and Australia: Trends, projections and impacts. In *Austral Ecology* 28(4), pp. 423–443). https://doi.org/10.1046/j.1442-9993.2003.01300.x.

Hunter D. and Heywood V.H. (Eds.), (2011). *Crop Wild Relatives. A Manual of In Situ Conservation*. Earthscan, London, Washington DC.

Huntley, B., Berry, P., Cramer, W., and McDonald, A. (1995). Modelling present and potential future ranges of some European higher plants using climate response surfaces. *Journal of Biogeography*, *22*(6), 967–1001. https://doi.org/10.2307/2845830.

Hurford, C. (2006). Identifying the Conservation Priority. In C. Hurford and M. Schneider (Eds.), *Monitoring Nature Conservation in Cultural Habitats* (pp. 61–64). Springer, New York. https://doi.org/10.1007/1-4020-3757-0_7.

HWS Database. (2012). *Harmonized world soil (HWS) Database (version 12)*. FAO, IIASA. Available at: http://webarchive.iiasa.ac.at/ Research/ LUC/ External-World-soil-database/HTML/.

Idle, E., and Bines, T. J. H. (2004). *Management Planning for Protected Areas: a Guide for Practitioners and Their Bosses.* Darwin Initiative and English Nature, London, UK.

IPCC (Intergovernmental Panel on Climate Change), (2014). Summary for Policymakers. In C. Field, V. Barros, D. Dokken, K. Mach, M. Mastrandrea, T. Bilir, M. Chatterjee, K. Ebi, Y. Estrada, R. Genova, B. Girma, E. Kissel, A. Levy, S. MacCracken, P. Mastrandrea, and L. White (Eds.), *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 1–32). Cambridge University Press.

IPCC (Intergovernmental Panel on Climate Change), (2019). *Climate Change and Land. An IPCC Special Report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. Summary for Policymakers.* Available at: https://www.ipcc.ch/site/assets/uploads/2019/08/Fullreport-1.pdf.

Iriondo, J. M., and De Hond, L. (2008). Crop wild relative *in situ* management and monitoring: The time has come. In N. Maxted, B. V. Ford-Lloyd, S. P. Kell, J. M. Iriondo, M. E. Dulloo, and J. Turok (Eds.), *Crop Wild Relative Conservation and Use* (pp. 319–330). CAB International, Wallingford. https://doi.org/10.1079/9781845930998.0319.

Iriondo, J. M., Maxted, N., and Dulloo, M. E. (Eds.), (2008). *Conserving Plant Genetic Diversity in Protected Areas*. CAB International, Wallingford.

Iriondo, J. M. (2011). *Atlas y Libro Rojo de la Flora Vascular Amenazada de España. Manual de Metodología del Trabajo Corológico y Demográfico*. Dirección General de Medio Natural y Política Forestal (Ministerio de Medio Ambiente, y Medio Rural y Marino)-Sociedad Española de Biología de la Conservación de Plantas. Madrid, Spain.

Iriondo, J. M., Maxted, N., Kell, S., Ford-Lloyd, B. V, Lara-Romero, C., Labokas, J., and Magos Brehm, J. (2012). Quality standards for genetic reserve conservation of crop wild relatives. In N. Maxted, M. E. Dulloo, B. V. Ford-Lloyd, L. Frese, J. M. Iriondo, and M. A. A. Pinheiro de Carvalho (Eds.), *Agrobiodiversity Conservation: Securing the Diversity of Crop Wild Relatives and Landraces* (pp. 72–77). CAB International, Wallingford. https://doi.org/10.1079/9781845938512.0072.

IUCN/SCC (2013). *Guidelines for Reintroductions and Other Conservation Translocations. Version 1.0.* (p. 57). IUCN Species Survival Commission, Gland, Switzerland.

IUCN-WCPA Task Force on OECMs (2019). Recognising and Reporting Other Effective Area-Based Conservation Measures. Gland, Switzerland: IUCN.

Jain, S. K. (1975). Genetic reserves. In O. H. Frankel and J. G. Hawkes (Eds.), *Crop* *genetic resources for today and tomorrow* (pp. 379–396). Cambridge University Press.

Jarvis, A., Reuter, H. I., Nelson, A., and Guevara, E. (2008). *Digital Elevation Models (DEM) of the Shuttle Radar Topography Mission (SRTM) Hole-filled SRTM for the globe Version 4*. http://srtm.csi.cgiar.org

Jarvis, S., Fielder, H., Hopkins, J., Maxted, N., and Smart, S. (2015). Distribution of crop wild relatives of conservation priority in the UK landscape. *Biological Conservation*, *191*, 444–451. https://doi.org/10.1016/j.biocon.2015.07.039

Kamburova, V. S., Nikitina, E. V., Shermatov, S. E., Buriev, Z. T., Kumpatla, S. P., Emani, C., and Abdurakhmonov, I. Y. (2017). Genome Editing in Plants: An Overview of Tools and Applications. In *International Journal of Agronomy* (Vol. 2017). https://doi.org/10.1155/2017/7315351

Karagöz, A. (1998). *In situ* conservation of plant genetic resources in Ceylanpınar State Farm. In N. Zencirci, Z. Kaya, Y. Anikster, and W. T. Adams (Eds.), *The proceedings of international symposium on in situ conservation pf plant diversity* (pp. 87–92). Central Research Institute for Field Crops.

Karger, D., Conrad, O., Böhner, J., Kawohl, T., and Kreft, H. (2017). *Climatologies at high resolution for the earth's land surface areas. Sci Data 4: 170122*.

Kell, S., Maxted, N., and Bilz, M. (2012). European crop wild relative threat assessment: Knowledge gained and lessons Learnt. In N Maxted, M. Dulloo, B. Ford-Lloyd, L. Frese, J. Iriondo, and M. Pinheiro de Carvalho (Eds.), *Agrobiodiversity Conservation: Securing the Diversity of Crop Wild Relatives and Landraces* (pp. 218–242). CAB International. https://doi.org/10.1079/9781845938512.0218

Kelly, E., and Phillips, B. (2015). Targeted gene flow for conservation. *Conservation Biology*, *30*(2), 259–267. https://doi.org/10.1111/cobi.12623

Kleinschmit, J., Kownatzki, D., and Gregorius, H. (2004). Adaptational characteristics of autochthonous populations—Consequences for provenance delineation. *Forest Ecology and Management*, *197*(1–3), 213–224. https://doi.org/https://doi.org/10.1016/j.foreco.2004.05.037

Kreyling, J., Bittner, T., Jaeschke, A., Jentsch, A., Steinbauer, J., Thiel, D., and Beierkuhnlein, C. (2011). Assisted Colonization: A Question of Focal Units and Recipient Localities. *Restoration Ecology*, *19*(4), 433–440. https://doi.org/10.1111/j.1526-100X.2011.00777.x

Kuhfuss, L., Le Coent, P., Préget, R., and Thoyer, S. (2015). Agri-environmental schemes in Europe: Switching to collective action. In J. Bennett (Ed.), *Protecting the Environment, Privately* (pp. 273–293). World Scientific Publishing Co. https://doi.org/10.1142/9789814675444_0013

Laguna, E. (1999). The plant micro-reserves programme in the region of Valencia , Spain. In H. Synge and J. Ackroyd (Eds.), *Second European Conference on the Conservation of wild plants. Proceedings Planta Europa 1998* (pp. 181–185). The Swedish Threatened Species Unit and Plantlife.

Lenoir, J., and Svenning, J. C. (2015). Climate-related range shifts - a global multidimensional synthesis and new research directions. *Ecography*, *38*(1), 15–28. https://doi.org/10.1111/ecog.00967

Lusty, C., Guarino, L., Toll, J., and Lainoff, B. (2014). Genebanks: past, present, and optimistic future. In N. Van Alfen (Ed.), *Encyclopedia of Agriculture and Food Systems* (pp. 417–431). Elsevier.

Magos Brehm, J., Gaisberger, H., Kell, S., Parra-Quijano, M., Thormann, I., Dulloo, M. E., and Maxted, N. (n.d.). Conservation planning of crop wild relative diversity in the SADC region. *(In Prep.)*.

Magos Brehm, J., Kell, S., Thormann, I., Gaisberger, H., Dulloo, M.E. and Maxted, N. (2017). Interactive Toolkit for Crop Wild Relative Conservation Planning version 1.0. University of Birmingham, Birmingham, UK and Bioversity International, Rome, Italy. Available at: www.cropwildrelatives.org/conservation-toolkit.

Mannetti, L. M., Göttert, T., Zeller, U., and Esler, K. J. (2019). Identifying and categorizing stakeholders for protected area expansion around a national park in Namibia. *Ecology and Society*, *24*(2). https://doi.org/10.5751/ES-10790-240205-

Maxted, N, Ford-Lloyd, B. V, and Hawkes, J. (1997a). Complementary conservation strategies. In N. Maxted, B. Ford-Lloyd, and J. Hawkes (Eds.), *Plant Genetic Conservation: The in situ Approach* (pp. 20–55). Chapman & Hall, London. https://doi.org/10.1007/978-94-009-1437-7_2.

Maxted, N., Guarino, L. and Dulloo, M.E., (1997b). Management and monitoring. In N. Maxted, B. Ford-Lloyd, and J. Hawkes (Eds.), *Plant Genetic Conservation: The in situ Approach*, (pp. 231-258). Chapman & Hall, London.

Maxted, N, Hawkes, J., Ford-Lloyd, B. V, and Williams, J. (1997c). A practical model for *in situ* genetic conservation. In N. Maxted, B. Ford-Lloyd, and J. Hawkes (Eds.), *Plant Genetic Conservation: The In Situ Approach* (pp. 339–367). Chapman & Hall, London. https://doi.org/https://doi.org/10.1007/978-94-009-1437-7_22.

Maxted, N, Ford-Lloyd, B. V, Jury, S., Kell, S., and Scholten, M. (2006). Towards a definition of a crop wild relative. *Biodiversity and Conservation*, *15*(8), 2673–2685. https://doi.org/10.1007/s10531-005-5409-6.

Maxted, N, Iriondo, J. M., De Hond, L., Dulloo, M. E., Lefèvre, F., Asdal, Å., Kell, S., and Guarino, L. (2008a). Genetic reserve management. In J. M. Iriondo, N. Maxted, and M. Dulloo (Eds.), *Conserving Plant Genetic Diversity in Protected Areas* (pp. 65–87). CAB International, Wallingford.

Maxted, N, Ford-Lloyd, B. V, and Kell, S. (2008b). Crop wild relatives: establishing the context. In N. Maxted, B. Ford-Lloyd, S. Kell, J. Iriondo, M. Dulloo, and J. Turok (Eds.), *Crop Wild Relative Conservation and Use*. CAB International, Wallingford.

Maxted, N., and Kell, S. (2009). Establishment of a global network for the *in situ* conservation of crop wild relatives: status and needs. *FAO Commission on Genetic Resources for Food and Agriculture*, 1–266. Rome, Italy.

Maxted, N, Kell, S., Ford-Lloyd, B. V, Dulloo, M. E., and Toledo, Á. (2012). Toward the systematic conservation of global crop wild relative diversity. *Crop Science*, *52*(2), 774–785. https://doi.org/10.2135/cropsci2011.08.0415.

Maxted, N., Kell, S., Brehm, J. M., and Kell, S. (2013). Crop Wild Relatives and Climate Change. In Jackson, M., Ford-Lloyd, B., and Parry, M. (Eds.). *Plant Genetic Resources and Climate Change*, (pp. 114-134). CAB International. Wallingford.

Maxted, N, and Palmé, A. (2015). Combining *ex situ* and *in situ* conservation strategies for CWR to mitigate climate change. In Valdani Vicari and Associati, Arcadia International, Wageningen UR: Centre for Genetic Resource the Netherlands, Plant Research International and the socio-economics research Institute, and Fungal Biodiversity Centre of the Royal Academy of Arts and Science and Information and Coordination Centre for Biological Diversity of the German Federal Office for Agriculture and Food (Eds.), *Better Integration of Ex Situ and In Situ Approaches Towards*

Conservation and Sustainable Use of GR at National and EU Level: From Complementarity to Synergy. Workshop Report for Preparatory action on EU plant and animal genetic resources (AGRI-2013-EVAL-. Directorate General for Agriculture and Rural Development, European Commission.

Maxted, N, Avagyan, A., Frese, L., Iriondo, J. M., Magos Brehm, J., Singer, A., and Kell, S. (2015a). ECPGR concept for *in situ* conservation of crop wild relatives in Europe. *European Cooperative Programme for Plant Genetic Resources*, *March*, 1–19.

Maxted, N, Avagyan, A., Frese, L., Iriondo, J. M., Magos Brehm, J., Singer, A., and Kell, S. (2015b). *Preserving diversity: a concept for in situ conservation of crop wild relatives in Europe: Version 2.* Available at: www.pgrsecure.org/documents/Concept_v2.pdf.

Maxted, N, Amri, A., Castañeda-Álvarez, N. P., Dias, S., Dulloo, M. E., Fielder, H., Ford-Lloyd, B. V, Iriondo, J. M., Brehm, J. M., Nilsen, L. B., Thormann, I., Vincent, H., and Kell, S. (2016). Joining up the dots: a systematic perspective of crop wild relative conservation and use. In Maxted, N., Dulloo, M. E., and Ford-Lloyd, B. V. (Eds.). *Enhancing Crop Genepool Use: Capturing Wild Relative and Landrace Diversity for Crop Improvement*, (pp. 87–124). CAB International, Wallingford. https://doi.org/10.1079/9781780646138.0087.

Maxted, N, Labokas, J., and Palmé, A. (2017). Crop wild relative conservation strategies. Planning and implementing national and regional conservation strategies. *Proceedings of a Joint Nordic/ECPGR Workshop*.

Maxted N., Hunter D., and Ortiz-Ríos R. (Eds.), (2020). *Plant Genetic Conservation*. Cambridge University Press. https://doi.org/10.1017/9781139024297.

McCouch, S., Baute, G., Bradeen, J., Bramel, P., Bretting, P., Buckler, E., Burke, J., Charest, D., Cloutier, S., Cole, G., Dempewolf, H., Dingkuhn, M., Feuillet, C., Gepts, P., Grattapaglia, D., Guarino, L., Jackson, S., Knapp, S., Langridge, P., … Zamir, D. (2013). Agriculture: Feeding the future. *Nature*, *499*(7456), 23–24.

McCoy, H. (2019). *Plant Genetic Engineering*. Callisto Reference, Forest Hills, New York, USA.

McDonald-Madden, E., Runge, M., Possingham, H., and Martin, T. (2011). Optimal timing for managed relocation of species faced with climate change. *Nature Climate Change*, *1*(5), 261–265. https://doi.org/10.1038/nclimate1170.

Midgley, G. F., Hannah, L., Millar, D., Rutherford, M. C., and Powrie, L. W. (2002). Assessing the vulnerability of species richness to anthropogenic climate change in a biodiversity hotspot. *Global Ecology and Biogeography*, *11*(6), 445–451. https://doi.org/10.1046/j.1466-822X.2002.00307.x.

Morris, W. F., and Doak, D. F. (2002). *Quantitative Conservation Biology: Theory and Practice of Population Viability Analysis.* Sinauer, Massachusetts, USA.

Mussmann, S. M., Douglas, M. R., Anthonysamy, W. J. B., Davis, M. A., Simpson, S. A., Louis, W., and Douglas, M. E. (2017). Genetic rescue, the greater prairie chicken and the problem of conservation reliance in the Anthropocene. *Royal Society Open Science*, *4*(2). https://doi.org/10.1098/rsos.160736.

O'Connor, M., Selig, E., Pinsky, M., and Altermatt, F. (2012). Toward a conceptual synthesis for climate change responses. *Global Ecology and Biogeography*, *21*(7), 693–703. https://doi.org/10.1111/j.1466-8238.2011.00713.x.

Painting, K. A., Perry, M. C., Denning, R. A., and Ayad, W. G. (1993). *Guidebook for Genetic Resources Documentation A self-teaching approach to the understanding, analysis and development of genetic resources documentation*. International Plant Genetic Resources Institute, p. 295. Available at: https://cgspace.cgiar.org/handle/10568/104239

Parmesan, C., and Yohe, G. (2003). A globally coherent fingerprint of climate change impacts across natural systems. *Nature*, *421*(6918), 37–42. https://doi.org/10.1038/nature01286.

Phillips, J., Magos Brehm, J., van Oort, B., Asdal, Å., Rasmussen, M., and Maxted, N. (2017). Climate change and national crop wild relative conservation planning. *Ambio*, *46*(6), 630–643. https://doi.org/10.1007/s13280-017-0905-y.

Pickering, R., Niks, R., Johnston, P., and Butler, R. (2004). Importance of the Secondary Genepool in Barley Genetics and Breeding II. Disease Resistance, Agronomic Performance and Quality. *Czech Journal of Genetics and Plant Breeding*, *40*(3), 79–85. https://doi.org/10.17221/3703-cjgpb.

Pinheiro de Carvalho, M. A. A., Nóbrega, H., Freitas, G., Fontinha, S., and Frese, L. (2011). Towards the establishment of a genetic reserve for *Beta patula aiton*. In N. Maxted, M. E. Dulloo, B. V. Ford-Lloyd, L. Frese, J. M. Iriondo, and M. A. A. Pinheiro de Carvalho (Eds.), *Agrobiodiversity Conservation: Securing the Diversity of Crop Wild Relatives and Landraces* (pp. 36–44). CAB International, Wallingford. https://doi.org/10.1079/9781845938512.0036.

Pinheiro de Carvalho, M. Â. A., Bebeli, P. J., Barata da Silva, A. M., Bettencourt, E., Slaski, J. J., and Dias, S. (2016). Agrobiodiversity: The Importance of Inventories in the Assessment of Crop Diversity and Its Time and Spatial Changes. In Ahuja M., Jain S. (Eds) G*enetic Diversity and Erosion in Plants*. Sustainable Development and Biodiversity, vol 8. Springer, Cham. (pp. 307–335). https://doi.org/10.1007/978-3-319-25954-3_9.

Rowe, J., and Maxted, N. (2019). *Lathyrus belinensis. The IUCN Red List of Threatened Species 2019: e.T176094A120103864.* https://dx.doi.org/10.2305/IUCN.UK.2019-2.RLTS.T176094A120103864.en.

Rubio Teso, M. L., Álvarez-Muñiz, C., Gaisberger, H., Kell, S., Lara-Romero, C., Magos-Brehm, J., Maxted, N., and Iriondo, J. M. (2020). *Crop wild relatives in Natura 2000 network* (p. 36). https://www.eurosite.org/wp-content/uploads/FP-Eurosite-Webinar-June-2020.pdf.

Safriel, U., Anikster, Y., and Waldman, M. (1997). Management of nature reserves for conservation of wild relatives and the significance of marginal populations. *Bocconea*, *7*, 233–239. Available at: http://www.herbmedit.org/bocconea/7-233.pdf.

Sánchez-Velásquez, L. (1991). *Zea diploperennis*: mejoramiento genético del maíz, ecología y la conservación de recursos naturales. *Tiempos de Ciencia*, *24*, 1–8.

Savolainen, O., Lascoux, M., and Merilä, J. (2013). Ecological genomics of local adaptation. *Nature Reviews Genetics* 14(11), pp. 807–820). https://doi.org/10.1038/nrg3522.

Schiffers, K., Bourne, E., Lavergne, S., Thuiller, W., and Travis, J. (2013). Limited evolutionary rescue of locally adapted populations facing climate change. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *368*(1610). https://doi.org/10.1098/rstb.2012.0083.

SDG. (2016). *The Sustainable Development Goals Report*. United Nations publication issued by the Department of Economic and Social Affairs (DESA), New York, USA. Available at: https://unstats.un.org/sdgs/report/2016/The%20Sustainable%20Development%20Goals%20Report%202016.pdf.

Serra, L., Pérez-Rovira, P., Deltoro, V., Fabregat, C., Laguna, E., and Pérez-Botella, J. (2004). Distribution, status and conservation of rare relict plant species in the Valencian community. *Bocconea*, *16*(2), 857–863.

Sgro, C., Lowe, A., and Hoffmann, A. (2011). Building evolutionary resilience for conserving biodiversity under climate change. *Evolutionary Applications*, *4*(2), 326–337. https://doi.org/10.1111/j.1752-4571.2010.00157.x.

Shands, H. L. (1991). Complementarity of Insitu and Ex-Situ Germplasm Conservation from the Standpoint of the Future User. *Israel Journal of Botany*, *40*, 521–528.

Stein, A., and Moser, C. (2014). Asset planning for climate change adaptation: Lessons from Cartagena, Colombia. *Environment and Urbanization*, *26*(1), 166–183. https://doi.org/10.1177/0956247813519046.

Stolton, S., Maxted, N., Ford-Lloyd, B., Kell, S., and Dudley, N. (2006). *Food Stores. Using Protected Areas to secure Crop Genetic Diversity* (p. 135). Available at: http://siteresources.worldbank.org/INTBIODIVERSITY/Resources/beyondbelief_final__2.pdf.

Suggitt, A. J., Wilson, R. J., August, T. A., Beale, C. A., Bennie, J. J., Dordolo, A., Fox, R., Hopkins, J. J., Isaac, N. J. B., Jorieux, P., MacGregor, N. A., Marcetteau, J., Massimino, D., Morecroft, M. D., Pearce-Higgins, J. W., Walker, K., and Maclean, I. M. D. (2014). *Climate Change Refugia for the Flora and Fauna of England* (N. E. C. Reports (Ed.)). Natural England. Available at: www.naturalengland.org.uk/copyright.

Thomas, L., and Middleton, J. (2003). Guidelines for Management Planning of Protected Areas. IUCN, Gland, Switzerland. https://doi.org/10.2305/iucn.ch.2003.pag.10.en

Thormann, I. (2020). The German Network of Genetic Reserves. *Crop Wild Relative Newsletter*, *12*, 23–26.

Thrush, S., Hewitt, J., Dayton, P., Coco, G., Lohrer, A., Norkko, A., Norkko, J., and Chiantore, M. (2009). Forecasting the limits of resilience: Integrating empirical research with theory. *Proceedings of the Royal Society B: Biological Sciences* 276(1671), pp. 3209–3217). https://doi.org/10.1098/rspb.2009.0661.

Thuiller, W., Lavorel, S., Araújo, M. B., Sykes, M. T., and Prentice, I. C. (2005). Climate change threats to plant diversity in Europe. *Proceedings of the National Academy of Sciences of the United States of America*, *102*(23), 8245–8250. https://doi.org/10.1073/pnas.0409902102.

USAID. (2005). *Biodiversity Conservation: A Guide for USAID Staff and Partners*. New York, USA. Available at: https://pdf.usaid.gov/pdf_docs/PNADE258.pdf

Valdani Vicari and Associati (VVA), Arcadia International, Wageningen University (WUR): Centre for Genetic Resource (CGN) Plant Research International (PRI) and the socio-economics research institute (LEI), Fungal Biodiversity Centre of the Royal Academy of Arts and Science (CBS-KNAW), and Information and Coordination Centre for Biological Diversity of the German Federal Office for Agriculture and Food (BLE/IBV). (2015).

The impact of climate change on the conservation and utilisation of crop wild relatives in Europe. Workshop Report for Preparatory action on EU plant and animal genetic resources (AGRI-2013-EVAL-7).

Valdani Vicari and Associati (VVA), Arcadia International, Wageningen University (WUR): Centre for Genetic Resource (CGN) Plant Research International (PRI) and the socio-economics research institute (LEI), Fungal Biodiversity Centre of the Royal Academy of Arts and Science (CBS-KNAW), and Information and Coordination Centre for Biological Diversity of the German Federal Office for Agriculture and Food (BLE/IBV). (2016). *Preparatory action on EU plant and animal genetic resources. Final report.*

Varty, A., and Zedler, J. (2008). How waterlogged microsites help an annual plant persist among salt marsh perennials. *Estuaries and Coasts*, *31*(2), 300–312. https://doi.org/10.1007/s12237-007-9019-2.

Vincent, H., Wiersema, J., Kell, S., Fielder, H., Dobbie, S., Castañeda-Álvarez, N. P., Guarino, L., Eastwood, R. J., Lén, B., and Maxted, N. (2013). A prioritized crop wild relative inventory to help underpin global food security. *Biological Conservation*, *167*, 265–275. https://doi.org/10.1016/j.biocon.2013.08.011.

Vogler, D., Macey, S., and Sigouin, A. (2017). Stakeholder Analysis in Environmental and Conservation Planning. *Lessons in Conservation*, *7*, 5–16. Available at: www.nps.gov/ncrc.

Volis, S., and Blecher, M. (2010). Quasi *in situ*: A bridge between *ex situ* and *in situ* conservation of plants. *Biodiversity and Conservation*, *19*(9), 2441–2454. https://doi.org/10.1007/s10531-010-9849-2.

Waddington, C. H. (1968). Towards a theoretical biology. *Nature*, *218*(5141), 525-527.

Wainwright, W., Drucker, A. G., Maxted, N., Magos Brehm, J., Ng'uni, D., and Moran, D. (2019). Estimating *in situ* conservation costs of Zambian crop wild relatives under alternative conservation goals. *Land Use Policy*, *81* (June 2018), 632–643. https://doi.org/10.1016/j.landusepol.2018.11.033.

Weeks, A. R., Sgro, C. M., Young, A. G., Frankham, R., Mitchell, N. J., Miller, K. A., Byrne, M., Coates, D. J., Eldridge, M. D. B., Sunnucks, P., Breed, M. F., James, E. A., and Hoffmann, A. (2011). Assessing the benefits and risks of translocations in changing environments: A genetic perspective. *Evolutionary Applications*, *4*(6), 709–725. https://doi.org/10.1111/j.1752-4571.2011.00192.x.

Whiteley, A., Fitzpatrick, S., Funk, W., and Tallmon, D. (2015). Genetic rescue to the rescue. In *Trends in Ecology and Evolution* 30(1), pp. 42–49). https://doi.org/10.1016/j.tree.2014.10.009.

Wilkening, J., Pearson-Prestera, W., Mungi, N., and Bhattacharyya, S. (2019). Endangered species management and climate change: When habitat conservation becomes a moving target. *Wildlife Society Bulletin*, *43*(1), 11–20. https://doi.org/10.1002/wsb.944.

Young, J. C., Jordan, A., R. Searle, K., Butler, A., S. Chapman, D., Simmons, P., and Watt, A. D. (2013). Does stakeholder involvement really benefit biodiversity conservation? *Biological Conservation*, *158*, 359–370. https://doi.org/10.1016/j.biocon.2012.08.018.

Appendices

Appendix 1. Useful terms on crop wild relative in situ conservation and management

Accessions: Distinct, uniquely identified samples of seeds, plants, or other germplasm materials, collected at a given time and that are maintained as an integral part of a germplasm collection (genebank) (Maxted *et al.*, 2015a).

Agrobiodiversity or agricultural biodiversity: All components of biological diversity of relevance to food and agriculture, and all components of biological biodiversity that constitute agro-ecosystems: the variety and variability of animals, plants and micro-organisms, at the genetic, species and ecosystem levels, which are necessary to sustain key functions of the agricultural ecosystem, its structure and processes (CBD, COP decision V/5, appendix - http://www.cbd.int/decision/cop/?id=7147).

Allele: Each of all alternative forms of a gene.

Conservation management plans: The plans that should be prepared for the species that require some form of management intervention to ensure the continued maintenance of viable population(s) (Hunter and Heywood, 2011).

Crop wild relatives (CWR): Plant taxa closely related to crops (or any socio-economically valuable species), which may be crop progenitors and to which the CWR may contribute beneficial traits, such as pest or disease resistance, yield improvement or stability. They are generally defined in terms of any wild taxon belonging to the same genus (or closely related genera) as the crop. A more detailed definition based on the ability of the taxa to cross with the crop or their taxonomic placement describes CWR as those taxa that belong to Gene Pools 1 or 2, or Taxon Groups 1 to 4 of the crop (Maxted *et al.*, 2006).

Ecogeography: Scientific discipline that studies the environment in relation to the geographical distribution of living organisms.

***Ex situ* conservation:** The conservation of components of biological diversity outside their natural habitats (CBD, 1992). It involves the location, sampling, transfer and storage of samples of the target taxa away from their native habitat (Maxted *et al.*, 1997a).

Gap analysis: a systematic method to identify gaps at *in situ* and *ex situ* conservation actions of specific taxa or particular traits. It involves the comparison of actual performance with potential or desired performance.

Gene bank: A facility where plant diversity is stored in the form of seeds, pollen, *in vitro* culture or DNA or, in the case of a field gene bank, as plants growing in the field (Maxted *et al.*, 2015a).

Genetic erosion: The loss over time of genetic diversity caused by either natural or man-made processes (Maxted *et al.*, 2015a).

Gene pool: The collection of all genes in an interbreeding population. Three gene pool classes are considered: Gene Pool GP1A–cultivated forms of the crop, GP1B-wild or weedy forms of the crop, GP2– secondary wild relatives (less closely related species from which gene transfer to the crop is possible but difficult using conventional breeding techniques), GP3–tertiary wild relatives (species from which gene transfer to the crop is impossible, or if possible, requires sophisticated techniques, such as embryo rescue, somatic fusion or genetic engineering) (Harlan and Wet, 1971).

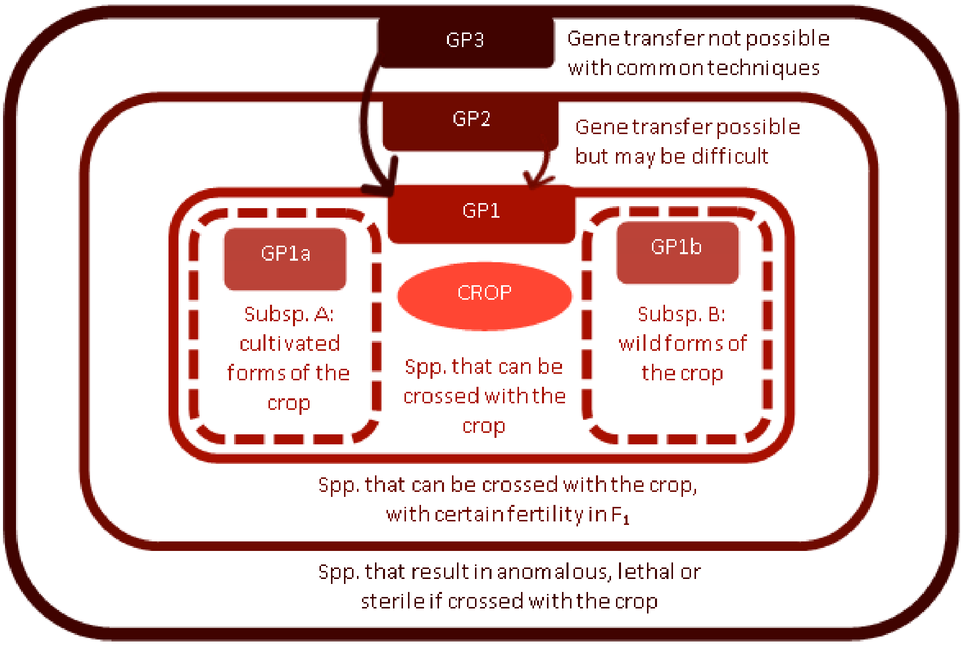


Figure 20. Gene pool concept.

Genetic reserve: An area designated for the management and monitoring of the genetic diversity of one or several plant species in its natural habitat. The occurrences selected for genetic reserves altogether represent the intra-specific diversity of the species and together form the network of genetic reserves https://netzwerk-wildsellerie.julius-kuehn.de/index.php?menuid=45andreporeid=47

Genetic resources: Any material of plant, animal, microbial or other origin containing functional units of heredity, of actual or potential value (CBD, 1992).

Genome: Set of all genetic material of an individual living organism.

Genotype: Particular allelic composition for a given gene or a set of genes of an individual.

Germplasm: Sexual or vegetative propagating materials of plants (Maxted *et al.*, 2015a).

Inbreeding: Breed from closely related relatives or selfing.

***In situ* conservation:** 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 (CBD, 1992). It involves the location, designation, management and monitoring of populations to conserve a particular species within its natural habitat or where it has developed its distinctive characteristic (Maxted *et al.*, 1997a).

Most Appropriate Wild Populations (MAWPs): MAWP is an actively conserved *in situ* CWR population that has been prioritized for being of most value and designated to be part of a conservation network at the national or regional level. It needs to meet a number of criteria in order to be included in the CWR conservation strategy (Maxted *et al.*, 2015a).

Outbreeding depression: Reduction of fitness as a result of crosses between two genetically distant groups or populations (Frankham *et al.*, 2011).

Phenotype: set of observable characters of an organism determined by the interaction of its genotype with the environment.

Plant Genetic Resources for Food and Agriculture (PGRFA): Any genetic material of plant origin of actual or potential value for food and agriculture (FAO, 2009). PGRFA consists of the diversity of genetic material contained in traditional varieties and modern cultivars grown by farmers as well as crop wild relatives and other wild plant species that can be used as food, and as feed for domesticated animals, fibre, clothing, shelter, wood, timber, energy, etc. (Maxted *et al.*, 2015a).

Population: All individuals of the same taxonomic group present in the same geographical area and capable of interbreeding (Maxted *et al.*, 2015a). From a genetic resources perspective and to delimitate a population to establish a genetic reserve, this should include all individuals that actually interbreed and constitute a distinct evolutionary unit *sensu* Kleinschmit *et al.* (2004).

Protected area: A clearly defined geographical space, recognized, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values (Dudley, 2008).

Taxon Group: Taxon group (TG) for a crop is a concept to apply to crop wild relatives when information about the gene pool they belong to is not available. It is based on taxonomic relatedness and six different groups are identified (Figure 21): TG1a (crop), TG1b (same species as crop), TG2 (same series or section as crop), TG3 (same subgenus as crop), TG4 (same genus), and TG5 (same tribe but different genus to crop) (Maxted *et al.*, 2015a).

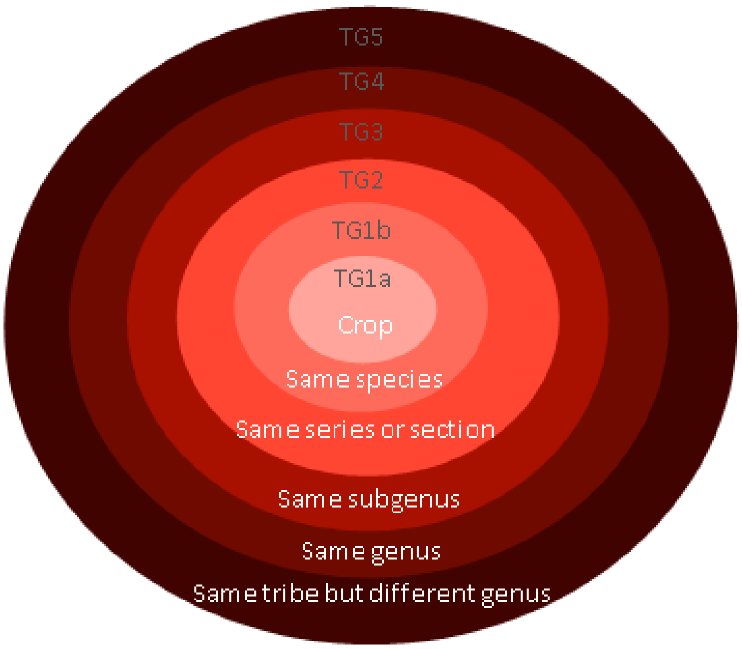


Figure 21. Taxon Group concept.

Appendix 2. Sample data sheets for target population documentation

Table S1. Sample data sheet to document population size, along with definition of population, individual, georeferencing, and information on herbarium specimens obtained at the population

Direct population census		
Taxon:		Date:
Population:		GPS coordinates:
Threshold distance between populations:		Definition of individual:
Name of data collector:		
Direct census		
Mature individuals:	Vegetative individuals:	Seedlings:
Herbarium specimen:		Observations:

Table S2. Sample data sheet to document population size in a plot/transect, along with definition of population, individual, georeferencing, and information on herbarium specimens obtained at the population.

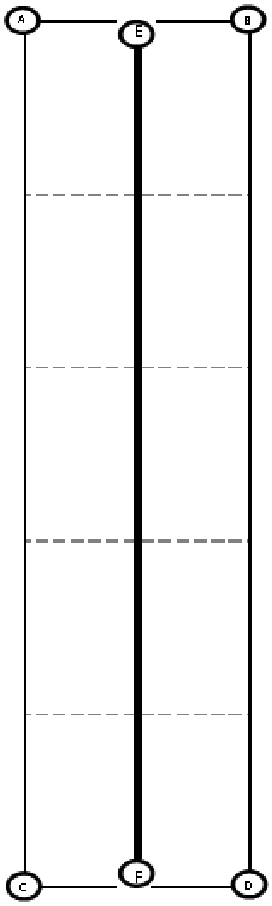
Estimation of population size: Plot/transect data		
Taxon:		Date:
Population:		GPS coordinates:
Threshold distance between populations:		Definition of individual:
Name of data collector:		
Plot/Transect number:		Plot/transect coordinates:
		A:
		B:
		C:
		D:
		E:
		F:
Mature individuals:	Vegetative individuals:	Seedlings:
Herbarium specimen:		Observations:

Table S3. Sample data sheet to estimate population size in a population from information obtained from data gathered, along with definition of population, individual, georeferencing, and information on herbarium specimens obtained at the population.

Estimation of population size: Population results						
Taxon:			Date:			
Population:			GPS coordinates:			
Threshold distance between populations:			Definition of individual:			
Name of data collector:						
Plot/ Transect No.	Plot/ Transect area (m^2)	No. mature individuals recorded	Density (ind/m^2)	Occupancy area (m^2)	Estimated population size	Observations
Herbarium specimen:			Observations:			

Table S4. Sample sheet with list of abiotic variables that can be obtained from the sources mentioned in Table 4 for the physical characterisation of the genetic reserve.

ABIOTIC COMPONENTS		
Genetic reserve:		
Type of information	Variable	Value
Topographic (Jarvis *et al.*, 2008)	Elevation	
	Northness	
	Eastness	
	Slope	
Edaphic (HWS Database, 2012)	Organic Carbon	
	pH	
	Water storage capacity	
	Soil depth	
	Cation exchange capacity of the soil and the clay fraction	

	Total exchangeable nutrients
	Lime and gypsum contents
	Sodium exchange percentage
	Salinity
	Textural class
	Granulometry
Climate (Fick and Hijmans, 2017)	Annual Mean Temperature
	Mean Diurnal Range
	Isothermality
	Temperature Seasonality
	Max Temperature of Warmest Month
	Min Temperature of Coldest Month
	Temperature Annual Range
	Mean Temperature of Wettest Quarter
	Mean Temperature of Driest Quarter
	Mean Temperature of Warmest Quarter
	Mean Temperature of Coldest Quarter
	Annual Precipitation
	Precipitation of Wettest Month
	Precipitation of Driest Month
	Precipitation Seasonality
	Precipitation of Wettest Quarter
	Precipitation of Driest Quarter
	Precipitation of Warmest Quarter
	Precipitation of Coldest Quarter

Table S5. Sample data sheet to gather information on biotic components in a genetic reserve.

BIOTIC COMPONENTS			
Genetic Reserve:			
Target CWR:			
Type of information	Common name	Scientific name	Abundance (low, medium, high, very high)
Co-occurring plants			
Pests and diseases			
Herbivores			
Pollinators			
Seed dispersers			

Appendix 3. Sample sheet to gather information on threat assessments of target CWR populations in the genetic reserve, based on the International Union for Conservation of Nature (IUCN) Threats Classification Scheme (https://www.iucnredlist.org/resources/threat-classification-scheme).

THREAT ASSESSMENT			
Genetic reserve:			
Target CWR:			
Threat type	Timing	Scope	Severity
1 Residential and commercial development			
1.1 Housing and urban areas			
1.2 Commercial and industrial areas			
1.3 Tourism and recreation areas			
2 Agriculture and aquaculture			
2.1 Annual and perennial non-timber crops			
2.1.1 Shifting agriculture			
2.1.2 Small-holder farming			
2.1.3 Agro-industry farming			
2.1.4 Scale Unknown/Unrecorded			
2.2 Wood and pulp plantations			
2.2.1 Small-holder plantations			
2.2.2 Agro-industry plantations			
2.2.3 Scale Unknown/Unrecorded			
2.3 Livestock farming and ranching			
2.3.1 Nomadic grazing			
2.3.2 Small-holder grazing, ranching or farming			
2.3.3 Agro-industry grazing, ranching or farming			
2.3.4 Scale Unknown/Unrecorded			
2.4 Marine and freshwater aquaculture			
2.4.1 Subsistence/artisanal aquaculture			
2.4.2 Industrial aquaculture			
2.4.3 Scale Unknown/Unrecorded			

THREAT ASSESSMENT
3 Energy production and mining
3.1 Oil and gas drilling
3.2 Mining and quarrying
3.3 Renewable energy
4 Transportation and service corridors
4.1 Roads and railroads
4.2 Utility and service lines
4.3 Shipping lanes
4.4 Flight paths
5 Biological resource use
5.1 Hunting and collecting terrestrial animals
5.1.1 Intentional use (species being assessed is the target)
5.1.2 Unintentional effects (species being assessed is not the target)
5.1.3 Persecution/control
5.1.4 Motivation Unknown/Unrecorded
5.2 Gathering terrestrial plants
5.2.1 Intentional use (species being assessed is the target)
5.2.2 Unintentional effects (species being assessed is not the target)
5.2.3 Persecution/control
5.2.4 Motivation Unknown/Unrecorded
5.3 Logging and wood harvesting
5.3.1 Intentional use: subsistence/small scale (species being assessed is the target [harvest]
5.3.2 Intentional use: large scale (species being assessed is the target) [harvest]
5.3.3 Unintentional effects: subsistence/small scale (species being assessed is not the target) [harvest]
5.3.4 Unintentional effects: large scale (species being assessed is not the target) [harvest]
5.3.5 Motivation Unknown/Unrecorded

THREAT ASSESSMENT
5.4 Fishing and harvesting aquatic resources
5.4.1 Intentional use: subsistence/small scale (species being assessed is the target) [harvest]
5.4.2 Intentional use: large scale (species being assessed is the target) [harvest]
5.4.3 Unintentional effects: subsistence/small scale (species being assessed is not the target) [harvest]
5.4.4 Unintentional effects: large scale (species being assessed is not the target) [harvest]
5.4.5 Persecution/control
5.4.6 Motivation Unknown/Unrecorded
6 Human intrusions and disturbance
6.1 Recreational activities
6.2 War, civil unrest and military exercises
6.3 Work and other activities
7 Natural system modifications
7.1 Fire and fire suppression
7.1.1 Increase in fire frequency/intensity
7.1.2 Suppression in fire frequency/intensity
7.1.3 Trend Unknown/Unrecorded
7.2 Dams and water management/use
7.2.1 Abstraction of surface water (domestic use)
7.2.2 Abstraction of surface water (commercial use)
7.2.3 Abstraction of surface water (agricultural use)
7.2.4 Abstraction of surface water (unknown use)
7.2.5 Abstraction of ground water (domestic use)
7.2.6 Abstraction of ground water (commercial use)
7.2.7 Abstraction of ground water (agricultural use)
7.2.8 Abstraction of ground water (unknown use)
7.2.9 Small dams
7.2.10 Large dams
7.2.11 Dams (size unknown)

THREAT ASSESSMENT
7.3 Other ecosystem modifications
8 Invasive and other problematic species, genes and diseases
8.1 Invasive non-native/alien species/diseases
8.1.1 Unspecified species
8.1.2 Named species
8.2 Problematic native species/diseases
8.2.1 Unspecified species
8.2.2 Named species
8.3 Introduced genetic material
8.4 Problematic species/diseases of unknown origin
8.4.1 Unspecified species
8.4.2 Named species
8.5 Viral/prion-induced diseases
8.5.1 Unspecified "species" (disease)
8.5.2 Named "species" (disease)
8.6 Diseases of unknown cause
9 Pollution
9.1 Domestic and urban wastewater
9.1.1 Sewage
9.1.2 Run-off
9.1.3 Type Unknown/Unrecorded
9.2 Industrial and military effluents
9.2.1 Oil spills
9.2.2 Seepage from mining
9.2.3 Type Unknown/Unrecorded
9.3 Agricultural and forestry effluents
9.3.1 Nutrient loads
9.3.2 Soil erosion, sedimentation
9.3.3 Herbicides and pesticides

THREAT ASSESSMENT
9.3.4 Type Unknown/Unrecorded
9.4 Garbage and solid waste
9.5 Air-borne pollutants
9.5.1 Acid rain
9.5.2 Smog
9.5.3 Ozone
9.5.4 Type Unknown/Unrecorded
9.6 Excess energy
9.6.1 Light pollution
9.6.2 Thermal pollution
9.6.3 Noise pollution
9.6.4 Type Unknown/Unrecorded
10 Geological events
10.1 Volcanoes
10.2 Earthquakes/tsunamis
10.3 Avalanches/landslides
11 Climate change and severe weather
11.1 Habitat shifting and alteration
11.2 Droughts
11.3 Temperature extremes
11.4 Storms and flooding
11.5 Other impacts
12 Other options

Appendix 4. Recommended descriptors for Crop Wild Relatives conserved under in situ conditions (CWRI v.1) (Alercia et al., 2020).

1. Genus
2. Species
3. Species authority
4. Subtaxon
5. Subtaxon authority
6. Country of occurrence
7. Location of occurrence site
7.1. Name of the location or nearest place
7.2. Distance to site
7.2.1 Type of distance
7.3 Direction from nearest named place
8. Latitude of occurrence site
9. Longitude of occurrence site
10. Coordinate *datum*
11. Elevation of site
12. Site protection
13. Observation date
14. Population identifier
15. Collecting number
16. Status of occurrence site
17. Biological status of the population
18. Managing institute, legal entity or individual name
18.1 Managing institute or individual address
19. Name of the institute holding *ex situ* samples
19.1 Address of the holding organization or individual
20. Code of the institute holding *ex situ* samples
20.1 FAO WIEWS institute code
20.2 Index Herbariorum code
21. Accession/specimen number
21.1 *Ex situ* accession number
21.2 Herbarium specimen number
22. Conservation actions in place
23. MLS status of the material
24. Links to associated information (URL)
25. Remarks