Conserving plant diversity for future generations

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Proposal for the establishment of a European network for *in situ* conservation and sustainable use of plant genetic resources

A first regional component of the global 'Vavilov Network'

A white paper prepared by Farmer's Pride collaborators

EXECUTIVE SUMMARY

In 2016, recognizing the vital ecosystem service provided by crop wild relatives and landraces as a reservoir of valuable traits for crop adaptation (including to climatic changes), and the threats posed to these resources, the European Commission called for activities to help build a network of *in situ* (including on-farm and in-garden) conservation sites and stakeholders[1]. The Farmer's Pride project is addressing this challenge and in this white paper, sets out a vision for a permanent 'European Network for *In Situ* Conservation and Sustainable Use of Plant Genetic Resources', and proposes mechanisms for its establishment and long-term governance.

The Network will be the first regionally-based initiative which brings together designated *in situ* crop wild relative and on-farm landrace populations and their custodians, with the common objective and commitment to long-term management to agreed minimum standards. We envisage that the European Network will be the first regional component of a global network that promotes *in situ* conservation and sustainable use of plant genetic resources—an endeavour that has been on the global agenda since 2009.

Membership of the Network will provide recognition of the importance of the resources that custodians maintain and their role in sustaining them, thus adding value to their activities. Critically, the function of the Network is not only to ensure long-term *in situ* conservation of plant genetic resources, but to promote the use of the conserved resources by farmers and other landrace maintainers, researchers, plant breeders, and any other professionals with an interest in sustainable use of PGR.

The justifications for the establishment of the European Network are clear:

1. *Meeting policy and legislative obligations* – The establishment of the European Network will contribute significantly to achieving globally agreed goals on biodiversity conservation and sustainable development. For example, Aichi Biodiversity Target 13 of the Convention on Biological Diversity's Targets, priority activities 2 and 4 of the FAO Second Global Plan of Action for Plant Genetic Resources for Food and Agriculture, and UN Sustainable Development Goal 2, 'Zero hunger'.
2. *Addressing the threats posed by climate change* – The magnitude that the impacts of climate change is already having on food production in Europe and elsewhere demands greater diversity to maintain or develop climate-smart crop varieties. Crop wild relatives and landraces provide the diversity needed to address this challenge but are themselves threatened by the environmental impacts of climate change. There is extensive demand among the user community for the availability of additional adaptive diversity for use in crop improvement programmes.
3. *Supporting local communities and livelihoods* – The direct use of landraces by farmers and other maintainers is important for their livelihoods, local economies, and to support local food and nutrition security. However, greater incentives and an improved policy environment are needed to support these stakeholders in their role as custodians of plant genetic diversity as a common good.
4. *Conserving threatened resources in a globally important hotspot* – Recent research has confirmed the extraordinary concentration of globally important crop wild relative and landrace diversity in

[1] H2020-SFS-2016-2017: New partnerships and tools to enhance European capacities for *in situ* conservation – ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/topic-details/sfs-04-2017

Europe. However, there is robust evidence of significant taxon and genetic erosion, particularly since the 1960s when estimates of existing diversity were first attempted. There is an implied obligation on Europe to systematically and effectively conserve the breadth of this diversity as a contribution to global food security.

5. *Filling the conservation gap* – Less than half of Europe's most important crop wild relatives for food and economic security are present in gene banks and there is only a handful of *in situ* genetic reserves for crop wild relative diversity conservation—none of which are actively managed to conserve genetic diversity to published standards. Since we know that landraces have been and continue to be lost, active conservation interventions are needed to halt and reverse this trend.
6. *Focusing at regional level* – A national approach to plant genetic resources conservation is essential because nations have sovereignty over the genetic resources within their jurisdiction and the responsibility to conserve them. However, national priorities vary between nations and may not take into account broader regional priorities. Therefore, a Europe-wide plant genetic resources conservation and sustainable use network is needed to ensure that regionally important resources are targeted for conservation action across their full range.
7. *Building on the scientific knowledge foundation* – Advances in our understanding of PGR diversity in Europe, as well as in planning and implementing *in situ* conservation actions, provides a solid foundation for the development of a strategic approach to CWR and LR conservation in Europe based on a range of commonly agreed and widely tested scientific concepts and techniques.

In the context of these clear justifications, we set out how key complementary crop wild relative and landrace sites or populations can be identified, once identified, how they will be included in the Network, how a Network governing body could be established to oversee its smooth running, and how the *in situ* conserved resources can be made available and accessible for sustainable use. We also elaborate the benefits of the Network to members, local communities and to the European community at large. Finally, we argue that for the Network to be sustainable, there is a need for an international agency to provide overarching governance support.

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1.0 BACKGROUND

1.1 *In situ* network context

In three major reports published over the past two decades, the UN Food and Agriculture Organization (FAO, 1998, 2010, 2019)—recognizing the critical importance of crop wild relative (CWR) and crop landrace (LR) diversity as vital resources for food, nutrition and economic security—has highlighted the need for concerted efforts to conserve them *in situ* (in nature and on-farm). These resources have significant value as provisioning ecosystem services: CWR have been utilized as sources of traits for crop improvement since the 1940s, and their use has increased significantly since the 1970s (Maxted and Kell, 2009), while the importance of LR is two-fold—they are of direct use in small-scale subsistence and commercial agriculture, and constitute a potential source of novel genetic diversity for crop improvement. Despite their recognized value, these under-conserved resources are threatened by changes in land use and management, replacement (of LR) with modern cultivars, habitat degradation, and climate change.

At the same time, the environmental impacts of climate change are causing significant challenges for the agricultural and horticultural industries. For example, in 2003, extreme weather events resulting from climate change in Europe caused estimated overall uninsured economic losses in the EU agriculture sector of €13 billion (Létard *et al.*, 2004). It is widely agreed that new climate resilient crop cultivars are required if food security is to be maintained (e.g., see Jones *et al*., 2003; Duveiller *et al*., 2007; FAO, 2008; Feuillet *et al*., 2008; Lobell et al., 2008; Deryng et al., 2011; Guarino and Lobell, 2011; Li et al., 2011; Luck et al., 2011; McCouch et al., 2013; Muñoz-Amatriaín et al., 2014). However, this requires a step change to improve the global plant genetic resources (PGR) use system, failings in which are currently restricting crop diversification and improvement (Kell *et al*., 2017a).

These concerns have been acknowledged by nation states worldwide, as evidenced by recommendations of the Commission on Genetic Resources for Food and Agriculture (CGRFA) and as reflected in international policies. At its Thirteenth Regular Session, the CGRFA recognized that the establishment of a global *in situ*/on-farm network would support efforts to meet germplasm users' needs and create more awareness of the value and necessity of *in situ* conservation and on-farm management as a means of addressing some of the challenges facing agricultural production, including climate change (FAO, 2011). The Commission therefore requested FAO to elaborate on the means and opportunities for establishing a global network for *in situ* conservation and on-farm management of PGRFA, avoiding duplication of efforts (FAO, 2011).

A technical workshop 'Towards the establishment of a global network for *in situ* conservation and on-farm management of PGRFA' was organised and held in Rome, 13 November 2012, to identify options, ways, and means for establishing a global network or networks (FAO, 2012). The workshop's recommendations on the means and opportunities for establishing a global network for *in situ* conservation and on-farm management of PGRFA were presented to the Fourteenth Regular Session of the Commission, held in Rome, 15–19 April 2013. In its report on the Fourteenth Session, the Commission requested FAO to prepare a concept note detailing the structure, functions and financial implications of the establishment of either a global network for *in situ* conservation and on-farm management, or two networks separately addressing these areas (FAO, 2013).

Within the European Union (EU), in line with the results of the 10th Conference of the Parties (COP) of the CBD, a new EU biodiversity strategy—*Our life insurance, our natural capital: an EU biodiversity*

strategy to 2020—was adopted by the European Commission (EC, 2011). This provided a framework for the EU to meet its own biodiversity objectives and its global commitments as a party to the CBD. The Strategy set out a long-term vision to be achieved by 2050, such as: "By 2050, European Union biodiversity and the ecosystem services it provides—its natural capital—are protected, valued and appropriately restored for biodiversity's intrinsic value and for their essential contribution to human wellbeing and economic prosperity, and so that catastrophic changes caused by the loss of biodiversity are avoided" (European Commission, 2011). The European Parliament stressed "the need for more effective cooperation at European level in the field of scientific and applied research regarding the diversity of animal and plant genetic resources in order to ensure their conservation, improve their ability to adapt to climate change, and promote their effective take-up in genetic improvement programmes" (European Parliament, 2012).

At its twelfth meeting, the European Cooperative Programme for Plant Genetic Resources (ECPGR) Steering Committee (SC) agreed that the ECPGR Task Force on EU matters would prepare a strategy paper that outlines gaps and required actions to improve the relationship between ECPGR and the European Commission (EC) (ECPGR, 2012). This Task Force proposed that the ECPGR *In Situ* and On-farm Conservation Working Groups should establish two Task Forces to develop concepts for (a) *in situ* conservation of CWR and (b) on-farm conservation of LR, which could then be reviewed, comments provided and finally endorsement by the ECPGR SC. Both concepts were prepared (see Maxted *et al.*, 2015; ECPGR, 2017) and endorsed by the ECPGR SC. The concepts would then be forwarded to the EC as an aid to developing European policy on *in situ* conservation of CWR and LR in the context of implementing the wider EU strategy for the conservation of genetic resources in food, agriculture and forestry. However, no significant response was received from the EC, therefore, another means of moving forward with the European *In Situ* Network was required.

This opportunity arose in the EC H2020 Call SFS-04-2017 'New partnerships and tools to enhance European capacities for *in situ* conservation' (Box 1). A consortium led by the University of Birmingham applied for and was funded under this call. The application 'Networking, partnerships and tools to enhance in situ conservation of European plant genetic resources' (short name, 'Farmer's Pride') is a three year EU-funded project which started in November 2017. The Farmer's Pride consortium and collaborators, is building a network for on-site conservation and sustainable use of Europe's plant diversity for food, nutrition and economic security throughout the region.

Box 1. Farmer's Pride: challenge addressed and scope of the action (H2020-SFS-2016-2017 – ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/topic-details/sfs-04-2017)

Specific challenge

In situ (including on-farm) conservation is an important complement to ex situ conservation efforts and particularly relevant for tackling Crop Wild Relatives (CWR) and LR. Unlike the more static conservation of genetic material in gene banks, *in situ* conservation is seen as a means of capturing the evolutionary adaptation of plants exposed to changing environmental and management conditions, thereby providing a reservoir of valuable traits for crop adaptation (including to climatic changes). To be effective, *in situ* conservation strategies require a complex multi-actor approach and need to be embedded into overall strategies to preserve plant genetic resources.

Scope

Activities will help to build (a) network(s) of *in situ* (including on-farm and on-garden) conservation sites and stakeholders in order to develop new partnerships between the conservation, farming,

gardening and breeding sectors and with the wider public. This will expand capacities to manage genetic resources in more dynamic and participatory ways and to support their use in breeding, farming and the food chain. Cooperation between conservation stakeholders will enhance knowledge of available resources, support the demonstration of *in situ* genetic resources to the wider public and improve access to this genetic reservoir. Exchanges with the breeding sector will provide openings to identify promising traits from LR and CWR and increase their use in breeding. Activities will also contribute to developing and showcasing strategies for *in situ* conservation and to linking *ex situ* and *in situ* conservation efforts more effectively. While targeting in particular European capacities, projects are encouraged to draw on good examples from elsewhere. The work is expected to benefit from the contribution of social sciences. Proposals should fall under the concept of the 'multi-actor approach'.

1.2 Network concept and vision

There are numerous types of networks that exist or could be newly established, including those for seed exchange, traditional or organic farming, and protected area managers. However, the prime focus here is to establish a **network of sites and/or populations and their custodians that is designed to optimize CWR and LR genetic diversity maintenance and use**. It is envisaged that the European Network will be the first regional component of a global network that promotes PGR *in situ* conservation and use (referred to here as the '**Vavilov Network**', named in honour of the Russian geneticist N.I Vavilov, one the first scientists to understand and promote the conservation of crop genetic diversity as an insurance for future food security). There are currently no existing initiatives or networks that duplicate the precise role foreseen for the European Network—that of promoting CWR *in situ* or LR on-farm conservation and sustainable use. This white paper therefore proposes a vision for a permanent 'European Network for *In Situ* Conservation and Sustainable Use of Plant Genetic Resources' (Box 2), and mechanisms for its establishment and long-term governance.

Box 2. European Network for *In Situ* Conservation and Sustainable Use of Plant Genetic Resources

Vision

A permanent European network for *in situ* conservation and sustainable use of plant genetic resources that is managed to conserve, and make available for use the maximum breadth of crop wild relative and landrace genetic diversity to achieve future food, nutrition and economic security.

The anticipated roles and benefits of the Network include:

- *Facilitating coordination* to ensure complementary conservation actions are planned and implemented to maximize the use of the available resources;
- *Encouraging effectiveness* by impacting positively on the coordination/harmonization of activities at national level;
- *Promoting new partnerships* and fostering existing ones between the diverse actors associated with CWR and LR diversity conservation and use at national, regional and global levels;
- *Involving local communities* that have maintained diversity for millennia to sustain traditional links between CWR and LR diversity, ecosystem services and human well-being;
- *Ensuring complementary conservation in situ and ex situ* to maximize the breadth of diversity conservation;
- *Enhancing resource availability and use* by providing a platform to improve access to PGR and associated data.

While a new network for *in situ* PGR conservation and sustainable use is being established, it will build on and foster partnerships between existing organizations and processes for PGR conservation and use. Examples of existing international site and stakeholder networks that have related (complementary) aims are: CBD Programme of Work on Protected Areas[2]; ECPGR[3]; EUROPARC Federation[4]; Eurosite[5]; FAO Globally Important Agricultural Heritage Systems[6]; IUCN Crop Wild Relative Specialist Group[7]; IUCN Key Biodiversity Areas[8]; Natura 2000 Network[9]; Plantlife Important Plant Areas[10]; UNESCO Man and Biosphere Programme[11]; and UNESCO World Heritage Sites[12]. Part of the process of establishing the European Network is to investigate how collaboration between such existing initiatives can help to achieve the vision.

Currently, there is only a handful of formally recognized active genetic reserves for *in situ* CWR conservation in Europe and similarly few examples of formally recognized long-term, on-farm managed LR populations—and this is equally the case globally. This does not mean that CWR diversity is not maintained in existing protected areas or LR have not been maintained on-farm (the latter particularly through the use of PDO, PGI, TSG[13] labels or registration as conservation varieties). However, in many cases, in terms of geographically unique genetic diversity, the populations (or sites where the populations are currently found), are not formally recognized and managed in a way to maintain that unique diversity or managed in an integrated manner to benefit from membership of a network. The establishment of the Network offers an opportunity for these populations/sites to gain formal recognition for the value of their unique diversity for food, nutrition and economic security.

In the Farmer's Pride project, collaborators are identifying (in liaison with national counterparts) CWR/LR sites/populations[14] across Europe that will be recommended to form the initial basis of the Network, and the custodians of those sites/populations. In addition, other stakeholders that are not managers of *in situ* diversity (e.g., gene/seed bank managers, researchers, plant breeders) have been invited to join the wider stakeholder community that will form part of the Network. This document provides a proposed approach to realise the European Network while retaining national sovereignty over CWR and LR genetic resources.

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[2] www.cbd.int/protected/
[3] www.ecpgr.cgiar.org/
[4] www.europarc.org/
[5] www.eurosite.org/
[6] www.fao.org/giahs/en/
[7] www.iucn.org/commissions/ssc-groups/plants-fungi/plants/plants-a-m/crop-wild-relative
[8] www.iucn.org/commissions/world-commission-protected-areas/our-work/biodiversity-and-protected-areas/key-biodiversity-areas
[9] ec.europa.eu/environment/nature/natura2000/index_en.htm
[10] www.plantlife.org.uk/uk/nature-reserves-important-plant-areas/important-plant-areas
[11] www.unesco.org/new/en/natural-sciences/environment/ecological-sciences/man-and-biosphere-programme
[12] whc.unesco.org/

[13] PDO (Protected Designation of Origin), PGI (Protected Geographical Indication), TSG (Traditional Speciality Guaranteed)

[14] Reference to 'sites/populations' is made because 'sites' are recognized and/or designated under various programmes and managed by specific agencies (e.g., with the EU's Natura 2000 Network). However, in the case of both CWR and LR (the latter which are managed by farmers and other custodians), it is populations within sites, or localities that will be actively managed within the Network. Rather than refer to CWR or LR populations within sites throughout the document, the shorthand version, 'sites/populations' is used for brevity.

1.3 Why a European *in situ* PGR network now?

1.3.1 Wealth of European PGR diversity

Europe has a wealth of native, endemic or long ago introduced CWR and LR diversity of regional and global socio-economic importance (Heywood and Zohary, 1995; Veteläinen *et al.*, 2009). Although in terms of inventories and systematic conservation planning, greater progress has been made with CWR diversity due to the baseline provided by numerous floristic botanist and the lack of historic interest in mapping and conserving crop species. All countries in Europe have unique CWR and LR diversity worthy of systematic conservation, but at least in terms of CWR, southern Europe appears as the global hotspot for taxon richness as evidenced by recent studies (Vincent *et al.*, 2013, 2019; Castañeda-Álvarez *et al.*, 2016). Examples of priority European CWR taxa include those related to alliums (onion, leek, garlic etc.), apple, asparagus, barley, blackcurrant, cabbage and other brassica crops, carrot, lettuce, oat, olive, plum, raspberry, rye, strawberry, sugarbeet, wheat, wine grape, and a range of fodder crops (Kell *et al*., 2012, 2016).

Just as CWR diversity is not spread evenly across the globe, it also seems likely that LR diversity is partitioned into regions of higher and lower diversity. Vavilov (1926), in defining his centres of origin/diversity, used concurrence of LR as one defining characteristic, although he did not quantify the relative numbers of LR found in each of his eight centres and outside of these centres. Although national attempts have been made to quantify the relative presence of LR diversity (Germany – Frese *et al.*, 2009; Portugal – Mendes Moreira and Veloso, 2009, Almeida *et al.*, in prep.; Italy – Negri *et al.*, 2013; Finland – Heinonen, 2016; – UK Scholten *et al.*, 2004, Kell *et al.*, 2009), there has been no recent attempt to validate Vavilov's LR findings at global or regional level. Therefore, if we assume there is a relationship between LR hotspots and the Vavilov centres, southern European is also likely to be a global centre of LR diversity. However, as for CWR diversity, when planning conservation at regional scale, LR populations throughout Europe must be included to ensure maximum regional diversity is conserved.

1.3.2 Threats to European PGR diversity

While Europe is a recognized centre of CWR and LR diversity, this diversity is increasingly threatened by genetic erosion and extinction. Kell *et al.* (2012) found that the main threats to CWR populations in the region are intensive farming and development for housing, tourism and recreation, and that out of 25 highly economically important food crops/crop groups in Europe, 14 contain threatened CWR species, including those related to sugarbeet, wheat, cabbage, lettuce and alliums. Also, in Europe, as elsewhere, LR loss is due to several factors, underlying which is the profound transformation of production systems and socio-economic context which occurred in the twentieth century (Grigg, 1994; Negri, 2005). These include: (a) replacement of traditional LR with modern cultivars that are often more productive under high input farming systems; (b) the inadvertent consequences on LR of seed certification systems associated with the establishment of plant breeders' rights (Velvé, 1992; Stickland, 1998); (c) eradication by perverse incentives associated with government policy (Maxted, 2006); and (d) the constant reduction in rural populations, the simplification of production processes due to high manpower costs, the ageing of the crop maintainers, and the breakdown in knowledge and genetic resources being passed from one farming generation to another (Negri, 2003; Heinonen and Veteläinen, 2007).

Unlike CWR, there is currently no widely applicable LR threat assessment methodology, but it is likely, as argued by Maxted (2006), that LR diversity is even more threatened than CWR diversity, the reasons

being: (a) globally and regionally we have no idea how many LR exist or where precisely in a country LR diversity is focused; (b) LR maintainers are almost always older and their numbers are naturally dwindling each year; (c) LR maintainers are farmers and by definition farming is a commercial activity—they grow crops for economic return and conservation, if considered at all, is a secondary consideration; (d) seed companies, breeders and governmental agencies actively promote novel cultivars that will replace LR; (e) in many countries no government agency has direct responsibility for LR conservation; and (f) although some countries have started work on LR inventories, currently no country has a comprehensive inventory of extant LR diversity. Further, although some farmers are creating new diversity, there is evidence in Europe that a vast number of unique LR have been lost and that the decline is continuing (Negri *et al.*, 2009; Maxted *et al.*, 2009; Veteläinen *et al.*, 2009).

1.3.3 Existing conservation measures

The *status quo* regarding current European CWR and LR diversity conservation does not provide society with the insurance needed to support agriculture into the future. The public goods value of PGR in Europe is not being currently appreciated or conservation action triggered as is necessary—particularly with the growing threat and potentially devastating impacts of climate change.

In terms of CWR conservation, research has shown that European species are poorly conserved both *in situ* (i.e., in their natural habitats) and *ex situ* (i.e., in gene banks) (Maxted *et al.*, 2016). Although many CWR are found within the boundaries of protected areas, including within the Natura 2000 Network, they are rarely actively conserved (i.e., populations are not monitored and there are no specific conservation management interventions to promote diversity maintenance). Further, many CWR populations occur outside protected areas—for example, in farmland and on roadsides where they are not subject to the required management interventions (Jain, 1975; Maxted *et al.*, 1997a). In their review of current CWR *in situ* conservation, Maxted *et al.* (2016) concluded that only a handful of active genetic reserves for CWR *in situ* conservation exist and these all fail to meet the set of quality standards for CWR genetic reserves proposed by Iriondo *et al.* (2012). Furthermore, site designation has thus far been *ad hoc* and opportunistic rather than as a result of any deliberate European scientific strategy. The situation for CWR *ex situ* conservation is better, but even here more than half of the species related to the crops of highest socio-economic importance in Europe have no samples held in *ex situ* seed collections at all, and of those that do, around 50% are represented by very few accessions (Kell *et al*., 2016). Further, Kell *et al*. (2012) reported that of the *ex situ* CWR collections that do exist, most species are represented by very few samples, are reported by only one gene bank, and have been collected from only a small part of the species' range—indicating that genetic diversity within the species is not adequately conserved.

In terms of LR conservation, it is currently unknown whether any but a small proportion of populations have been maintained *in situ* (on-farm or in-garden) over an extended time period, although there are notable exceptions, such grape vine in Georgia which are thought to have been systematically maintained for an extended period (Ketskhoveli *et al*., 1960), or those LR populations that have relatively recently been granted quality labels or regional uniqueness, or that have specific legislative protection. The EU has established three schemes to promote LR maintenance:

- PDO (Protected Designation of Origin) – covers agricultural products and foodstuffs that are produced, processed and prepared in a given geographical area using recognized know-how.

- PGI (Protected Geographical Indication) – covers agricultural products and foodstuffs closely linked to the geographical area. At least one of the stages of production, processing or preparation takes place in the area.
- TSG (Traditional Speciality Guaranteed) – highlights the traditional character, either in the composition or means of production.

The EU also established the legislative basis for LR conservation with Commission Directive 2008/62/EC on seed production and marketing to safeguard LR diversity of interest for agriculture, which has subsequently been implemented through national nomination and associated legislative protection. However, although these initiatives are a positive step, their take-up at a national level has been sketchy and their impact minimal.

In terms of *ex situ* LR conservation, a query of EURISCO (http://eurisco.ecpgr.org) for holdings carried out in August 2019 indicates that European gene banks hold 297,833 LR accessions (14.83% of the total holdings) compared to global LR holdings of 3,256,000 accessions (44% of the total holdings) (FAO, 2010). It should also be recognized that the figure of 14.83% of holdings quoted above is not only for accessions collected in Europe, it will also include accessions collected in other continents and stored in Europe. Further, without an estimate of the number of European LR populations maintained by farmers and other growers, it is impossible to estimate the effectiveness of European efforts to conserve its LR diversity *ex situ*.

1.3.4 Policy and legislative context

EU member states are committed to conservation and sustainable use of PGR under the UN Convention on Biological Diversity (CBD, 1992) Strategic Plan for Biodiversity 2011–2020 (Target 13) (CBD, 2010a) and Global Strategy for Plant Conservation 2011 (Target 9) (CBD, 2010b), as well as in the context of the UN Food and Agriculture Organization (FAO) Second Global Plan of Action for Plant Genetic Resources for Food and Agriculture (Second GPA) (FAO, 2011) and International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) (FAO, 2001). Further, PGR conservation and sustainable use actions are critical to meet the UN Sustainable Development Goals (UN, 2015)—particularly Target 2.5, which concerns agricultural biodiversity maintenance and specifically calls for effective genetic conservation of PGR diversity. Despite this solid global policy context, the legislative foundation for CWR/LR diversity conservation is patchy, with no known legislation in Europe that offers protection for specifically for PGR.

The EU Biodiversity Strategy (specifically Targets 57 and 60) indicates the Common Agricultural Policy (CAP) as a means to achieve the conservation of PGR through the agri-environmental measures. Regulation (EU) No 1305/2013 of the European Parliament and of the Council of 17 December 2013 on support for rural development by the European Agricultural Fund for Rural Development (EAFRD) and repealing Council Regulation (EC) No 1698/2005 already foresees that support may be provided for the conservation, sustainable use and development of genetic resources that are under threat of genetic erosion (Article 28). The EAFRD has been used as a means of protecting, monitoring and enhancing the utility of PGR on-farm in some countries—for example, in Italy, through Regional Laws, networks of farmers maintaining LR are supported. However, EU Member States have yet to receive clear guidance from the European Commission on how or where to enact these measures, and as a result, member states have taken diverse approaches to the implementation of the Regulation.

To assist free availability of seed of species covered by national varietal lists and promote on-farm conservation and management activities, the Commission introduced Directives 2008/62/EC of 20 June 2008, 2009/145/EC of 26 November 2009 and 2010/60/EU of 30 August 2010 on seed production and marketing, that also aim "to ensure *in situ* conservation and the sustainable use of plant genetic resources" as a core premise. Commission Directive 2008/62/EC provides for certain derogations for acceptance (i.e. for the registration of LR and varieties in the Common Catalogue and the marketing of their seed) of agricultural LR and varieties which are naturally adapted to the local and regional conditions and threatened by genetic erosion, and for marketing of seed and seed potatoes of those LR and varieties. The derogations are addressed to the so-called "agricultural species" (but widely interpreted as field crops) in terms of European seed legislation (i.e. Directives 66/401/EEC, 66/402/EEC, 2002/54/EC, 2002/56/EC and 2002/57/EC). Besides providing the definitions of 'conservation *in situ*', 'genetic erosion' and 'landrace', Commission Directive 2008/62/EC defines criteria and requirements for the acceptance of LR and varieties as conservation varieties, with particular regard to the historical linkage to their region of origin, and establishes rules for the marketing, certification and limited sales. In particular, the Directive establishes annual quantitative restrictions of the seed marketed for each conservation variety. Derogations from the standard rules are also foreseen in relation to varieties where there are limited denominations, and variety synonyms are admitted contrary to the rules that apply for conventional varieties in the Regulation CE n. 637/2009 on variety denominations.

Similarly to Directive 2008/62/EC, the Commission Directive 2009/145/EC of 26 November 2009 provides for certain derogations for the acceptance (in the Common Catalogue) of: a) vegetable LR and varieties which have been traditionally grown in particular localities and regions and are threatened by genetic erosion; and b) vegetable varieties (i.e. those covered by Directive 2002/55/EC) with no intrinsic value for commercial crop production but developed for growing under particular conditions and for marketing of seed. This Directive has two parts. The first addresses conservation varieties and gives the same definitions and criteria of Directive 2008/62/EC concerning the requirements for registration, marketing, denomination, certification and controls. Restrictions on seed quantities allowed to be marketed are foreseen (as established by Directive 2008/62/EC for agricultural species), but they are calculated with different criteria. The second part of Directive 2009/145/EC addresses vegetable varieties with no intrinsic value for commercial crop production that have been developed under particular conditions, otherwise known as 'amateur' varieties. The conditions for this group are far less restrictive than those established for conservation varieties. In particular, there is no region of origin and, consequently, no geographic restrictions for their marketing. Notably, the definition of 'conservation variety' given in both Directive 2008/62/EC and 2009/145/CE also allows old cultivars that were de-listed from the Common Catalogue at least two years, eligible to be registered again as conservation varieties.

Following the publication of the above mentioned Directives, 159 conservation varieties of agricultural species (potato, wheat, maize and pea), 25 conservation varieties and 454 amateur varieties of vegetable species (including pepper, French bean, tomato, leek, curly kale, marrow, broad bean, celery, and white cabbage) were registered in the Common Catalogue in March 2013—however, the true status of the majority of the registered materials is questionable (Spataro and Negri, 2013). In addition, the Commission Directive 2010/60/EU of 30 August 2010 provides for certain derogations for marketing of fodder plant seed mixtures intended for use in the preservation of the natural environment. This Directive has a different basis because it focuses on fodder crop 'preservation

mixtures' for the purpose of recreating and preserving natural habitats. The main differences from the other Directives is that neither registration of the mixture components nor certification of the mixtures is required. In addition, there is the possibility to include forage species not covered by directive 66/401/EEC in a preservation mixture. Finally, the Commission Implementing Decision of 18 March 2014 on the organization of a temporary experiment provides certain derogations for the marketing of populations of wheat, barley, oat and maize.

The directives produced in recent year are evidence that the European Commission understands the problems adverse incentives acting to limit traditional landrace conservation on-farm and commercial sale. However, the community engaged in LR conservation and management would argue the rate of LR genetic erosion and LR extinct is such that even more positive action is required by the Commission if the policy and legislative context is to be seen as systematically encouraging LR maintenance.

1.3.5 Users' demand for diversity

To adequately meet the increased demand to feed the global population in 2050, it is likely that food supplies will need to increase by 60% globally, and 100% in developing countries over 2005 levels (FAO, 2011). While over the same time-scale climate change is predicted to reduce agricultural production by 2% per decade, resulting in up to 40% yield reduction by 2050 (Porter *et al.*, 2014). Addressing this challenge will require more effective utilisation of LR diversity and the largely, yet untapped, wealth of genetic diversity found in CWR. Plant breeders are increasingly looking for traits beyond the traditional pool of diversity they utilize towards the use of more 'exotic' germplasm (Tanksley and McCouch, 1997; Volbrecht and Sigmon, 2005; McCouch *et al.*, 2013). The importance of CWR for crop improvement was further specifically highlighted by Feuillet *et al.* (2008) who questioned the ability of breeders to increase or simply sustain crop yield and quality in the face of dynamic biotic and abiotic threats without more systematic exploitation of the diversity contained in CWR populations. CWR contain greater breadth of diversity because they have not been subject to the genetic bottleneck of domestication or human directed migration, and LR have not been deliberately bred for uniformity because their maintainers value diversity which better sustains overall production in marginal cropping environments. Both CWR and LR are a tried and tested means of providing access to novel genetic diversity for utilization, particularly that required for climate change mitigation (Maxted *et al.*, 2016) and new technology for incorporating traits from 'exotic' germplasm into commercial cultivars are making such incorporation easier (Maxted and Kell, 2009).

1.3.6 *In situ* conservation research foundation

Historically, PGR conservation has focused on seed collection and storage in gene banks to enable relatively easy access to germplasm for the user community. However, the range of PGR sampled and conserved *ex situ* only represents a small proportion of species and genetic diversity found in nature and on-farm, and much of this diversity is being lost (Hammer *et al.*, 1996; Negri 2003; Maxted *et al.*, 2016). Furthermore, there are significant challenges in conserving CWR *ex situ* due to the wide range of breeding systems and seed characteristics of the species, as well as the complexities and resources required for regeneration. Critically, *ex situ* conservation does not conserve continuing evolving adaptations of wild plant populations to their abiotic / biotic environment or reflect the rapid genetic changes that can occur in LR populations (Maxted *et al.*, 1997b).

Since the inception of the CBD in 1992, the vital importance of *in situ* biodiversity conservation has been acknowledged worldwide and has been cemented in other policy and legislative instruments

(see section 1.3.4). However, while the science of PGR conservation *ex situ* was already well advanced in the 1990s (Smith *et al.*, 2003), it has taken some time for the knowledge base required to implement *in situ* conservation actions to catch up. Hawkes (1991) concluded that *in situ* PGR conservation was still in its infancy—however, knowledge of PGR diversity and its conservation *in situ* (in nature and on-farm) has developed significantly since the 1990s, particularly in Europe through the establishment of the ECPGR *In Situ* and On-farm (stakeholder) Network in May 2000. The list of relatively recent achievements (Box 3) is not exhaustive, but demonstrates that a solid foundation for PGR conservation *in situ* exists. However, it also highlights that practical management of *in situ* and on-farm populations remains currently very limited.

Box 3. Major recent advances in *in situ*/on-farm conservation

- Defining CWR and LR (e.g., Zeven, 1998; Camacho Villa *et al.*, 2005; Maxted *et al.*, 2006; Negri *et al*. 2009);
- Creation of CWR/LR checklists and inventories (Zeven and Zhukovsky, 1975; Heywood and Zohary, 1995; Maxted et al., 2007; Idohou *et al.*, 2013; Vincent *et al.,* 2013; Hammer *et al.*,1990, 1999; Hammer, 2001; Negri (2003);
- CWR/LR prioritization (Maxted *et al.*, 1997c; Kell *et al.*, 2012, 2015, 2016, 2017b; Maxted *et al.*, 2009);
- CWR threat assessment (Kell *et al.*, 2012);
- Locating CWR and LR diversity (Maxted *et al.*, 1997a; Negri *et al.*, 2013; Magos Brehm *et al.*, 2017; Pacicco *et al.,* 2018);
- *In situ* and on-farm conservation site selection (Maxted *et al.*, 2008; Vincent *et al.,* 2013; Vincent *et al.,* 2019; Magos Brehm *et al.*, 2017; Pacicco *et al.*, 2018);
- *In situ* and on-farm population management (Tosti and Negri, 2005; Tiranti and Negri, 2007; Iriondo *et al.*, 2008; Polegri and Negri, 2010; Iriondo *et al.*, 2012; Torricelli *et al.*, 2013);
- *In situ* and on-farm *in situ* conservation networks (Maxted and Kell, 2009; FAO, 2013; FAO, 2014; Maxted *et al.*, 2015);
- Multiple aspects of *in situ* conservation (Jain, 1975; Safriel *et al.*, 1997; Zencirci *et al.*, 1998; Meilleur and Hodgkin, 2004; Heywood and Dulloo, 2005; Hunter and Heywood, 2011);
- Multiple aspects of on-farm conservation (Brush, 1995; Brush, 2000; Veteläinen *et al.*, 2009; Jarvis *et al.*, 2011; Sthapit *et al.*, 2012; Jarvis *et al.*, 2016);
- Promoting the use of the *in situ* conserved resource (Curtis, 2008; Heywood, 2008; Polegri and Negri 2010; Maxted *et al.*, 2016; Magos Brehm *et al.*, 2017).

2.0 TOWARDS A EUROPEAN NETWORK

2.1 A network of networks

The ECPGR published two 'concepts' for *in situ* and on-farm PGR conservation in Europe (see Maxted *et al.*, 2015 for CWR and ECPGR, 2017 for LR) to guide EU and national policy development and provide blueprints to drive concerted *in situ* and on-farm PGR actions throughout the region. Both concepts propose an integrated strategy involving interventions at national and regional levels. This is because although nations have sovereignty over the genetic resources within their jurisdiction and the responsibility to conserve them, priorities vary between nations and cumulative national priorities do not necessarily constitute a coherent regional strategy. Therefore, a European strategy would necessarily encompass both national and broader regional priorities (Maxted et al., 2015), and in the case of CWR populations, may cross political borders and therefore be a shared responsibility (Kell *et al*., 2017b). A Europe-wide PGR conservation strategy is therefore essential to ensure that regionally important PGR are conserved across their full range, as well as to provide a framework for directing European policy on the conservation of regionally important populations.

Three further levels also come into play when considering a holistic approach to PGR conservation (Maxted *et al.*, 2016)—the local (or subnational), subregional, regional and global levels. The subnational level recognizes that although the conservation of PGR populations ultimately falls under the jurisdiction of national agencies, they are actively managed by local administrations, farmers, and other private land managers. The subregional level accounts for the approach taken for example in the Nordic region to develop a CWR conservation strategy that targets diversity important to that region and that becomes the shared responsibility of the Nordic countries (Fitzgerald *et al.*, 2019). The global level recognizes the interdependency of nations and regions on PGR and has been advocated by the FAO CGRFA (FAO, 2013, 2014). Therefore, the establishment of the European Network would necessarily need to be complemented by and build upon *in situ* and on-farm activities at the subnational, national and sub-regional geographic scales, so *de facto* this would form a 'network of networks' providing a framework for directing *in situ* and on-farm conservation policy at each level, and eventually merging into a global network driven by existing policies—most notably, the ITPGRFA, CBD Strategic Plan, and GPA.

Because the European Network will be a 'network of networks', it may be considered a 'virtual' network in the sense that it will comprise selected existing sites/populations largely drawn from sub-regional, national and subnational networks, and the sites/populations will be managed/overseen at country level by national authorities or NGOs (Fig. 1). It may rarely be the case that a particular CWR or LR population is identified externally as being regionally important, so it does not belong to a current network or the population is not currently conserved, due to the national sovereignty over CWR or LR diversity in such a case the person or group identifying the site would need to report its value to the National PGR Coordinator and they could then nominate the site for Network inclusion, even if it was not formally part of an existing network. Therefore the European Network secretariat could not nominate sites / populations to join the Network itself, but it is likely to collaborate with the national implementing bodies to: (a) highlight which priority PGR diversity should be conserved; (b) recommend management interventions to meet agreed minimum quality standards; and (c) coordinate regular evaluation of the effectiveness of nationally implemented European Network sites using agreed standard indicators. Thus, in Figure 1 the bottom layer are all Individual CWR and LR populations present in a country, some of these, as indicated by the linking line, will be formally recognized and included in National *in situ* conservation and on-farm networks, then again some of

these, as indicated by the linking line, will be formally recognized and included in European Regional *in situ* conservation and on-farm networks, and finally, some of the European Regional populations will be included in the Global *in situ* and on-farm conservation network. This approach is: (a) inclusive because the Network is built on nationally administered sites; (b) decentralized in that all countries could nominate sites from their national network to be included in the European Network; and (c) locally owned, in that each site within the Network would remain under national agency control. The success of the Network would therefore depend on the collective contribution of nationally administered sites—the collaborative whole being greater than its constituent parts due to the benefit of Network membership for individual sites and the public good value of the resources conserved.

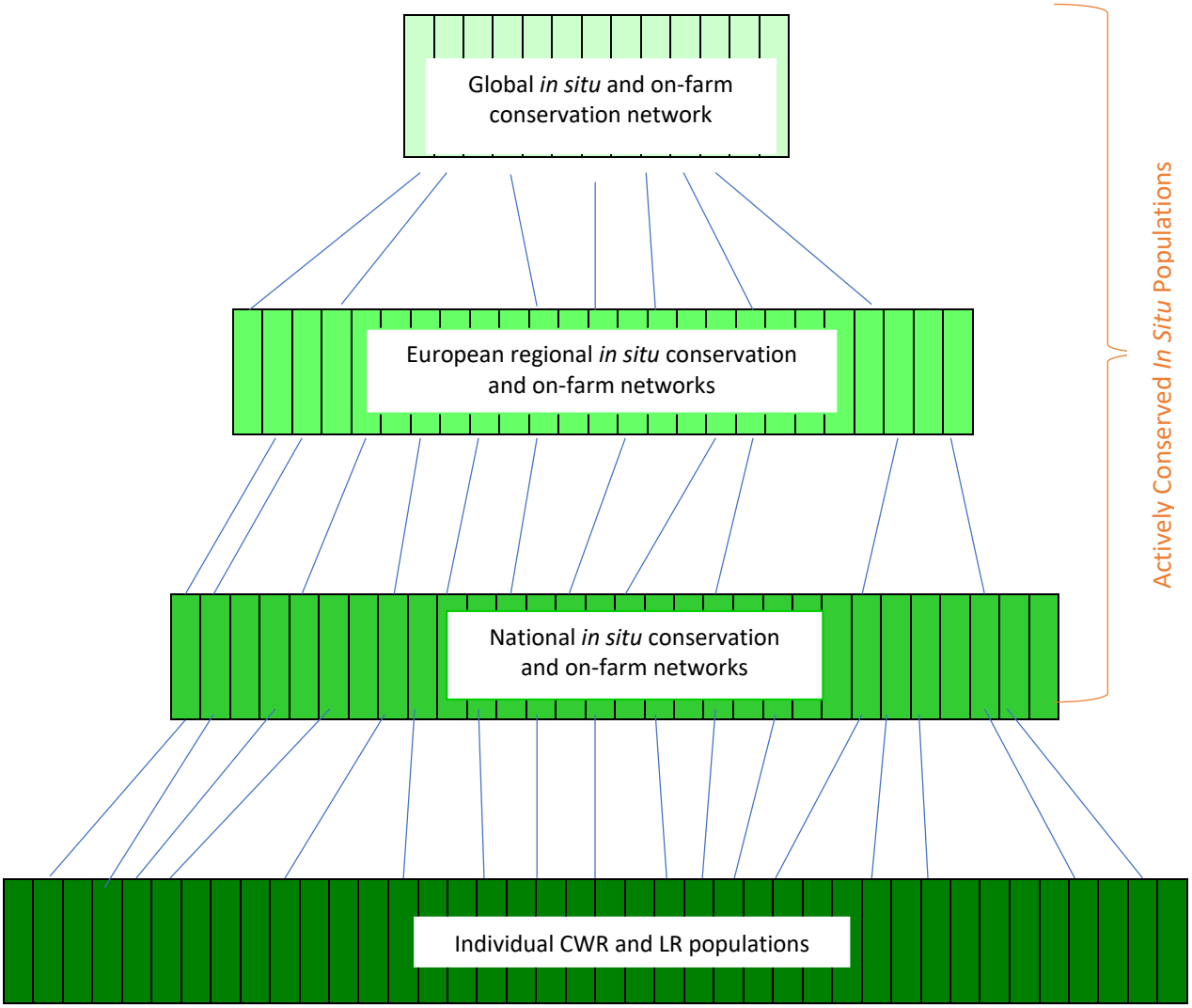

Figure 1. Network of networks design of the European Network, also as part of a global 'Vavilov Network'. The links between levels indicate any number of single sites/populations that may be included.

2.2 Functions of the Network

If the Network is to be sustainable, its value must be clear to European PGR stakeholders. Before the Network is established, a process of stakeholder engagement is required to identify, agree and achieve endorsement of its functions. To ensure efficiencies, and especially avoid wasteful duplication of efforts, these functions must fulfil a role which is currently not being catered for by any other agencies or network. Such functions must also be pertinent to and help attain relevant global, European and

national targets (e.g., the implementation of the GPA [FAO, 2011], meeting the Aichi Biodiversity Targets of the CBD, the objectives of the ITPGRFA, and the SDGs). Box 4 outlines six anticipated key functions of the Network.

Box 4. Key anticipated functions of the European Network

- *Enhanced conservation and sustainable use* – Achieving the desired fundamental outcome of more systematic *in situ* conservation and on-farm management of PGR to better safeguard a wide variety of PGR for use either directly by farmers, local communities or plant breeders for crop enhancement and food and nutrition security;
- *Facilitated coordination* – Promoting coordination between existing PGR conservation networks to reduce duplication of effort and improve the overall efficiency and effectiveness of *in situ*/on-farm PGR conservation activities throughout the region;
- *Enhanced partnerships* – Fostering stronger partnerships between (a) national, European and global *in situ*/on-farm conservation activities; (b) PGR and biodiversity conservation communities; (c) *in situ* and *ex situ* PGR conservation communities; (d) *in situ*/on-farm conservation activities and germplasm users; and (e) conservationists, land managers, farmers and local communities;
- *Facilitated access to and exchange of information* – by bringing together gene bank, *in situ* and on-farm documentation, the Network will not only improve data exchange and standardization, but by building upon the existing gene bank germplasm location tool (EURISCO) to include *in situ* and on-farm germplasm data, will ultimately provide a one-stop platform for users searching for particular diversity.
- *Benefits to local communities* – Achieve positive country- and site-level impact on PGR conservation while demonstrating benefit to the ultimate custodians of PGR, the local communities that may be found in and around protected areas/reserves, and farmers and farming communities who are involved in day-to-day management of CWR and LR diversity.

To achieve these general functional goals, it is envisioned that the Network will have a set of core functions/guiding principles and these may be summarized as providing:

- *Coordination oversight* through neutral and transparent Network coordination, communication, publicity and integration with other food security and sustainable development initiatives. Therefore, being included in the Network will ensure the site managers are automatically involved with other key stakeholders in the implementation of associated initiatives relevant to *in situ* and on-farm conservation of PGR in Europe;
- *Increased awareness of* in situ*/on-farm PGR value* by demonstrating the importance of *in situ*/on-farm PGR conservation to complement existing *ex situ* activities in terms of food and nutritional security, safeguarding the environment, potential income generation, and improved livelihoods;
- *Integration of local, national, European and global conservation actions* by balancing local, national, European and global conservation priorities overall the Network is inclusive of economic and social valuations, and major and minor crops, demonstrating the value of sites away from the main centre of diversity in Southern Europe and highlighting other priorities, such as berry and forage conservation in northern Europe;
- *A clearinghouse mechanism* by disseminating genetic conservation information and research findings, developing a scientific evidence base for the promotion of best practices in *in situ* and on-farm PGR conservation, extending access to technology resources, validating and sharing data, and connecting local conservation practitioners, farmers, and plant breeders;
- *Partnership enhancement* through a credible platform to help strengthen partnerships that foster viable communities of practice for the management, i.e. conservation and sustainable use, of

PGRFA outside of the established gene banks to breeder linkage in Europe. Especially, catalyse the involvement of more diverse stakeholders and provide a bridge between diverse interests particularly the Ministries of Agriculture and of Environment, farmers, the plant breeding sector and the seed sector;

- *A platform for* in situ *and on-farm related research* by identifying and prioritizing European *in situ* and on-farm conservation related research, establishing a strategic European approach and translating evidence-based knowledge into adaptive conservation practice at local, national and European levels;
- *A platform for dissemination of CWR/LR and* in situ*/on-farm information and knowledge* by establishing a conservation evidence-based information and expertise environment accessible via the Internet, particularly of the latest scientific information informing the practices of *in situ* / on-farm conservation and adaptive management[15];
- *Improved access to* in situ*/on-farm PGR* by assisting in promoting linkages between PGR conservation and use, providing a working roadmap that helps resource users obtain CWR/LR diversity conserved *in situ*/on-farm, irrespective of national boundaries, that ensures users' access to conserved resources and benefit sharing associated with sustainable development;
- *Technical support* by leveraging resources and exploring sustainable mechanisms for fundraising to support the research and conservation activities relevant to sustain *in situ* and on-farm conservation of PGR, as well as adding value to existing networks by identifying new opportunities and synergies, and avoiding the duplication of efforts;
- *Policy support* for National PGR programmes in their efforts related to *in situ* and on-farm conservation, particularly supporting the implementation of existing global conventions, instruments, initiatives and processes with reliable data and information, such as implementation of Article 5 of the ITPGRFA and the fulfilment of Aichi Target 13 of the CBD.

As a guiding principle, it is expected that Network coordination will be flexible in its operation and would promote creative solutions to local, national, regional and global obstacles to *in situ* and on-farm PGR conservation.

A critical function of the Network is not only to promote crop diversity preservation through the integration of systematic *in situ* conservation of CWR and on-farm management of LR diversity, but to also promote the sustainable use of the *in situ* conserved resources. This can be achieved by working with farmers to develop models of on-farm systems that enhance value chains for their unique products (e.g., niche markets), raising the value of their resources and so sustaining their maintenance and conservation, as well as raising awareness of the adaptive trait diversity value of CWR. In both cases, the perceived value of the PGR will be increased which in turn will increase the likelihood of resource maintenance. It is also vital that the Network confers benefits that directly support local communities (e.g., those in and around protected areas/reserves and/or farming communities who are involved in day-to-day management of crops and varieties for their livelihoods). Without such a

[15] Relevant research topics include plant taxonomy, autecology ecology of CWR or management of the target LR, agroecology of the farming systems in which the target plants are found, techniques for measuring and monitoring genetic diversity, management practices for wild areas or agroecosystems for the maintenance of target genetic diversity, sampling technology for propagules and for genetic monitoring, and documentation and bioinformatic practices involved with using GIS, mapping, gathering and accessing traditional knowledge, GAP analyses and surveys, and use of characterization, evaluation, and molecular marker data.

direct linkage between the European Network and local community benefit, the Network is unlikely to be sustainable and have a long-term impact.

In designing and implementing the Network there will be a requirement to maximize the use of the conserved resources by all potential users. To achieve this, access linked to benefit sharing should be encouraged, actual or predictive characterization of *in situ* or on-farm conserved resources undertaken (Bhullar *et al.*, 2009), participatory approaches to development of the resources promoted (Friis-Hansen and Sthapit, 2000), and routine *ex situ* backup of the diversity carried out. In this way, *in situ* and *ex situ* PGR conservation, and conservation and use are not seen as alternatives or distinct entities but as an integrated whole—a continuum from the raw resource to climate novel smart crop variety.

As already noted, sub-regional or national CWR/LR *in situ* networks are only beginning to appear in Europe (Iriondo *et al.*, 2016), therefore part of establishing the European Network will be to encourage establishment and strengthen sub-regional and national *in situ* and on-farm management networks and promote their contribution to the establishment and sustainability of the European Network. The support that Network membership could provide to sub-regional and national networks would: (a) underpin the value and utility of CWR and LR for farmer livelihoods; (b) sustain the resource pipeline of novel adaptive traits for current and future plant breeding; (c) initiate a closer dialogue between farmers and breeders; (d) raise awareness of the value of CWR and LR population diversity for food security; and (e) raise awareness of the value of continued CWR and LR population evolution *in situ* or on-farm.

2.3 Network linkage to germplasm use

The *raison d'être* for PGR conservation is use of the conserved resources, this is as true for *in situ* / on-farm conserved resources as it is for those resources maintained *ex situ* (Maxted *et al.*, 1997a). In fact, Maxted *et al.* (2016) argued further that *in situ* / on-farm conservation without use of the conserved resources by farmers, breeders and other uses would threaten the long-term sustainability of *in situ* / on-farm conservation itself. Therefore, central to Network design is the role of the Network in promoting use by diverse stakeholders of the conserved resource in crop improvement, enhancing future crop improvement and food security options—in particular, to provide as wide pool of diversity as possible as insurance against the negative impacts of climate change on crop production.

But how are in situ conserved resources to be made available to users? There are two obvious approaches either (a) germplasm can be directly made available by the *in situ*/on-farm site manager (PA manager or farmer) or (b) via the *in situ* safety back-up sample that will be placed *ex situ* in a backup genebank, although both of these option have drawbacks. In light of the Nagoya Protocol and other germplasm access and benefit legislation the supply of germplasm requires adherence to protocols and completion of material transfer agreements and experience from the initial *in situ* / on-farm conservation sites thus far established it that *in situ*/on-farm site manager do not have the required skills or the desire to acquire the skills necessary to be able to supply germplasm to a third party. Whereas genetic centre managers must necessarily have such skills to supply their existing germplasm user. However, concern has been raised over the potential additional and significant financial burden that would be placed on gene banks being required to incorporate *in situ* back-up samples into their *ex situ* collection and making them available to users (Valdani Vicari & Associati *et al*., 2016). Maxted and Palmé (2016) suggested a distinction might be made between standard long-term *ex situ* sampling of CWR diversity and populations sampled as *in situ* back-up, to reduce the

resource burden on the *ex situ* collection. Populations sampled for *in situ* back-up might be regarded as like 'black box' samples, small seed samples held safely but only available to the donor as part of their *in situ* monitoring programme, not routinely monitored, regenerated or made available to the user community (Figure 2). Such an approach would significantly reduce the potential cost of *in situ* back-up where resources were limiting, but would not meet the requirement to provide access to the *in situ* conserved resource. A potential compromise between the two approaches would to periodically collect *in situ* back-up samples (possibly once a decade), document them and make them available to germplasm users, but do not routinely monitor viability or regenerated the back-up. The regular re-sampling of the *in situ* population would obviate the need for monitoring or regeneration and the lack of the latter would significantly reduce the financial burden of *in situ* germplasm supply on the plant genetic resource centre and it would facilitate access to the *in situ* conserved resource and avoid direct contact with the *in situ* site manager.

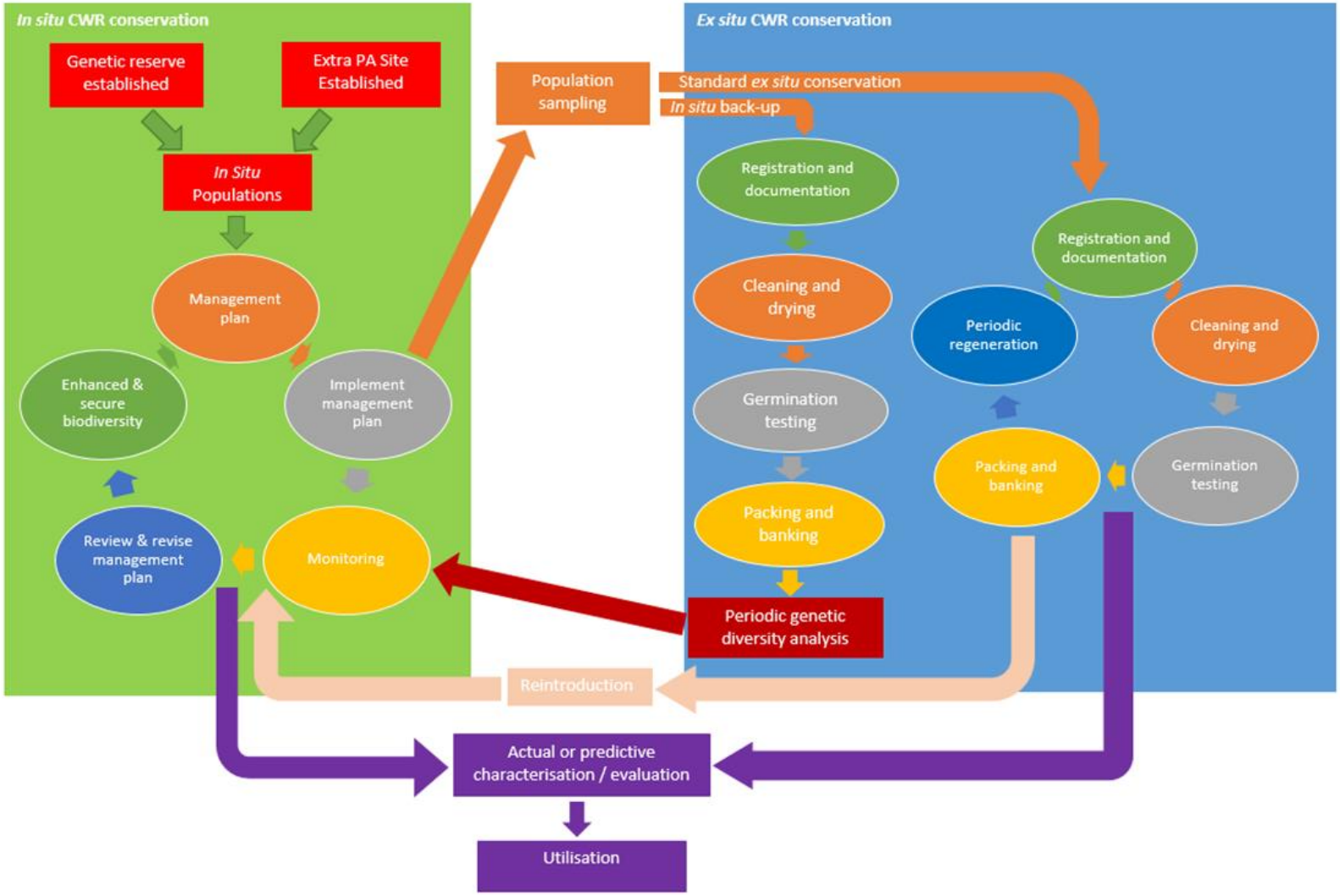

Figure 2. Integration of *in situ* and *ex situ* CWR conservation with utilization (Maxted and Palmé, 2016). Note PA=protected area.

3.0 ESTABLISHING THE EUROPEAN NETWORK

3.1 Site/population eligibility

To ensure the sustainability of the Network, and to maximize the PGR diversity conserved, it is intended that sites/populations nominated for inclusion meet a set of minimum criteria (Box 5), and that for CWR, designated sites/populations are managed to minimum standards (Box 6).

Sites/populations will often be selected pragmatically to contain multiple CWR or LR populations using gap analysis techniques—therefore, designated sites may often be found in PGR hotspots. However, to form a coherent, integrated network, they will also need to be complementary and may in certain cases contain single populations to ensure the full breadth of PGR diversity is included—for example, the *Beta vulgaris* subsp. *maritima* populations from the Kalundborg Fjord area, Denmark, which contain resistance to beet necrotic yellow vein virus. Ideally, designated *in situ* conservation sites would occur within formally designated protected areas for ease of management, but many PGR populations of value occur outside protected areas. Therefore, sites/populations included in the Network may either occur within or outside of formal protected areas, as long as they are designated for active and sustained *in situ* conservation management.

Box 5. Proposed minimum criteria for CWR or LR population inclusion in the Network

Crop wild relatives (Maxted *et al.*, 2015)

- Is native at that location, or if introduced, has existed at that location for sufficient generations (>10) to be significantly distinct from the founder source material;
- Contains distinct or complementary genetic diversity, ecogeographic diversity as a proxy for genetic diversity, or specific traits of interest that enhance the overall value of the Network;
- Should not be specifically threatened, or if initially threatened is actively managed to remove the threat, so there is a good chance of long-term survival (conventionally thought to mean a 99% survival probability over 1000 years; Shaffer, 1981), but here interpreted as having no existential population threat and potential threats from site development or climate change have been modelled and found negligible at the site in the foreseeable (≥50 years) future;
- Is sampled at regular intervals for complementary *ex situ* conservation;
- Is accessible for utilization in accordance with the provisions of the ITPGRFA from a known national *ex situ* facility as part of the Multilateral System (MLS);
- Is actively and sustainably managed as a long-term *in situ* conservation resource according to the minimum quality standards for CWR *in situ* conservation (see Iriondo *et al.*, 2012).
- Sites collectively are designed to capture maximum genetic diversity.

Landraces (Negri and Raggi pers. comm.)

- Contains distinct or complementary genetic diversity, or specific traits of interest that enhance the overall value of the Network[16]
    - — Improves the quality / economic value of the product
    - — Is adapted to harsh/marginal conditions
    - — Provides a link to local socio-cultural contexts;
- Is foreseen to be cultivated by the maintainer(s) for at least the next 15 years;

[16] For example, Santorini tomatoes (Greece), Solina wheat (Italy), Shetland cabbage (UK) and Broa maize (Portugal).

- Is made accessible for research or other forms of utilization by its maintainer(s) in compliance with the provisions of the ITPGRFA and Nagoya Protocol.

Box 6. M**inimum quality standards proposed for CWR population management** (adapted from Iriondo *et al.*, 2012).

Location

- Located following rigorous scientific process
- Located in a protected area network or less formal but recognized site

Spatial structure

- Clear boundaries of the site should be defined
- Sufficient extent to conserve CWR populations and associated abiotic / biotic natural processes

Target taxa

- Demographic survey of target CWR taxa has been carried out within site

Populations

- Target CWR populations sizes are large enough to sustain populations in the long-term

Management

- Site recognized by appropriate national agencies
- Management plan formulated
- Monitoring plans are designed and implemented
- Local community involved in site management
- Clearly-defined procedure to regulate the use of genetic material

Quality standards for the protected areas

- Site has legal foundation
- Site management plan acknowledges conservation of PGR genetic diversity

3.2 Network site/population identification and nomination

Maxted *et al*. (2015) proposed that systematic and effective *in situ* conservation of PGR diversity can only be achieved via three interrelated geographic, or more precisely, geopolitical levels (national, regional, and integrated), each level including nationally and regionally identified/nominated sites/populations (Figure 3). Although the identification of CWR/LR sites/populations can result from national, regional or even global research initiatives, all are necessarily managed at national level because the sites/populations are in a specific location within a country and post-CBD countries have national sovereignty over their biological resources. Therefore, nomination is always bottom-up by the national PGR coordinator, and national conservation agencies will manage individual sites/populations. Therefore, national coordinators/agencies will retain oversight of national PGR resources and their continuing support will be essential to the success of the European Network.

The identification/nomination process (Figure 4) will involve:

1. Identification of CWR/LR sites/populations of particular value worthy of inclusion in the Network through national, regional (or even global) research initiatives.

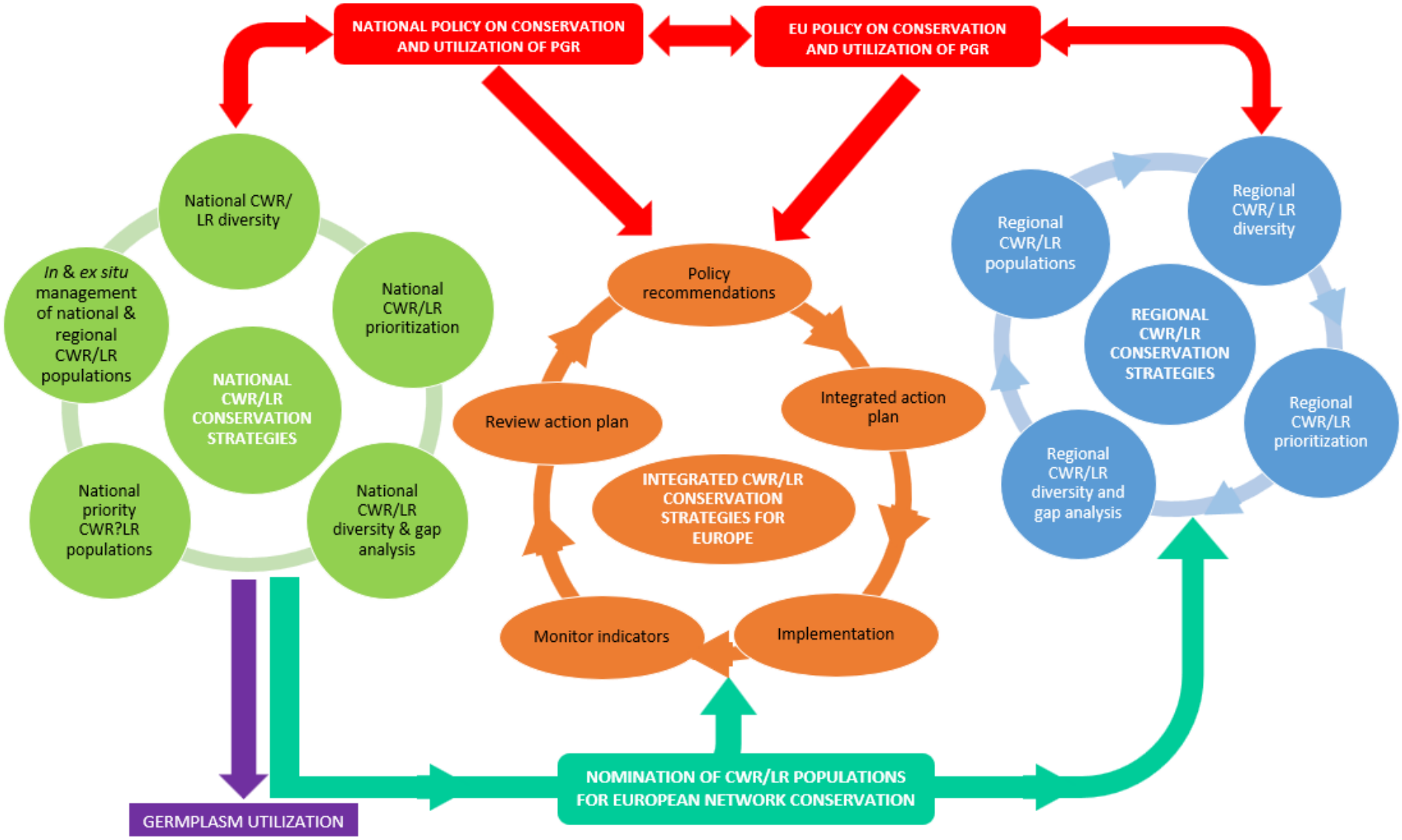

Figure 3. Schematic representation of the concept for *in situ* conservation of CWR in Europe (Maxted *et al.*, 2015).

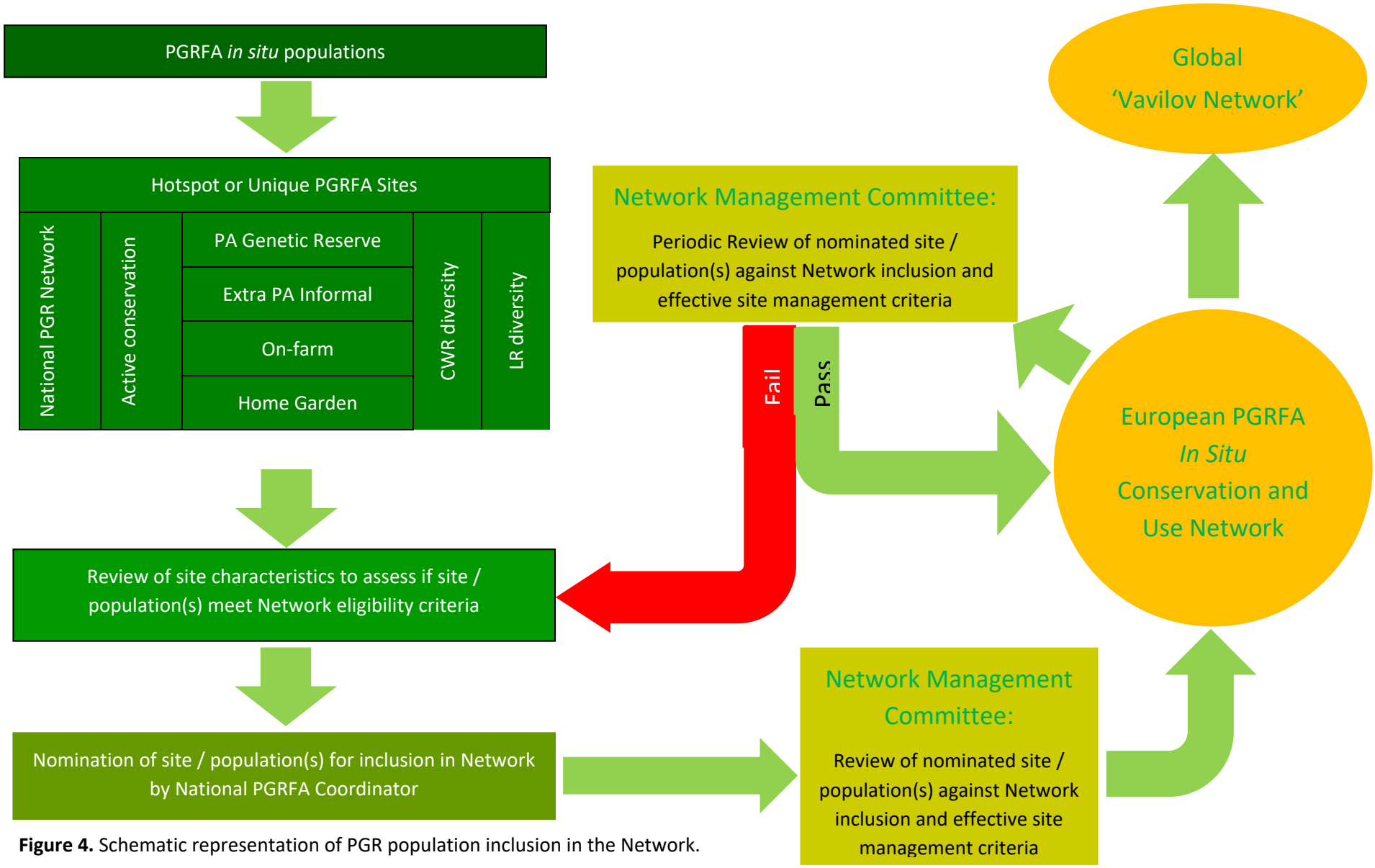

Figure 4. Schematic representation of PGR population inclusion in the Network.

2. Review of recommended sites/populations by the appropriate national authorities to establish whether they meet the eligibility criteria.
3. National authorities send their nominations with supporting documentation to the Secretariat of the Network management committee (see section 3.4).
4. Network management committee members assess whether the nomination meets the site eligibility criteria and if the *in situ* site nomination descriptors are complete. A protocol for decision-making will be established and either the inclusion of the nominated sites/populations will be endorsed, or if not deemed acceptable, sent back to the national PGR coordinator for amendment.

As indicated by the cyclical flow of the related strategies in Figure 2, planning and implementing European *in situ* conservation of PGR diversity will be an iterative process requiring periodic review and updating as conservation and utilization policy, science and practice develops. Critically, to achieve its aim, the Network must facilitate user access to the conserved resource. Promoting awareness of the value of CWR and LR diversity for food and economic security, strengthening the interface between *in situ*, *ex situ* and use of PGR, and raising additional funding, will be critical to ensure the long-term success of the Network.

3.3 Network governance and funding

The Network will require the establishment of a governing body to oversee its operation—for example, to review new national site/population nominations, evaluate the effectiveness of existing ones, liaise with national PGR coordinators, and provide support at policy level. Critically, the governing body needs to operate under the umbrella of a European organization or agency that integrates systematic national and European level PGR conservation, as this would be likely to have good commitment and support throughout the region, and funding opportunities to resource site management at both geographic levels. Furthermore, such an organization or agency could provide links to the global, European and national user communities, and to European and global policy instruments (e.g., EC Directives, CBD, ITPGRFA). A possible option for the governing body would involve representatives of:

- EC Directorate Generals for Agriculture and Rural Development, and/or Environment
- Eurosite and the Europarc Federation
- ECPGR Executive Committee (ExCo), On-farm Conservation and Management, Wild Species Conservation in Genetic Reserves and crop Working Groups (including national gene bank representatives)
- Agro- and in-garden conservation NGOs
- Euroseeds

The roles of the governing body would include:

- Assessment of whether nationally nominated sites meet minimum criteria for inclusion in the Network;
- Periodic review of nationally managed sites to ensure they continue to meet minimum criteria for inclusion in the Network, and continue to fulfil Network reporting obligations;
- Promote dynamic *in situ* conservation regionally and nationally of important CWR/LR diversity;

- Promote access to *in situ* conserved CWR/LR diversity linked to sustainable utilization and benefit sharing;
- Provide advice, expertise and access for site managers to appropriate *in situ* CWR and LR conservation, access and benefit sharing and sustainable utilisation knowledge and expert systems;
- Assist with provision of grants from funds, in-kind assistance from various regional and national institutions, national governments and co-financing from institutions who have a stake in the Network;
- Provision of management tools, protocols and training for Network site management;
- Develop effective strategies for gathering, documenting and disseminating baseline information on globally important CWR and LR populations;
- Recommend research projects to countries and make proposals on the organization of regional or international cooperation;
- Coordinate international cooperation of Member States participating in the Network;
- Coordinate international scientific programmes in Europe and relations with such programmes outside of Europe related to PGR research;
- Consult with international NGOs on scientific or technical questions;
- Increase awareness of the importance to agriculture and the environment of CWR and LR diversity among governments, institutions, decision-makers and the general public.

The management of Network sites/populations will be under the sole control of national authorities, possibly within the context of an existing national PGR network. The governing body will collaborate and work with national governments as lead national focal institutions and with the proactive participation of farmer/producer cooperatives, farming communities, youth and women's groups, research centres and academics, and other relevant local or national organizations.

The governing body would be required to meet at least annually to review Network activities, membership and new site/population nominations. Sites/populations included within the Network would need to be reviewed periodically (e.g., every 5 years) to ensure they still meet agreed inclusion and management criteria. If necessary, recommendations for changes would be made, and the sanction of de-selection from the Network would be available.

Formally establishing the Network governing body will require a legal document to be drawn up to include the statutes, define the legal status, mission, vision, functions, membership etc. of the Network. This will likely take some time, therefore, within the timescale of the Farmer's Pride project, immediate nominations would be reviewed by the proposed members of the Network governing body who are collaborators in Farmer's Pride (e.g., Eurosite, ECPGR ExCo, On-farm Conservation and Management, Wild Species Conservation in Genetic Reserves and crop Working Groups, Arche Noah, Pro Specie Rara and Euroseeds). This is seen as a pragmatic option to ensure the Network is established within the Farmer's Pride project lifetime, but the full Network governing body will be established as soon as possible. The formal establishment of the governing body will commence as soon as this proposal is endorsed during Farmer's Pride Workshop 2 in October 2019.

The basic costs associated with individual site/population management would be met nationally. It is envisaged that Network designated sites would be within existing PA and outside of PA largely on-farm, here funding to cover population maintenance and meet Network inclusion criteria would be met from environmental stewardship or agricultural support regulations. It is also important to note that thus far experience has shown the additional costs associated with active CWR conservation have proved deliverable within existing PA resource allocations—the real additional costs are out-weighed by the additional ecosystem services value of conserve PGR resource and the positive publicity associated with the conservation action. In the longer term, it would be desirable to ensure additional resources were available for Network sites, particularly for LR on-farm sites where more active intervention was required to sustain the target population.

In addition to national level resourcing, there would be operational costs for the Secretariat of the governing body of an estimated €250,000 per annum. This marginal cost needs to be viewed in the context of Pimentel *et al.* (1997) who estimated a 30% crop production increase due to the contribution of genetic resources and that the introduction of new genes from wild relatives alone contributes approximately US$ 115 billion toward increased crop yields per year worldwide. More recently, PWC (2013) estimated the potential value of CWR to the future production of 29 highest priority crops to be $120bn annually, compared with an annual gross production value of these crops of $581bn in 2010. These valuation figures do not take account of the economic enhancement associated with use of CWR in breeding of the other 3,971 global crops or the use of LR in breeding, which significantly exceeds CWR breeding use, but for which no estimated figures are available. It is obvious that the potential benefits of establishing the Network significantly exceed the potential costs, notwithstanding the significant additional benefit for food and nutritional security provided by having the Network in place.

3.4 Benefits of Network membership

The Network will *de facto* contain national, European and global priority germplasm diversity of value as a resource for present and future generations. Following their nomination and designation by national PGR coordinators, sites/populations will remain under national sovereign jurisdiction, so why should individual national agencies propose sites for inclusion in the European Network?

The over-arching benefit of Network membership will be that of belonging to an international community of appreciation and concern for the value of PGR diversity and facilitated access to the conserved resources for sustainable use. Countries which nominate sites for inclusion in the Network will help to underpin global, regional and national food security and natural heritage, and contribute to a shared commitment to preserve this legacy and resource for future generations. The prestige that comes from having national sites included in the Network is foreseen as acting as a catalyst to raise awareness and leverage resources for further PGR conservation and sustainable use.

Further, the possible establishment of a legacy trust fund would assist countries in identifying, preserving and promoting CWR and on-farm conservation. Emergency assistance may also be made available for urgent action to repair sites or populations damaged by human-made or natural disasters. In the case of Network sites thought to be in danger, the attention and the funds of both the national and the international community would be focused on the conservation needs of these particularly threatened

sites. It is hoped that the inclusion of a site or population in the Network would act as a magnet for European cooperation and may thus receive financial assistance for heritage conservation projects from a variety of sources.

Sites/populations included in the Network would also benefit from the elaboration and implementation of a comprehensive management plan that sets out adequate preservation measures and monitoring mechanisms. In support of these, experts from the appropriate European agency providing the necessary governance support would offer technical training to the local site management team.

Specifically, in the case of farmers and other landrace maintainers, the Network will bring direct benefits through assisted development of alternative, enhanced value chains for their unique products (e.g., niche markets), raising the value of their resources and thus sustaining their maintenance and conservation (Heinonen and Veteläinen, 2009; Nikolaou and Maxted, 2009; Martin *et al.*, 2009; Veteläinen *et al.*, 2009; Polegri and Negri, 2010; Ciancaleoni *et al.*, 2013).

Finally, membership of the Network would bring increased public awareness of the value of the CWR or LR genetic diversity included, thus also increasing the possibility for sustainable tourism activities and associated income generation.

4.0 CONCLUSION

This white paper proposing the establishment of the European Network for *In Situ* Conservation and Sustainable Use of Plant Genetic Resources argues the case for why such a network is required now—the fundamental justification being the need for climate smart varieties suited to rapidly changing growing environments and the requirement for greater breadth of gene pool diversity to meet this need. This is in the context that the elements of the gene pool that can provide this diversity are currently poorly conserved and therefore unavailable for use, and furthermore that they are threatened by increasing genetic erosion and even extinction. The fact that we now have the expertise to establish such a Network is timely given the current urgency of the requirement for greater breadth of gene pool diversity. Therefore, in this white paper, we have presented a proposal for how: (a) key complementary sites or CWR/LR populations might be identified both using a bottom-up and top-down approaches; (b) once identified, they can be included in the Network through a process of nomination by national PGR coordinators; (c) a Network governing body could be established to oversee its smooth running; and (d) the *in situ* conserved resources can be made available and accessible for sustainable use. Finally, we have argued that for the Network to be sustainable, there is a need for an international agency to provide overarching governance support. The European Commission has already made a significant investment through resourcing Farmer's Pride (and the sister project, Dynaversity), and it is difficult to foresee how that investment could be secured without the governance support envisaged. There would be little point in establishing the European and first global PGR *in situ* conservation and use network unless it is sustainable into the foreseeable future.

REFERENCES

Bhullar, N.K., Street, K., Mackay, M., Yahiaoui, N. and Keller, B., (2009). Unlocking wheat genetic resources for the molecular identification of previously undescribed functional alleles at the Pm3 resistance locus. *PNAS*, 106: 9519-9524. DOI: 10.1073/pnas.0904152106.

Bilz, M., Kell, S.P., Maxted, N. and Lansdown, R.V., (2011). *European Red List of Vascular Plants*. Luxembourg: Publications Office of the European Union. http://ec.europa.eu/environment/nature/conservation/species/redlist/downloads/European_vascular_plants.pdf

Brush, S.B. (1995) *In situ* conservation of landraces in centers of crop diversity. Crop Science, 35: 346-354.

Brush, S.B. (2000) The issues of *in situ* conservation of crop genetic resources. In: Brush S.B. (ed.) Genes in the field. IPGRI, Rome/IDRC, Ottawa/Lewis Publishers, Boca Raton, FL, pp. 3-26.

Camacho Villa, T.C., Maxted, N., Scholten, M.A. and Ford-Lloyd, B.V. (2005) Defining and identifying crop landraces. *Plant genetic resources: characterization and utilization*, 3(3), 373–384.

Castañeda-Álvarez, N.P., Khoury, C.K., Achicanoy, H.A., Bernau, V., Dempewolf, H., Eastwood, R.J., Guarino, L., Harker, R.H., Jarvis, A., Maxted, N., Müller, J.V., Ramírez-Villegas, J.A., Sosa, C.C., Struik, P.C., Vincent, H. and Toll, J. (2016) Global priorities for crop wild relative conservation for food security.

CBD, (2010a) *Global Strategy for Plant Conservation*. Secretariat of the Convention on Biological Diversity, Montreal, Canada. www.cbd.int/gspc/

CBD, (2010b) *Strategic Plan for Biodiversity 2011-2020*. Secretariat of the Convention on Biological Diversity, Montreal, Canada.

Ciancaleoni, S., Chiarenza, G.L., Raggi, L., Branca, F. and Negri V., (2013). Diversity characterisation of broccoli landraces for their on-farm (*in situ*) safeguard and use in breeding programs. *Genetic Resources and Crop Evolution*, DOI: 10.1007/s10722-013-0049-2.

Convention on Biological Diversity (1992) *Convention on Biological Diversity: Text and Annexes*. Secretariat of the Convention on Biological Diversity, Montreal.

Curtis, S., (2008) Use of wild plant species: the market perspective. In: Maxted, N., Ford-Lloyd, B.V., Kell, S.P., Iriondo, J.M., Dulloo, E. and Turok, J. (eds.), *Crop Wild Relative Conservation and Use.* Pp. 632–637. CAB International, Wallingford.

Deryng, D., Sacks, W.J., Barford, C.C. and Ramankutty, N. (2011) Simulating the effects of climate and agricultural management practices on global crop yield. Global Biogeochemical Cycles 25, GB2006. DOI: 10.1029/2009GB003765

Dias, S., Dulloo, M.E. and Arnaud, E., (2012). The role of EURISCO in promoting use of agricultural biodiversity. 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*. CAB International, Wallingford. pp 270-277.

Duveiller, E., Singh, R.P. and Nicol, J.M. (2007) The challenges of maintaining wheat productivity: pests, diseases, and potential epidemics. Euphytica 157(3), 417–430. DOI: 10.1007/s10681-007-9380-z

ECPGR, (2012). *Report of the 13th ECPGR Steering Committee Meeting was held at the Federal Ministry of Agriculture, Forestry, Environment and Water Management Austria on 4-7 December 2012*. Available at http://www.ecpgr.cgiar.org/about-ecpgr/steering-committee/13th-sc-meeting/ (Accessed 06.03.2015).

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.

European Commission. 2011. Communication from the Commission to the European Parliament, the Council, the Economic and Social Committee and the Committee of the Regions. Our life insurance, our natural capital: an EU biodiversity strategy to 2020. COM (2011) 244 final. (eur-lex.europa.eu/legalcontent/EN/TXT/PDF/?uri=CELEX:52011DC0244&from=EN) (accessed on 16.03.2015).

European Parliament. 2012. Our life insurance, our natural capital: an EU biodiversity strategy to 2020 (2011/2307(INI)). European Parliament resolution of 20 April 2012 on our life insurance, our natural capital: an EU biodiversity strategy to 2020. (2011/2307(INI). (ec.europa.eu/ environment/nature/biodiversity/comm2006/pdf/EP_resolution_april2012.pdf) (accessed on 16.03.2015).

FAO (1998) *State of the World's Plant Genetic Resources for Food and Agriculture*. UN Food and Agriculture Organization of the United Nations, Rome, Italy. Available at www.fao.org/agriculture/crops/thematic-sitemap/theme/seeds-pgr/sow/en/ (Accessed 06.03.2015).

FAO (2008) Climate Change and Biodiversity for Food and Agriculture. Food and Agriculture Organization of the United Nations, Rome. www.fao.org/uploads/media/FAO_2008a_climate_change_and_biodiversity_02.pdf (accessed 19 January 2018)

FAO (2010) *Second report on the State of the World's Plant Genetic Resources for Food and Agriculture*. Food and Agriculture Organization of the United Nations, Rome, Italy. Available at http://www.fao.org/agriculture/seed/sow2/en/ (Accessed 06.03.2015).

FAO (2011a) *Second Global Plan of Action for Plant Genetic Resources for Food and Agriculture.* UN Food and Agriculture Organization of the United Nations, Rome, Italy. Available at: http://www.fao.org/docrep/015/i2624e/i2624e00.htm (Accessed 06.03.2015).

FAO (2011b) *Thirteenth Regular Session of the Commission on the Genetic Resources for Food and Agriculture, CGRFA-13/11/Report*. UN Food and Agriculture Organization of the United Nations, Rome, Italy. Available at: http://www.fao.org/docrep/meeting/024/mc192e.pdf (Accessed 06.03.2015).

FAO, (2001). *International Treaty on Plant Genetic Resources for Food and Agriculture*. UN Food and Agriculture Organization of the United Nations, Rome, Italy.

FAO, (2012). FAOSTAT. Food and Agriculture Organization of the United Nations, Rome. Available online: http://faostat.fao.org/site/339/default.aspx (Accessed 11.05.16).

FAO, (2012). *Towards the establishment of a global network for in situ conservation and on-farm management of plant genetic resources for food and agriculture*", Report from Technical Workshop. UN Food and Agriculture Organization of the United Nations, Rome, Italy. Available on-line at:

http://typo3.fao.org/fileadmin/templates/agphome/documents/PGR/Reports/Report-Technical_workshop_131112.pdf (Accessed 11.03.19).

FAO, (2013). Fourteenth Regular Session of the Commission on the Genetic Resources for Food and Agriculture, Rome, Italy, 15-19 April 2013. CGRFA-14/13/Report, paragraph 96. UN Food and Agriculture Organization of the United Nations, Rome, Italy. Available on-line at: http://www.fao.org/docrep/meeting/028/mg538e.pdf (Accessed 11.03.19).

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 05.04.13).

FAO, (2014) *Concept note on global networking on in situ conservation and on - farm management of plant genetic resources for food and agriculture*. Information document to the 7th Session of the Intergovernmental Working Group on Plant Genetic Resources for Food and Agriculture (CGRFA/WG-PGR-7/14/Inf.3, Commission for Genetic Resources for Food and Agriculture, UN Food and Agriculture Organization of the United Nations, Rome, Italy. Available at: http://www.fao.org/3/a-ml477e.pdf (Accessed 06.03.2015).

FAO, (2019). *State of the World's Biodiversity for Food and Agriculture*. (eds. Bélanger, J. & Pilling, D.). UN Food and Agriculture Organization of the United Nations, Rome, Italy. Available at http://www.fao.org/3/CA3129EN/CA3129EN.pdf (Accessed 30.05.19).

Feuillet C, Langridge P and Waugh R (2008) Cereal breeding takes a walk on the wild side. *TRENDS in Genetics* 24: 24-32.

Fitzgerald, H., Palmé, A., Asdal, Å., Endresen, D., Kiviharju, E., Lund, B., Rasmussen, M., Thorbjörnsson, H., and Weibull, J., (2019). Plant Genetic Resources: Characterization and Utilization, 17(2): 196–207. doi:10.1017/S147926211800059X

Frese, L., Reinhard, U., Bannier, H.-J. and Germeier, C.U., (2009). *Landrace inventory in Germany – preparing the national implementation of the EU directive 2008/62/EC* In: Veteläinen, M., Negri, V. and Maxted, N. (eds.), *European Landraces: On-farm conservation, Management and Use.* Bioversity Technical Bulletin 15. Pp. 70-78. Bioversity International, Rome, Italy.

Friis-Hansen E and Sthapit B (2000) *Participatory Approaches to the Conservation and Use of Plant Genetic Resources*. International Plant Genetic Resources Institute, Rome, Italy.

Grigg, D. (1994) *Storia dell'Agricoltura in Occidente* (The Transformation of Agriculture in the West. Basil Blackwell, Oxford, 1992) Il Mulino, Bologna, Italy.

Guarino, L. and Lobell, D.B. (2011) A walk on the wild side. Nature Climate Change 1, 374–375. DOI: 10.1038/nclimate1272

Guarino, L., Maxted, N. and Chiwona, E.A., (2006). *A methodological model for ecogeographic surveys of crops*. IPGRI Technical Bulletin No. 9. pp. 1-58. IPGRI, Rome.

Hammer, K, Laghetti, G. and Perrino, P., (1999). A checklist of the cultivated plants of Ustica (Italy). *Genetic Resources and Crop Evolution* 46, 95-106.

Hammer, K., (1990). Botanical checklists prove useful in research programmes on cultivated plants. *Diversity*, 6 (3-4), 31-34.

Hammer, K., Hanelt, P. and Tittel, C., (1977). Sammlung autochthoner Kulturpflanzen auf dem Gebiet der DDR. *Kulturpflanze,* 25, 89-99.

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.

Heinonen, M. and Veteläinen, M., (2009). Cereal landrace inventories in Finland. In: Veteläinen, M., Negri, V. and Maxted, N. (eds.), *European Landraces: On-farm conservation, Management and Use.* Bioversity Technical Bulletin 15. Pp. 70-78. Bioversity International, Rome, Italy.

Heinonen, M., (2016). Landrace inventories and recommendations for in situ conservation in Finland. In: Maxted, N., Dulloo, M.E. and Ford-Lloyd, B.V. (eds.), *Enhancing Crop Genepool Use: Capturing Wild Relative and Landrace Diversity for Crop Improvement*. CAB International, Wallingford. Pp. 335–341.

Heywood, V.H. and Dulloo, M.E., (2005). In situ *conservation of wild plant species – a critical global review of good practices*. IPGRI Technical Bulletin No. 11. International Plant Genetic Resources Institute, Rome.

Heywood, V.H. and Zohary, D. (1995) A Catalogue of the Wild Relatives of Cultivated Plants Native to Europe. *Flora Mediterranea* 5, 375–415. www.herbmedit.org/flora/5-375.pdf (accessed 18 January 2018)

Heywood, V.H., (2008) The use and economic potential of wild species: an overview. In: Maxted, N., Ford-Lloyd, B.V., Kell, S.P., Iriondo, J.M., Dulloo, E. and Turok, J. (eds.), *Crop Wild Relative Conservation and Use.* Pp. 585–604. CAB International, Wallingford.

Hunter, D. and Heywood, V., (2011). *Crop wild relatives: a manual of* in situ *conservation*. Earthscan, London, UK.

Hunter, D., Guarino, L., Spillane, C. and McKeown, P. (2017) Handbook of Agricultural Biodiversity. Routledge, UK

Idohou, R., Assogbadjo, A.E., Fandohan, B., Gouwakinnou, G.N., Kakai, R.L.G., Sinsin, B. and Maxted, N. (2013) National inventory and prioritization of crop wild relatives: case study for Benin. *Genetic Resources and Crop Evolution* 60(4), 1337–1352.

Iriondo, J.M., Fielder, H., Fitzgerald, H., Kell, S.P., Labokas, J., Magos-Brehm, J., Negri, V., Phillips, J., Rubio-Teso, M.L., Sensen, S., Taylor N. and Maxted, N., (2016). National strategies for the conservation of crop wild relatives. 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. 161-171. CAB International, Wallingford, UK.

Iriondo, J.M., Maxted, N. and Dulloo, E. (eds.), (2008). *Plant Genetic Population Management*. CAB International, Wallingford.

Iriondo, J.M., Maxted, N., Kell, S.P., Ford-Lloyd, B.V., Lara-Romero, C., Labokas, J., 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. (eds.) *Agrobiodiversity*

Conservation: Securing the Diversity of Crop Wild Relatives and Landraces. Pp. 72-77. CAB International, Wallingford.

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

Jarvis, D. I., Hodgkin, T., Brown, A.H.D., Tuxill, J., Lopez 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 and London.

Jarvis, D.I., Hodgkin, T., Sthapit, B.R., Fadda, C. and Lopez-Noriega, I. (2011) An heuristic framework for identifying multiple ways of supporting the conservation and use of traditional crop varieties within the agricultural production system. Critical Reviews in Plant Sciences 30: 125-176.

Jones, P.D., Lister, D.H., Jaggard, K.W. and Pidgeon, J.D. (2003) Future climate change impact on the productivity of sugar beet (*Beta vulgaris* L.) in Europe. *Climatic Change* 58(1–2), 93–108. DOI: 10.1023/A:1023420102432

Kell, S.P., Maxted, N., Allender, C., Astley, D., Ford-Lloyd, B.V. and contributors (2009) *Vegetable Landrace Inventory of England and Wales*. The University of Birmingham, UK. 117 pp. Defra Science and Research Project IF0164. Available at Web sitehttp://randd.defra.gov.uk (accessed 11 November 2016).

Kell, S.P., Maxted, N. and Bilz, M., (2012). European crop wild relative threat assessment: knowledge gained and lessons learnt. In Maxted, N., Dulloo, M.E., Ford-Lloyd, B.V., Frese, L., Iriondo, J.M. and Pinheiro de Carvalho, M.A. (eds.) *Agrobiodiversity Conservation: Securing the Diversity of Crop Wild Relatives and Landraces*. CAB International, Wallingford. pp. 218–242.

Kell, S.P., Qin, H., Chen, B., Ford-Lloyd, B.V., Wei, W., Kang, D. and Maxted, N., (2015). China's crop wild relatives: Diversity for agriculture and food security. *Agriculture, Ecosystems and Environment*, 209: 138–154.

Kell, S.P., Ford-Lloyd, B.V. and Maxted N., (2016). Europe's crop wild relative diversity: from conservation planning to conservation action. In: Maxted, N., Ehsan Dulloo, M. & Ford-Lloyd, B.V. (eds.), *Enhancing Crop Genepool Use: Capturing Wild Relative and Landrace Diversity for Crop Improvement*. Pp. 125-136. CAB International, Wallingford, UK.

Kell, S.P., Marino, M. and Maxted, N. (2017a) Bottlenecks in the PGRFA use system: stakeholders' perspectives. Euphytica 213:170. DOI: 10.1007/s10681-017-1935-z.

Kell, S.P., Ford-Lloyd, B.V., Magos Brehm, J., Iriondo, J.M. and Maxted, N., (2017b). 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.

Ketskhoveli, N., Ramishvili, M. and Tabodze, D., (1960). *Ampelography of Georgia*. Georgian Academy of Sciences, Tbilisi, Georgia. P. 439.

Létard, V., Flandre, H. and Lepeltier, S. (2004) Information Report No 195 (2003–2004) done on behalf of the joint mission of information (1) 'France et les Français Face à la Canicule: Les Leçons d'une Crise' (France and the French Facing a Heat Wave: The Lessons of a Crisis), 391 pp. www.senat.fr/rap/r03-195/r03-195.html

Li, X., Takahashi, T., Suzuki, N. and Kaiser, H.M. (2011) The impact of climate change on maize yields in the United States and China. Agricultural Systems 104(4), 348–353. DOI: 10.1016/j.agsy.2010.12.006

Lobell, D.B., Burke, M.B., Tebaldi, C., Mastrandrea, M.D., Falcon, W.P. and Naylor, R.L. (2008) Prioritizing climate change adaptation needs for food security in 2030. Science 319(5863), 607–610. DOI: 10.1126/science.1152339

Luck, J., Spackmand, M., Freemand, A., Trębicki, P., Griffiths, W., Finlay, K. and Chakraborty, S. (2011) Climate change and diseases of food crops. Plant Pathology 60(1), 113–121. DOI: 10.1111/j.1365-3059.2010.02414.x

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/.

Martin, P., Wisehart, J., Cromarty, A. and Chang, A., (2009). New markets and supply chains for Scottish Bere barley. In: Veteläinen, M., Negri, V. and Maxted, N. (eds.), *European Landraces: On-farm conservation, Management and Use.* Bioversity Technical Bulletin 15. Pp. 244-250. Bioversity International, Rome, Italy.

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., Dulloo, M.E. and Ford-Lloyd, B.V. (eds.), *Enhancing Crop Genepool Use: Capturing Wild Relative and Landrace Diversity for Crop Improvement*. CAB International, Wallingford. Pp. 87–124.

Maxted, N. (2006) UK land-races – a hidden resource? *Plant Talk* 44, 8.

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. 211 pp. Available at: http://www.fao.org/docrep/013/i1500e/i1500e18a.pdf (Accessed 06.03.2015).

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, Stegelitz, Germany. Pp. 11-19. Bioversity International, Rome, Italy.

Maxted, N., Avagyan, A. Frese, L., Iriondo, J.M., Magos Brehm, J., Singer, A. and Kell, S.P. (2015) *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: http://www.pgrsecure.org/documents/Concept_v2.pdf (Accessed 06.03.2015).

Maxted, N., Ford-Lloyd, B.V. and Hawkes, J.G., (1997b). 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., Jury, S., Kell, S.P. and Scholten, M.A. (2006) Towards a definition of a crop wild relative. *Biodiversity and Conservation*, 15(8), 2673–2685.

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., Hawkes, J.G., Ford-Lloyd, B.V. and Williams, J.T., (1997a). A Practical Model for *In Situ* Genetic Conservation. In: *Plant genetic conservation: the* in situ *approach* (eds. Maxted, N., Ford-Lloyd, B.V. and Hawkes, J.G.), pp. 545-592. Chapman & Hall, London.

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

Maxted, N. and Palmé, A., (2015). *Combining ex situ and in situ conservation strategies for CWR to mitigate climate change*. Conference: 'The impact of climate change on the conservation and utilization of crop wild relatives in Europe', Barcelona, Spain, 15th December 2015.

Maxted, N., Scholten, M.A., Codd, R. and Ford-Lloyd, B.V., (2007). Creation and Use of a National Inventory of Crop Wild Relatives. *Biological Conservation*, 140: 142-159.

Maxted, N., Veteläinen, M. and Negri, V., (2009). Landrace Inventories: Needs and Methodologies. In: Veteläinen, M., Negri, V. & Maxted, N. (eds.), European Landraces: On-farm conservation, Management and Use. Bioversity Technical Bulletin 15. Pp. 45-52. Bioversity International, Rome, Italy.

McCouch, S., Baute, G.J., Bradeen, J., Bramel, P., Bretting, P.K., Buckler, E., Burke, J.M., Charest, D., Cloutier, S., Cole, G., Dempewolf, H., Dingkuhn, M., Feuillet, C., Gepts, P., Grattapaglia, D., Guarino, L., Jackson, S., Knapp, S., Langridge, P., Lawton-Rauh, A., Lijua, Q., Lusty, C., Michael, T., Myles, S., Naito, K., Nelson, R.L., Pontarollo, R., Richards, C.M., Rieseberg, L., Ross-Ibarra, J., Rounsley, S., Sackville Hamilton, R.S., Schurr, U., Stein, N., Tomooka, N., van der Knaap, E., van Tassel, D., Toll, J., Valls, J., Varshney, R.K., Ward, J., Waugh, R., Wenzl, P. and Zamir, D. (2013) Agriculture: Feeding the future. *Nature* 499 (7456), 23-24.

Meilleur, B.A. and Hodgkin, T., (2004). *In situ* conservation of crop wild relatives. *Biodiversity and Conservation*, 13, 663—684.

Mendes Moreira, P.M.R. and Veloso, M.M., (2009). "Landrace inventory for Portugal" 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. 124-136.

Muñoz-Amatriaín, M., Cuesta-Marcos, A., Endelman, J.B., Comadran, J., Bonman, J.M., Bockelman, H.E., Chao, S., Russell, J., Waugh, R., Hayes, P.M. and Muehlbauer, G.J. (2014) The USDA barley core collection: genetic diversity, population structure, and potential for genome-wide association studies. PLoS ONE 9(4), e94688. DOI: 10.1371/journal.pone.0094688

Negri V. (2005) Agro-Biodiversity Conservation In Europe: Ethical Issues. *J. of Agricultural and Environmental Ethics* 18, 1: 3-25.

Negri, V. (2003) Landraces in central Italy: Where and why they are conserved and perspectives for their on farm conservation. *Genetic Resources and Crop Evolution* 50, 871-885.

Negri, V. Maxted, N. and Vetelainen, M., (2009) European landrace conservation: an introduction. In: (Vetelainen, M., Negri V. and N. Maxted eds.) '*European Landraces: On-farm Conservation, Management and Use*'. Bioversity Technical Bulletin No. 15, Bioversity International, Bioversity International publ., Rome, Italy, pp 1-22 ISBN 978-92-9043-805-2, also available at:

http://www.bioversityinternational.org/index.php?id=19&user_bioversitypublications_pi1%5bshowUid%5d=3252" \t "_blank

Negri, V., Pacicco, L., Bodesmo, M. and Torricell,i R., (2013). The first Italian inventory of in situ maintained landraces. On CD ROM. ISBN 978-88-6074-279-7. Morlacchi Editrice, Perugia. Also available at http://vnr.unipg.it/PGRSecure/start.html/

Negri. V., Pacicco, L., Bodesmo, M. and Torricelli, R., (2013) The first Italian inventory of *in situ* maintained landraces. Morlacchi Editrice, Perugia, Italy. Available at http://vnr.unipg.it/PGRSecure/start.html (accessed 23.11.2018).

Nikolaou, L. and Maxted, N., (2009). Community-based Landrace Conservation: Lentils of Eglouvi, Lefkada. In: Veteläinen, M., Negri, V. and Maxted, N. (eds.), *European Landraces: On-farm conservation, Management and Use.* Bioversity Technical Bulletin 15. Pp. 223-232. Bioversity International, Rome, Italy.

Pacicco, L., Bodesmo, M., Torricelli, R. and Negri, V., (2018). A methodological approach to identify agrobiodiversity hotspots for *in situ* conservation. *PLOS one*, doi https://doi.org/10.1371/journal.pone.0197709

Pimentel, D., Wilson, C., McCullum, C., Huang. R., Dwen, P., Flack, J., Tran, Q., Saltman, T. and Cliff. B., (1997). Economic and environmental benefits of biodiversity. *BioScience*, 47: 747–757.

Polegri L. and Negri V., (2010). Molecular markers for promoting agro-biodiversity conservation: a case study from Italy. How cowpea landraces were saved from extinction. *Genetic Resources and Crop Evolution*, 57: 867-880.

Polegri, L. and Negri, V., (2010). Molecular markers for promoting agro-biodiversity conservation: a case study from Italy. How cowpea landraces were saved from extinction. *Genetic Resources and Crop Evolution*, 57: 867-880 DOI: 10.1007/s10722-009-9526-z

Porter, J.R., Xie, L.Y., Challinor *et al.* (2014) Food Security and Food Production Systems. In: Field, C.B. *et al.*, eds. *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press, pp. 485–533.

PwC, (2013) Crop wild relatives: A valuable resource for crop development. PwC Valuations, PwC, London.

Safriel, U.N., Anikster, Y. and Waldman, M. (1997) Management of nature reserves for conservation of wild relatives and the significant of marginal populations. *Bocconea* 7, 233–239.

Scholten, M., Maxted N. and Ford-Lloyd, B.V. (2004) *UK National Inventory of Plant Genetic Resources for Food and Agriculture*. Unpublished Report, Defra, London.

Shaffer, M.L. (1981) Minimum population sizes for species conservation. *Bioscience*, 31(2), 131-134.

Smith, R.D., Dickie, J.B., Linington, S.H., Pritchard, H.W. and Probert, R.J. (2003) *Seed Conservation: turning science into practice*. Royal Botanic Gardens, Kew, UK.

Sthapit, B., Subedi, A., Jarvis, D., Lamers, H., Rao, R. and Reddy, B.M.C (2012) Community-based approach to on-farm conservation and sustainable use of agricultural biodiversity in Asia. Indian J. Plant Genet. Res. 25: 97-110

Stickland, S. (1998) *Heritage vegetables: the gardeners' guide to cultivating diversity*. Gaia Books Ltd., London, UK.

Tanksley, S.D. and McCouch, S.R., (1997). Seed banks and molecular maps: Unlocking genetic potential from the wild. Science, 277: 1063–1066.

Tiranti, B. and Negri, V., (2007). Selective micro-environmental 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.

Tosti, N. and Negri, V., (2005). On-going on-farm microevolutionary processes in neighbouring cowpea landraces revealed by molecular markers. *Theoretical and Applied Genetics*, 110:1275-1283 DOI: 10.1007/s00122-005-1964-1

United Nations, (2015). *Transforming our world: the 2030 Agenda for Sustainable Development*. Paragraph 54 of United Nations Resolution A/RES/70/1 of 25 September 2015. UN, New York.

Valdani Vicari & Associati, Arcadia International, Wageningen UR: Centre for Genetic Resource, the Netherlands, Plant Research International and the socio-economics research institute, Fungal Biodiversity Centre of the Royal Academy of Arts and Science and Information and Coordination Centre for Biological Diversity of the German Federal Office for Agriculture and Food, (2016). *The impact of climate change on the conservation and utilisation of crop wild relatives in Europe*. Workshop Report for Preparatory action on EU plant and animal genetic resources (AGRI-2013-EVAL-7). Directorate General for Agriculture and Rural Development, European Commission, Brussels, Belgium.

Vavilov, N.I., (1926). Tzentry proiskhozhdeniya kulturnykhrastenii. [The centers of origin of cultivated plants]. Works of Applied Botany and Plant Breeding, 16(2), 248 P: [Russian, English].

Velvé, R. (1992) *Saving the seed: genetic diversity and European agriculture*. Earthscan Publications, London.

Veteläinen, M., Negri, V. and Maxted, N. (eds.), (2009). *European Landraces: On-farm conservation, Management and Use.* Bioversity Technical Bulletin 15. Pp. 1-359. Bioversity International, Rome, Italy.

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). Securing food security: global priorities for crop wild relative in situ conservation. *Communications Biology*, 2:136 | https://doi.org/10.1038/s42003-019-0372-z.

Vincent, H., Wiersema, J., Kell, S., Fielder, H., Dobbie, S., Casteñeda-Álvarez, N.P., Guarino, L., Eastwood, R., León, B. and Maxted, N. (2013) A prioritized crop wild relative inventory to help underpin global food security. *Biological Conservation*, 167, 265–275.

Vollbrecht, E. and Sigmon, B. (2005) Amazing grass: developmental genetics of maize domestication. *Biochemical Society Transactions*, 33, 1502–1506.

Zencirci, N., Kaya, Z., Anikster, Y. and Adams, W.T. (eds.), (1998). *The proceedings of international symposium on* in situ *conservation of plant diversity*. Central Research Institute for Field Crops, Ankara, Turkey.

Zeven, A. and Zhukovsky, P. (1975) *Dictionary of Cultivated Plants and their Centres of Diversity. Excluding Ornamentals, Forest Trees and Lower Plants*. PUDOC, Wageningen. http://edepot.wur.nl/350203 (accessed 18 January 2018)

Zeven, AC. (1998) Landraces: A review of definitions and classifications. *Euphytica* 104, 127-139.