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Challenges of In Situ Conservation of Crop Wild Relatives

Vernon Hilton HEYWOOD

Plant Science Laboratories, School of Biological Sciences, University of Reading, Reading RG6 6AS - UK

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Abstract: Crop wild relatives (CWRs) will gain in importance as changing climates put both traditional and advanced cultivars under increasing stress, leading to a need for plant breeding to produce new varieties able to grow under the new climate regimes. Traditionally, the approach to the conservation of CWRs has been ex situ – the collection and maintenance of seed accessions in national, regional, and international germplasm banks, supplemented by field genebanks for species with recalcitrant seeds. More recently the need to maintain CWRs in their natural habitats (in situ) has been advocated. This is very different from on-farm conservation of traditional land races and is a complex multidisciplinary process. Particular problems that have to be addressed include the adoption of a workable definition of what is a CWR, application of priority-determining mechanisms because of the large number of candidate species of CWRs, assessment of the effectiveness of conservation approaches, the relative costs of in situ and ex situ approaches, integration of CWR in situ conservation into national programmes, and the challenges posed by global change. CWRs may be conserved in both protected and non-protected areas. Presence in the former is no guarantee of their survival and in most cases some degree of management intervention is required. Experience derived from recent EU- and GEF-funded CWR conservation initiatives will be drawn upon.

Key Words: Crop wild relatives, conservation, in situ, global climate change

Introduction

The importance of CWRs

In the introduction to Hoyt's *Conserving the Wild Relatives of Crops* (1998), IBPGR, IUCN, and WWF wrote 'The conservation of crop genetic resources–the plants that feed us and their wild relatives–is one of the most important issues for humankind today'. This statement is as true, if not more so today, as when it was written 20 years ago. One of the challenges of global change now facing us is how to provide adequate nutrition for the steadily growing world population in the face of changing climatic conditions and continuing habitat loss. In meeting that challenge, as wide a range as possible of genetic material will be needed to breed the new cultivars required and crop wild relatives will be an important source of that variation. As an economic appraisal of crop genetic resources from the United States Department of Agriculture notes, crop genetic resources are essential to maintaining and improving agricultural productivity: 'Without continued genetic enhancement using diverse germplasm from both wild and modified sources, the gains in crop yields obtained over the past seven decades are not sustainable, and yields might eventually grow more slowly or even decline. Agricultural production increasingly relies on "temporal diversity," changing varieties more frequently to maintain resistance to pests and diseases' (Rubenstein et al., 2005).

In fact, it is likely that in situ genetic variation of crop wild relatives will now be of more value to plant breeders, especially in the light of recent advances in biotechnology which allow breeders increasingly to use genetic material found in wild populations. Furthermore, these populations contain valuable alleles at low frequencies that have so far evaded capture in previous sampling and breeding programmes (Williams, 1991; Franks, 1999).

On the other hand, Hajjar and Hodgkin (2007) argue that despite such molecular and other improved procedures, the contributions of crop wild relatives to the development of new cultivars are less than they might have been expected, and so clearly there is great potential still to be exploited (but cf. Rubenstein et al., 2006).

* E-mail: vhheywood@btinternet.com

In today's context of global change, Lane (2007) notes, 'The irony ... is that plant breeders will be relying on wild relatives more than ever as they work to develop domesticated crops that can adapt to changing climate conditions. Yet because of climate change, we could end up losing a significant amount of these critical genetic resources at precisely the time they are most needed to maintain agricultural production'. The likely impacts of climate change on crop wild relatives will be considered below.

Crop Wild Relatives in SW Asia

As Erna Bennett reminded us at the first Plant Life of South-West Asia conference in Edinburgh in 1970 (Bennett, 1971), the region is one of the cradles of cultivated plants and indeed of Western civilisation. Hundreds of crop wild relatives occur in the region[1], including cereals such as wheat (*Triticum*), barley (*Hordeum*), rye (Secale), *Aegilops*, legumes such as lentil (*Lens*), chickpea (*Cicer*), fodder plants (*Medicago*, *Onobrychis*), and in particular many fruits such as cherries (*Prunus*), pears (*Pyrus*), apples (*Malus*), plum (*Prunus*), pomegranate (*Punica*), quince (*Cydonia*), azarole (*Crataegus*), medlar (*Mespilus*), figs (*Ficus*), and grapevine (*Vitis*), and nuts such as hazelnut (*Corylus*), walnut (*Juglans*), and pistacio (*Pistacia*). It is appropriate therefore to consider what advances have been made in the conservation and sustainable use of these valuable resources in the intervening years.

The natural landscapes of SW Asia have been subjected to considerable change over the past decades as a result of change in land use, alterations in disturbance regimes, loss of habitats or their conversion for agricultural use, and climatic fluctuations, all of which have adversely affected the populations of crop wild relatives that occur there. Coordinated action is urgently needed to ensure that as much as possible of this important genetic variation survives for present and future generations. Because of the international dimensions of crop genetic resources, this is not just a problem that affects the region, but is of global significance.

Problems of definition of crop wild relatives

The term crop wild relative is not a precise one and has been variously defined and debated. Meilleur and Hodgkin (2004) consider that a workable, consensus-driven definition would help clarify discussions of the topic and direct efforts more effectively and suggest as a possible definition that 'CWRs should include the wild congeners or closely related species of a domesticated crop or plant species, including relatives of species cultivated for medicinal, forestry, forage, or ornamental reasons'.

In general terms, a CWR is a plant that is more or less closely related to a crop and to which it may contribute genetic material, but unlike the crop species has not been domesticated; they are also likely to be the progenitors or direct ancestors of crops. Crops are interpreted here as including not just food, fodder, and forage crops, but also medicinal and aromatic plants, condiments, ornamental, forestry, oils, and fibre species that are cultivated or extensively harvested from the wild. But as Heywood et al. (2007) note, being a CWR is in itself relative: some taxa are more closely related than others to the crop. There are 2 ways in which such relatedness can be judged–genecological and taxonomic.

The genecological approach often uses the Harlan and de Wet (1971) gene pool concept to define the degree of relatedness, based on the relative ease with which genes can be transferred from them to the crop, so that close relatives that readily intercross are found in the primary gene pool (GP1) while more remote relatives occur in the secondary gene pool (GP2), which contains all the biological species that can be crossed with the crop but where hybrids are usually sterile, and the tertiary gene pool (GP3), which comprises those species that can be crossed with the crop only with difficulty and where gene transfer is usually only possible with radical techniques. An example of the use of such an approach is the survey of the wild relatives of food crops of Armenia and Nakhicheva by Gabrielian and Zohary (2004), which focused on primary wild gene pools (GP-1) with occasional mention of more distant relatives in the secondary and tertiary wild gene pools.

[1] The region of South-West Asia may be defined in several different ways and no clear indication is given in the proceedings of the first Plant Resources of South-West Asia conference. It coincides partly with the area known as the Middle East, but extends further to the east. Here I have interpreted it loosely so as to include Armenia, Azerbaijan, Bahrain, Cyprus, Georgia, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Palestinian Territories, Qatar, Saudi Arabia, Syria, Emirates, Yemen, and at least the Asian parts of Egypt and Turkey. Afghanistan, Kazakhstan, Kyrgyzstan, western parts of Pakistan, Tajikistan, Turkmenistan, and Uzbekistan may also be included.

The drawback of the gene pool concept that limits its application is the fact that information on genetic diversity and crossability required to apply the gene pool concept to the majority of crop complexes is usually lacking. As a consequence, it is necessary to infer the likelihood of crossability rather than basing it on direct evidence. This means that although the system is theoretically applicable to a wide range of crop plants (Smartt, 1981) in practice it is limited to well known and studied crop complexes.

The simplest taxonomic approach to defining CWRs is to apply it to the genera to which the crops and their relatives belong. Such an approach, which was adopted by the European project PGR Forum (Maxted et al., 2006), is simple and attractive and can be argued on the grounds that species judged to be sufficiently similar to belong to the same genus are likely to be related genetically. Applying such a definition runs the risk of including as wild relatives species that range from closely related to the crop to those that are much more distantly related. On the other hand, with the advances in biotechnology mentioned above, it is likely that genetic material can be readily transferred between wild relatives even though they do not belong to the same primary or secondary gene pool. A bigger problem, however, is that the number of species recognised as CWRs becomes so large as to be unmanageable. This was the consequence when applied to the floras of Europe and the Mediterranean in the PGR Forum project, with c. 80% of the total species of the region (Kell et al., in preparation) considered as CWRs. Given that resources for conservation are severely limited, a further triage is necessary with priority given to those CWRs most closely related to the crop and from which the desired traits can be most readily transferred to it.

A refinement of the taxonomic approach to the definition of crop wild relatives proposed by Maxted et al. (2006) and adopted by the PGR Forum is the Taxon Group Concept. This relies on the likelihood of the existing taxonomic classification reflecting degree of genetic relationship or crossability in the partial or total absence of genetic diversity data. The taxon group categories are as follows[2]:

Taxon Group 1a – crop

Taxon Group 1b – same species as crop

Taxon Group 2 – same series or section as crop

Taxon Group 3 – same subgenus as crop

Taxon Group 4 – same genus as crop

Taxon Group 5 – different genus to the crop

Using the Taxon Group Concept, a formal definition of a CWR has been proposed by Maxted et al. (2006): 'A crop wild relative is a wild plant taxon that has an indirect use derived from its relatively close genetic relationship to a crop; this relationship is defined in terms of the CWR belonging to gene pools 1 or 2, or taxon groups 1 to 4 of the crop'. (Taxon Group 1 [TG1] = taxa within the same species; TG2 = taxa within the same section or series; TG3 = taxa within the same subgenus; TG4 = taxa within the same genus; TG5 = taxa in different but related genera).

While the Taxon Group concept may serve as a useful proxy indicator of the degree of genetic relatedness or distance between taxa, it is more likely to hold in groups whose taxonomy has been well studied and in those cases where there is general agreement as to the classification to be adopted. Moreover, the majority of genera have not been divided into subgenera, series sections, or series, and for those that have it is increasingly being found as a result of detailed study, including molecular methods, that in many genera such subdivisions are not tenable. Use of the Taxon Group concept still leads to the recognition of unacceptably large numbers of CWRs. For the Euro-Mediterranean region, the number of CWRs recognised by the PGR Forum project was around 20,000 while for a single country such as Portugal it led to over 2000 taxa being inventoried (Magos Brehm et al., 2007).

Need for national and regional inventories and information systems

Inventory is the starting point of CWR conservation and is an essential component of a national strategy for biodiversity conservation in general and of crop wild relatives in particular (cf. Maxted et al., 2007).

The preparation of an inventory of CWRs is just the first, albeit essential, step in developing a national or regional strategy (Maxted et al., 2007; Kell et al., 2008). In addition to the taxonomic core of the inventory, a baseline of knowledge about these taxa should then be established. The main elements of a knowledge baseline for CWRs are given in Box 1. Some of this information

[2] http://www.pgrforum.org/TG_illustration.htm

will be gathered as a desk exercise while other elements will require field work and observation and the term ecogeographical survey is often applied to one or other or both of these components.

The information gathered in the knowledge baseline should be stored and made accessible electronically. Two major initiatives have addressed the issues of management, sharing, and exchange of data on CWRs. The first of these, the PGR Forum has developed a Crop Wild Relative Information System (Kell et al., 2005) for Europe and the Mediterranean. This includes descriptors and has links to information on individual species held within other online systems. The second is the UNEP/GEF/Bioversity International "*In situ* conservation of crop wild relatives through enhanced information management and field application" project. As the name suggests, one of the principal aims of the project is to devise national information systems in the 5 countries involved – Armenia, Bolivia, Madagascar, Sri Lanka, and Uzbekistan – which will bring together the data held by the various institutions in each country and make them readily available both within the country and to other countries so that it can be used as a tool to help in the various decision-making procedures involved in developing conservation actions. In addition, an International Information System is being developed that will link together the data in the national systems and be available through the Internet.

The Nordic Gene Bank and Bioversity International have through their GBIF Nodes joined forces to develop The Crop Wild Relatives Global Portal, which uses the GBIF central web services to link names and specimen and observation records served through GBIF with other data resources important for the conservation and sustainable use of crop wild relatives.[3] The aim is that eventually the contributions by each country will be linked and made available globally and in this way the dispersed information held by individual countries, international agencies, and other institutions and organisations will be readily available to assist conservation decision-making.

Box 1. Elements needed for a knowledge baseline on crop wild relatives (from Heywood & Dulloo, 2006).

1. Bring together information on the main wild species of economic use in the country or region on:
   – the correct identity
   – distribution
   – reproductive biology
   – breeding system
   – demography
   – conservation status
2. Gather information on how they are used, including local traditional knowledge
3. Gather information on the nature and extent of trade in these species
4. Gather information on the extent to which (if relevant) they are harvested from the wild and the consequences of this on the viability of wild populations
5. Gather information on their cultivation and propagation
6. Gather information on their agronomy if cultivated
7. Establish which of them occur in Protected Areas
8. Gather information on the availability of germless and authenticated stock for cultivation
9. Gather information of what (if any) other conservation activities (including ex situ, ecogeographical surveys) on the species exist

3 http://cwrint.grinfo.net/index.php?page=welcome

The number of CWRs identified in a national inventory will usually exceed that for which resources will be available to undertake effective conservation. According to Brown and Brubaker (2002), in the case of wild relatives, the number of candidate species is likely to be at least an order of magnitude higher than the crops to which they are related. In order to select which of the CWR taxa should be candidates for conservation action a prioritisation process is required. In this process, a wide range of factors may be taken into account (see Box 2). In addition, a number of special factors may apply such as:

- Degree of coverage (percentage of the total cover) occupied by the species
- Occurrence in marginal habitats
- General distribution pattern (widespread, disjunct populations, narrow localised species, metapopulations) – which will affect the genetic architecture and the amount of variation
- Existence of ecotypic (genecological) variation
- Existence of chemical variation
- Existence of clinal variation
- How far the populations and even individuals have been mapped, their population structure, and variation patterns known
- Competitive ability, which may affect degree of management intervention required
- Special desirable features such as chemical variation that needs to be covered in the populations selected
- Genetic integrity at risk
- Genetic contamination in native stands
- Capacity for natural regeneration

Some countries in the region have comprehensive or partial listings such as Armenia, Turkey, and Uzbekistan, while in others little information has been gathered. Thus, whatever definition of CWR is adopted, it is not possible to give an accurate estimate of the total number in South-west Asia.

Box 2. General criteria for selecting target species (from Heywood & Dulloo, 2006).

- Actual or potential economic use
  - Crop relative
  - Medicinal or aromatic herb, shrub, tree
  - Forest timber tree
  - Fruit tree or shrub
  - Ornamental herb tree, shrub
  - Agroforestry species
  - Forage species
  - Species used for habitat restoration or rehabilitation
  - Other
- Current conservation status: the degree and nature of threats
- Endemism
- Restricted range
- Recent rate of decline
- Rarity
- Threat of genetic erosion
- Ecogeographical distinctiveness

- Biological characteristics and importance
- Cultural importance or of high social demand
- Occurrence and frequency in current Protected Areas
- Status of protection
- Ethical considerations
- Taxonomic or phyletic uniqueness or isolation
- Focal or keystone status/ecosystem role
  - Indicator species
  - Umbrella species
  - Keystone
  - Flagship

In addition to preparing national inventories and developing national strategies, consideration should be given to establishing a regional system for SW Asia comparable to the European Crop Wild Diversity Assessment and Conservation Forum (PGR Forum[4]). Given that some CWRs occur in more than one country in the area, a regional approach would have many advantages and facilitate transboundary cooperation.

Conservation in situ and its effectiveness

Some of the issues of in situ conservation of populations of plants and animals and the ecosystems in which they occur were outlined at the Edinburgh conference in a paper by Poore (1971), which led to substantial discussion. This was, of course, before the development of conservation biology and the science and methodology of genetic conservation.

Traditionally, the main approach to the conservation of CWRs has been ex situ–the collection and maintenance of seed accessions in national, regional, and international germplasm banks, supplemented by field genebanks or other techniques for species with recalcitrant seeds.

More recently the need to maintain CWRs in their natural habitats (in situ) has been advocated (Hoyt, 1988; Valdés et al., 1997; Kaya et al., 1997; Meilleur & Hodgkin, 2004) and this is in line with the Convention on Biological Diversity (Article 8(d): Promote the protection of ecosystems, natural habitats and the maintenance of viable populations of species in natural surroundings). This is very different from on-farm conservation of traditional land races, which is also in situ.

Considerable ambiguity and misunderstanding surrounds the concept of in situ conservation. As noted by Heywood and Dulloo (2006), in the minds of many people, it is taken to mean the creation of protected areas and implies a narrow ecosystem approach, with the inclusion of local communities and conservation of species being incidental. However, this attitude is now rapidly changing, as more focus is placed on individual target species and the needs and well-being of local communities and people are beginning to receive more consideration (Kaya et al., 1997; Zencirci et al., 1998).

The main general aim and long-term goal of in situ conservation of target species such as CWRs is to protect, manage, and monitor the selected populations in their natural habitats so that the natural evolutionary processes can be maintained, thus allowing new variation to be generated in the gene pool that will allow the species to adapt to changing environmental conditions such as global warming, changed rainfall patterns, acid rain, or habitat loss.

In practice, the conservation of species in situ depends critically on identifying the habitats in which they occur and then protecting both the habitat and the species through various kinds of management and/or monitoring.

[4] http:// www.pgrforum.org/

In the case of threatened species, their conservation in situ also requires that the threats to them are removed, mitigated, or at least contained. Thus, although in situ species conservation is essentially a species-driven process, it also necessarily involves habitat protection (Heywood & Dulloo, 2006).

Species conservation in situ also covers a broad spectrum of activities: it ranges from the preparation and implementation of detailed single-species recovery plans in the case of species that are critically endangered, through single-species management plans and monitoring for those species that are rare, not threatened or only vulnerable, to multi-species recovery plans and management plans and habitat protection. It may often include some ex situ conservation activities. A species oriented-approach to in situ conservation is a complex multidisciplinary process and involves a wide range of conservation techniques and expertise. It is perhaps the most challenging task facing plant conservation today.

It is often stated that a species-based approach to conservation is not possible because of the sheer numbers of entities involved, whereas a habitat/ecosystem-based approach allows a large number of species to be given some form of protection at the same time. While there is a great deal of justification for such a position, it oversimplifies the situation. In many cases, there is no substitute for focusing effort on species as in the case of the large numbers of economically, culturally important plants, such as plants of agriculture, horticulture, medicinal, and aromatic plants, locally important wild food and fibre plants, and non-woody timber products (Heywood, 1993).

The strategy of protecting enough habitat so as to ensure the presence of viable populations of all the native species of a region, as some authors have suggested, is a laudable aim but is seldom possible and is fraught with difficulties. For most wild species the best that we can hope for is their presence in some form of protected area where, provided the area itself is not under threat, and subject to the dynamics of the system and the extent of human pressures, some degree of protection may be afforded. But the fact is that most species occur outside currently protected areas.

The notion that in situ conservation of species is assured simply by their presence in a protected area without any further action is absurdly optimistic–it is conservation at the stroke of a pen. This is known as the 'hands-off' or 'benign neglect' approach and is widely advocated: in the words of one recent study, '…for species which are not under threat of destruction, the most sensible and effective policy is to leave the material to conserve itself, in the wild…' (Holden et al., 1993). It is also known as 'passive' conservation (Maxted et al., 1997; Agee, 2002) in that the existence of particular species is coincidental and passive, and not the result of active conservation management. It contrasts with 'active' conservation, which requires positive action to promote the sustainability of the target taxa and the maintenance of the natural, semi-natural, or artificial (e.g. agricultural) ecosystems that contain them, thereby implying the need for associated habitat monitoring.

The reason that passive conservation is often not effective lies in the dynamics of change to which populations, species, and ecosystems are subjected. As Heywood and Dulloo note (2006), these dynamics comprise: '(1) those of the environmental factors (climatic, edaphic, biotic) that affect the ecosystem itself and today involves a new factor–that of global change; (2) those of the ecosystem itself, which may show considerable change over short periods of time; and (3) those of the populations of the species that make up the ecosystem that may fluctuate considerably in size, distribution, genetics, and composition even from one year to another'. Conservation, as I have noted elsewhere is management for change. In the case of forests, for example, as Agee (2002) comments 'A major […] ecology principle in these areas is that the only constant is change.' The level of management intervention will vary in intensity according to the individual circumstances (Lleras, 1991).

This is not to suggest that occurrence in a protected area is not an important factor in species conservation. On the contrary, presence in a protected area, provided the area is adequately managed, will afford some degree of protection to the species housed within it, and by definition it obviates the need to seek and place an area under reserve for the target species concerned. Obviously, if the target species is dominant in its ecosystem, such as forests of *Cedrus* or *Abies* in Lebanon and Turkey, then the conservation of the habitat will effectively safeguard it and it will logically be included in the area's management plan. For species that are threatened or endangered, the removal or containment of the factors causing the threat means that some form of intervention is necessary so that a hands-off approach is not appropriate. But even if the wild populations of target CWR taxa selected for in situ conservation need little management, the processes involved in the assessment of their distribution, ecology, demography, reproductive biology, and genetic variation and in the selection of number and size of populations and sites to be conserved are still onerous.

It is obvious that in situ conservation cannot be the sole mode of conservation of CWRs: because of cost considerations or other land-use reasons it will simply not be feasible to turn the location of every population of wild plants into a protected area. As a consequence, in situ conservation will need to be complemented by ex situ conservation where appropriate and some sites will need to be managed with local stakeholders in a participative manner. For the large number of target species that occur outside protected areas, alternative approaches should be considered such as easements that afford some degree of protection to the target species through agreements with landowners to reduce the level of exploitation and to refrain from activities that would harm the target species or to contain threats to them. In addition, much greater attention should be paid in engaging local communities in protecting species in their natural habitats and in their sustainable utilisation. As Putz et al. (2000) note, 'Promoting more biodiversity-sensitive management of ecosystems outside protected areas, especially of those known to contain target species, needs to be given high priority'.

It should be noted that managed in situ conservation of CWRs is an expensive procedure and requires justification in terms of public funding. As Rubenstein et al. (2005) note, 'The same public goods problem that inhibits optimal international investment in ex situ conservation of genetic resources–the inability of conserving nations to capture all the benefits from that conservation–also hinders optimal investment in in situ conservation'. They note also that in situ conservation is subject to several additional constraints, such as the uncertainty surrounding the likely magnitudes of the benefits of in situ conservation, which is probably larger than it is for ex situ conservation. Also, the range of stakeholders and economic agents involved in any in situ conservation actions is likely to be considerably larger than for ex situ programmes, making it more difficult to coordinate all the different actions.

In situ conservation activities concerning CWRs in South-West Asia

A number of in situ species conservation projects have been undertaken in South-West Asia. The most extensive are the landmark studies known as the Ammiad Project on the in situ conservation of wild emmer wheat (*Triticum dicoccoides*) (Anikster et al., 1997; Safriel et al., 1997), which is considered to be the progenitor of most cultivated tetraploid and hexaploid wheats. The wild relative occurs in patches throughout much of the Fertile Crescent in the Middle East. In 1984 the Israeli Ministry of Science and Technology commissioned a multidisciplinary 5-year scientific project named 'Dynamic conservation of the wild wheat in Israel', which undertook a series of studies on the genetic diversity and conservation of a *Triticum dicoccoides* population at Ammiad, a mountainous rocky pastureland belonging to a farming settlement in Eastern Galilee. Although the site is very small (1 ha) it has been the subject of extensive studies and analysis of spatial and temporal population dynamics, phenotypic and genotypic variability, phenotypic plasticity, and sensitivity to pathogens.

In Armenia, the Erebuni Reserve, which is located not far from Yerevan City, Armenia, was established in 1981 specifically to protect wild relatives of grain crops. It covers some 89 ha on either side of the road from Yerevan to Garni and houses populations of *Triticum araraticum, T. boeoticum, T. urartu, Secale vavilovii*, and *Hordeum spontaneum* (Damania, 1994, 1998; Damania et al., 1998). Armenia is also a partner in the GEF-supported project "*In situ* conservation of crop wild relatives through enhanced information management and field application" mentioned above.

A wide range of crop wild relatives were selected as target species for in situ conservation in a major GEF/World Bank project on conservation of genetic diversity in Turkey (Firat & Tan, 1997; Kaya et al., 1997; Tan, 1998; Tan & Tan, 2002). The goal of the project was to develop in situ gene conservation programmes for target plant species selected from wild relatives of crop (*Triticum*, *Lens*, *Pisum*), fruit tree (*Castanea*), and globally important forest tree species (*Abies*, *Pinus*) in selected pilot sites. The project adopted the concept of 'Gene Management Zones' (GMZs)–natural and semi-natural areas that are set aside for maintaining genetic diversity of certain species and provide the necessary conditions for natural evolutionary processes to continue in a natural setting for the species of interest - which were originally developed in California in the 1960s. A key element of GMZs is local community participation, which preserves local people's access to the GMZ and enables them to practice traditional activities important to local livelihoods. The programme of GMZs was initiated in 1993 by the Turkish Ministries of Agriculture and Rural Affairs (MARA), Forestry (MOF), and Environment (MOE) as part of the above GEF-supported in situ conservation project. Ten GMZs were established in 2 pilot sites, at Kaz and Bolkar Mountains, with a total area of 24,374 ha for the target species *Pinus brutia*, *Pinus nigra* subsp. *caramanica*, *Cedrus libani*, *Abies equi-trojani*, *Juniperus excelsa*, and *Castanea sativa* (Kaya et al., 1997; Kaya & Raynal, 2000).

Turkey is apparently the first country to produce a National Plan for in situ conservation of genetic diversity (Kaya et al., 1997). It was developed by the Ministry of the Environment in collaboration with the Ministry of Agriculture and Rural Affairs and the Ministry of Forestry. It aims at the in situ conservation of selected (target) species of the wild relatives of herbaceous and woody plants and important forest trees so as to provide efficiency and continuity in conservation programmes in Turkey by establishing GMZs for target species throughout the country.

A GEF-supported project on 'In-Situ conservation of Kazakhstan's mountain agrobiodiversity' includes in situ conservation of crop wild relatives by strengthening management of protected areas and priority habitats within Kazakhstan's Tien Shan Mountains and is developing and applying new methods and tools for conservation, including partnerships among conservation and land-use agencies, local governments, local communities, and the private sector.

Another GEF project 'In Situ/On-Farm Conservation and Use of Agricultural Biodiversity (Horticultural Crops and Wild Fruit Species) in Central Asia' aims at the conservation and sustainable use of horticultural crops and wild fruit species genetic diversity in Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan. It will also develop and make available participatory management models that will contribute to the conservation of the genetic diversity of these species both within and outside the 5 target countries.

A UNDP/GEF 5-year project to promote in situ conservation and sustainable use of dryland agrobiodiversity in Jordan, Lebanon, the Palestinian Authority, and Syria was launched in 1999. The project aimed at promoting the conservation of wild relatives and landraces of important agricultural species in the Fertile Crescent (Near East region), by introducing and testing in situ and on-farm mechanisms and techniques to conserve and sustainably use agrobiodiversity. Selected sites in each of the participating countries were used for the in situ conservation of 16 target crops or crop groups of global significance and their wild relatives. The field crops included *Triticum*, *Hordeum*, *Lens*, *Vicia*, *Lathyrus*, *Medicago*, *Trifolium*, and *Allium* species. In addition, the project also planned to conserve wild and local varieties of *Olea* (olive), *Prunus* spp. (apricot, cherry, plum, almond), *Pyrus* (pear), *Pistacia* (pistachio), and *Ficus* (fig) that originated in the Near East (Ahmed Amri et al., 2002).

Examples of protected forest ecosystems dominated by target species but without any specific species-level management plans are the cedar (*Cedrus libani*) forests of Lebanon, which grow in the Mount Lebanon chain. They are protected by forestry law or are declared as nature reserves by the Ministry of Environment. Two of them (Al-shouf cedar and the Ehden nature reserves) have been included in a nationwide in situ conservation programme supported by the government of Lebanon with support from UNDP and GEF. It focused on the integration of biodiversity conservation and sustainable human development and was designed to safeguard endemic and endangered species of flora and fauna and to conserve their habitats (Sattout et al., 2007a). A recent study shows that that their successful management depends to some extent on religion, geographical location, and land ownership play (Sattout et al., 2007b).

The spatial distribution of some of the species of CWRs can pose serious problems for in situ conservation. This can be exemplified by in situ conservation projects for medicinal plants in St Catherine's Protectorate in Sinai, Egypt, where enclosures have been used to protect certain species, whose populations are small and consist of scattered widely separated individuals, from grazing animals. The longer-term sustainability of such micro-reserves is very much open to question although it is very difficult to suggest any effective alternative.

The challenges posed by global change

Prospects for the in situ conservation of CWRs may be adversely affected by global change–demographic, land-use, and climatic. The degradation, fragmentation, simplification, and loss of terrestrial and aquatic habitats, caused by demographic growth and population movements, changes in disturbance regimes, increasing urbanisation, industrialisation and the expansion and intensification of agriculture are likely to place many species of CWRs at risk. In addition, the likely consequences of climate change on the conservation of CWRs are a cause of major concern. Recent reports, such as the Stern Review on the Economics of Climate Change (Stern, 2007), the IPCC Reports (IPCC, 2007), and 'Confronting Climate Change: Avoiding the Unmanageable and Managing the Unavoidable' (SEG, 2007), together present a picture of large, serious, and damaging climatic impacts on our way of life and on biodiversity, in the short, medium, and long term. Recently published findings tend to add confirmation of this assessment. There is, however, considerable uncertainty in current projections due to gaps in our scientific knowledge, and lack of knowledge about the climatic patterns at the local scale and about the ways in which plants (and animals) will respond under new ecoclimatic regimes (Slater et al., 2007). Consequently it is not possible at present to predict their likely impacts on wild biodiversity and agricultural biodiversity with any degree of precision.

Despite these uncertainties, the effects of global change in South-West Asia are expected to be serious, although perhaps less so than in the adjacent Mediterranean region. Major changes in the composition and distribution of vegetation types of semi-arid areas–for example, grasslands, rangelands, and woodlands–are anticipated. In arid and semi-arid Asia (as defined by the IPCC), the major impact of climate change is likely to be an acute shortage of water resources associated with significant increases in surface air temperature and ould exacerbate threats to biodiversity resulting from land-use/cover change and population pressure (McCarthy et al., 2001).

In general terms, the risk is that the ecosystems/habitats/reserves in which CWRs occur may not survive under the changed conditions so that any species occurring within them will be at risk. 'New' ecosystems based on different groupings of species will emerge and many of the CWR species may be unable to survive in the new conditions or to migrate to more suitable ecoclimatic conditions.

A recent study of the ability of CWRs to survive in the new ecoclimatic envelopes that will develop in response to global change would indicate that many species of crop are likely to be seriously threatened, even with the most conservative estimates regarding the magnitude of climate change (Lane et al., 2006; Jarvis et al., 2007; Lane, 2007). Ecoclimatic/bioclimatic modelling is currently the subject of considerable research and debate (Martínez-Meyer, 2005; Heikkinen et al., 2006). For example, the approach has been severely criticised (e.g., by Pearson & Dawson, 2003) for not taking into account various factors other than climate, such as biotic interactions, evolutionary change, and dispersal abilities, that can affect significantly the distribution of species and the rate of changes to them. Once the limitations of the models have been resolved and if reliable and acceptable approaches can be developed more empirical data will need to be gathered and applied on a wide scale. This would enable us to obtain a reasonable picture of the likely effects of climate change on future species' distributions and ecosystem composition in particular areas such as South-West Asia.

Conclusions

• CWRs represent a valuable heritage in the countries of South-West Asia and concerted efforts are needed to keep this resource available for the benefit of local people and for the development of new cultivars adapted to the expected new socioeconomic and ecoclimatic conditions, thus benefitting people both within and outside the region

• It is recommended that national and regional inventories of CWRs in South-West Asia should be undertaken and their conservation status assessed.

• Lists of priority species for conservation and sustainable use should be drawn up and appropriate conservation actions, both in situ and ex situ, put in hand.

• Although important work has been carried out on in situ approaches to the conservation of CWRs in several countries in the region, much greater effort is needed both within and outside protected areas.

• Ideally, a national strategy for CWR conservation should be developed in each country and published or incorporated into the National Biodiversity Action Plan.

• Urgent consideration should be given to developing a South-West Asian regional strategy and action plan along the lines of the European PGR Forum.

• The likely consequences of global change should be factored into CWR conservation strategies. This is likely to increase the demand for breeding new cultivars both for use within and outside the region and this underscores the importance of conserving CWRs both in situ and ex situ so that the genetic variability that might be used for such breeding continues to be available.

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