PRO-GRACE

PROMOTING A PLANT GENETIC
RESOURCE COMMUNITY FOR EUROPE

DELIVERABLE 1.3

Systems for describing, managing, and accessing *in situ* conserved populations and interfacing with EURISCO

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Promoting a plant genetic resource community for Europe

Deliverable No. D1.3

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Table of Contents

Abbreviations

CBD	Convention on Biological Diversity
CGIAR	Consultative Group on International Agricultural Research
CWR	Crop wild relative
DOI	Digital object identifier
ECPGR	European Cooperative Programme for Crop Genetic Resources Networks
EURISCO	European Search Catalogue for Plant Genetic Resources
FAO	Food and Agriculture Organization of the UN
GIS	Geographic information system
GR	Genetic reserve
GRC	Genetic Resource Centre
ITPGRFA	International Treaty for Plant Genetic Resources for Food and Agriculture
IUCN	International Union for the Conservation of Nature and Natural Resources
KBA	IUCN Key Biodiversity Areas
LR	Crop landrace
MAWP	Most Appropriate Wild Population
NBSAP	National Biodiversity Strategy and Action Plan
NUS	Neglected and under-utilized Species
OECM	Other effective area-based conservation measures
PA	Protected area
PGR	Plant genetic resource
PGRFA	PGR for food and agriculture
WFP	Wild food plants
WHP	Wild harvested species

Summary

This project deliverable reviews the value of PGR diversity in relation to crop varietal improvement in a rapidly changing environment. The main components of PGR are defined, but the review focuses on CWR, WHP and LR diversity and implementation of conservation strategies and techniques, while stressing the link between PGR conservation and use. The principles of PGR Conservation and Use Congruence are introduced, they are to ensure: (a) long-term, sustainable, maintenance of PGR diversity, (b) active conservation of crop, varietal and CWR diversity using complementary techniques, and (c) conserved resource availability for utilisation. Assessment of whether conservation actions meets the principle's three objectives allows validation of the conservation approach applied.

To understand how *in situ* / on-farm conservation of PGR 'works', the components that constitute *in situ* genetic reserve and on-farm conservation are summarised, from creation of checklist and inventories, through conservation planning, target population management and monitoring, to pheno- and genotypic resource description, and utilization by farmers, breeders and other end users. The argument is made that *in situ* genetic reserve and on-farm of CWR, WHP and LR diversity conservation cannot be achieved without collaboration between national Genetic Resource Centre (GRC) staff (or other appropriate national PGR agency or PGR-based NGOs) and PGR field population maintainers (i.e. reserve / protected area managers, landowners, farmers or gardeners). Also, that because the resource is maintained outside of a controlled managed unit, the local community to the *in situ* / on-farm resource must be willing collaborators. Whether conserving CWR / WHP in genetic reserves within PA or OECM sites or LR on-farm, there is a practical logic in linking the sites and populations in PGR *in situ* or on-farm national and European networks and this infrastructure integration is reviewed. The need for monitoring standards to ensure the long-term effectiveness of conservation actions is presented, both in the context of managing and monitoring *in situ* and on-farm populations, and for membership and review of membership of PGR *in situ* or on-farm networks.

PGR conservation is distinct from other forms of biodiversity conservation, as for PGR conservation the end point is not conservation itself, but the use of the conserved resource. Therefore, it is critical, when describing *in situ* or on-farm applications, how the user accesses diversity? Initially it may be thought directly from the conserved resource either in nature or cultivated on-farm, but this is impractical as the resource maintainer (i.e., farmer, land owner, PA manager) generally do not have the necessary skills or resources to meet user demands. Five alternative options are discussed, but the preferred option is via *in situ* backup and end user supply, in which the *in situ* maintainer send an *in situ* sample to a nominated national GRC for *ex situ* backup, here the samples is stored using a bespoke minimal processing route and the *in situ* sample is then made available to users.

To further aid user access to the *in situ* conserved resource, there is a need for possible access and any characterisation and evaluation information to be flagged to potential users. The existing means of user selection of accessions in genebank collections is providing additional descriptive data (passport, characterization, and evaluation) to users via EURISCO – the European search catalogue for conserved PGR. A recently implemented application, which extends EURISCO to cover information on both *ex situ* and *in situ* conserved germplasm, is described and critically evaluated.

Horizon scanning in a community driven process that enables future threats and opportunities to be identified. The process was first applied to PGR conservation in Europe at a symposium in Funchal, Madeira in 2010. Sufficient time has now elapsed to review the successes of the short- and long-term priorities agreed in 2010 and then now to propose fresh issues to be resolved by 2035. The review of the 2010 European PGR horizon scanning short-term issues had a mixed success, for CWR all countries now have CWR checklist / inventories, but very few have National CWR Strategies and Action Plans or implemented CWR genetic reserves, while for LR issues, there are a few partial national LR inventories and there is limited use of European conservation variety, protected designation of origin or protected geographical indication designations to promote LR maintenance, but positively a methodology for LR threat assessment has recently been proposed. As a result, some 2010 horizon scanning issues are reiterated in the new list, along with further issues more recently highlighted. Finally, the most critical contemporary PGR conservation issues are here elaborated.

Preface

PRO GRACE is developing a concept for a novel European Research Infrastructure, GRACE-RI, which will address the growing challenges of PGR threat mitigation and conservation of its breadth of diversity, while facilitating its potential exploitation for wealth creation and food security across Europe. Deliverable D1.3 is specifically focusing on describing, managing, and accessing *in situ* conserved populations, including the interfacing of conserved resource descriptive data with EURISCO – the Search Catalogue for European PGR. By understanding how *in situ* conservation 'works', we can better plan effective and efficient data flow, management, and analyses. Thus, D1.3 is linked to D2.3, which uses the conservation experience presented to build and integrate *in situ* PGR conservation data descriptors for the benefit of PGR stakeholders and broader societal benefit. The target audience are therefore PGR conservationists, germplasm users, informaticians, and biodiversity policy makers.

1. Introduction

Plant genetic resources (PGR), the taxonomic and genetic diversity of plants that is of value as a resource for the present and future generations of humans (IPGRI, 1991), are the basis of food and economic security, and their intrinsic value, conservation and use is of existential importance for humankind. Specifically, they are defined by the nature of the resource conserved and utilised, which form an array of plant types between the most advanced cultivars and wild species, which includes:

- **Current cultivars** —Generally genetically uniform or clonal crop varieties bred by plant breeders, and currently on national varietal lists and cultivated by farmers, the exception being forage and grasses or service plants where commercial varieties may be a selection from a wild population.
- **Obsolete cultivars** — Former cultivars that are no longer commercially grown and may not appear on current national variety lists, but which may possess genes useful to plant breeders.
- **Breeding lines, clones, populations and genetic stocks** — Material used by plant breeders to develop new cultivars and for basic agricultural, biodiversity or environmental research.
- **Crop Landraces** (LR) — Dynamic population(s) of a cultivated plant that have historical origin, distinct identity and lacks formal crop improvement, as well as often being genetically diverse, locally adapted and associated with traditional farming, horticultural and cultural systems. The term LR here includes many synonyms such as farmers, folk, heritage, heirloom, and traditional varieties, as well as new organic and landraces.
- **Crop Wild Relatives** (CWR) — Wild plant taxa that are closely related to a crop, and may be crossed with the crop, either using conventional or genetic engineering techniques, to introduce adaptive beneficial genes/traits for crop improvement.
- **Wild Food Plants** (WFP) — Wild food plants are taxa that naturally occur in nature and the food is collected from the wild and consumed as food by humans or other animals.
- **Wild Harvested Plants** (WHP) — Wild harvested plants are species that naturally occur in nature and are not cultivated, but are collected from the wild for their medical, forestry, recreational or ornamental value, as well as including WFP.

Another category that might be include are **Neglected and Underutilised Crops** (NUS), but strictly they are like any other kind of crop, composed of modern or obsolete cultivars, breeders lines or landraces, though they have significant potential for further cultivation / production.

The aim of PGR conservation is to maximise the maintenance of genetic diversity, but further it is explicitly utilitarian, it is also to ensure the conserved resource is available for utilisation (Figure 1). The model of plant genetic conservation includes a series of steps starting with the full range of genetic diversity for all plant species, through the prioritisation of target taxa, the planning of conservation action, the implementation of the conservation action and leading through characterisation and evaluation to farmer, breeder, or researcher-based utilisation. The application of this model is at the core of global, regional, national, and local efforts to achieve food security, poverty alleviation and the well-being of humankind, enabling many of the UN Sustainable Development Goals (UN, 2015) to be attained. Central to the model of plant genetic conservation are two general strategies for conservation, each composed of a range of specific techniques. The two strategies are *ex situ* and *in situ* conservation defined by the Convention on Biological Diversity (CBD, 1992) thus:

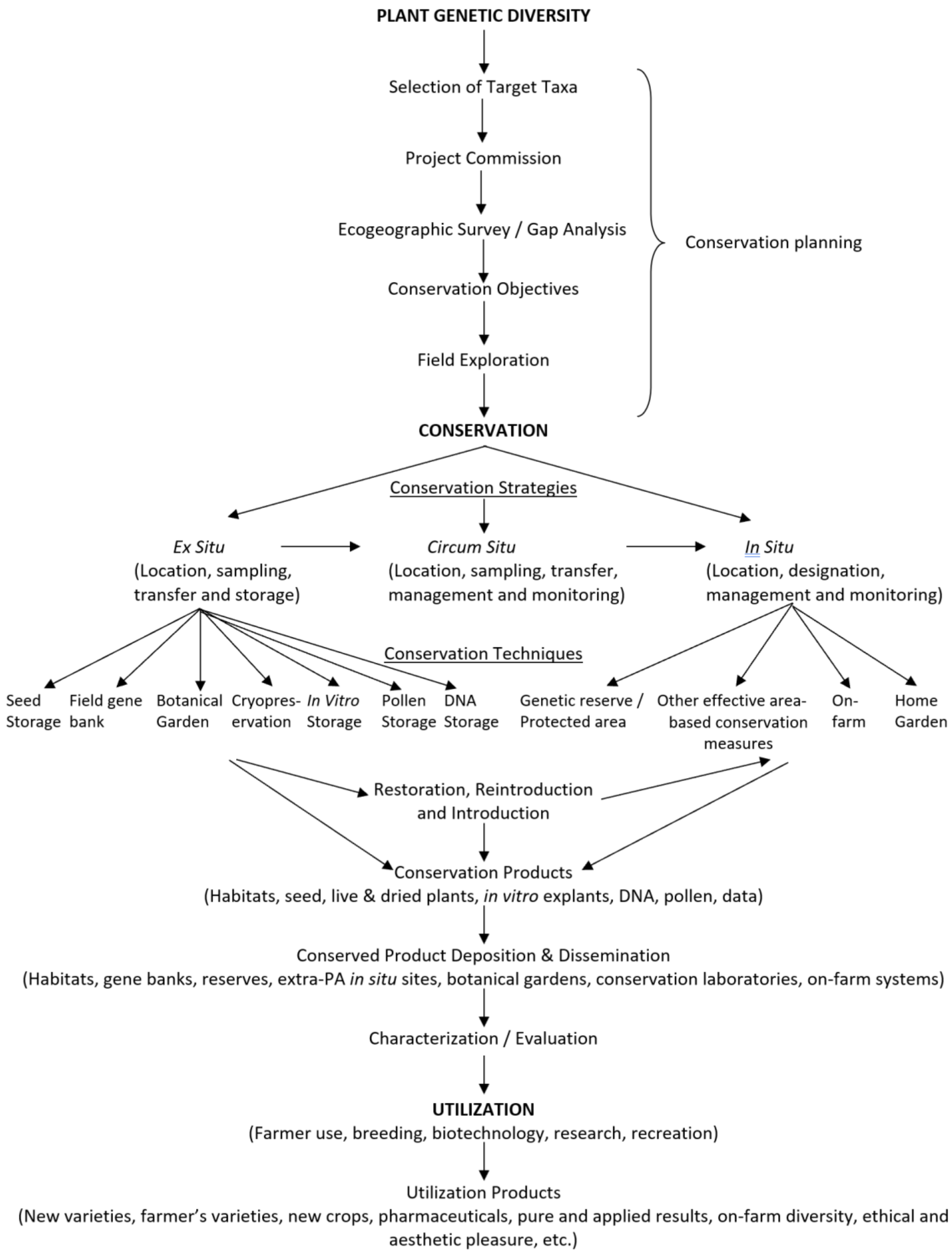

Figure 1. Model of plant genetic conservation (adapted from Maxted *et al.*, 1997a).

> "*Ex situ* conservation means the conservation of components of biological diversity outside their natural habitats."
>
> "*In situ* conservation means 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 domesticates or cultivated species, in the surroundings where they have developed their distinctive properties."

There is an obvious fundamental difference between these two strategies: *ex situ* conservation involves the location, sampling, transfer and storage of the species, the resource is conserved away from the original location where they were found. Whereas *in situ* conservation involves the location, designation, management, and monitoring of species at the location where they grow naturally or are cultivated. The two general strategies are subdivided into specific conservation techniques (Table 1).

Table 1. Genetic conservation strategies and techniques (Maxted *et al.*, 2020).

Strategies	Techniques	Definition
Ex situ conservation	Seed storage	The sampling, transfer, and storage of seed at a low moisture content (≈10-25% RH), and sub-zero temperature (≈-20ºC)[1].
	Cryopreservation	The sampling, transfer, and storage of tissue (seed, pollen, shoot tips, dormant bud) samples at ultra-low temperature (-196ºC).
	In vitro storage	The sampling, transfer, and maintenance of explants at low temperature in sterile, pathogen-free environment on nutrient media.
	DNA / Pollen / Tissue Storage	The sampling, transfer and storage of DNA, pollen, or tissue in sub-zero temperatures (≈-20ºC).
	Field gene bank storage	The sampling, transfer, and maintenance of living plants under field or plantation conditions.
	Botanic garden / Arboretum	The sampling, transfer, and maintenance of living plants (tree species for arboreta) in a garden.
In situ conservation	Genetic reserve conservation	The location, management, and monitoring of genetic diversity of natural wild populations within formally managed, defined areas, designated for active, long-term conservation.
	Other effective area-based conservation measures	The location, management, and monitoring of genetic diversity of natural or naturalised wild populations in informally managed, defined areas, designated for active, medium to long-term conservation. In practice, CWR / WHP populations are often found as weeds in on-farm or in anthropogenic habitats (e.g., historic sites, graveyards, verges).
	On-farm conservation	The location, management, and monitoring of genetic diversity of locally developed traditional crop varieties, with associated wild and weedy species or forms, by farmers often within traditional agricultural, horticultural, or agri-silvicultural cultivation systems.
	Home garden	The location, management, and monitoring of genetic diversity of locally developed traditional crop varieties or forms by a householder within their individual garden, backyard, or orchard cultivation systems for home consumption.

[1] This describes the methodology used for standard long-term seed storage, but higher temperatures (0-10°C) may also be used for medium-term, storage of 'active collections'. While 'community seed banks' (CSB) may also employ air/sun-drying (or reactivable desiccants) of seed samples and their stored in hermetic sealed plastic/glass containers at even higher ambient temperatures.

In terms of *in situ* conservation, the conserved plant types may be cultivated, such as landraces (LR), or wild, such as crop wild relatives (CWR) or wild harvested species (WHP). LR are ''Dynamic population(s) of a cultivated plant that have historical origin, distinct identity and lacks formal crop improvement, as well as often being genetically diverse, locally adapted and are often associated with traditional farming, horticultural and cultural systems'' (Camacho Villa *et al.*, 2007; Maxted *et al.*, 2020). Whereas CWR are 'wild plant taxa that are relatively closely related to a crop, and may be crossed with the crop, either using conventional or genetic engineering techniques, to introduce adaptive beneficial genes/traits for crop improvement' (Maxted *et al.*, 2006). WHP are non-cultivated, wild plant species that are harvested from nature to be consumed as food or drink or serve some other human use value (Teixidor-Toneu *et al.*, 2022); it is from these species that crops were originally domesticated. In subsistence farming systems, WFP specifically are often utilized in times of scarcity and/or hunger (FAO *et al.*, 2023; Harisha *et al.*, 2023) and may also be periodically used due to their strong cultural and traditional associated value (Pinela *et al.*, 2017).

2. The Principles of PGR Conservation and Use Congruence

The aim of PGR conservation may be summarised in three fundamental principles, to ensure:

a. *long-term, sustainable, maintenance of plant genetic resource diversity,*
b. *active conservation of crop, varietal and related wild taxon diversity using complementary techniques, and*
c. *conserved resource availability for utilisation.*

The use of complementary techniques is a means of providing additional security by using multiple, diverse approaches to conserve the resource, which ensures greater security as each technique backs-up and supplements the others applied. There could as well be other subordinate objectives, such as maintaining seed viability, phenotypic / genotypic characterization, ensuring standard material transfer agreement (SMTA) enforcement, etc., but these three fundamental objectives should hold true for whatever form of conservation strategy is applied. Together these objectives may be referred to as the *Principles of PGR Conservation and Use Congruence* – overall, conservation should in the long-term maintain the full breadth of genetic diversity, employ multiple conservation techniques, and make the conserved resource available to actual or potential users.

These three objectives are routinely met for *ex situ* holdings – *ex situ* PGR conservation and use is well tested, and we know it already 'works' – but there is now a need to further develop *in situ* conservation approaches. Hawkes (1991) commented in the early 1990s that *in situ* techniques were in their "infancy", and although advances in this area have been made (Maxted *et al.*, 2020), *in situ* and on-farm conservation is still largely experimental and not based on 60 years of practice and the associated evidence base as is *ex situ* conservation. Additionally, effective standardization of *in situ* conservation techniques is itself challenging, as their application occurs in natural or semi-natural environments, or on-farm locations where diverse socio-cultural factors impact the target taxa and site managers (e.g., farmers, foresters, estate managers, etc.) are not professional conservationists. This is not to devalue the efforts of farmers or other LR maintainers, who have been actively engaged in maintaining LR diversity for millennia. However, the clear implication of the principles is that if *in situ* PGR conservation is to 'work' and be appropriately resourced, it must meet all three principles and objectives as *ex situ* approaches. The *in situ* resource must maintain populations and diversity in the long-term, there must be complementary application of techniques, and the conserved resource must be available to users. This may initially seem a rather trivial point, but if *in situ* PGR conservation does not ensure availability of the conserved resource, it will not meet the *Principles of PGR Conservation and Use Congruence*, it is unlikely ever to be seen as truly complementary to *ex situ* conservation and so will not reach its use potential in harnessing the full diversity within CWR for wealth creation and food security.

3. Description of *in situ* / on-farm conservation process

To understand how *in situ* / on-farm conservation 'works' and describe its many processes is a misnomer in the sense that, unlike *ex situ* seed conservation, there are very few examples of active *in situ* or on-farm conservation that have been or can be observed, analysed, and reported. As such, their description is closer to a proposal for what *a priori* is believed should be done to achieve the three core objectives of PGR conservation and use congruence, i.e., maximise long-term, sustainable maintenance of PGR populations by applying a mix of conservation techniques and ensuring the conserved resource is freely available for utilisation, in the *in situ* context. What do we propose would be the ideal PGR conservation – utilization pathway? Once this is clarified, the associated data can be standardized for collation and monitoring by the responsible authority (national focal point or other), and recognition of the conservation management status of a given accession acknowledged. It would also help determine a set of indicators that could be used to evaluate the efficiency of PGR conservation and use and provide a basis for suggested improvements. Such detailed ontological and descriptor review and development will form the basis of D2.3, here the focus is on description of *in situ* application. The conservation – utilization continuum is summarized in Figure 1 (Maxted *et al.,* 1997a) and further elaborated for *ex situ* conservation in Figure 2 (Maxted *et al.,* 2020) and extended to *in situ* conservation in Figure 3. Figures 2 and 3 demonstrate the *Principles of PGR Conservation and Use Congruence* and can be summarized in four essential steps:

1. *Conservation Planning*: PGR diversity is found either growing naturally in nature or as weeds on-farm as CWR or WHP or cultivated either on-farm or in-garden as LR. Its components are:

   a. *Selection of target conservation units* – Given the wealth of PGR diversity and insufficient resources to actively conserve all valued resources immediately, the first step is to prioritize (Maxted *et al.,* 1997a). The *selection of target conservation units* involves choosing which taxa and populations representing CWR or WHP taxa or crop LR need immediate active conservation.

   The prioritization is often based on relative value or threat. For CWR, there are numerous criteria that can be used for prioritization (Maxted *et al.,* 1997b), but most commonly:

   i. *crop value* – higher value crops usually measure as area cultivated or monetary value of the crop product being prioritized;
   ii. *crop relatedness* – the closer the CWR is to the crop, the more likely it is that the CWR will be used for adaptive trait transfer, relative relatedness being established by ease of crossing and genepool concept (Harlan and Wet (1971) or phylogeny taxonomic hierarchy (Maxted *et al.*, 2006);
   iii. *extinction or erosion threat* – the greater the threat, the higher the priority (Kell *et al.*, 2016; Taylor *et al.*, 2017). Threat is commonly estimated using IUCN Red List Criteria and Categories (IUCN, 2012). However, it should be noted that these Criteria are routinely applied at species level and do not take account of the distribution of genetic diversity within each taxon.

   Prioritization allows the extensive CWR checklist (all CWR taxa in a geographic unit) to be reduced to a shorter list that is easier implementable CWR inventory (highest priority CWR).

   The practical conservation of WHP is directly comparable to CWR; they are both simply wild plant species that have food or other utilisation value. The WHP relative worth is associated with direct food or other use, while for CWR they have moderate or no direct food value, as it is the genes or alleles within their genome which are of value not the taxon itself. As for CWR, the numbers of potential WHP taxa is large, and therefore an extensive WHP checklist (all WHP taxa found within a geographic unit) will need to be reduced to an implementable priority WHP inventory for active conservation. The distinction between WHP and CWR in terms of prioritization, is that for WHP crop relatedness would not be an appropriate criterion to prioritize taxa, as ease of gene or trait transfer is not involved, therefore for WHP extinction or erosion threat and commodity value could be used. It should also be noted that in many cases one wild plant species may be both a CWR and a WHP / WFP, or a CWR and WHP; CWR, WFP and WHP are all drawn from a limited subset of wild plant species that overlap when defined like three circles in Venn diagram.

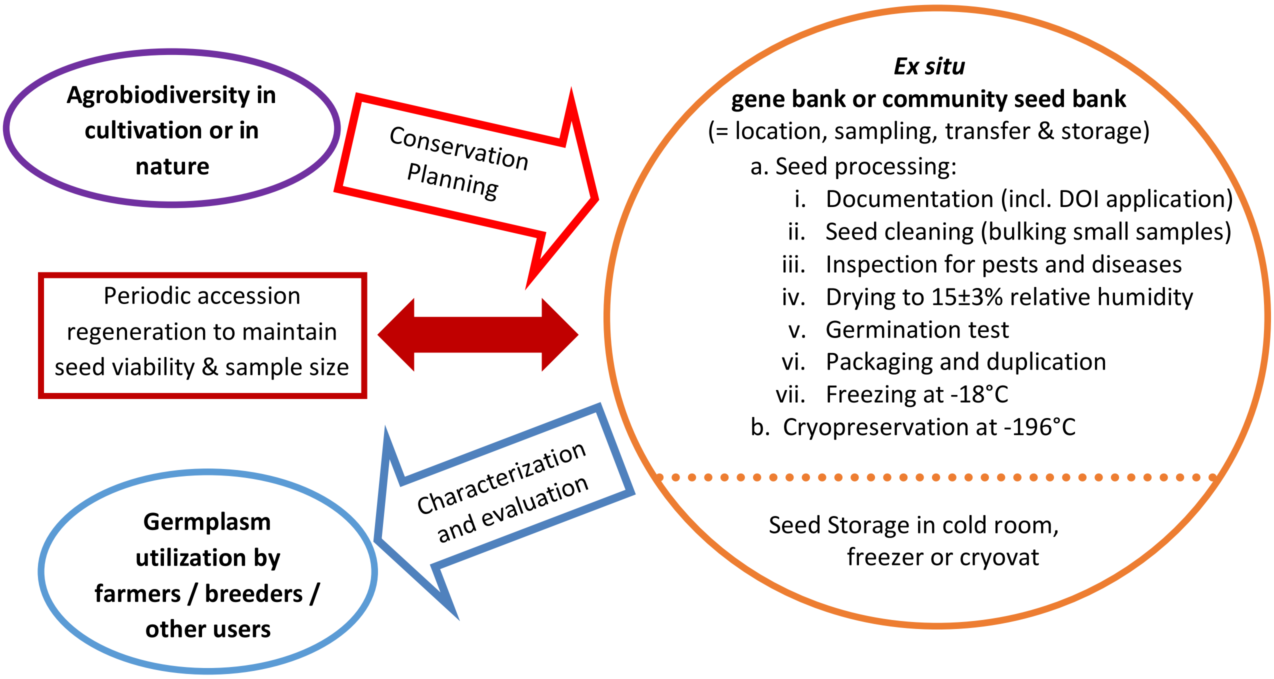

Figure 2. Schematic description of key elements of *ex situ* conservation (Maxted *et al.,* 2020).

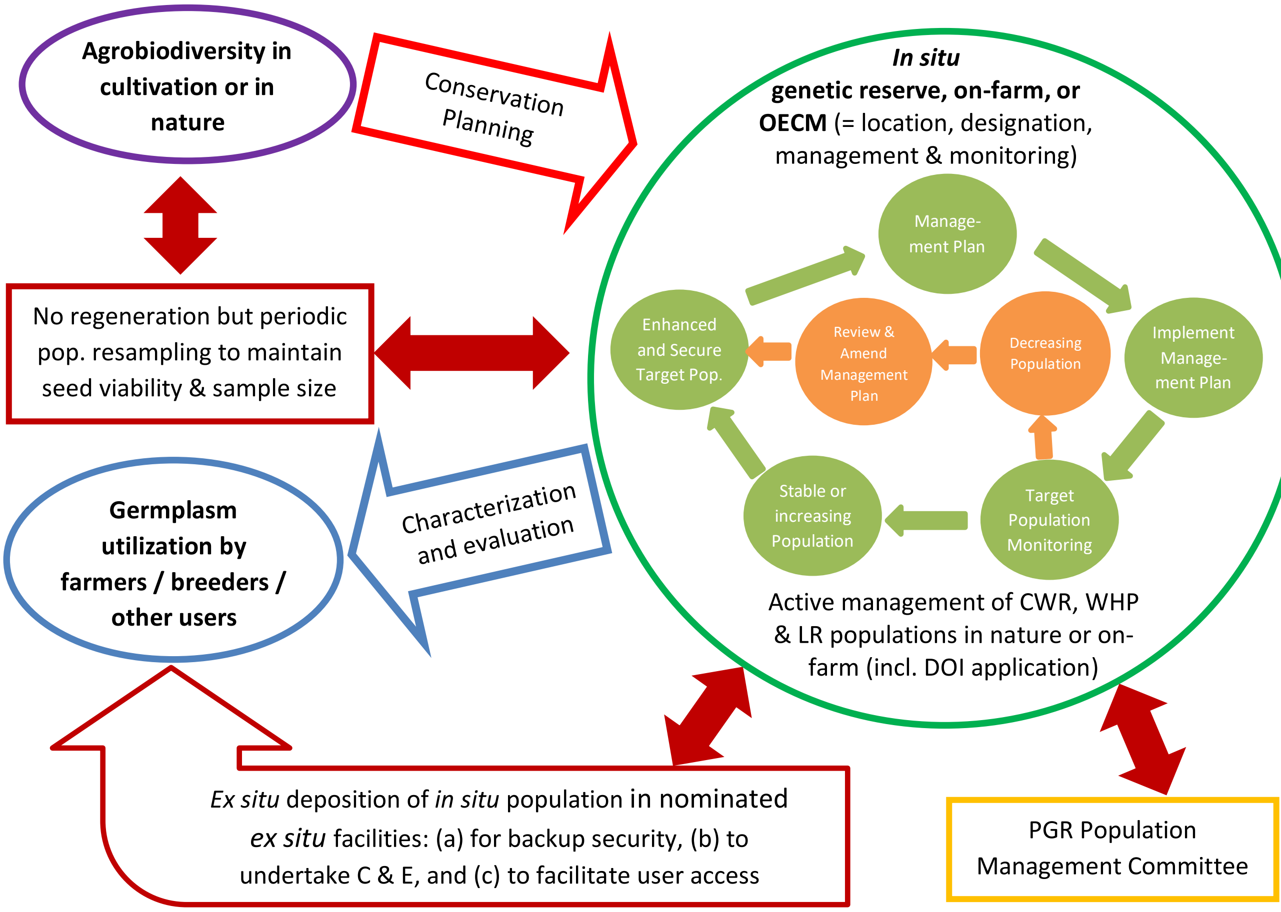

Figure 3. Schematic description of key elements of *in situ* conservation.

Although it can be argued that LR conservation is the earliest form of biodiversity conservation, as soon as crops were domesticated, the maintenance of seeds for cultivation was a priority for community survival. Despite this, the process of on-farm conservation of LR diversity that has sustained diversity since domestication has not been comprehensively described. Only recently are national PGR programmes fully appreciating the value of and threats impacting LR diversity and attempting more systematic conservation (Veteläinen *et al.*, 2009a; Holubec *et al.*, 2020; Raggi *et al.*, 2022). As such, thus far the primary, formal approach to LR conservation has been via *ex situ* techniques, primarily seed storage in genebanks, and active on-farm conservation of LR diversity is absent. The lack of comprehensive active on-farm conservation may be linked to the absence of LR inventories at the local, national, and international levels, as well as an effective method for LR threat assessment. Unless the magnitude and breadth of, and threats toward, LR diversity are known, conservation planning is hindered, and conservation implementation is likely to be ineffective. Hence, historically there has been no need to prioritize LR conservation actions. But as the magnitude and breadth of LR diversity becomes better known, prioritization will be required and it is likely to be based on *crop value*, *relative threat* (applying the newly proposed methodology - Almeida *et al.*, 2024), and the growing need for specific *adaptive traits* to mitigate environmental instability / climate change, or other adaptive requirements.

b. *Ecogeographic and gap analyses* – These activities collate the basic information for the planning of effective *in situ* / on-farm conservation.
   i. Survey the distribution of taxonomic and genetic diversity, ecological requirements, and the reproductive biology of the chosen species over its entire geographic range. Also highlight gaps in *ex situ* collections that might be filled by in situ or on-farm applications.
   ii. Compare the PGR diversity that exists in nature or on-farm with the sample of that diversity that is actively conserved *in situ* / on-farm, to identify gaps in active conservation coverage and better target additional PGR populations for active conservation.
   iii. Where little ecogeographic data are available a preliminary course grid survey mission to collate the necessary background biological data on the species may be required (see Castañeda Álvarez *et al.*, 2011, for details of associated data type to be recorded).

Whether conserving CWR or WHP taxa, or LR diversity, the concentration of conservation units will also be a critical factor in identifying selected sites, the more target taxa or LR present at a site the greater the optimization of resources devoted to *in situ* conservation. In contrast, focusing conservation on sites with only a single CWR, LR or WHP present must be less cost effective (Maxted *et al.*, 2020). It is notable that CWR populations are often found in disturbed anthropogenic habitats, such as field margins, orchards, traditional agricultural systems (Jarvis *et al.*, 2015), as well as habitats not primarily managed for agro-horticultural reasons, such as archaeological and historic sites, graveyards and roadside verges, and military or international borderlands (Labokas *et al.*, 2024). The product of ecogeographic and gap analyses are clear, concise sets of conservation objectives which state the practical steps that must be taken to conserve the species using both *in situ* and *ex situ* techniques, which are climate-smart (the likely impact of climate change considered) and links the conserved diversity to potential utilisation.

c. *Field exploration and alternate site assessment* – For *in situ* / on-farm conservation, there is a larger investment in each PGR population's conservation than for *ex situ*, therefore before establishing the reserve or on-farm active conservation, the competing potential sites will require surveying to 'ground truth' the predictions from the ecogeographic and gap analyses and identify specific locations where target species and genetic diversity are to be conserved in genetic reserves, other effective area-based conservation measure (OECM) sites or on-farm.

The 'ground truthing' should try to ensure that the sites for active PGR population conservation cover the maximum range of genetic diversity and ecological amplitude of the chosen taxa. The populations and sites are actively selected to complement each other and represent the breadth of the CWR, WHP or LR genepools. Although pragmatically, the final selection of sites will be subject to constraints ranging from economic and political to organizational, and final site selection is rarely based on scientific principles alone. The proposed way forward in scientific, economic, and political terms is for countries or regions to establish a network of complementary *in situ* genetic reserves, OECM or on-farm sites, which are scientifically expedient, and likely to engender benefit to local people and humankind through the increased availability of genetic diversity.

2. *Conservation technique implementation*: the CWR, WHP or LR resource is actively managed either in nature for CWR or WHP or cultivated on-farm or in-garden for LR diversity.

a. *Reserve design* – Although individual target taxa will vary depending on their breeding system, life form, etc., generally all sites selected should at least contain the *minimum viable population number* for that target taxon, for most taxa between 5,000-10,000 mature individuals of each target CWR or WHP species, irrespective of pollination or sexual system. This population size is larger than the *effective population number* (N_e) of 500-1000 mature individuals that would be needed to prevent natural or anthropogenic catastrophes causing severe genetic drift or population unsustainability (Hawkes *et al.*, 2000; Dulloo *et al.*, 2008; Iriondo *et al.*, 2021).

An equivalent population size for each LR conserved on-farm has not yet been proposed as the number of individuals that can realistically be conserved varies significantly depending on the specific crops considered. However, given it will be a commercial crop, the population size is likely to be greater than 10,000 individuals for a field crop and potentially fewer for perennial crops like fruit trees. However, given a LR is vulnerable to a farmer deciding to cease cultivation for many reasons (e.g., age, lack of cultivation machinery, lack of product market, etc.; Veteläinen *et al.*, 2009b), ideally a LR population conserved on-farm should be maintained by at least five independent farmers each cultivating ≈10,000 plants per year but fewer for berries, fruits, shrubs and other perennial crops. It can also be noted that when establishing an on-farm site it could involve research and recovery of neglected and even forgotten LR from that location, returning lost LR to commercial production from *ex situ* storage or local community cultivation.

For CWR or WHP taxa conservation, each genetic reserve or OECM site should ideally be surrounded by a buffer zone of the same vegetation type(s), to facilitate immigration of individuals and gene flow, but also where experiments on management regimes might be conducted and visits by the public allowed, under supervision. A similar requirement is unnecessary for LR maintenance on-farm, but it would ideally be desirable for the farmers cultivating LR to employ multiple farming systems in diverse agri-environments to promote genetic diversity retention. Indeed, it has already been found that LR diversity can be highly structured with significant genetic differences occurring between different farmers cultivating the same LR (Tiranti and Negri, 2007).

The conservation of CWR or WHP *in situ* requires close cooperation between a wide diversity of stakeholders — environmental 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 (Iriondo *et al.*, 2021). While stakeholder buy-in is critical to the success of all conservation effort, it is fundamental for successful LR conservation, as here the LR farmers / LR maintainers, are not professional conservationists with the sole goal of conserving the target resource, enabling its continued cultivation, but are engaged in professional food production, which might result in conflicting cultivation priorities. It is important to note that there is not one type of LR farmer / maintainer, ranging from family farms with small-scale production grading to estate-based large-scale production, or whether maintainers engage in experimental production or are active local diversity maintainers. All of these could potentially contribute the LR diversity conservation, therefore, it is essential to ensure collaboration of all key stakeholders from the initial design of the conservation project to its successful implementation.

b. *Formulation of the management plan* – The site and included CWR, WHP or LR populations will have been selected because they contain abundant and potentially genetically diverse populations of the target taxa / crop. Therefore, the first step in formulating the management plan is to observe the current management regime and establish the biotic and abiotic interactions and social / economic / political context of the site. Once these dynamics within the reserve or on-farm site are known and understood, a management plan that incorporates these elements, at least as they relate to target taxa / crop maintenance, can be proposed to effectively conserve the target population(s) whether within a genetic reserve or OECM site.

The management plan should contain Maxted et al. (2008):

i. site description, with definition of the management units;
ii. target taxon/taxa and representative population description;
iii. site characterisation, describing the physical habitat characteristics in terms of topography, geology, soil, and climate, and the co-occurrent plant species, pollinators, herbivores, seed dispersers, pests, and diseases, as well as the existing and potential threats. In addition, for LR details of the farming system, mass selection criteria for LR, cultivation regime, seed/plant multiplication and any product enhancement are also required;
iv. Site human interactions, socio-economic and cultural dimensions of local community and the broader public that impact the sites physical environment, biotic interactions, target populations and their management. Given that many genetic reserves will be established on land not owned or directly managed by conservation agencies, another key component is the written agreement that is made with the landowner, whether it is public or private property, concerning the medium and long-term target population management;
v. management objectives focused on maintaining the viability of target CWR, WHP or LR populations;
vi. prescriptions detailing the actual management intervention to be undertaken to sustain the target populations (for CWR or WHP these may include level / timing of grazing control, burning, erosion control, invasive species control, nutrient control, herbicide usage, disturbance, assisted propagation / breeding or for LR subsidies, development of niche markets, adding value; Raggi *et al.* 2022);
vii. active work plan, containing specific tasks and a time limit for their implementation, required resources, assumptions made, outcomes, role and responsibilities of personnel and budget, and
viii. 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, WHP or LR populations that may affect their viability as well as to determine and assess the outcomes of management actions.

See Iriondo *et al.* (2021) for more detail of data standards for management plan inclusion and Maxted *et al.* (2002) for adaptation of CWR management plans for LR on-farm application. Although, Heywood (2015) notes that for most countries management and recovery plans are too often absent or difficult to obtain. He concludes this makes it difficult to assess the effectiveness of the conservation effort and argues for the creation of a compilation or database of in situ conservation actions and management plans as a basis for conservation management and monitoring.

c. *Implementation of the management plan* – It is unlikely that any management plan will be wholly appropriate when first applied; it will require detailed monitoring of conservation targets and experimentation with the site management before a more stable, beneficial plan can evolve. The plan may involve experimentation with several management interventions to ensure the final plan meets the conservation objectives, particularly in terms of maintaining taxonomic and genetic diversity. *In situ* conservation is a process-oriented way of maintaining genetic resources; it will maintain the evolutionary potential of a population, as well as maintaining effective population sizes. The actual style of the management plan will vary depending on target taxa, location and implementing agency but is likely to cover preamble, conservation context, site abiotic description, site biotic description, site anthropogenic description, general taxon description, site-specific taxon description, site-management policy, taxon and site-population research recommendations and intervention prescription (Iriondo *et al.*, 2008; 2021).

To reiterate, it is important when initiating the management plan to involve local, national, and regional stakeholders to:

i. ensure institutional and financial support to sustain the conserved population;
ii. aid development of an efficient communication strategy;
iii. apply an appropriate information system to register management (actions, decisions), monitoring data and descriptive access data to facilitate user's choice;
iv. review and ensure harmonisation / application of national, regional, and international policies impacting the site, product development and germplasm access; and
v. facilitating links to a back-up genebank to enable access and use of the conserved CWR (Iriondo *et al.*, 2021).

In the LR on-farm context it is important to add that a major concern is securing and adding product value, therefore:

vi. provide enhanced commercial prospects adding value or even developing new niche markets for LR, increasing their value to the maintainer and further securing its continued production.

If the target CWR, WHP or LR populations are 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 frequent monitoring. Several management techniques, including conservation translocations, habitat management and enhancement of evolutionary resilience, can be applied to mitigate the effects of climate change (Maxted *et al.,* 2015a; Iriondo *et al.*, 2021).

The management plan is not fixed permanently, it will require regular amendment following monitoring, particularly if the monitoring indicates reduction in target population sizes or loss of genetic diversity. The periodicity of monitoring will be shorter for annual species / crops, but longer for perennials (for further discussion see Iriondo *et al.*, 2021). Personal experience of conservation in genetic reserves near Madrid, Spain (Iriondo, Pers. Comm.) and outside of formal protected areas was that site management was dynamic and the management plan required amendment every two or three years, in which case employing a concise and dynamic plan was most practical.

d. *Resource monitoring* – Within each genetic reserve, OECM or on-farm site the target populations should be monitored systematically at a set time interval and the results fed back in an iterative manner to enhance the evolving management regime. The monitoring is likely to take the form of measures of taxon abundance (numbers of individuals per taxon), diversity (including direct and/or indirect genetic diversity estimation), density and economic viability of the LR or crop, further discussion of specific data types is provided in Iriondo *et al.* (2008; 2021). There will be a need to establish a clear data management plan and clear workflow between management partners to ensure changes in population characteristic, demographic and genetic, are noted and appropriate management actions taken in response to deleterious changes. Also, increasingly it will be important to survey for the impact of climate change on target populations, as well as using the data in predicting its further impact and in response amending management regimes.

e. *Conserved resource partnerships* – It seems self-evident that unless the third fundamental objective of the *Principles of PGR Conservation and Use Congruence* is met, to ensure the conserved resource is available for utilisation, *in situ* PGR conservation is unlikely to be effective. There is a need to form a partnership with *ex situ* collections (gene bank, field gene bank, *in vitro* banks, botanical gardens or conservation laboratory), not only to provide an *in situ* population safety backup duplication (as a source for target population restoration in times of ecosystem instability), but also to ensure utilisation access to germplasm with the appropriate passport and descriptive data for traditional or local, public and professional users. The target populations should be sampled at regular intervals for *ex situ* backup, to avoid the need for *ex situ* regeneration, ensure that sufficient sample size is available to meet user demands and maintain seed germination levels at agreed genebank standards for PGRFA (FAO, 2014). The conservation site also forms a natural platform for ecological and genetic research, as well as providing educational opportunities for awareness raising at the school, higher educational and public levels.

3. *Conserved resource description*: The first stage of utilisation will involve the recording of genetically controlled characteristics (characterisation), and the material may be grown out under diverse environmental conditions to evaluate the populations for biotic and abiotic tolerance or resistance. Characterization is based on recording simply inherited descriptors that are often highly heritable and are expressed in all environments. The main objective of characterization is to describe and determine the value of plant germplasm, while specific objectives include the true taxonomic identification, suitable morphological description, and assessment of phenotypic variability. Evaluation depends on recording characters showing more complex inheritance and is often influenced by the environment and relationships between characters. Its main objective is the accurate and precise assessment of the agronomic value of genebank accessions (Maxted *et al.*, 2020). Increasingly, morphological and genomic (based on rapidly evolving techniques e.g. DNA barcoding) data is a valuable resource to aid selection of germplasm by breeders, reinforcing the decision to include such data alongside germplasm passport data in EURISCO (2015).

A key question remains, how to characterize and evaluate *in situ* conserved CWR, WHP or LR populations? The resource could be characterized and evaluated *in situ*, at least in theory as the characterization traits are highly heritable, but who would undertake the activity? Barata (Pers. Comm., 2024) reports that such *in situ* characterisation has been employed for medicinal and aromatic species, and for PGR populations this would potentially be feasible for more valuable adaptive traits. But in general, this is thought impractical for protected area managers, landowners, or farmers, who have other professional priorities and limited experience of applying characterization and evaluation techniques. However, predictive characterization and evaluation based on the ecogeographic description of provenance sites may be feasible (Thorman *et al.*, 2014).

A more practical alternative proposal is for the *in situ* population sample that is duplicated *ex situ* to be characterized and evaluated along with the complementary *ex situ* conserved CWR, WHP or LR samples held in the genebank. There is no evidence that the proposed solution has been applied previously and it would require additional genebank resources, but at least in theory it would resolve the *in situ* characterization dilemma. In this case, characterization could be done only once as the descriptors states are genetically fixed, but for other environmentally adaptive traits, the evaluation could be repeated every 10 years as the environment changes. Further, phenotypic characterization of *in situ* populations is likely to require a long-term approach to capture the full range of trait expression across different environmental conditions and life stages. This is important for species with long life cycles (e.g. perennials), where traits may vary significantly over time. Longitudinal studies and repeated measurements are essential to understand the temporal dynamics of these populations.

4. *Utilization*: The *in situ* conserved resource is likely to be used in breeding and biotechnology programmes, either using alleles or genes from CWR as a source of adaptive traits or using the whole or part of the plant for WHP and LR to provide improved food, fuel, medicines, industrial products, as well as also providing recreation and education value at their original location. Particularly with WHP, the collection of the whole plant should be discouraged as it could negate the conservation goal and considered carefully. It is important also note that adaptive changes can occur in *in situ* conserved populations over a relatively short period (Nevo *et al.*, 2012), meaning that if the *in situ* material is obtained for use from its backup in *ex situ* collections, it is appropriate for it to accurately represent the phenotypic and genotypic diversity of the *in situ* population it was sampled from (Nevo *et al.*, 2012). Therefore, such *in situ* backup samples should be taken at regular intervals to ensure they accurately reflect the genetic diversity found in their *in situ* origin populations (discussed further below). Locally the materials held in the reserve, OECM or on-farm

may have traditionally been used as food or in construction, craft, adornment or transport. This form of traditional utilisation of the reserve by local people should be encouraged providing it is not deleterious to the target taxon or taxa. Promoting local traditional use is essential to help foster local support for conservation actions if the reserve is to be sustainable in the medium to long-term. Off-site use will be subject to the CBD and ITPGRFA regulation and therefore there will be a need to establish an access and benefit sharing (ABS) agreement between the original resource provider and the resource beneficiary.

4. Managing *in situ* / on-farm conservation networks

4.1 Management collaboration

The management of CWR, WHP or LR populations in genetic reserves, OECM or on-farm sites has already been partially discussed in the previous descriptive section and Figure 3, but the pertinent question to answer is not only, how the populations are managed, but who should oversee and implement the management interventions? As noted above, given that the conserved genetic resource is actively managed by the reserve / protected area manager, landowner, farmer or even gardener, they might be assumed to be the most appropriate *in situ* management coordinators. However, it is impractical for them to play such a management role given: (a) the lack of practical use to them of the conserved populations, (b) their lack of skills and expertise in field trials or genomic analysis, (c) their existing heavy core activity loads managing biodiversity populations or producing food, (d) the lack of an existing information system to aid *in situ* population management and transfer of germplasm to the end user, and (e) the absence of a multi-site governance authority, a role that might be played by the national PGR responsible agency.

Therefore, as Maxted *et al.* (2016) argued, the practical alternative proposal is for the *in situ* / on-farm population to be managed collaboratively by national Genetic Resource Centre (GRC) staff (or other appropriate national PGR agency or PGR-based NGOs) together with the PGR field population maintainer (i.e. the reserve / protected area manager, landowner, farmer or gardener), resulting in conservationists and population maintainers working successfully together to sustain the critical PGR resource. Further, as the resource is maintained outside of a controlled managed unit, the local community within the vicinity of the *in situ* / on-farm resource must also be willing collaborators in the conservation project. Their roles are likely to vary depending on target taxa and location. Individual role definition should follow from stakeholder discussion and negotiations, but their likely expertise and areas of responsibility are listed in Table 2. While Figure 4, redraws Figure 3 highlighting which elements would be managed by the national GRC staff, except for those directly associated with individual CWR, WHP or LR population management, which by the *in situ* site owner or manager, and which would be undertaken jointly. Collaboration between the National GRC staff and PGR population maintainers in *in situ* conservation would be critical and would be enabled via regular meetings of the PGR *In Situ* Population Management Committee.

Both field population maintainers and national GRC roles would be extended to active management of the target PGR populations and facilitating the availability of the conserved resources availability for use. However, for those maintaining the PGR populations (the field maintainers), given the target populations have ideally been selected because of their 'health', the additional workload is not foreseen as being significant, but the kudos of providing additional food security and ecosystem services would underpin the public goods value of the site they manage. Further, in some countries, it may mean that the additional targeted PGR conservation could generate additional subsidies/added income for the site maintainers / owners through government funding (such as payments for ecosystem services), so the benefit to PGR field population maintainer could be substantial.

The change in management from passive to active may simply be implemented by monitoring of the target populations, rather than a change in the management prescription. As outlined, the change for the national GRC would be more significant but would fall within the existing genebank's remit (ECPGR European Genebank Managers Network; https://www.ecpgr.org/about/genebank-managers-network and ECPGR AEGIS https://www.ecpgr.org/aegis) and would substantially and positively boost the genebank's role in conservation. It would also mean, as argued by Maxted and Magos Brehm (2023), a potential doubling of the diversity available for breeders and other stakeholder's use, which must be a genebank core objective.

Table 2. Collaborative activities of national GRC staff and PGR population maintainers.

CWR, WHP or LR *in situ* population conservation		
National GRC staff's role		*PGR population maintainer's role*
International, national, and local PGR policy development and awareness. Assist with writing and implementation of site management plans.		Preparation and implementation of the site management plan.
Periodic revision of *in situ* site management plan.		Periodic revision of *in situ* site management plan.
National conservation planning.		Management of target populations.
Target population national network management.		Monitoring of target populations.
Target population DOI application, characterization and evaluation.		Periodic collection of target populations for *ex situ* representative backup samples.
Ensuring user access to *in situ* conserved resources (via the *ex situ* backup sample).		Promotion of PGR integration into the broader biodiversity community.
Creation and care of a national database related to *in situ* population conservation and use, except population level information held by maintainers.		Creation and maintenance of network and site database for all *in situ* population conservation management and monitoring information.
Lead and participate in the *PGR* In Situ *Population Management Committee*.		Participation in the *PGR* In Situ *Population Management Committee*.

Although collaborating partners, in terms of target population management, it should be noted that National GRC staff have a specific PGR conservation remit, that those maintaining PGR population *in situ* or on-farm are likely to lack. Yet for the PGR population maintainers such collaboration will involve additional time and other resource commitment, it will have an additional cost, and there is the need to find how to resource this cost, even if envisioned to be a marginal additional cost. While for the National GRC staff, there is also an additional cost of the collaboration, but in their case the additional benefit from conserving and making available for use additional germplasm adds significantly to diversity value of their collections and so better fulfils their professional remit.

As a final point, the collaboration as outlined above and below in Section 6, involves the transfer of *in situ* or on-farm samples from their original locality to a nominated *ex situ* genebank for back-up and to facilitate access for germplasm users. This means application of the International Treaty on PGRFA (FAO, 2001) and CBD Nagoya Protocol (CBD, 2011) are triggered and there is the need for a Material Transfer Agreement (MTA) between the *in situ* maintainer and the recipent nominated genebank. This would need enacting even if the genebank had no intension to utilise the germplasm, but simply conserve the *in situ* or on-farm sample and make it in turn available to more active use. The relationship between the *in situ* or on-farm source, the genebank and the end user would need to address the fair and equitable sharing of benefits arising from the sample's utilization. The actual scope of the three-way (source, genebank and end user) relationship would require expert codification to ensure fair and equitable sharing of any utilization benefits and is therefore beyond the scope of this document but must be in place before any germplasm transfer occurs.

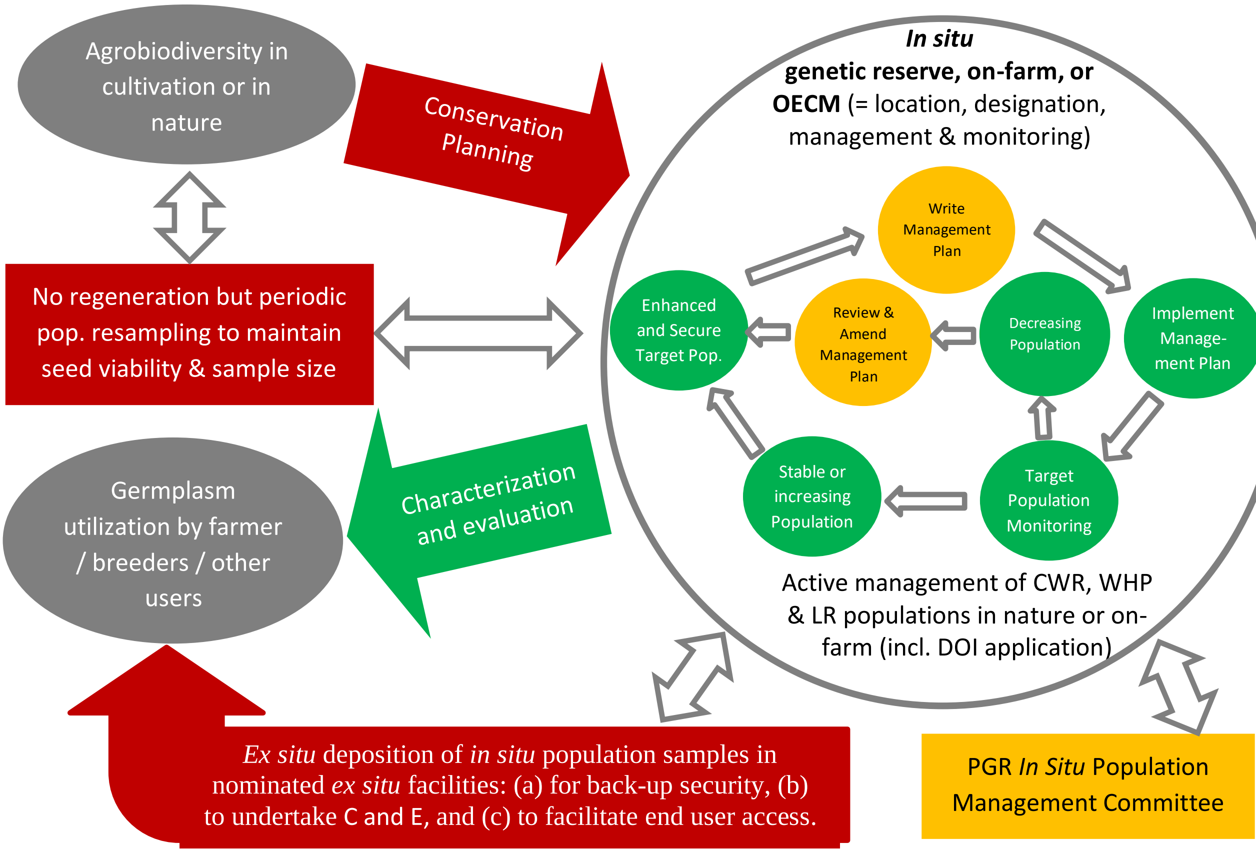

Figure 4. Schematic description of key elements of *in situ* conservation, highlighting GRC staff (dark red outline), *in situ* populations manager (green outline) and joint (gold outline) responsibilities.

4.2 The call to establish PGR *in situ* and on-farm networks

A comprehensive and effective approach to *in situ* conservation aims at the systematic conservation of CWR, WHP and LR diversity as a means of maintaining global food security and meeting continuing demands for consumer choice. It is also recognised that having multiple stand-alone *in situ* sites / populations, each managed independently, would not be as efficient or effective as establishing a series of local, national, regional, or even globally managed networks. The advantage of such *in situ* and on-farm networks would:

- Facilitate systematic coordination and reporting (e.g. for reporting, such as that required for countries that have ratified the Global Plan of Action on PGRFA; FAO, 1996; 2011).
- Foster stronger partnerships and mutual support.
- Integrate global, regional, and national actions.
- Link local communities of practice with common goals.
- Facilitate ABS for protected areas and farmers / farming communities.
- Enable truly integrated, long-term complementary *in situ–ex situ* conservation.
- Promote access to PGR held in protected areas and farming communities via GRC.
- Safeguard evolving *in situ* PGR populations for perpetuity.

In response to this challenge, the FAO Commission on Genetic Resources for Food and Agriculture (CGRFA) called for the development of a network of *in situ* conservation areas to conserve CWR diversity (Activity 4 of the *Global Plan of Action for the Conservation and Sustainable Utilization of Plant Genetic Resources for Food and Agriculture* – FAO 2011). Within this context, the CGRFA commissioned a thematic background study on 'The establishment of a global network for the *in situ* conservation of crop wild relatives: status and needs' (Maxted and Kell, 2009). Preliminary recommendations for establishing such a global network for priority CWR species from the 14 crop gene pools were initially proposed by Maxted and Kell (2009) and extended for 1,261 CWR taxa from 167 major crop genepools by Vincent *et al.* (2019), who identified 170 locations on five continents where 65.7% of the global priority CWR taxa could be conserved *in situ*. Many of these sites were in the centres of crop diversity identified by Vavilov (1926), which remain, with a few additions, the global hotspots of CWR, WHP and LR origin / diversity today (Maxted and Vincent, 2021).

The 13th Regular Session of FAO CGRFA (FAO, 2011) recognized the importance of establishing the global, regional, and national networks for *in situ* CWR conservation and LR on-farm management. The FAO initiated a consultation process and held a technical workshop 'Towards the establishment of a global network for *in situ* conservation and on-farm management of PGRFA' in November 2012, to identify options, ways, and means for establishing networks (FAO, 2014). The discussion agreed the need to establish a broad, decentralized and participatory networks for both CWR *in situ* and LR on-farm conservation to support the coordination of efforts, help raise resources and create more awareness of the value and necessity of *in situ* and on-farm conservation of agrobiodiversity; further implementation is still being actively discussed.

There is a convincing logic for an inter-governmental institution focusing on biodiversity for food security to cooperate with international partners from the environment and agriculture sectors to lead the required research on and establishment of global CWR, WHP and LR diversity networks. They would take the lead in ensuring effective conservation and use, developing supportive policies, generating resources, provide practical tools, methods, and skills (FAO, 2013). However, in practice, all *in situ* actions are necessarily implemented at specific localities, and so national agencies will need to take the lead on practical implementation. There is therefore a parallel onus on developing both global and regional networks, which are both based on a foundation of national CWR, WHP and LR diversity *in situ* national networks of genetic reserves, OECM and on-farm sites. National networks necessarily mean that governments will maintain their national sovereignty over their PGR, but also that national sites, as well as being of national value, may also contribute to the regional and in turn global *in situ* or on-farm networks. There have been regional initiatives to establish *in situ* networks in the Middle East (Amri *et al.*, 2007), Europe (Kell *et al.*, 2016), the Nordic countries (Ansebo, 2015; Fitzgerald *et al.*, 2016, 2019, 2023; Palmé *et al.*, 2019) and the Southern African Development Community (http://www.cropwildrelatives.org/sadc-cwr-project/; Bioversity International, 2016; Magos Brehm *et al.*, 2022). Further, in Europe the 13th meeting of the European Cooperative Programme for Plant Genetic Resources Steering Committee (ECPGR, 2012) acknowledged the importance of *in situ* and on-farm conservation and recommended the development of conservation planning concepts for Europe. These were subsequently proposed by Maxted *et al.* (2015b) and ECPGR (2017). Key elements of these were converted into approaches for action and 2030 targets in the Plant Genetic Resources Strategy for Europe (ECPGR 2021).

The above discussion is primarily limited to CWR, with potential extension to WHP, but it does not relate to the LR networks; considerable progress has been made in *in situ* CWR conservation in recent years, but much less so in LR diversity conservation and associated networking. However, it is especially important to stress that LR cultivation by farmers and its use in maintaining crop production, has been successful for millennia and has resulted in the diversity available today (Brush, 2000; Jarvis *et al.*, 2007, 2016; Veteläinen *et al.*, 2009b; Khanhafkhan and Altieri, 2017). In terms of PGR networking and promotion of LR diversity in Europe, the activities of NGOs, such as Arche Noah, Propelinear, Rete Semi Rurali, Let's Liberate Diversity, and Garden Organic, have made a significant contribution to LR conservation, but their activities have not specifically focused on systematic LR diversity conservation, not surprisingly their focus is on promoting diversity for the benefit of their network members.

Returning to the *Principles of PGR Conservation and Use Congruence*, as a blueprint for how PGR conservation should be practically applied, current NGO-based LR on-farm activities do not meet the three *Principles* (maintain the full breadth of genetic diversity, employ multiple conservation techniques, and make the conserved resource available to any users), so they do not provide an equivalence to *ex situ* gene banking. The prime focus of NGO-based farming systems is promoting diversity in crops and varieties grown (whether native or introduced), not to maximise overall conserved PGR diversity and ensure its availability to all users. The time is overdue for the PGR community to reassess and develop an on-farm conservation approach that does maximise overall systematic PGR diversity and promotes its availability for use either by other farmers or breeders.

Such a goal, as Veteläinen *et al.* (2009a) highlighted, will be difficult to achieve due to the extremely high numbers of extant LR for many crops, the poor distinction between maximising overall LR diversity maintenance and promoting LR diversity in specific locations. But Veteläinen *et al.* stress that coherent networks of on-farm conservation sites offered the preferable means of LR conservation. The role of numerous NGOs and community-based networks, focused on traditional or diverse LR-based farming systems, will continue to be essential, and in collaboration with more formal PGR conservationists, planning and implementing the three *Principles* in the LR on-farm context.

Therefore currently, from the conservation perspective, overall LR diversity continues to be degraded, despite being increasingly valued as an agricultural, heritage and commercial resource of substantial economic value. It is vital for the future of European agriculture, food security and wealth creation that a more conservation-based approach is immediately taken to LR diversity conservation and LR conservation networking. Such an approach would complement and build upon the existing networking initiatives outlined above, more formal sector initiatives and should involve a wide range of collaborators to ensure the best outcomes. The importance of establishing LR conservation networks was reiterated by FAO (2014), but as concluded above, little concrete progress has been made thus far, but national LR inventories would be the solid first step towards this goal's achievement.

4.3 Network PGR population management criteria

The establishment of networks of national sites, each selected to contain multiple taxa, is likely to be more cost-effective overall for national conservation programmes, rather than establishing large numbers of single taxon genetic reserves. However, it may also prove expedient for high priority taxa or populations that contain valued traits located in a single, isolated population to also be included in the network. To ensure the scientific validity of any regional or national CWR, WHP and LR *in situ* networks and to maximize the diversity conserved, it is advisable that populations nominated for inclusion in a network meet jointly agreed criteria. In the context of establishing a European CWR *in situ* conservation networks, Iriondo *et al.* (2012) and Maxted *et al.* (2015) proposed two complementary sets of criteria, which could be adapted for application to national or global networks:

- The CWR population is native to the location, or if introduced, has existed at that location for at least fifteen generations, and has had time to evolved unique alleles / traits.
- The CWR population contains distinct or complementary genetic diversity, or possibly ecogeographic diversity used as a proxy for genetic diversity, or specific traits of interest. An example of the latter is beet necrotic yellow vein virus (BNYVV) resistance in *Beta vulgaris* subsp. *maritima* populations from the Kalundborg Fjord area of Denmark (Capistrano *et al.*, 2014). The high utilization value of such traits would enhance the overall value of the *in situ* network.
- The CWR population should not be threatened, so there is a high likelihood of long-term survival (conventionally thought to mean having a >95% probability of persistence for over 100 years; Traill *et al.*, 2007) and site / population threats such as development or climate change will need to have been assessed / modelled and found negligible. If target PGR populations are threatened, as might be the case with rare taxa, and no 'healthy' alternative populations are available, then *ex situ* conservation will need to be a priority, an assisted propagation programme linked to reintroduction commenced and the threat eliminated.

- The CWR population is actively and sustainably managed as a long-term *in situ* conservation resource according to the minimum quality standards for genetic reserve conservation (Iriondo *et al.*, 2012). These are summarised as:
  - Location
    - — Located following a rigorous scientific process.
    - — Located in a site with long-term protection.
  - Spatial structure
    - — CWR populations are mapped, and clear boundaries of the genetic reserve defined.
    - — Reserves are of sufficient extent to permit self-sustaining CWR populations and natural processes.
  - Target taxa
    - — Genetic reserves are designed to collectively capture maximum genetic diversity.
    - — Demographic survey of target CWR taxa have been undertaken.
  - Populations
    - — Population sizes are sufficiently large enough to sustain long-term viability.
  - Management
    - — Site is managed as part of a national *in situ* PGR network.
    - — Site is recognised as conserving CWR diversity by the appropriate national (and multi-national or even global) agencies.
    - — Management plan is formulated.
    - — Monitoring plans are designed and implemented.
    - — Local communities participate in site management.
    - — Clearly-defined procedure to regulate the use of genetic material from the site.
  - Quality standards for the protected areas that contain genetic reserves.
    - — Site protection has legal foundation.
    - — Site management plan acknowledges genetic conservation of the target populations.
- The CWR population is re-sampled and held in a backup *ex situ* facility every fifteen generations for an annual species / crop or longer for perennial species / crops.
- The CWR population is accessible for research and utilisation in accordance with the ITPGRFA from a designated *ex situ* facility as part of the multilateral system.
- The CWR population is nominated for network inclusion by an appropriate national agency or designated person (e.g. National PGR Coordinator).

Current experience in working towards regional or multi-national CWR *in situ* conservation networks indicates that the sites proposed do not meet the full set of criteria to be nominated for inclusion in a network (Maxted *et al.*, 2016) or the quality standards for CWR genetic reserves (Iriondo *et al.*, 2012), because their designation has been *ad hoc* and opportunistic rather than a result of deliberate scientific decision. Also, so far, many established genetic reserves have been independent of each other and so do not together constitute an integrated network of genetic reserves. The FAO Commission on Genetic Resources for Food and Agriculture (CGRFA) is leading a discussion of the options for establishing a global network for *in situ* PGRFA conservation (FAO, 2013). Such a global network would provide the necessary platform to raise awareness of the social and economic value of *in situ* conservation (including on-farm management) in partnerships with national and regional level activities, but it is apparent that such a network requires further debate, a governance structure, an evidence and research base and financial security, so is unlikely to be put in place soon.

4.4 Establishing *in situ* and on-farm networks

CWR, WHP and LR *in situ* conservation sites / populations and networks should be geographically integrated. Meaning the sites should be integrated like nested dolls, with some sites, likely containing the highest concentration of target populations of multiple CWR, WHP or crop taxa, being selected and incorporated into the national *in situ* and on-farm networks, and subsequently some of these sites from multiple countries forming the subregional or continental regional *in situ* networks, and some of these networks from multiple countries and continents forming the global *in situ* and on-farm conservation networks (Figure 5). At whichever geographic network level, the inclusion of sites and populations in the network should be selective and based on scientific principles; only the 'most suitable' should be included, with one condition – all sites / populations are by definition located in a country, and as the CBD established "*The Convention stresses that the conservation of biological diversity is a common concern of humankind, but recognizes that nations have sovereign rights over their own biological resources …*". Therefore, it must be a national agency which nominates all sites / populations to join national, regional, or global networks. However, it is hoped that national nomination will be guided by scientific evidence. Such a system for agreeing 'most suitable' locations for *in situ* network inclusion was proposed by Maxted *et al.* (2015b) and ECPGR (2017) and is summarised in Figure 6. The specific model was developed initially for CWR implementation, but the general approach could be applied and extended for WHP *in situ* and LR on-farm application.

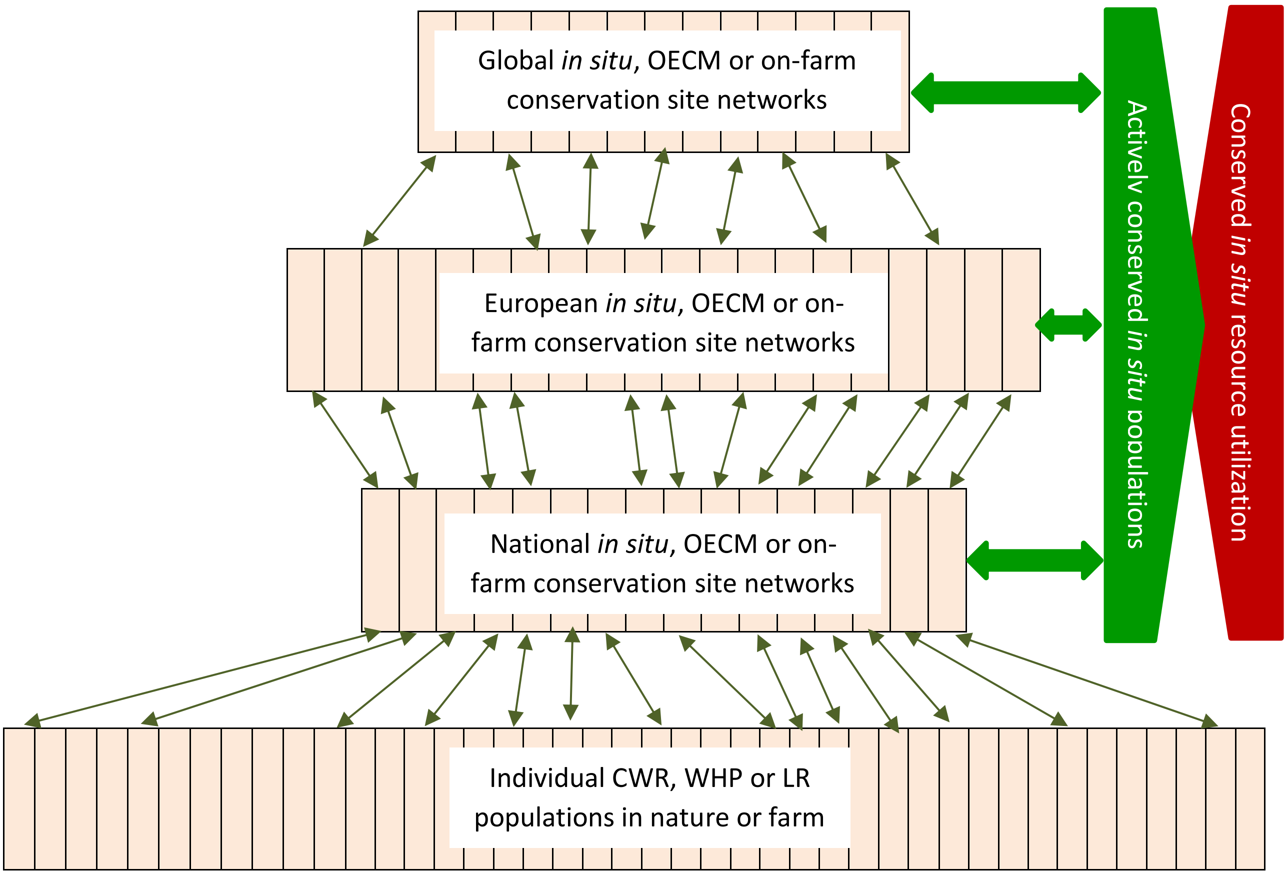

Figure 5. Integrated *in situ* networks of CWR / WHP / LR populations (Maxted *et al.*, 2015b).

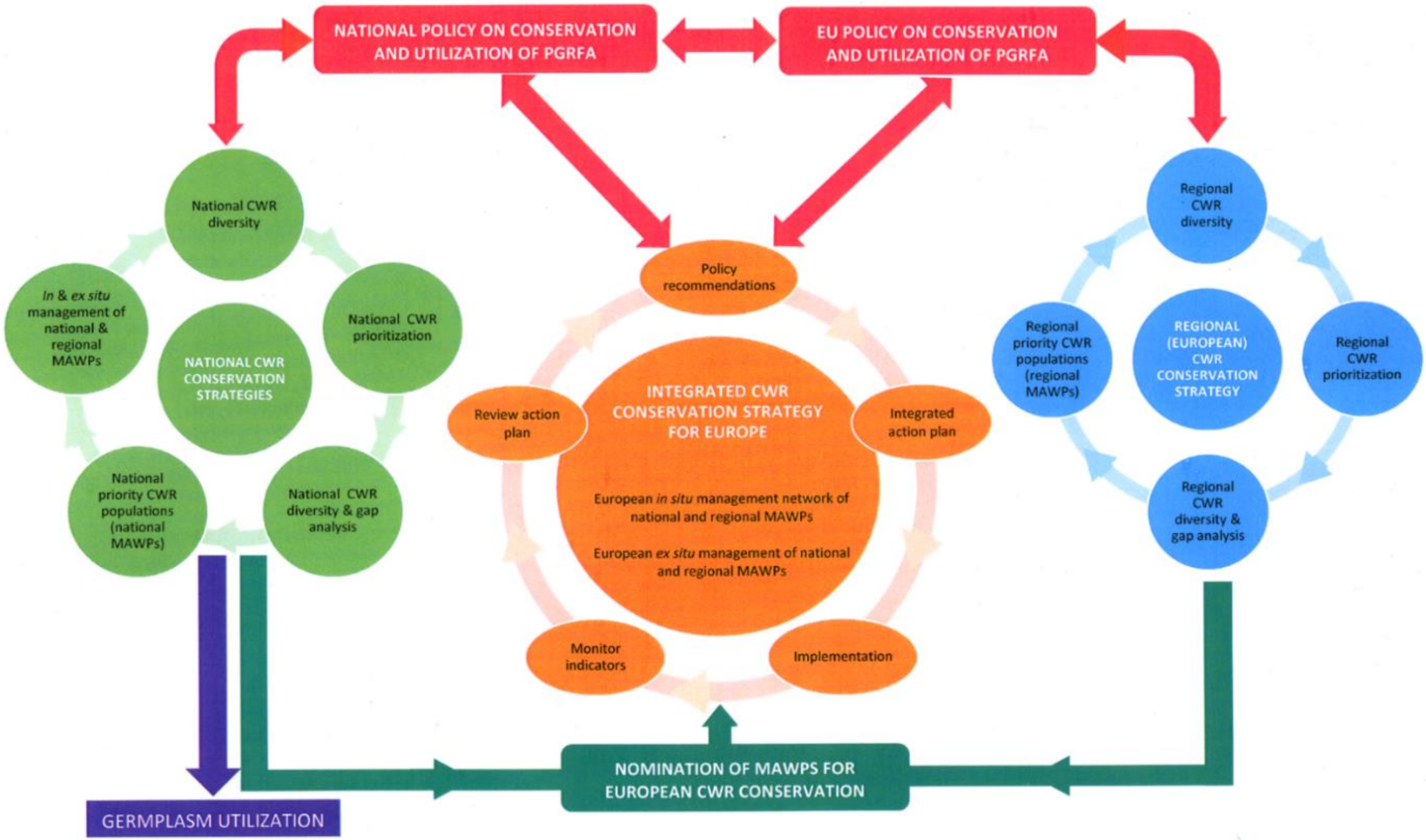

Figure 6. Inclusion of CWR / LR populations in the continental *in situ* network (Maxted *et al.*, 2015b).

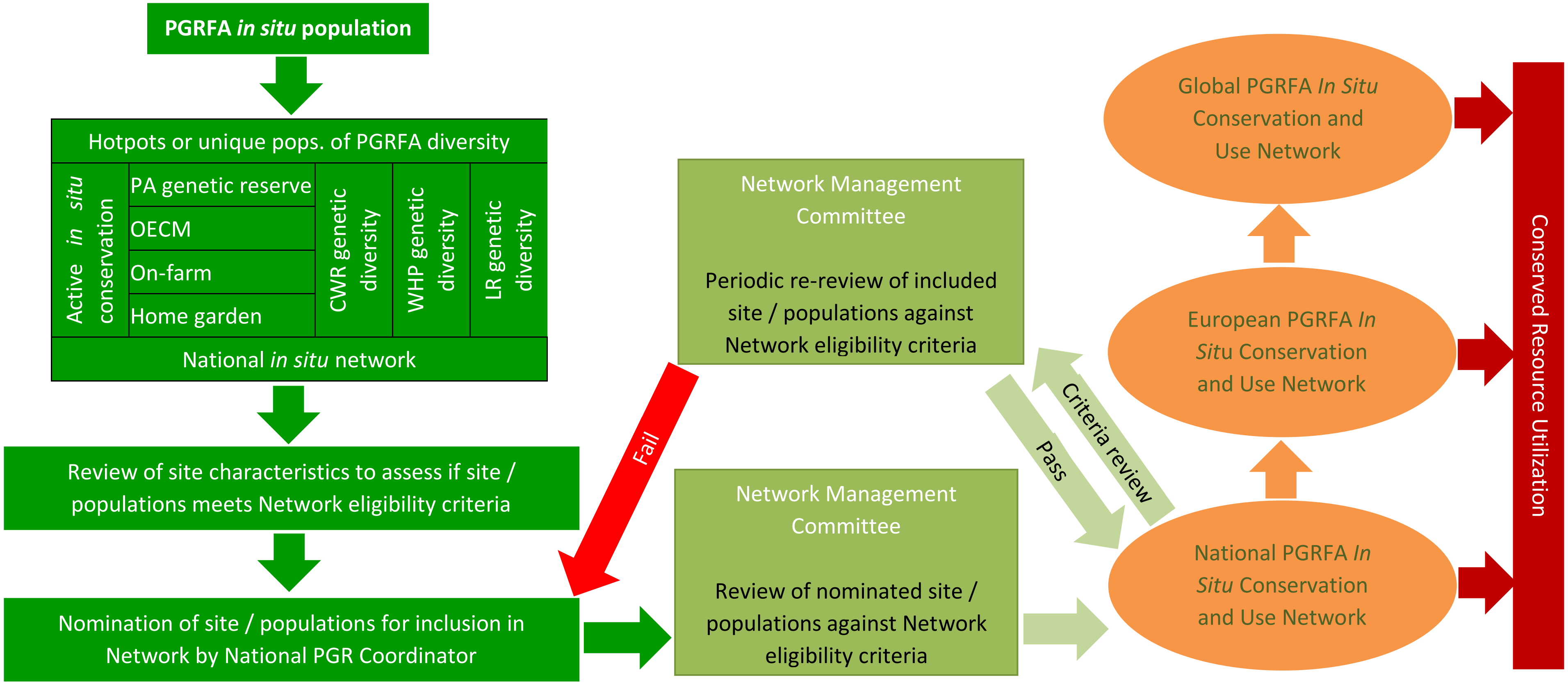

Figure 7. Review process of site and population inclusion in national *in situ* network (Maxted et al., 2016).

The combined bottom-up and top-down approaches to identify priority sites containing regionally important PGR diversity for inclusion in the European networks will require research by national and regional authorities to identify sites containing nationally and regionally important PGR populations. Sites could be proposed by countries where genetic reserves or on-farm sites might be established (Figure 6 in dark green). Therefore, the final integrated European *in situ* and on-farm networks would contain both conservation sites identified by individual countries (bottom-up, i.e., sites that are priority at the national level) and those initially identified by regional or even global research (top-down, i.e., sites that are priority at the regional or global level). The latter's nomination for inclusion in the integrated European networks would be decided by individual countries and the PGR conservation planning, practical management and monitoring would necessarily be implemented at the national level, though potentially with international support. The integrated *in situ* network is, therefore, integrated because it contains both the bottom-up and top-down site inclusions.

The integrated European PGR *in situ* networks would be driven by international, regional, and national policy on conservation and utilization of PGR (Figure 6 in red) and implemented at national level (Figure 6 in dark green). The aim of the integrated strategy is to preserve PGR for use in crop improvement and to maintain cultivar development options—in particular, to provide a wide pool of diversity as insurance against the negative impacts of climate change on crop production. Therefore, a fundamental element is making conserved germplasm available to the user community (Figure 6 in purple). To achieve this, the interface between *in situ*, *ex situ* and use of PGR conservation needs to be strengthened. As indicated by the cyclical flow of the related strategies in Figure 6, planning and implementing European PGR *in situ* and on-farm conservation will be an iterative process requiring periodic review and updating as conservation and utilization policy, science and practice develop. Promoting awareness of the value of PGR to food and economic security as well as raising additional funding, will be critical to support this process and ensure long-term *in situ* PGR conservation.

Once identified CWR / WHP / LR sites / populations of value and potential inclusion in the national *in situ* and on-farm networks, a review and inclusion process should include (Figure 7):

1. National or local agencies in the country nominate sites / populations for network inclusion by application to the responsible national PGR Coordinator.
2. The national PGR Coordinator reviews the application, and if they support the application forwards it to the national authority overseeing the network.
3. The national authority, the Secretariat of the Network Management Committee reviews the application to ensure the sites / populations meets the network eligibility criteria. If the nomination descriptors are complete and meet the inclusion criteria, the sites/populations will be endorsed and join the network. However, if not deemed acceptable, the application will be sent back to the national PGR coordinator for further review and amendment.
4. Within the national *in situ* network, populations would be periodically reviewed to ensure they continue to meet the inclusion criteria, and where this is not the case, recommendations for changes would be made, the sanction of de-selection from the network would be available.
5. The process is mediated by both the creation and maintenance of a national *in situ* database containing target taxon and population level conservation and use information as well network and site *in situ* population conservation management and monitoring information.

Ultimately the goal would be for the *in situ* and on-farm PGR networks to contain a significant breadth of genetic diversity, that is actively managed CWR / WHP / LR sites / populations, where germplasm from the sites is available easily from *ex situ* facilities, where individual sites are managed by national GRC staff in collaboration with individual field population maintainers, and where the *in situ* networks at the local, national, regional and global level are integrated to maximise effectiveness.

5. Accessing *in situ* conserved populations

The end point of PGR conservation is not conservation itself, but conserved germplasm utilisation. As argued above, the linkage and partnerships between those conserving and using PGR are of existential importance; unless PGR are used, the specific argument for their conservation lacks validity. The conserved PGR may have multiple other uses and justifications for conservation, but their PGR value is negated. This is vital in the *in situ* conservation context. The pathway of use for *ex situ* conserved PGR is tried and tested, but for *in situ,* it has still to be established beyond the positive activities of the NGOs focusing on PGR and farming systems networking. Without the *in situ* conservation-to-use link, it is doubtful if *in situ* conservation sites and site networks will ever be established (Maxted, 2019). Therefore, establishing links between *in situ* resources and their use will help ensure additional germplasm access and promotes *in situ* conservation itself (Maxted and Magos Brehm, 2023).

Maxted and Kell (2008), Maxted and Palmé (2016) and Maxted (2019) each reviewed potential models for how conserved *in situ* resource might be linked to user access, either sampled for use directly from the *in situ* population or indirectly via an *ex situ* conservation facility (Figure 8).

- **Option 1 – Direct *in situ* supply**: describes the user being made aware of the availability of particular *in situ* PGR populations and their characteristics, contacting the PGR *in situ* maintainer and the maintainer sending the sample directly to the user.
- **Option 2 – Standard *ex situ* conservation**: describes the standard *ex situ* route germplasm takes within the genetic resource centre (GRC): populations are sampled from the wild or on-farm location, transferred to the GRC, registered and documented, cleaned and dried to 15 ±3 % RH, the germination percentage is tested and if over 85%[2], packaged and long-term banked at -18 ±3°C, upon user request, a viable seed sample of ≈40-50 seeds is made available (FAO, 2014). So, for Option 2 the *in situ* backup sample would be treated as a normal *ex situ* sample, but a link would be maintained to the *in situ* population from which it was sampled.
- **Option 3 – Blackbox *in situ* safety back-up**: a backup *in situ* sample is either collected by the *in situ* maintainer and sent to a nominated GRC or collected by their staff and taken to the nominated facility, deposited, and treated as an *ex situ* 'black box' sample. It is registered and documented, cleaned, and dried, the germination evaluated, then packaged and banked, with the banked sample only being available to the donor for monitoring or population reinforcement.
- **Option 4 – *In situ* demand and supply**: proposed by van Hintum *et al.* (2021) to minimise the GRC's additional workload. It involves the user identifying the *in situ* population they wish to obtain, asking the GRC for a sample, GRC collectors traveling to the site, collect a sample and supplying the user. This may involve either direct supply of the sample to the user or more regular *ex situ* sample processing before supply to the user but will incur additional GRC costs.
- **Option 5 – *In situ* backup & supply**: Iriondo *et al.* (2012) proposed as one of the minimum standards for *in situ* conserved populations, that each *in situ* population should be backed-up *ex situ* to facilitate reintroduction of the original material, if necessary. The sample could be collected by the *in situ* maintainer and sent to the nominated GRC. On arrival, it would be processed as with an *ex situ* sample, except two steps would be omitted: regeneration and germination monitoring (Maxted, 2019). Regeneration is expensive it means growing samples out to improve viability, this could be avoided by regular *in situ* population resampling. However, inexpensive periodic germination testing could be retained to confirm the initial quality of the sampled seeds and as an indicator to trigger *in situ* population resampling.

[2] Lower initial viability thresholds are often accepted for many CWR (due mainly to dormancy-issues), and this is accepted by FAO standards (FAO, 2014).

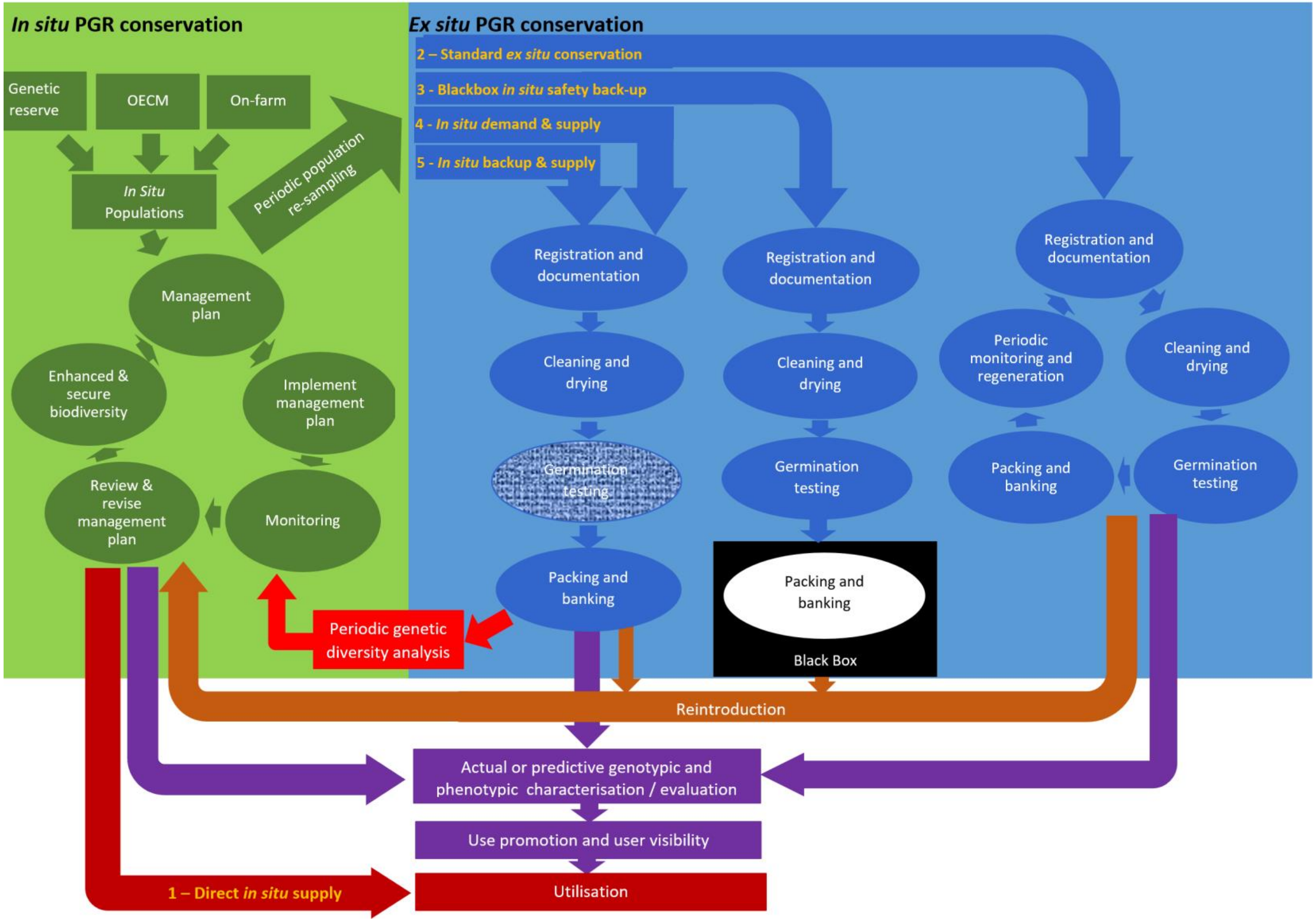

Figure 8. Five options to link PGR *in situ* conserved resources to user access.

With each option, except option 3, upon user request, an *in situ* PGR population sample of ≈40-50 viable seeds would be dispatched to the end user, fulfilling the *in situ* to use prerequisite. For option one, direct *in situ* supply could, in theory, work and the *Principles of PGR Conservation and Use Congruence* is met. However, practical experience has found reserve / protected area managers, landowners, farmers, and gardeners who actively manage *in situ* populations have no experience of and are unable to engage in direct user supply. Direct *in situ* supply arguably would not work because: (a) the suppliers (protected area managers, farmers, land agents, gardeners, etc.) do not see germplasm supply as one of their core activities; (b) germplasm supply requires legislative knowledge following CBD and ITPGRFA related to national / international ABS statutes (FAO, 2001; Art. 12.3(h) and Art. 15.1(b)) and they do not have the appropriate knowledge; (c) germplasm supply outside of the country of origin often requires plant phytosanitary certificates/passports and testing to ensure seeds are free from specific pests/pathogens and the supplier would not have the required skills; (d) while it might be feasible to supply such knowledge to potential suppliers, such as PA managers, supplying it to all potential farmers, land agents, gardeners, is unrealistic; (e) training in germplasm supplier skills would be almost meaningless as the chances of each individual *in situ* suppliers actually supplying *in situ* conserved germplasm would be very limited given their relatively large number and the limited number of seed requests; and finally, (f) the *in situ* maintainer could only supply germplasm during the PGR fruiting season, so there would likely be a delay between request and user supply.

Conversely, the GRC: (a) have been effectively meeting user requests for germplasm for the past 100 years; (b) have built up an existing working knowledge of national and international germplasm transfer and phytosanitary legislation; (c) are the source users are accustomed to approach to access germplasm; and (d) have the potential to extend their duties to supply *in situ* conserved samples. Therefore, germplasm supply options 2–5, each meet the users supply requirements, via an *in situ* backup accession held in the GRC collection, commonly the national genebank. These are different approaches to the *in situ* back-up and supply from the GRC.

Option two, standard *ex situ* conservation, is very well established, it works, and we know it meets the *Principles of PGR Conservation and Use Congruence*. But, if as foreseen, each country has 30–50 sites where CWR are conserved and each of these contains 10–15 CWR taxa and their multiple populations, along with possibly similar numbers for WHP taxa and populations, and approximately 250–500 LR populations, then this is a significant number of additional *ex situ* accessions for the GRC to process and make available to users. It will require additional resources to service the *in situ* supply, and some GRC may not wish to undertake this role alone, even if it does provide the user with significant additional germplasm to choose from to meet their needs.

Option three, given that one of the imperatives of the *Principles of PGR Conservation and Use Congruence* is that conserved PGR should be available for utilization, is excluded because black box *in situ* back-up does not meet this requirement for user supply and therefore ineffective as a PGR conservation measure. Although it would be wrong to assume that making the conserved resource available for use is always obligatory. If the *in situ* population is rare, highly threatened or has known unique, adaptive allelic diversity, then it should be conserved *in situ* and backed up *ex situ*. The assumption being that availability would be granted by the *in situ* maintainer in the future when target population levels had risen, and black box *in situ* back-up would not be the long-term preferred option.

Option four, *in situ* demand and supply, was proposed as an option that minimised the additional workload of the GRC (van Hintum, *et al.*, 2021). It involves the user identifying the *in situ* population they wish to be sampled, they request the GRC for the sample and GRC collectors travel to the site, collect a sample and supply the user. This may involve direct delivery of the fresh sample to the user or the normal *ex situ* sample processing and then supply. This option would undoubtedly require least intervention by GRC staff, apart from the population sampling, though potentially this associated cost might be passed onto the user or the *in situ* maintainer could be asked to collect and forward the PGR sample to the GRC. However, from the *in situ* perspective, this would not be ideal, as the *in situ* population samples would not be equally accessible compared to *ex situ* conserved material. The user would need to know if a particular *in situ* population had adaptive traits, from experience of the *in situ* population or by applying predictive characterisation techniques (Thormann *et al.*, 2014).

The additional steps complicate the user access, which might deter some users from requesting *in situ* population samples limit the value of *in situ* conserved populations. Further, seasonality of supply would also be a further limitation on option four (Maxted, 2019). Germplasm is usually supplied in the form of seed samples, and standard *ex situ* accessions in the GRC are available for distribution year-round, but mature seed are only available *in situ* or on-farm for a few weeks of the year following fruit ripening, so a user may have to wait for some time before the sample is available, which is a disadvantage compared to standard *ex situ* storage and availability.

Option five, *in situ* back-up and supply, proposes using the *in situ* population backup sample to promote use. As noted above, Iriondo *et al.* (2012) proposed minimum standards for *in situ* conservation, that require that each *in situ* conserved population should be backed-up *ex situ* to allow reintroduction of the original population sample, when necessary. So, there would be an *in situ* sample for each PGR population in the GRC, and for option five, this sample is distributed to supply the user's needs. To minimise the GRC costs, the sample and associated data could be collected by the *in situ* population manager and sent to the GRC. On arrival, it could be processed as per standard *ex situ* samples, except that two steps would not be necessary: regeneration and germination testing[3]. Regeneration involves the population sample being grown out in trial fields, polyhouses, or glasshouses, bulked-up and germination levels raised to ≥85%. Regeneration also has an ancillary disadvantage, in that by growing the sample in an alien environment, there is selection pressure on the regenerated sample, and crucial alleles may be lost or genetically eroded. Alternatively, if the *in situ* back-up sample becomes depleted over time due to user demand, the source population can be re-sampled to bulk up the back-up, avoiding the need for regeneration. The *in situ* population will evolve over time in a changing environment, and so to ensure its genetic diversity is a true reflection of the *in situ* population it should be resampled. Further, if the *in situ* population is periodically resampled, then routine germination testing would be unnecessary, though initial testing on arrival of the sample at the GRC may be desirable to confirm germplasm supplied to users was viable when it entered the GRC. As such, option five achieves the *Principles of PGR Conservation and Use Congruence*, supplies the conserved *in situ* resource to users via the GRC and does not put too high an additional burden on the GRC staff and resources. The *in situ* back-up sample could be characterized and evaluated alongside standard GRC *ex situ* accessions, so promoting utilisation of the *in situ* resource.

Such an approach has not been currently implemented in any European country, thus far. Initially there has been resistance to changes in role and responsibilities from both the current *in situ* site managers and the genebank staff. For both, however, it will require little additional work beyond their existing commitments. At the same time, it will be mutually beneficial to both communities, National genebank staff, should be able to at least double the diversity they can offer to germplasm users. For *in situ* site managers, it presents a good example of applied additional ecosystem services from the site they manage, as well as graphically demonstrating the fundamental value of protected area-based conservation to the public. Provision of access to *in situ* population samples via the GRC, uses their expertise in user seed supply, unlike the *in situ* population managers, and is a natural extension of their existing role to meet user's demand for genetic diversity. Further, adoption of the proposal would be expanded if the additional commitment was minimal for site managers and genebank staff, and fully adequately resourced.

Maxted *et al.* (2016) argued for this expansion in the role of existing genebanks, from essentially '*ex situ* conservation and user supply' to the broader 'complementary conservation and user supply'. They proposed the change in role should be reflected in the change of name from 'genebank' to 'genetic resource centre' and would necessarily need to be accompanied by an upgrade in resourcing to reflect the additional responsibilities of the GRC. The critical partnership is between the *in situ* population maintainer and the *ex situ* GRC staff. To ensure this relationship is effective it is preferable that each *in situ* population is partnered with a nominated *ex situ* GRC, most likely this will

[3] Note for CWR samples, it may be difficult to collect recommended standard sample sizes quantities (FAO, 2014) and therefore, initial sample seed bulking may be required before formal seed storage, especially if the sample is to be used subsequently for characterization and evaluation, and user provision.

be with the national GRC, but in countries with a decentralised network of genebanks linking specific crop group CWR, WHP or LR with specialist genebanks in cereal, fruit, vegetable, forage etc. is appropriate and would be beneficial.

The preceding discussion has focused on the role of the *in situ* site managers and the GRC staff, but increasingly community biodiversity management is being shown to have a role in facilitating local user access to PGR; a role that seems particularly pertinent in the *in situ* context linking to local PGR conservation effort to local PGR use. It seems unlikely that many local communities would be interested in CWR use because of the problems of interspecific traits and linkage drag of unwanted additional traits, but WHP and LR could be used directly via community seed banks by the local communities. Local community seed banks could also function as a conduit to the more formal *ex situ* community, aiding *in situ* characterization, adaptive trait recognition, *in situ* population sampling for *ex situ* duplication and backup, and even CWR-based prebred-varietal introductions, as well as provision of associated datasets. This could encourage greater recognition of the informal conservation sector, provision of resources and skills training, and inclusion of community seed bank holdings in national PGR inventories. Community seed banks could take the role of LR population maintainer working in collaboration with GRC staff to maximise diversity maintenance. Improve integration between the PGR formal and informal systems will surely prove mutually beneficial and secure existentially important food security resources.

6. Interfacing *in situ* conserved populations with EURISCO

6.1 Background

Significant progress has recently been achieved in advancing *in situ* PGR conservation through the incorporation of information on active *in situ* population conservation in EURISCO, the European Search Catalogue for Plant Genetic Resources (https://www.ecpgr.org/working-groups/crop-wild-relatives/cwr-in-eurisco). The project, funded by the German Federal Ministry of Food and Agriculture, was instrumental in helping *in situ* conservation achieve the third *Principle of Plant Genetic Resource Conservation and Use Congruence* "to ensure the conserved resource is available for utilisation". The project commenced in Nov 2021 and focused on country-based case study incorporation of CWR *in situ* population data in EURISCO, from Albania, Bulgaria, Cyprus, Czech Republic, Georgia, Germany, Italy, Lithuania, The Netherlands, Poland, Portugal, Romania, Slovenia, Spain, and the United Kingdom. Although initially developed for CWR populations, a similar approach could in future be implemented for WHP and LR population data – a significant step forward in PGR science.

Implementation of this project is endowing the European region with a centralized, public and web searchable inventory of *in situ* CWR priority population' passport data and with a fine-tuned data flow mechanism utilizing an internationally agreed data exchange standard. An initial set of data from a few pilot countries has already been made available. The extension of EURISCO to *in situ* data creates a link with the existing *ex situ* data and thus improve the *ex situ* / *in situ* conservation interface in both directions, as well as significantly increasing the diversity available for user selection.

The new *in situ* module of the EURISCO catalogue was built in compliance with the 'FAIR principles' of Findable, Accessible, Interoperable and Reusable data (Wilkinson *et al.*, 2016). The online central catalogue of *in situ* CWR populations' data has been available since the beginning of 2024 and further European countries are being trained and encouraged to add their country data, provide easy-to-access information to potential users seeking novel sources of diversity to be included into breeding and pre-breeding programmes. The implementation of these international commitments prioritized by the CBD, GPA and ITPGRFA, as well as by the European PGR Strategy, will prove beneficial to both PGR conservationists and users, and so engender food security and well-being.

6.2 Achievement of the EURISCO project

A draft proposal setting out the 'Principles for the inclusion of CWR data into EURISCO' was completed in 2022 with a consultancy assigned to two members of the EURISCO Advisory Committee (the Chair

Theo van Hintum, CGN, Wageningen, The Netherlands, and the *in situ* CWR expert José Iriondo, URJC, Madrid, Spain). The document, including principles and requirements for data inclusion, definition of a data flow mechanism and the proposed data exchange standard (CWR passport descriptors), was approved by all the partners and other relevant bodies and published on the ECPGR website (van Hintum and Iriondo, 2022). It included recommendations on the most relevant CWR populations to be considered as *in situ* populations to be recorded in EURISCO should be those whose current presence and precise location are known, are being actively conserved to guarantee their long-term persistence, and are available for access under the Multilateral System of the ITPGRFA.

The document describes the structure of information shared between the CWR-National Inventory (CWR-NI) and EURISCO, the necessary steps to upload CWR-NI elements into EURISCO and the required changes in EURISCO. Two annexes containing 'Descriptors recommended for the generation of a National Inventory of *in situ* Crop Wild Relatives' and 'Descriptors for uploading passport data of *in situ* CWR to EURISCO' complete the document.

The approach suggested was based on various existing documents and discussions held on various platforms. Its implementation will enable countries to comply with the recommendations of international plans, treaties, and conventions, including the Plant Genetic Resources Strategy for Europe. As the upload of data from the CWR-National Inventories should be done by a nationally authorized focal point, the ECPGR Secretariat invited National Coordinators to identify their "*in situ* CWR National Inventory Focal Points". These nominations have been obtained for the initial project partners and were registered on the ECPGR website (https://www.ecpgr.org/contacts-in-ecpgr/ecpgr-contacts/iin-situi-crop-wild-relatives-national-inventory-focal-points).

Pilot institutions, on behalf of their respective countries, committed at various levels to identifying priority taxa and populations, preparing the national database structure, organizing the network of data providers, collecting, and organizing the data according to the agreed principles and data exchange format, and eventually providing the data to EURISCO. The EURISCO extension, including the database structure, import tool and data integrity procedures has been completed. The web interface has also been completed. By June 2024, seven countries (Albania, Bulgaria, Cyprus, Germany, Italy, the Netherlands, and Spain) have provided *in situ* CWR data to EURISCO, with data from a total of 3,035 populations.

6.3 Postscript

The assimilation of *in situ* data in EURISCO is a key step towards addressing some of the accessibility issues related to *in situ* material that have been discussed in this document. The EURISCO project has already played a key role in establishing *in situ* PGR conservation as being truly complementary to *ex situ* in Europe and is helping to ensure that *in situ* conservation meets the *Principles of PGR Conservation and Use Congruence*. Further, it was clearly the case that without such an initial step, the establishment of *in situ* genetic reserves would have made slower progress towards implementation. It has meant that for the first time *in situ* conserved resources are available to users. However, there are outstanding questions that remain to be resolved in relation to the project outcomes:

a. What additional *in situ* data should be included in EURISCO and how will the decision be made?
b. How often should *in situ* data uploading be repeated?
c. What supporting documents and resources need to be developed to help others integrate *in situ* data into EURISCO?

Aside from these specific questions related directly to incorporating *in situ* data in EURISCO, the broader aspects of integrating *in situ* and *ex situ* conservation also remain and include the following:

a. How will countries develop their national inventories of *in situ* PGR populations? Some guidance is provided by Magos Brehm *et al.* (2017) and van Hintum and Iriondo (2022).
b. What ABS documentation is required in the context of national ratification of the International Treaty on PGRFA (FAO, 2001) and CBD Nagoya Protocol (CBD, 2014) to permit transfer of germplasm samples from *in situ* to *ex situ*, and then to users?
c. Who will take responsibility for collecting *in situ* material for users? This is discussed in above under Chapter 5, but the proposal is repeated here that the *in situ* population maintainer will collect a sample of the *in situ* population and send it to the nominated GRC.
d. Who will take responsibility for collecting the data associated with *in situ* populations for inclusion in EURISCO? This is likely to be either the National *In Situ* PGR Focal Point or the National PGR Documentation Focal Point, whichever is nominated nationally by the National PGR Coordinator, but the national decision need to be made and the EURISCO team informed.
e. Can genebanks sustainably change their role to become GRC, and where will the resources to support such a change come from?

Any genebank nominated nationally by the National PGR Coordinator can become a GRC if they agree to take leadership for national PGR conservation related issues and responsibility for overseeing and applying both *ex situ* and *in situ* techniques national. Depending on the country, the role could be played by one genebank or shared by multiple GRC, each with distinct coverages (e.g. cereal, forages, fruit trees, etc.). This extension of genebanks roles will involve additional commitment that are likely to require additional resources, which are likely to be provided from governmental sources. However, it is not foreseen that the additional funds required will be prohibitive. These challenges are likely to be addressed through an iterative process to ensure that describing, managing, and accessing *in situ* material is achieved alongside the successful interaction with EURISCO.

7. Horizon scanning of future *in situ* conservation priorities

7.1 Introduction

With agrobiodiversity conservation budgets limited and becoming tighter, it is imperative to maximise the efficiency of conservation expenditure. Horizon scanning is a participatory approach to the establishment of future priorities and is increasingly recognized by governments (King and Thomas 2007), commercial organizations and conservation agencies (Sutherland *et al.*, 2008; 2010) as a useful tool to help prioritize and plan conservation action. It is now routinely used in wider biodiversity conservation for strategic planning, risk management, research priorities and policy making. It aids policy makers and practitioners to make informed resource allocation decisions and provides an evidence base and comparative assessment of the potential options as a basis for conservation implementation. It was initially used in the PGR context by Maxted et al (2012).

Horizon scanning is currently timely, especially as this deliverable is associated with the PRO GRACE project and the development of the GRACE Research Infrastructure, which is associated with the promotion of PGR conservation and use and the establishment of a network for sustainable *in situ* PGR conservation sites throughout Europe. Clearer understanding of the scope of such a network and its implementation will not only maximise PGR conservation but facilitate making that diversity easily available to various European PGR user communities.

7.2 European PGR Horizon scanning (2010)

The initial use of horizon scanning in the PGR context took place as part of the Funchal, Madeira, September 2010 symposium "Towards the establishment of genetic reserves for crop wild relatives and landraces in Europe". To identify short-term and long-term PGR conservation priorities a list of actions associated with effective CWR and LR was agreed and each of the 32 European countries represented were asked to comment on their countries status as regard to each action. For CWR diversity, the actions included whether there existed: (a) a National Action Plan for CWR survey, monitoring and conservation; (b) a National CWR inventory; (c) a prioritization list of CWR species; (d) a CWR information system; (e) systematic gap analysis had been used to aid CWR conservation; (f) *in situ* genetic reserves for CWR conservation; (g) *ex situ* germplasm holdings of CWR diversity; (h) a threat assessment using IUCN Red List Criteria of CWR diversity; (i) routine national utilization of CWR diversity; (j) public awareness of CWR value; and (k) a legislative / policy framework to enhance CWR conservation. While for LR diversity the actions included whether there was a complete, partial, or no national LR inventory, and if not complete what was the limiting factor. To establish the longer-term agrobiodiversity conservation priorities, horizon scanning was used, amended from the approach taken by Sutherland *et al.* (2008; 2010). All eighty-three delegates at the symposium were asked to identify emergent issues that they felt were of European importance or may have a local effect on CWR and LR diversity in Europe in the future 20-30 years. For each issue they submitted they were asked to outline the Strengths, Weaknesses, Opportunities, Responsibilities and Threats associated with the issue for European diversity. This identified a set of fifteen issues for CWR concerns and 13 issues for LR concerns, were raised by 12 people from 10 European countries for CWR issues and 11 people from 9 European countries for LR concerns. Maxted *et al.* (2012) provide further elaboration of the process.

The Short Term Issues (2010-2020) identified were as follows:

CWR related issues	
Issue	**2024 Review**
• Lack of National CWR Checklist and Inventories.	48 European countries have at least an initial Checklist produced by the EU funded PGR Forum project[4].
• Inadequate CWR information system, with links to EURISCO for promoting user accessing of CWR population samples.	Some progress, the *in situ* data to EURISCO project has shown it is possible, but no such *in situ* management system in place yet.
• Systematic use of CWR diversity in breeding.	Some progress, if the *in situ* data to EURISCO project were enacted it would promote CWR use.
• Lack of national CWR strategies and action plans based on ecogeographic and gap analysis.	About 10% of European countries have National CWR Strategies and Action Plans published.
• Lack of mention of CWR conservation or protection in national conservation legislation.	Slight progress, only a few examples of active CWR conservation under legal protection Germany, Finland, and the UK.

[4] Albania, Andorra, Armenia, Azerbaijan, Austria, Belarus, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Czech Republic (Czechia), Denmark, Estonia, Finland, France, Georgia, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Latvia, Liechtenstein, Lithuania, Luxembourg, Malta, Moldova, Montenegro, Netherlands, North Macedonia, Norway, Poland, Portugal, Romania, Russia, San Marino, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine, United Kingdom,

• Lack of national and European level genetic reserves to actively conserve CWR diversity.	Still currently very few genetic reserves meet minimum technical standards (Iriondo *et al.*, 2012; Maxted *et al.*, 2016).
• Lack of national and European level on-farm conservation to actively maintain CWR diversity.	No known examples of active CWR conservation on-farm in Europe.
• Lack of legislative protection for CWR populations and genetic diversity at both national and European levels.	Currently legal support for CWR populations is only available via genetic reserves located in existing protected areas.
• Lack of active support for CWR populations and genetic diversity at both national and European levels.	Currently financial support for CWR populations is only available in England.

LR related issues	
Issue	**2024 Review**
• Lack of National LR Inventories.	14 European countries[5] have some form of National LR checklist.
• Lack of national LR strategies and action plans based on ecogeographic and gap analysis.	No European countries have national LR strategies and action plans.
• Lack of tried and tested methodologies for creating National LR Inventories.	Although methods (Maxted and Scholten, 2007; FAO, 2019) are published they have not been widely applied.
• Lack of an appropriate threat assessment methodology for application to LR– IUCN Red Listing cannot be used for LR threat assessment as it fails to consider sub-taxonomic and genetic diversity.	A methodology has recently been published by Almeida *et al.* (2024) and publication of exemplar applications is in preparation.
• Existence of conflicting national incentives that threaten national LR diversity.	Still thought to be the case but there has been no systematic review of their existence or impact.
• Varied national application of seed legislation concerning seed production and sale.	Known to be the case but there has been no systematic review of their existence or impact.
• Lack of legislative protection for LR populations and genetic diversity at both national and European levels.	Currently there is limited legal support for LR populations via European Conservation Variety and PDO (Protected Designation of Origin), PGI (Protected Geographical Indication), TSG (Traditional Speciality Guaranteed), etc.

[5] Austria, Croatia, Czech Republic (Czechia), Denmark, Estonia, Finland, Germany, Greece, Italy, Portugal, Romania, Spain, Sweden, and United Kingdom,

• Lack of active support for LR populations and genetic diversity at both national and European levels.	Currently financial support for LR populations is only available in England, Italy, and regions of Spain.

The Long Term Issues (2020-2035) identified were as follows:

CWR related issues	
Issue	**2024 Review**
• Lack of establishment of a European network of CWR *in situ* conservation sites that systematically conserve the highest priority CWR diversity.	Little progress toward European Network establishment noted, but model of building on national network informally agreed.
• Lack of establishment of a national network of CWR *in situ* conservation sites that systematically conserves the highest priority CWR diversity.	Several countries are making progress toward national CWR Network establishment.
• Few examples of national network establishment for CWR *in situ* conservation that can function as models for further countries.	Several national CWR network establishment reports published but need wider distribution to encourage broader application.
• Lack of integration between agrobiodiversity and biodiversity communities to promote mutual benefit.	Limited progress, although in a few countries progress in CWR *in situ* conservation in protected areas. Initial positive contact with the EUROSITE has stalled.
• Incomplete assessment of CWR threat using IUCN Red List Categories and Criteria.	Sound progress, approx. 50% of global priority CWR taxa threat assessed.
• Lack of appropriate threat assessment methodology for CWR application – IUCN Red Listing widely used for CWR threat assessment but fails to consider genetic diversity.	No progress, remains a limitation in precise conservation planning.
• Lack of integration of CWR *in situ* conservation that involves local communities, engendering mutual benefit.	Little progress towards local communities' involvement.
• Characterisation and evaluation of conserved LR accessions / populations as means of promoting utilization	Progress is being made especially in terms of genomic analysis, which is becoming less expensive and more routinely applied.
• Encouraging pre-breeding with use of diverse CWR taxa.	Considerable progress has been made in pre-bred line production that are then made freely available for use (Bohra *et al.*, 2021).
• Requirement to ensure that ≥ 70% of European CWR diversity is conserved to meet European and global policy commitments.	Despite several CWR international conservation initiatives (e.g., Palmé *et al.*, 2019; Eastwood *et al.*, 2022), ≥ 70% of

	European CWR diversity has failed to be actively conserved.

LR related issues	
Issue	**2024 Review**
• Lack of consistency in national application of potential EU LR support schemes or consideration of more active LR support schemes in non-EU countries.	Currently financial support for systematic LR population cultivation is only known to be available in England, but support for limited LR maintenance is available in other countries.
• Lack of legislative support to promote and facilitate LR cultivation.	Few European countries are known to have specific national legislation to promote and facilitate LR cultivation.
• Lack of evidence that home gardens are a persistent reservoir of LR diversity, despite anecdotal evidence.	This hypothesis has still to be evaluated by any national PGR programme, scientific proof would empower growers and raise awareness of PGR value / conservation.
• Lack of evidence that maintainer's names for LR correlate with genetic distinction.	This hypothesis has still to be adequately evaluated by any national PGR programme, this remain a fundamental question to aid effective conservation and could be easily resolved using standard genomic tools.
• Lack of national LR inventories and active LR on-farm management is inhibiting establishment of a European network of LR *in situ* conservation and systematic conservation.	Little progress toward establishing a European on-farm Network establishment based on national networks.
• Given the long-term fragility of much LR cultivation, there is need to establish national Landrace Protection Schemes.	Apart from the Scottish Landrace Protection Scheme (Green *et al.*, 2009), no other countries have developed similar schemes to ensure systematic continued LR cultivation.
• Lack of awareness of LR on-farm conservation among more general farming community.	Little progress towards general farming community awareness raising, even though progress is evident for the raised public awareness and local LR valuation,
• Encouraging pre-breeding using LR conserved resources and closer links with breeders.	Progress is being made, especially since the availability of additional characterization and evaluation data to facilitate LR selection by breeders.
• Promotion of more biodiversity friendly agriculture systems that incorporate LR diversity maintenance.	There is a general trend toward employment of more biodiversity friendly

	agriculture systems possibly because of consumer demands.
• More 'joined-up' coordinated conservation on-farm that incorporates both LR and CWR active conservation.	Improved with the trend towards more biodiversity friendly agriculture systems.

7.3 European PGR Horizon scanning (2024)

The PGR horizon scanning exercise for current European *in situ* issues and action was repeated in 2024 to be implemented by 2035. It involved members of the EU funded PRO GRACE project 23 Experts from 11 countries + ECPGR Secretariat), members of the ECPGR On-farm (85 Experts from 43 countries) and CWR Working Groups (87 Experts from 38 countries) were asked to identify emergent issues that they felt were of European importance or may have a local effect on CWR, WHP and LR diversity in Europe in the future 10 years. This identified a set of twenty-four issues related to CWR / WHP and also 24 issues related to LR concerns. The *in situ* PGR issues to be targeted and resolved between 2024-2035 were:

CWR related issues
1. Given that all European countries have CWR checklists (see Kell *et al.*, 2008), but some lists are still too comprehensive to facilitate immediate conservation implementation, **national checklists should be prioritized to produce CWR inventories of the highest priority taxa**, or the entire checklist graded into high, medium, and lower priority taxa to aid conservation.
2. Given that all European countries have CWR checklists, and many have prioritized inventories, much of the baseline information is already available for **global or regional assessment of threat and conservation status**. IUCN threat assessment of priority CWR taxa (not just species but sub-taxa) and conservation status assessment should be an urgent action.
3. The application IUCN threat assessment involves the estimate of threats affecting the assessed taxon, this information could be used as a basis for a **review of overall threats facing CWR / WHP, particularly from climate change**. The review should involve GIS modelling the help clarify the relationship between CWR / WHP and threat, and so inform conservation implementation.
4. For CWR / WHP taxa found to be **rare and threatened (Critically Endangered – CR, Endangered – EN, or Vulnerable – VU) recovery plans** should be developed and implemented to improve the CWR taxa conservation effectiveness, which may involve population assisted propagation and even augmentation from other local populations.
5. Compared to CWR, there has been limited national progress in **WHP conservation checklist or inventory development**. The focus on WHP, and particularly WFP, is over-due and experience gained from similar CWR conservation planning and implementation should now be applied or adapted for application of WHP.
6. A specific **CWR / WHP national strategy and action plan** should be prepared, ideally as part of the National Biodiversity Conservation Strategy, or as a free-standing document.
7. All **CWR / WHP conserved *in situ* should be maintained at site with site / population plans**, it would be useful to make all plans available via the national PGR authority website to indicate active CWR conservation and as an aid to formulating CWR population management at other conservation sites and demonstrating CWR integration into broader biodiversity management.

8.	CWR and WHP *in situ* conservation should aim to **maximise overall CWR / WHP conservation efficiency**, so maximum taxonomic and genetic diversity representation within minimum site number, so conservation of CWR / WHP populations in identified geographic hotspots is desirable. However, this focus should not preclude *ad hoc* siting of active conservation CWR / WHP sites for single taxa or in non-hotpots when opportunities arise.
9.	Conservation planning analyses including CWR / WHP ecogeographic data collation, GIS analysis and field 'ground truthing' of potential conservation targets should be used to help **identify geographic CWR / WHP hotspots, look at the possible overlap with IUCN Key Biodiversity Areas (KBA), and site best suited for the establishment of GR sites**.
10.	To conserve PGR diversity adequately, multiple GR sites will need to be established and to ensure sustainable and integrates diversity conservation **CWR / WHP sites and populations require grouped into a European Network for *In Situ* CWR Conservation and Use**. This would facilitate tool and guideline use, assist population management and monitoring, including back-up of priority *in situ* populations in *ex situ* collections to aid user access to the resource.
11.	The preferred method of *in situ* CWR / WHP conservation is in genetic reserves either in existing protected areas or OECM sites, but there also the possibility of more loosely targeted CWR / WHP outside of formal genetic reserves. **CWR / WHP taxa, conservation tools and management guidelines should be applied alongside biodiversity protection in national networks**.
12.	The establishment of CWR / WHP GR sites will involve collation of passport, curatorial, management, and characterization and evaluation data for targeted conserved populations by national PGR programmes. The **passport, curatorial and management data held at national level should be included in agreed data structure and coordinated collation processes**.
13.	A subset of the data collated for targeted CWR / WHP conserved *in situ* populations will have broader usage, notably the **passport, and characterization and evaluation data should be uploaded to EURISCO to promote its use**. Descriptors and process was proposed by van Hintum and Iriondo (2022) and should now be implemented by all European countries.
14.	**Regular monitoring of priority CWR / WHP populations maintained in GR** should be undertaken using both demographic and genomic techniques to check management success and promote usage. The genomic monitoring might also be integrated with characterization and evaluation to identify user desired traits to further aid user selection of conserved germplasm.
15.	It is expedient to establish CWR / WHP GR in existing PAs, but CWR are often associated with disturbed, anthropogenic habitats, not climax communities in PA (Jarvis *et al*., 2015). **Critical analysis of OECM's potential** for CWR / WHP conservation in pre-climax communities (including on-farm sites), resulting in awareness raising, management guidelines adaptation and extension of conservation implemented.
16.	All CWR / WHP conservation is undertaken by professional conservation but a role for citizen science could be developed to aid formal conservation efforts. A **critical analysis of the capacity and potential of citizen science and local communities to CWR / WHP conservation** and partner the formal PGR community activities should be undertaken.
17.	Years of experience has shown it is difficult to promote **conservation integration between agrobiodiversity and biodiversity communities**, the lack of a joined-up approach results in unnecessary duplication and inefficiency, while better collaboration would promote mutual benefits and enhanced conservation outcomes.

18. Despite the rapid advance of CWR / WHP conservation science, there remains a lack of awareness among biodiversity conservationists and policy makers of CWR / WHP value. **CWR / WHP awareness raising among policy makers should be raised and translated into national and European legislation and actions for further protection**.	
19. The **conservation effectiveness of current CWR / WHP actions could be evaluated by a targeted genomic analysis of conserved and unconserved populations**. Such analysis would not only demonstrate conservation effectiveness but would also identify conservation gaps to be filled.	
20. The sustainable exploitation effectiveness of current CWR / WHP conservation could be enhanced by mor**e extensive genomic trait prediction and discovery in conserved CWR / WHP populations**. This initiative might be undertaken in partnership with commercial companies.	
21. Whether CWR / WHP diversity is conserved in a form of *in situ* genetic reserves in a PA or OECM, there is an growing assumption that all *in situ* conserved populations will be backed-up with *ex situ* samples to provide long-term security and user access, but the **Access and Benefit Sharing rights associated for *in situ* maintainers (farmers, land-owners, etc.) require clarification**.	
22. Although CWR diversity is increasingly used in a widening array of crop breeding, it remains well below its full potential for exploitation. Further **public support for pre-breeding of a wider range of crops with CWR genes or traits** would be of significant benefit to public and commercial breeders.	
23. There is a need to **raise public awareness of the concepts of value and economic potential of CWR / WHP taxa and their genetic diversity** and therefore, the importance of more systematic taxonomic and genetic conservation and use of these critical resources for humankind future.	
24. To evaluate and monitor the success of CWR / WHP conservation and sustainable use there is a need to **develop and application of a set of taxonomic and genetic conservation indicators for PGR** for which data could be regularly collated and analysed to monitor and assess the efficiency of PGR conservation and use, providing a basis for enhanced effectiveness.	

LR related issues
1. Given that less than half of European countries have national LR checklists, there is an urgent requirement for immediately **prepare national LR checklists and inventories**. This could be achieved in two stages: first a **list of all LR found in a country**, and second, producing a more detailed comprehensive **list of all LR populations found in a country**.
2. As national LR checklists become available it is likely that they will be too comprehensive to facilitate immediate conservation implementation, therefore the checklist should be prioritized to produce LR inventories of the highest priority LR or the entire **LR checklist is graded into high, medium, and lower priorities** to aid conservation planning and implementation.
3. As national LR checklists become available, it will be feasible for the first time to perform **threat assessment of LR using the recently proposed specific methodology** (Almeida *et al.*, 2024), such threat assessment is required as an aid to active conservation planning and implementation.
4. The threat assessment methodology proposed involves the estimate of threats affecting the assessed LR, this information could function as a basis for a **critical review of threats facing LR, particularly from climate change**. The review should involve GIS modelling the help clarify the relationship between LR diversity and potential threat, to inform conservation implementation.

5. As currently no country has a comprehensive list of all LR populations found within its borders, which means it is difficult, if not impossible, to effectively develop a LR national strategy and action plan, therefore there is an urgent priority **to survey LR population, gather ecogeographic data and perform gap analyses as a basis for LR national strategy and action plan development**.
6. LR *in situ* on-farm conservation should aim to **maximise overall LR conservation efficiency**, so maximum crop, varietal and inherent genetic diversity representation within minimum site number, so conservation of LR populations in identified geographic hotspots is desirable.
7. Conservation planning analyses including LR ecogeographic data collation, GIS analysis and field 'ground truthing' of potential conservation targets should be used to help **identify geographic LR hotspots and site best suited for the establishment of on-farm conservation sites**.
8. There is a requirement for guidelines for on-farm LR conservation that highlight the diverse communities involved (farmer, local communities, diversity networks and formal sector) and their collaboration to conserve the resource. Building upon existing proposals for *in situ* landrace propagation management (Caproni *et al.*, 2020) and community seed banking (Bartha *et al.*, 2021), produce **practical guidelines for LR on-farm conservation and management**.
9. The establishment of nationally recognised LR on-farm diversity conservation sites will involve collation of passport, curatorial, management, and characterization and evaluation data for targeted conserved populations by national PGR programmes. The **LR passport, curatorial and management data held at national level should be included in agreed data structure and coordinated collation processes**.
10. A subset of the data collated for targeted LR diversity conserved in on-farm populations will have broader usage, notably the **passport, and characterization and evaluation data should be uploaded to EURISCO to promote its use**. It is assumed that the descriptors and process used could be adapted from van Hintum and Iriondo (2022) and applied in all European countries.
11. **Regular monitoring of priority LR populations maintained on-farm using both demographic and genomic techniques** should be used to check management success and promote usage. The genomic monitoring might be used to identify user desired traits to further aid user selection of conserved germplasm.
12. The comprehensiveness and effectiveness of LR conservation and the diversity available to users has not been evaluated, due to the lack of national LR checklists and inventories, but the as LR national strategy and action plans become available, there is a requirement for **implementation of systematic national *in situ* on-farm and *ex situ* LR conservation**.
13. Systematic LR conservation will require active on-farm conservation at multiple sites to effectively conserve LR diversity, these LR and their maintainers **grouped into coherent networks composed of collaborating farmers (LR maintainers), community groups and formal conservation sector representatives**. This would help maintainer use of tools, incentives, and guidelines to aid management and monitoring systems, including *ex situ* back-up.
14. Biodiversity conservation using OECM is a recent innovation to promote wild species based conservation, but the concept might be applied to LR-based on-farm conservation. A **critical analysis of the potential of OECMs for LR conservation** would potentially expand the professional and public awareness of LR value, conservation, and encourage sustainable use.

15. On-farm LR conservation is often implemented based on nomenclatural identification of targeted LR, but the relationship between nomenclatural and actual distinction has not been evaluated. **Genomic analysis of the relationship between nomenclatural and genetic identification of LR populations** should be evaluated. Such analysis would clarify the congruence and aid conservation gap filling.
16. It is assumed that LR conserved on-farm will be backed-up with *ex situ* samples to provide long-term security and user access, but the **Access and Benefit rights associated with off-farm backup requires clarification and straightforward guidance** to ensure farmer's protection.
17. Lack of active support for LR populations in most countries and at regional European levels is threatening LR diversity, which is compounded by diverse national implementation of support. There is a need to extend beyond geographic or heritage designations and conservation varieties. A **critical review of types and sustainability of incentives for LR maintenance is needed as a basis for implementation**.
18. The continuance of LR maintenance within farming systems is often linked to adding products value and development of niche markets, an evidence-based database of case studies of good practice exist (https://www.ecpgr.org/in-situ-landraces-best-practice-evidence-based-database), the **evidence-based database needs expanding and reviewed for potential policy enhancement**.
19. On-farm, more than any other form of conservation, requires a fully integrated approach that bring together farmers, communities, diversity networks and formal PGR conservationists to be successful it is noted that the farmer does the conservation. A **critical review of formal and informal sector integration is required** as a basis for systematic LR diversity conservation.
20. It seems likely that in some countries, home gardens are reservoirs of LR diversity lost from commercial farming systems. To evaluate the hypothesis there is a need for a **critical review of evidence that demonstrates whether home gardens act as persistent reservoir of LR diversity**.
21. All LR conservation is undertaken by farmers so their role is far from passive, their potential role as citizen scientise should be developed to aid formal conservation efforts. A **critical analysis of the capacity and potential of farmers to take a more active leadership and practical role in LR conservation,** in partnership with the formal PGR sector should be undertaken.
22. Despite the recent advances in LR conservation science, there remains a lack of awareness among biodiversity conservationists and policy makers of LR value beyond heritage and heirloom value to breeding resource value for all crop production. **LR value awareness among biodiversity conservationists and policy makers should be raised and translated into national and European LR legislation and actions for further protection**.
23. Beside the need for raising LR value awareness among biodiversity conservationists and policy makers, there is an associated need to **raise public awareness of the concepts of, value and economic potential of more systematic LR conservation and use**; placing LR diversity firmly on mainstream supermarket shelves.
24. To test and monitor the threats impacting LR diversity and the success of its conservation and use there is a need to **develop and application of a set of taxonomic and genetic conservation indicators for PGR** for which data could be regularly collated and analysed to monitor and assess the efficiency of PGR conservation and use, providing a basis for enhanced effectiveness.

It is anticipated that the results presented above will be used in three ways. First, that policy makers will examine the issues identified, and how they might influence policy and on what time scale. Secondly, it is expected that this exercise will help the PGR research community better target their activities for the immediate and longer-term future, considering the relative success of the previous PGR horizon scanning initiative. It is hoped that researchers, funders, and those working on PGR policy and regulation will use the outcome from this exercise when considering the future direction of strategic CWR / WHP and LR research. Finally, third this exercise may encourage further consideration and debate about the issues that are on the horizon and the ways in which scientists and decision makers can best communicate about them.

8. Discussion

Complementary conservation

The role of PGR conservation is the preservation and protection of genetic diversity / species / populations / habitats / ecosystems to ensure their availability for perpetuity, and where necessary, to restore them to self-sustaining systems. To conserve these systems, we need to use a sustainable approach that includes both *in situ* and *ex situ* actions. One without the other is unsustainable as neither alone can ensure that diversity is protected and available for use indefinitely. The three main objectives of PGR conservation, summarised in the *Principles of PGR Conservation and Use Congruence*, are:

(a) to maximise the long-term, sustainable maintenance of plant genetic diversity;
(b) to actively conserve resource diversity using complementary conservation techniques; and
(c) to ensure the conserved resource is available for utilisation.

To achieve these objectives, it is necessary that both conservation strategies and complementary techniques are integrated in an effective and sustainable manner. The strengths of each conservation strategy or technique together ensure maximum long-term, sustainable maintenance of plant genetic diversity. *In situ* conservation is vulnerable to detrimental changes in the environment where PGR are located, either through human induced or natural changes and disasters. *Ex situ* conservation is vulnerable as the resources cannot continue to evolve and their genetic adaptability to the present environmental conditions may be compromised. However, the vulnerability of *in situ* resources to adverse environmental changes and other disturbances can be mitigated by *ex situ* back-up, and the limited genetic diversity represented by *ex situ* accessions can be bolstered by conserving multiple diverse populations *in situ*, highlighting the fundamental need for both active *in situ* and *ex situ* conservation of PGR.

Sustainability of *in situ* conservation

The vulnerability of *in situ* conservation to environmental and habitat changes is a risk when sites / populations are poorly managed or poorly planned in terms of long-term conservation. This is where systematic *in situ* conservation planning, including ecogeographic, gap and climate change analyses can help to identify appropriate and sustainable *in situ* sites and populations. It is also where *ex situ* conservation can help to restore adversely affected populations. Although *in situ* populations may be vulnerable to environmental change this is also a key reason for conducting *in situ* conservation, as the genetic diversity in populations will be continually adapting to these changing conditions, something which *ex situ* conservation cannot facilitate.

***In situ* conservation networks**

There is a strong need to develop integrated *in situ* PGR networks at all levels using both bottom up and top-down approaches. These networks should be identified based upon sound scientific principles. The layer of networks would include:

- Global *in situ,* OECM and on-farm network;
- European *in situ*, OECM and on-farm network;
- National *in situ*, OECM and on-farm network;
- Community seed banks related to on-farm conservation and management;
- Individual CWR, WHP and LR populations in nature or on-farm.

The scope, objectives and activities of these networks will vary depending on individual circumstances but general guidance on the issues that could be discussed is reviewed by Maxted and Kell (2009) and Maxted et al (2014). Such networks could be one of the GRACE-RI services provided for the PGR community. However, the writing of the management for the sites / populations at any level will be those from the local / national agencies (ideally including the GRC) and use of any PGR will be covered under an SMTA.

Genetic resource centres (GRC)

A critical step to help integrate *in situ* and *ex situ* conservation is to ensure that both are being managed in an interoperable way. Moving from genebanks to GRC supports the integration of both methods of conservation. These GRC can lead on *in situ* and *ex situ* national PGR activities and can lobby for more resources are allocated for their activities. GRC staff will take a lead role in the national level network of *in situ* reserves and will be able to support those maintaining the PGR populations *in situ*. This support can include the development of management and monitoring plans and collecting material for *ex situ* conservation and utilisation.

EURISCO

The EURISCO database will be key in ensuring that *in situ* conservation meets the three pillars of PGR conservation and use. Updating the database to incorporate *in situ* data will ensure the link between conservation and use can be achieved. This needs to be developed with input from the *in situ* PGR maintainers as well as with input from those who want to use the material and those who maintain the online database.

GRACE-RI

GRACE-RI should provide existential support for *in situ* PGR conservation in Europe. The current initiative within the European Union’s Horizon Europe research and innovation programme, PRO GRACE project’s *raison d'être* is to develop the GRACE Research Infrastructure (RI) which is conceived as a:

> “*Novel, pan-European Research Infrastructure that aims to bring together the European institutions working actively on the conservation and characterization of plant genetic resources. Our vision is to ensure that plant genetic resources are conserved and shared, and the associated knowledge is improved and made available for future generations*.“

An obvious goal for the GRACE RI within its promotion of PGR conservation and use is to establish a network for sustainability *in situ* PGR conservation throughout Europe and many of the subordinate goals outlined above; the potential of such a network to at least double the available germplasm to the European PGR user community would along with it other proposed benefits described justify support for GRACE RI.

Next steps

The next steps are to start to evaluate the proposed methods set out in Section 5 for utilising *in situ* materials and integrating them into EURISCO. It will be necessary to evaluate this from different perspectives:

- Users who want material from a site they have identified often need to access characterization data to precisely define their target populations, accessions and related traits.
- Users who want material from *in situ* sites already identified and published in the EURISCO database.
- Database managers who need to integrate *in situ* and *ex situ* data
- *In situ* site / population managers who maintain the populations
- GRC curators and technicians who will duplicate and/or distribute *in situ* accessions.
- Germplasm health units (GHUs) who will need to evaluate the *in situ* accessions for distribution to comply with national and international phytosanitary requirements.

There will need to be an iterative approach to developing the integrated *in situ* and *ex situ* conservation of PGR which will require cooperation at all levels of the process from the population maintainers and managers to the users. Collaboration across diverse groups in the PGR community, and also between them and other stakeholder communities, will be key to future more effective conservation of PGR from national to regional to global levels.

References

Almeida, M.J., Barata, A.M., De Haan, S., Joshi, B.K., Magos Brehm, J., Yazbek, M. and Maxted, N., (2024). Towards a practical threat assessment methodology for crop landraces. *Frontiers in Plant Science*, 15: 1336876. doi: 10.3389/fpls.2024.1336876.

Amri, A., Ajlouni, M., Assi, R., Sbeih, Y., Saad, A., Khoury W. and Khnifes A., (2007). Major Achievements of the West Asia Dryland Agrobiodiversity Conservation Project. *Proceedings of the International Conference on 'Promoting community-driven in situ conservation of dryland agrobiodiversity'*. ICARDA, Aleppo, Syria.

Ansebo, L., (2015). *Ecosystem services: Genetic resources and crop wild relatives*. Available online: http://www.nordgen.org/index.php/en/content/view/full/2934 (accessed 06.11.2024).

Bartha, B., Fehér, J., Platzer, E., Poulsen, G., (2021). *Community seedbank management guidelines along four network showcases.* 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/19/2021/07/D2.3_Community_seedbank_management_guidelines.pdf (accessed 06.11.2024).

Bioversity International, (2016). *Safeguarding and using crop wild relatives for food security and climate change adaptation*. Available online: http://www.bioversityinternational.org/cwr/ (accessed 06.11.2024).

Bohra, A., Kilian, B., Sivasankar, S., Caccamo, M., Mba, C., McCouch, S.R. and Varshney, R.K., (2021). Reap the crop wild relatives for breeding future crops. *Trends in Biotechnology*, 40(4): 412-431. DOI: https://doi.org/10.1016/j.tibtech.2021.08.009

Brush, S.B., (2000). *Genes in the field: on-farm conservation of crop diversity*. Lewis Publishers, Boca Raton, USA.

Camacho Villa, T.C., Maxted, N., Scholten, M. and Ford-Lloyd, B.V., (2007) Defining and identifying crop landraces. *Plant Genetic Resources*, 3(3): 373–384. DOI: https://doi.org/10.1079/PGR200591.

Capistrano, G.C., Ries, D., Minoche, A., Kraft, T., Frerichmann, S.L.M., Holtgräwe, D., Soerensen, T.R., Varrelmann, M., Uphoff, H., Mechelke, W., Schechert, A., Himmelbauer, H., Weisshaar, B. and Kopisch-Obuch, F., (2014). Fine mapping of rhizomania resistance using in situ populations of the wild beet *Beta vulgaris* ssp. *maritima*. *Proceedings of the Plant & Animal Genome*, 22: 673.

Castañeda Álvarez, N.P., Vincent, H.A., Kell, S.P., Eastwood, R.J. and Maxted, N., (2011). Ecogeographic surveys. In Guarino, L., Ramanatha Rao, V. and Goldberg, E. (editors). *Collecting Plant Genetic Diversity: Technical Guidelines. 2011 update*. Bioversity International, Rome. Available online: http://cropgenebank.sgrp.cgiar.org/index.php?option=com_content&view=article&id=679. (accessed 06.11.2024).

CBD, (1992). *Convention on Biological Diversity: Text and Annexes*. pp. 1-34. Secretariat of the Convention on Biological Diversity, Montreal, Canada. Available at https://www.cbd.int/doc/legal/cbd-en.pdf (accessed 06.11.2024).

CBD, (2011). *Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization to the Convention on Biological Diversity: text and annex*. Secretariat of the Convention on Biological Diversity, Montreal, Canada. Available at: https://www.cbd.int/abs/doc/protocol/nagoya-protocol-en.pdf (accessed 06.11.2024).

Caproni, L., Raggi, L. and Negri V., (2020) *In situ* landrace propagation management and access guidelines. 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/wpcontent/uploads/sites/19/2020/09/D2.4_In_situ_landrace_propagation_management_guidelines.pd f (accessed 06.11.2024).

Dulloo, M.E., Labokas, J. Iriondo, J.M. Maxted, N., Lane, A. Laguna, E. Jarvis A. and Kell S.P., (2008). Genetic Reserve Location and Design. In: Iriondo, J.M., Maxted, N. and Dulloo, E. (Eds.), *Plant Genetic Population Management*. Pp. 23-64. CAB International, Wallingford.

Eastwood, R.J., Tambam, B.B., Aboagye, L.M., Akparov, Z.I., Aladele, S.E., Allen, R., Amri, A., Anglin, N.L., Araya, R., Arrieta-Espinoza, G., *et al.*, (2022). Adapting agriculture to climate change: a synopsis of coordinated national crop wild relative seed collecting programs across five continents. *Plants*, 11: 1840. https://doi.org/10.3390/plants11141840.

ECPGR European Genebank Managers Network, (2024). *Genebank Managers Network*. Available et: https://www.ecpgr.org/about/genebank-managers-network#:~:text=In%202023%2C%20the%20Steering%20Committee,leading%20and%20managing%20a%20genebank. (accessed 06.11.2024).

ECPGR, (2012). *Report of the 13th ECPGR Steering Committee Meeting* held at the Federal Ministry of Agriculture, Forestry, Environment and Water Management, Austria on 4-7 December 2012. Available online: http://www.ecpgr.cgiar.org/about-ecpgr/steering-committee/13th-sc-meeting/ (accessed 06.11.2024).

ECPGR, (2015). *Data exchange standard for uploading characterisation and evaluation data from National Inventories to EURISCO*. ECPGR, Bioversity International, Rome, Italy. Available at: https://eurisco.ipk-gatersleben.de/apex/eurisco_ws/r/eurisco/c-e-data (accessed 06.11.2024).

ECPGR, (2017). *ECPGR Concept for on-farm conservation and management of plant genetic resources for food and agriculture*. European Cooperative Programme for Plant Genetic Resources, Rome, Italy. Available at: https://www.ecpgr.org/fileadmin/bioversity/publications/pdfs/ECPGR_Concept_for_on_farm_final__05_05_2017_bis.pdf (accessed 06.11.2024).

ECPGR. (2021). *Plant Genetic Resources Strategy for Europe*. European Cooperative Programme for Plant Genetic Resources, Rome, Italy. Available at: https://www.ecpgr.org/resources/ecpgr-publications/publication/plant-genetic-resources-strategy-for-europe-2021 (accessed 06.11.2024).

EURISCO, (2015). C&E data. *EURISCO Newsletter,* December 2015. Available at file:///C:/Users/nigel/Downloads/EURISCO_newsletter_December_2015%20(3).pdf. (accessed 06.11.2024).

FAO, (1996). *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, pp. 1-510. Available online: https://openknowledge.fao.org/handle/20.500.14283/aj631e (accessed 06.11.2024).

FAO, (2001). *International Treaty on Plant Genetic Resources for Food and Agriculture*. Food and Agriculture Organization of the United Nations, Rome, Italy. Available online: http://www.fao.org/ag/cgrfa/itpgr.htm (accessed 06.11.2024).

FAO, (2011). *Second Global Plan of Action for Plant Genetic Resources for Food and Agriculture.* Food and Agriculture Organization of the United Nations, Rome, Italy. Available at: http://www.fao.org/docrep/015/i2624e/i2624e00.htm (accessed 06.11.2024).

FAO, (2013). *Towards the establishment of a global network for in situ conservation and on-farm management of PGRFA*. Report of Technical Workshop held in Rome, Italy 13th November 2012. Food and Agriculture Organization of the United Nations, Rome, Italy. Available at: http://www.fao.org/agriculture/crops/core-themes/theme/seeds-pgr/itwg/6th/technical-workshop/en/ (accessed 06.11.2024).

FAO, (2014). *Gene bank Standards for Plant Genetic Resources for Food and Agriculture*. Rev. Ed. Food and Agriculture Organization of the United Nations, Rome, Italy. Available at: http://www.fao.org/3/a-i3704e.pdf (accessed 06.11.2024).

FAO, (2019). Voluntary Guidelines for the Conservation and Sustainable Use of Farmers' Varieties/Landraces. Rome. Available at: http://www.fao.org/3/ca5601en/ca5601en.pdf. (accessed 06.11.2024).

FAO, IFAD, UNICEF, WFP and WHO, (2023). The State of Food Security and Nutrition in the World 2023: Building resilience for peace and food security. Rome, FAO. Available at: https://www.fao.org/publications/home/fao-flagship-publications/the-state-of-food-security-and-nutrition-in-the-world/en (accessed 06.11.2024).

Fitzgerald, H., Kiviharju, E., Palmé, A. and Hyvärinen, M., (2023). Complementary analysis and implementation plan for conservation of crop wild relatives in Finland. *Plants*, 12: 3313. https://doi.org/10.3390/plants12183313

Fitzgerald, H., Korpelainen, H. and Veteläinen, M., (2016). Developing a crop wild relative strategy for Finland. In: Maxted, N., Dulloo, E.M. and Ford-Lloyd, B.V. (eds.), *Enhancing Crop Gene pool Use: Capturing Wild Relative and Landrace Diversity for Crop Improvement*. Pp. 206-216. CAB International, Wallingford, UK.

Fitzgerald, H., Palmé, A., Asdal, Å., Endresen, D., Kiviharju, E., Lund, B., Rasmussen, M., Thorbjornsson, H. and Weibull, J., (2019). A regional approach to Nordic crop wild relative *in situ* conservation planning. *Plant Genetic Resources Characterisation and Utilization*, 17(2), 196-207. doi:10.1017/S147926211800059X

Green, N., Campbell, G., Tulloch, R. and Scholten, M., (2009). Scottish Landrace Protection Scheme. In: Veteläinen, M., Negri, V. and Maxted, N. (eds.) *European Landraces: On-farm conservation, Management and Use.* Bioversity Technical Bulletin 15. Bioversity International, Rome, Italy. Pp. 233-243. Available at: https://hdl.handle.net/10568/106154 (accessed 06.11.2024).

Harlan, J.R. and Wet, J.M.J., (1971). Toward a rational classification of cultivated plants. *Taxon*, 20, 509–517. doi: 10.2307/1218252

Hawkes, J.G., (1991). International workshop on dynamic *in situ* conservation of wild relatives of major cultivated plants: summary of final discussion and recommendations. *Israel Journal of Botany*, 40, 529-536.

Hawkes, J.G., Maxted, N. and Ford-Lloyd, B.V., (2000). *The* ex situ *conservation of plant genetic resources*. pp. 1-250. Kluwer, Dordrecht.

Heywood, V.H., (2015). *In situ* conservation of plant species – an unattainable goal? *Israel Journal of Plant Sciences*, 63(4), 211-231. https://doi.org/10.1080/07929978.2015.1035605.

Holubec V., Janovská D. and Papoušková, L., (2020). *Methodology of on farm conservation of obsolete cultivars and landraces. (Metodika on-farm konzervace starých a krajových odrůd zemědělských plodin).* VURV Praha, 50 str. ISBN: 978-80-7427-331-5. Available at: https://www.vurv.cz/wp-content/uploads/2021/06/ISBN-978-80-7427-331-5_Holubec_Vojtech_Certifikovana_metodika_Metodika_onfarm_konzervace_starych_a_krajovych-odrud_zemedelskych_plodin.pdf (accessed 06.11.2024).

IPGRI, (1991). *Elsevier's Dictionary of Plant Genetic Resources*. Elsevier, Amsterdam, Netherlands.

Iriondo, J.M., Magos Brehm, J., Dulloo, M.E. and Maxted, N. (eds.) (2021). *Crop Wild Relative Population Management Guidelines*. Farmer's Pride: Networking, partnerships and tools to enhance *in situ* conservation of European plant genetic resources. ECPGR, Rome, Italy. Available at University of Birmingham, Birmingham, UK. https://more.bham.ac.uk/farmerspride/key-documents/crop-wild-relatives/ (accessed 06.11.2024).

Iriondo, J.M., Maxted, N. and Dulloo, E. (eds.), (2008). *Conserving Plant Genetic Diversity in Protected Areas: Population Management of Crop Wild Relatives*. Pp. 1-212. CAB International, Wallingford, UK.

Iriondo, J.M., Maxted, N., Kell, S.P., 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: Maxted, N., Dulloo, M.E., Ford-Lloyd, B.V., Frese, L., Iriondo, J.M. and Pinheiro de Carvalho, M.A.A. (eds.) *Agrobiodiversity Conservation: Securing the Diversity of Crop Wild Relatives and Landraces*. Pp. 72-77. CAB International, Wallingford, UK.

IUCN, (2012). *IUCN Red List categories and criteria*, version 3.1, second edition. Gland and Cambridge, IUCN. Available at: https://portals.iucn.org/library/node/10315 (accessed 06.11.2024).

Harisha, R.P., Siddappa Setty, R., Ravikanth, G., (2023). Wild Food Plants: History, Use, and Impacts of Globalization. In: Kumar, A., Singh, P., Singh, S. and Singh, B. (eds) *Wild Food plants for zero hunger and resilient agriculture*. Plant Life and Environment Dynamics. Springer, Singapore. DOI: 10.1007/978-981-19-6502-9_3.

Jarvis, D.I., Hodgkin, T., Brown, A.H.D., Tuxill, J., López Noriega, I., Smale, M. and Sthapit, B., (2016). *Crop genetic diversity in the field and on the farm: principles and applications in research practices*. Yale University Press, New Haven, USA.

Jarvis, D.I., Padoch, C. and Cooper, H.D., (2007). *Managing biodiversity in agricultural ecosystems*. Columbia University Press, New York, USA.

Jarvis, S., Fielder, H., Brotherton, P., Hopkins, J.J., Maxted, N. and Smart, S., (2015). Distribution of crop wild relatives of conservation priority in the UK landscape. *Biological Conservation*, 191: 444–451.

Kell, S.P., Ford-Lloyd, B.V., Magos Brehm, J., Iriondo, J.M. and Maxted, N., (2016). Broadening the base, narrowing the task: prioritizing crop wild relative taxa for conservation action. *Crop Science*, 57:1042–1058. doi: 10.2135/cropsci2016.10.0873.

Kell, S.P., Knüpffer, H., Jury, S.L., Ford-Lloyd, B.V. and Maxted, N., (2008). Crops and wild relatives of the Euro-Mediterranean region: making and using a conservation catalogue. In: Maxted, N., Ford-Lloyd, B.V., Kell, S.P., Iriondo, J., Dulloo, E. and Turok, J. (eds.) *Crop Wild Relative Conservation and Use*. Pp. 69-109. CAB International, Wallingford, UK.

King, D.A. and Thomas, S.M., (2007). Taking science out of the box – foresight recast. *Science*, 316, 1701–1702.

Khanhafkhan, P. and Altieri, M.A., (2017). *Forgotten Agricultural Heritage: Reconnecting Food Systems and Sustainable Development*. Earthscan from Routledge, London, UK.

Labokas, J., Lisajevičius, M., Uogintas, D., and Karpavičienė, B., (2024). Enhancing in situ conservation of crop wild relatives for food and agriculture in Lithuania. *Agronomy*, 14(9): 2126. https://doi.org/10.3390/agronomy14092126.

Maggioni, L., (2023). *Extension of EURISCO for Crop Wild Relatives (CWR)* in situ *data and preparation of pilot countries' data sets*. Proposal submitted for funding to the German Federal Office for Agriculture and Food. Secretariat of the European Cooperative Programme on Plant Genetic Resources (ECPGR), Rome, Italy. Available at: https://www.ecpgr.org/fileadmin/templates/ecpgr.org/upload/WORKING_GROUPS/WILD_SPECIES/CWR_in_EURISCO_proposal.pdf (accessed 06.11.2024).

Magos Brehm, J., Gaisberger, H., Kell, S.P., Parra-Quijano, M., Thormann, I., Dulloo, M.E. and Maxted, N., (2022). Planning complementary conservation of crop wild relative diversity in southern Africa. *Diversity and Distributions*, DOI:10.1111/ddi.13512.

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/ (accessed 06.11.2024).

Maxted N., Amri. A., Castañeda-Álvarez, N.P., Dias, S., Dulloo, M.E., Fielder, H., Ford-Lloyd, B.V., Iriondo, J.M., Magos Brehm, J., Nilsen, L-B., Thormann, I., Vincent, H. and Kell, S.P., (2016). Joining up the dots: a systematic perspective of crop wild relative conservation and use. In: Maxted, N., Ehsan Dulloo, M. 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, UK.

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

Maxted, N., Guarino, L., Myer, L. and Chiwona, E.A., (2002). Towards a methodology for on-farm conservation of plant genetic resources. *Genetic Resources and Crop Evolution*, 49: 31-46.

Maxted, N. and Kell, S.P., (2008). Linking *in situ* and *ex situ* conservation with use of crop wild relatives. In: Maxted, N., Ford-Lloyd, B.V., Kell, S.P., Iriondo, J., Dulloo, E. & Turok, J. (eds.) *Crop Wild Relative Conservation and Use*. Pp. 448-468. CAB International, Wallingford, UK.

Maxted, N. and Kell, S.P., (2009). *Establishment of a network for the* in situ *conservation of crop wild relatives: status and needs*. Commission on Genetic Resources for Food and Agriculture. Food and Agriculture Organization of the United Nations, Rome, Italy. 211 pp. http://www.fao.org/docrep/013/i1500e/i1500e18a.pdf (accessed 06.11.2024).

Maxted, N., Kell, S.P. and Magos Brehm, J., (2014). *Global Networking on in situ Conservation and on-farm Management of Plant Genetic Resources for Food and Agriculture*. Food and Agriculture Organization of the United Nations, Rome, Italy. 14 pp. Available at: http://www.fao.org/3/a-mm537e.pdf (accessed 06.11.2024).

Maxted, N. and Magos Brehm, J., (2023). Maximizing the crop wild relative resources available to plant breeders for crop improvement. *Frontiers in Sustainable Food Systems*, 7: doi.org/10.3389/fsufs.2023.1010204.

Maxted, N. and Palmé, A., (2016). Combining *ex situ* and *in situ* conservation strategies for CWR to mitigate climate change. In: *The impact of climate change on the conservation and utilization of crop wild relatives in Europe* (Eds. Valdani Vicari & Associati *et al.*), Barcelona, Spain, 15th December 2015. Preparatory action on EU plant and animal genetic resources (AGRI-2013-EVAL-7) Workshop Report, Directorate General for Agriculture and Rural Development, European Commission, Brussels, Belgium.

Maxted, N. and Scholten, M.A., (2007). Methodologies for the creation of National / European inventories. In: Del Greco, A., Negri V. and Maxted, N. (compilers) *Report of a Task Force on On-farm Conservation and Management, Second Meeting*, 19-20 June 2006, Stieglitz, Germany. Pp. 11-19. Bioversity International, Rome, Italy. Available at: https://www.ecpgr.org/fileadmin/bioversity/publications/pdfs/1200.pdf (accessed 06.11.2024).

Maxted, N. and Vincent, H., (2021). Review of congruence between global crop wild relative hotspots and centres of crop origin / diversity. *Genetic Resources and Crop Evolution*, 68(4): 1283-1297. DOI 10.1007/s10722-021-01114-7.

Maxted, N., (2019). Another look at *in situ* / *ex situ* CWR conservation linkage. *Crop Wild Relative*, 11: 22–25.

Maxted, N., Akparov, Z.I., Aronsson, M., Asdal, Å., Avagyan, A., Bartha, B., Benediková, DT. Berishvili, T., Bocci, R., Cop, J., Curtis, T., Daugstad, K., Dias, S., Duarte, M.C., Dzmitryeva, S., Engels, J.M.M., Fasoula, D.A. Ferant, N., Frese, L., Freudenthaler, P., Hadas, R. Holly, L., Ibraliu, A. Iriondo, J.M., Ivanovska, S., Jinjikhadze, T., Kamari, G., Kell, S.P., Kik, C., Koop, L., Korpelainen, H., Kristiansen, K., Kyratzis, A. Labokas, J., Maggioni, L., Magos Brehm, J., Maloupa, E., Martinez, J.J.R., Mendes Moreira, P.M.R., Musayev, M., Radun, M., Ralli, P., Sandru, D. Sarikyan, K., Schierscher-Viret, B., Smekalova, T., Stehno, Z., Stoilova, T., Strajeru, S., Tan, A., Veteläinen, M., Vögel, R., Vorosvary, G. and Negri, V., (2012). Current and future threats and opportunities facing European crop wild relative and landrace diversity. In: Maxted, N., Dulloo, M.E., Ford-Lloyd, B.V., Frese, L., Iriondo, J.M. and Pinheiro de Carvalho, M.A.A. (eds.) *Agrobiodiversity Conservation: Securing the Diversity of Crop Wild Relatives and Landraces*. Pp. 333-354. CAB International, Wallingford, UK.

Maxted, N., Avagyan, A., Frese, L., Iriondo, J.M., Kell, S.P. Magos Brehm, J., Singer, A. and Dulloo, M.E., (2015a). Conservation planning for crop wild relative diversity. In: Redden, R., Yadav, S.S., Maxted, N., Dulloo, M.E., Guarino, L. and Smith, P. (Eds.), *Crop wild relatives and climate change*. Pp. 88-107. John Wiley & Sons, Inc., Hoboken, USA.

Maxted, N., Avagyan, A., Frese, L., Iriondo, J.M., Magos Brehm, J., Singer, A., Kell, S.P., (2015b). ECPGR Concept for *in situ* conservation of crop wild relatives in Europe. Wild Species Conservation in Genetic Reserves Working Group, European Cooperative Programme for Plant Genetic Resources, Rome, Italy. Available at: www.ecpgr.org/fileadmin/templates/ecpgr.org/upload/WG_UPLOADS_PHASE_IX/WILD_SPECIES/Concept_for_in__situ_conservation_of_CWR_in_Europe.pdf (accessed 06.11.2024).

Maxted, N., Ford-Lloyd, B.V. and Hawkes, J.G., (1997a). Complementary conservation strategies. In: *Plant genetic conservation: the* in situ *approach* (eds. Maxted, N., Ford-Lloyd, B.V. and Hawkes, J.G.), pp. 20-55. Chapman & Hall, London.

Maxted, N., Ford-Lloyd, B.V. and Kell, S.P., (2008). Crop wild relatives: establishing the context. In: Maxted, N., Ford-Lloyd, B.V., Kell, S.P., Iriondo, J., Dulloo, E. and Turok, J. (eds.), *Crop Wild Relative Conservation and Use*. Pp. 3-30. CAB International, Wallingford, UK.

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: 2673–2685.

Maxted, N., Hawkes, J.G., Guarino, L. and Sawkins, M., (1997b). The selection of taxa for plant genetic conservation. *Genetic Resources and Crop Evolution*, 44: 337-348.

Maxted, N., Hunter, D. and Ortiz Rios, R.O., (2020). *Plant genetic conservation*. 560 pp. Cambridge University Press, Cambridge.

Nevo, E., Fu, Y.B., Pavlicek, T., Khalifa, S., Tavasi, M., and Beiles, A., (2012). Evolution of wild cereals during 28 years of global warming in Israel. *Proceedings of the National Academy of Sciences*, 109(9), 3412-3415.

Palmé, A., Fitzgerald, H., Weibull, J., Bjureke, K., Eisto, K., Endresen, D., Hagenblad, J., Hyvärinen, M., Kiviharju, E., Lund, B., Rasmussen, M. and Þorbjörnsson, H., (2019). *Nordic Crop Wild Relative conservation. A report from two collaborative projects 2015–2019*. Nordic Council of Ministers, Copenhagen Denmark. Available at: https://norden.diva-portal.org/smash/get/diva2:1335894/FULLTEXT02.pdf (accessed 06.11.2024).

Pinela, J., Carvalho, A.M. and Ferreira, I.C.F.R., (2017). Wild edible plants: Nutritional and toxicological characteristics, retrieval strategies and importance for today's society. *Food and Chemical Toxicology*, 110: 165–188.

Raggi, L., Ciro Pacicco, L., Caproni, L., Álvarez-Muñiz, C., Annamaa, K., Maria Barata, A., Batir-Rusu, D., Díez, M.J., Heinonen, M., Holubec, V., Kell, S.P., Kutnjak, H.P., Maierhofer, H., Poulsen, G., Prohens, J., Ralli, J., Rocha, F., Rubio Teso, M.L., Sandru, D., Santamaria, P., Sensen, S., Shoemark, O., Soler, S., Străjeru, S., Thormann, I., Weibull, J., Maxted, N. and Negri, V., (2022). Analysis of landrace cultivation in Europe: a means to support in situ conservation of crop diversity. *Biological Conservation*, 267: 109460.

Sutherland, W.J., Bailey, M. J., Bainbridge, I.P., Brereton, T., Dick, J.T.A., Drewitt, J., Dulvy, N.K., Dusic, N.R., Freckleton, R.P., Gaston, K.J., Gilder, P.M., Green, R.E., Heathwaite, A.L., Johnson, S.M., Macdonald, D.W., Mitchell, R., Osborn, D., Owen, R.P., Pretty, J., Prior, S.V., Prosser, H., Pullin, A.S., Rose, P., Stott, A., Tew, T., Thomas, C.D., Thompson, D.B.A., Vickery, J.A., Walker, M., Walmsley, C., Warrington, S., Watkinson, A.R., Williams, R. J., Woodroffe, R., Woodroof, H.J., (2008). Future novel threats and opportunities facing UK biodiversity identified by horizon scanning. *Journal of Applied Ecology*, 45(3), 1365-2664.

Sutherland, W.J., Clout, M., Côté, I.M., Daszak, P., Depledge, M.H.,, Fellman, E., Fleishman, E., Garthwaite, R., Gibbons, D.W., De Lurio, J., Impey, A.J., Lickorish, F., Lindenmayer, D., Madgwick, J., Margerison, C., Maynard, T., Peck, L.S., Pretty, J., Prior, S., Redford, K.H., Scharlemann, J.P.W., Spalding, M. and Watkinson, A.R., (2010). A horizon scan of global conservation issues for 2010. *Trends in Ecology and Evolution*, 1198, 1-7.

Taylor, N.G., Kell, S.P., Holubec, V., Para-Quijano, M., Chobot, K. and Maxted N., (2017). A systematic conservation strategy for crop wild relatives in the Czech Republic. *Diversity and Distribution,* 23: 448-462.

Tiranti, B. and Negri, V., (2007). Selective microenvironmental effects play a role in shaping genetic diversity and structure in a *Phaseolus vulgaris* L. landrace: implications for on-farm conservation. *Molecular Ecology*, 16: 4942-4955. DOI: 10.1111/j.1365-294X.2007.03566.x

Teixidor-Toneu ,I., Giraud, N.J., Karlsen, P., Annes, A. and Kool, A., (2023), A transdisciplinary approach to define and assess wild food plant sustainable foraging in Norway. *Plants, People, Planet*, 5(1): 112–122.

Thormann, I., Parra-Quijano, M., Endresen, D.T.F., Rubio-Teso, M.L., Iriondo, M.J. and Maxted, N., (2014). *Predictive characterization of crop wild relatives and landraces. Technical guidelines version 1*. Bioversity International, Rome, Italy. Available online at: http://www.bioversityinternational.org/index.php?id=244&tx_news_pi1%5Bnews%5D=4967&cHash=7cd3c6c2b8360927b83fa6ef7cc28d99 (accessed 06.11.2024).

Traill, L.W., Bradshaw, C.J.A. and Brook, B.W., (2007). Minimum viable population size: a meta-analysis of 30 years of published estimates. *Biological Conservation*, 139: 159–166.

United Nations, (2015). *Sustainable development goals*. Available at: https://www.un.org/sustainabledevelopment/sustainable-development-goals/ (accessed 06.11.2024).

van Hintum, T. And Iriondo, J.M., (2022). Principles for the Inclusion of CWR Data in EURISCO. European Cooperative Programme for Plant Genetic Resources (ECPGR), Rome, Italy. Available online at: https://www.ecpgr.org/resources/ecpgr-publications/publication/principles-for-the-inclusion-of-cwr-data-in-eurisco-2022 (accessed 06.11.2024).

van Hintum, T., Iriondo, J., Van Treuren, R., Rubio Teso, M.L. and Álvarez , C., (2021). *Guidelines for integrated in situ and ex situ PGR conservation*. Farmer's Pride, University of Birmingham, Birmingham, UK. Available at: https://more.bham.ac.uk/farmerspride/wp-content/uploads/sites/19/2021/07/D2.6_Guidelines_for_integrated_in_situ_and_ex_situ_conservation.pdf (accessed 06.11.2024).

Vavilov, N.I., (1926). The centers of origin of cultivated plants. *Applied Botany and Plant Breeding*, 16(2): 248.

Veteläinen, M., Negri, V. and Maxted, N., (eds.), (2009a). *European landraces: on-farm conservation, management and use.* Bioversity Technical Bulletin 15. Pp. 1-359. Bioversity International, Rome, Italy. Available online at: http://www.bioversityinternational.org/index.php?id=244&tx_news_pi1%5Bnews%5D=4967&cHash=7cd3c6c2b8360927b83fa6ef7cc28d99 (accessed 06.11.2024).

Veteläinen, M., Negri, V. and Maxted, N., (2009b). A European Strategic Approach to Conserving Crop Landraces. In: Veteläinen, M., Negri, V. and Maxted, N. (eds.), *European Landraces: On-farm conservation, Management and Use.* Bioversity Technical Bulletin 15. Pp. 305-325. Bioversity International, Rome, Italy. Available online at: http://www.bioversityinternational.org/index.php?id=244&tx_news_pi1%5Bnews%5D=4967&cHash=7cd3c6c2b8360927b83fa6ef7cc28d99 (accessed 06.11.2024).

Vincent, H., Amri, A., Castañeda-Álvarez, N.P., Dempewolf, H., Dulloo, M.E., Guarino, L., Hole, D., Mba, C., Toledo, A. and Maxted, N., (2019). Modelling of crop wild relative species identifies areas globally for *in situ* conservation. *Communications Biology*, 2:136.

Wilkinson, M.D., Dumontier, M., Aalbersberg, I.J., Appleton, G., Axton, M., Baak, A., Blomberg, N., Boiten, J.-W., da Silva Santos, L.B., Bourne, P.E., Bouwman, J., Brookes, A.J., Clark, T., Crosas, M., Dillo, I., Dumon, O., Edmunds, S., Evelo, C.T., Finkers, R., Gonzalez-Beltran, A., Gray, A.J.G., Groth, P., Goble, C., Grethe, J.S., Heringa, J., Hoen, P.A.C, Hooft, R., Kuhn, T., Kok, R., Kok, J., Lusher, S. J., Martone, M.E., Mons, A., Packer, A.L., Persson, B., Rocca-Serra, P., Roos, M., van Schaik, R., Sansone, S.-A., Schultes, E., Sengstag, T., Slater, T., Strawn, G., Swertz, M.A., Thompson, M., van der Lei, J., van Mulligen, E., Velterop, J., Waagmeester, A., Wittenburg, P., Wolstencroft, K., Zhao, J., and Mons, B., (2016). The FAIR Guiding Principles for scientific data management and stewardship. *Scientific Data*, 160018(3-1): 2052-4463. https://doi.org/10.1038/sdata.2016.18.