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In situ conservation of crop wild relatives: status and trends

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Abstract. Recognized as a priority three decades ago, *in situ* conservation of crop wild relatives has developed theoretical and methodological focus and achieved significant on-the-ground progress in the last 10 years, most notably under the impetus of the plant genetic resources community. Literature and Internet searches and interviews with experts were undertaken as a basis for reviewing the current status and trends of this effort worldwide. Country-by-country summaries on *in situ* crop wild relatives conservation activities are presented, and recommendations are made for future action. Principal recommendations include 'flagging' of appropriate taxa as crop wild relatives in botanical and conservation databases, undertaking gap analyses to locate crop wild relatives hotspots, and enhancing cooperation between the plant genetic resources and plant conservation communities.

Introduction

Agricultural scientists identified crop wild relatives (CWRs) as a target group for conservation over 30 years ago. Accelerating rates of species extinctions were identified at that time as threats to the genetic base of world agriculture, and effort and resources were expended during the following decades to collect CWRs and maintain them in *ex situ* (off-site) conservation programs. By the late 1980s, after what was deemed to be unsatisfactory progress in conserving CWRs in this way, the agricultural community began turning toward integrated or complementary conservation[1] as a better way to preserve CWRs, with more emphasis placed on *in situ* (on-site) conservation.

By the mid-1990s this strategic reorientation had generated a wave of treaties, position statements, scientific publications, and on-the-ground projects addressing *in situ* CWR conservation. A second wave of international and national projects is now coming on line and several major initiatives are being planned. In this article we

[1] The agricultural conservation community employs the term 'complementary conservation' in much the same sense as the wild plant conservation community uses the term 'integrated plant conservation' (Maxted et al. 1997).

summarize accomplishments of *in situ* CWR conservation during the last decade, present the status and trends of this effort, and make recommendations for future action.

Methods

The activities summarized in Table 1, the discussion that ensues and the recommendations and conclusions presented follow a review of information obtained from the web, literature searches and communications with CWR experts, project leaders and data managers during April–July 2001 while the senior author served as a CWR project consultant to the International Plant Genetic Resources Institute (IPGRI) in Rome[2]. IPGRI staff, delegates of the countries involved in the CWR project and representatives of the collaborating international organizations provided information and guidance. This input led to other experts who supplied additional information on past, ongoing and planned CWR projects.

Why are CWRs important?

Vavilov recognized the potential of CWRs for crop improvement in the 1920s and 1930s and included them in his plant genetic resource (PGR) collecting programs (Loskutov 1999, pp. 55–81). Agricultural researchers began using CWRs in the 1940s and 1950s to improve major crops (Plucknett et al. 1987; Hodgkin et al. 1992). By the 1960s and 1970s, breeding successes involving CWRs had accelerated (Harlan 1976, 1984; Hawkes 1977; Prescott-Allen and Prescott-Allen 1981; Hoyt 1988), especially using species within the primary gene pools of crops (Harlan and de Wet 1971). It also became recognized that CWRs were instrumental in the productivity and stability of traditional agro-ecosystems through natural genetic exchange between landraces and their wild, weedy relatives (Harlan 1965).

By the 1980s and 1990s application of genetic engineering to crop improvement allowed genes from distantly related and even non-related taxa to be incorporated into crops, thereby broadening the value of CWRs by expanding their usefulness into secondary and tertiary crop gene pools.

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[2] This article is a shortened version of a report prepared for IPGRI in Rome. IPGRI received a PDF B grant from the United Nations Environment Program, using Global Environment Facility funds, to coordinate a multi-country effort to develop a global project titled '*In situ* conservation of crop wild relatives through enhanced information management and field application' in collaboration with national executing agencies from Armenia, Bolivia, Madagascar, Sri Lanka, and Uzbekistan and five international agencies (BGCI, DIVERSITAS, FAO, IUCN, and UNEP-WCMC). One of the project's elements was to review and analyze the current status of *in situ* CWR conservation activities throughout the world and the senior author was retained by IPGRI as a consultant to undertake this task. In October 2002 the Global Environmental Facility approved a full project on crop wild relatives that is expected to start during 2003.

Table 1. Instances of purposeful activity involving *in situ* conservation of crop wild relatives (CWRs), by country.

Country	Taxa/project focus	Reference	Location/comments	Activity
Armenia	CWRs	Armenia web site	Nationwide inventory	1
	Wheat CWRs	Damania (1996)	Erebuni Nature Reserve NE of Yerevan	4
	CWRs	Ghandilyan et al. (1999)	A list of some CWRs in Armenia, with historical notes	1
	CWRs	www.unep.org/gef/resources/resources.htm	Nationwide GEF project	1,3,5,6
Australia	Selected taxa	CSIRO web site	Under consideration for *in situ* conservation	6-planning?
	Melaleuca, *Vitis* CWRs, *Potamophila parviflora* (rice CWR)	N. Rice, pers. comm.	Ecogeographic assessments	2
Azerbaijan	*Beta lomatogona* (beet CWR)	Frese et al. (1999)	Site in Talish Mountains recommended by research team for protection	2,3
Bolivia	CWRs in PAs	K. Williams, pers. comm.	Bolivian National Parks, herbaria, and other relevant dbases surveyed for eventual *in situ* conservation management in PAs and site selection	1,2,3
	Potato CWRs (*Solanum* spp.)	Hijmans et al. (2000)	Evaluating geographic representation of genebank collections of wild potatoes	1,2
	CWRs	www.unep.org/gef/resources/resources.htm	Nationwide GEF project	1,3,5,6
Bulgaria	*Trifolium, Medicago, Vicia, Onobrychis, Lolium, Dactylis, Bromus, Festuca, Poa, Agrostis* CWRs	Keova et al. (1998)	Site selection for CWRs of forage taxa for possible protection; creation of an associated dbase; continued research	1,2,3,5?
China	115 CWRs	He et al. (2000)	Inventoried for site recommendation and management plans (Sichuan)	1,2,3
Costa Rica	*Phaseolus lunatus*	Degreef and Baudoin (1996)	Demographic/phenologic studies for potential *in situ* conservation	2
Ecuador	*Caryodaphnopsis (Persea) theobromifolia*	Hoyt (1988)	'A relict forest protected . . . '	4?
Egypt	*In situ* CWR conservation best practice	V. Heywood, pers. comm.	PDF-B proposal submitted	6-being planned
Ethiopia	Coffee CWRs	Hoyt (1988)	Protected in special conservation areas since 1984	4?
	Coffee CWRs	Dulloo et al. (1998)	Six sites identified for *in situ* conservation	2,3
	C. arabica CWRs	Gole et al. (unpublished)	Countrywide inventory of *C. arabica* genetic diversity; three sites proposed in 1998 by Demel et al. – no action taken due to financial constraints	1,2,3
	C. arabica	IBPGR (1985)	Calls for *in situ* conservation of *C. arabica* in SW Ethiopia	3
Europe	CWRs (primary gene pool)	Heywood and Zohary (1995)	Catalogue for Europe (based on *Flora Europaea*)	1
	Survey of CWRs in PAs	Hoyt (1988)	IBPGR Eur. Cooperative Program	1,2
	Wide-ranging actions on CWRs (European forum)	B. Laliberté, pers. comm.	EU countries (funded by EU in 2002)	2,3,4,6
Germany	CWRs	Hammer and Schlosser (1995)	Countrywide list within larger inventory of PGRs; inventory of CWRs in E. German PAs (1983–86)	1

Table 1. (*Continued*)

Country	Taxa/Project focus	Reference	Location/Comments	Activity
Guatemala	Teosinte CWRs	Wilkes (1993)	Village level conservation in conjunction with ICTA-Guatemalan government agency	4?
	CWRs	K. Williams, pers. comm.	Survey of Guatemalan NPs in planning stage for eventual *in situ* conservation management	6-being planned
Hungary	*Populus nigra*	Cagelli and Lefèvre (1997)	8 stands (about 60 ha) protected on private land	4?
India	*Myristica*, rice, corn, wheat, *Citrus* CWRs	Gadgil et al. (1996) & WWF web page	Malabar, E. & W. Ghats, Dandali, Tura range, etc.; Andaman Isls. sites protected and proposed	1,2,3,4
	Citrus	Hoyt (1988)	Garo Hills	4?
	Citrus indica	Hodgkin and Arora (1999)	Garo Hills sanctuary established in 1981, now an Indian Min. of Environment Biosphere Reserve	4
	Banana, sugar cane, rice and mango CWRs	Hoyt (1988)	Reserves being planned	6-planning?
	CWRs	Arora and Nayar (1984)	Countrywide survey	1
	CWRs of rice, wheat, maize, millet, oil-seed, spices, legumes	Sharma (1998) Financial Express article	Biodiversity Conservation Prioritisation Project of WWF calls for *in situ* conservation of CWRs (no locations or site names)	1,2,3
Iran	*Beta lomatogona* (beet CWR)	Frese et al. (1999)	Site in the Talish Mountains recommended by research team for conservation	2,3
	Vicia CWRs	Maxted (1995)	Suggests genetic reserves	1,2,3
Iraq	*Vicia* CWRs	Maxted (1995)	Suggests genetic reserves	1,2,3
Ireland	*Brassica* CWRs	IGRCT web site	Countrywide survey	1
Israel	Cereal/pulse CWRs	Anikster and Noy-Meir (1991)	Inventories, research at Ammiad	1,2,3
	Vicia CWRs	Maxted (1995)	Suggests genetic reserves	3
Italy	CWRs	Hammer et al. (2000)	Countrywide inventories of CWRs and of selected Mediterranean Islands	1
	CWR occurrences in Ital. PAs	Mazzola et al. (1997)	Compared to Heywood and Zohary (1995)	1,2
Japan	*Vigna angularis* population genetic survey	Xu et al. (2000)	Population genetic survey for possible reserve recommendations (research only)	2
Jordan	16 target groups of cultivated taxa and their CWRs	ICARDA web site	GEF/UNDP project in Jordan, Lebanon, Palestinian Authority and Syria to promote and undertake *in situ* conservation of target crops and their CWRs	1,2,3,6-training
	In situ CWR conservation best practice	V. Heywood, pers. comm.	PDF-B proposal submitted	6-being planned
Lebanon	CWRs	ICARDA GEF project	(see Jordan)	1,2,3,6-training
	In situ CWR conservation best practice	V. Heywood, pers. comm.	PDF-B proposal submitted	6
	Vicia CWRs	Maxted (1995)	Suggests genetic reserves	1,2,3
Lithuania	CWRs of *Corylus*, *Fragaria*, *Origanum*, *Thymus*, *Vaccinium*, *Mentha*, *Trifolium*, etc.	Labokas (1998)	Used for selecting 24 PGR conservation sites *in situ* (wants to create associated dbase)	1,3,5?
Madagascar	CWRs	FAO (1996b)	Have started a CWR list	1
	CWRs	www.unep.org/gef/resources/resources.htm	Nationwide GEF project	1,3,5,6
Mauritius	*Coffea* spp.	Dulloo et al. (1998)	CMAs exist to protect some Mascarene rare plants, but not specifically for *Coffea*; ecogeographic surveys of *Coffea* CWRs done; recommends reserves	1,2,3
Mexico	Teosinte (*Zea* spp.) *Phaseolus coccineus* and *Ph. vulgaris*	Benz (1988), Debouck (2000)	Sierra de Manantlan in Jalisco; a MAB reserve established to protect teosinte; includes a CIMMYT monitoring plan	2,3,4

Table 1. (*Continued*)

Country	Taxa/Project focus	Reference	Location/Comments	Activity
Morocco	*In situ* CWR conservation best practice	V. Heywood, pers. comm.	PDF-B proposal submitted	6-being planned
Nepal	*Oryza rufipogon*	Vaughan and Chang (1992)	Ajigara, Bahadurganj in the Terai recommended sites (no action yet per Shrestha)	2,3
	Fagopyrum CWRs	R. Rao, pers. comm.	Sites recommended for conservation by Japanese–Nepalese research team (no action yet taken)	2,3
Nicaragua	Teosinte	K. Williams, pers. comm.	USDA-funded project to protect teosinte populations from overgrazing	6
Palestinian Authority	CWRs	ICARDA GEF project	(see Jordan)	1,2,3,6-training
Paraguay	CWRs of 22 crop genera	Garvey (1998); K. Williams, pers. comm.	CWR survey of herbaria records, etc. to determine locations and then conservation actions in PAs + recommend new sites for conservation; ARS/Paraguay project (1998–2001)	1,2,3
Slovak Republic	*Trifolium*, *Poa*, *Phaseolus*, *Festuca*, *Dactylis*, etc. CWRs	Hauptvogel (1998)	CWRs inventoried as targets for possible revised PA management	1
Former Soviet Union	Wheat and fruit tree CWRs	Hoyt (1988)	'... high in the Caucasus Mountains ... between the Black Sea and the Caspian Sea ... a reserve' exists	4?
	Wild apples, peaches, and pistachios	Tuxill and Nabhan (1998)	Protected stands in the Caucasus Mountains (set aside in the 1950s)	4?
	CWRs of walnuts, apples, pears, prunes	Hoyt (1988)	Sary-Chelek Reserve (part of Chatkal Mts. Bios. Res. in Kirgiz SSR) preserves CWRs	4?
	CWRs of pistachio, apricot, almond, and fodder grasses	Hoyt (1988)	Kopet Mts. just north of the Iranian border	4?
	CWRs	Lunyova and Ulyanova (1997)	Vavilov Institute compiled a list of CWRs for Central Asia in 1981 in the Flora of the former Soviet Union (by Brezhnev and Korovina 1981)	1
	Fodder grasses, apricot, pistachio, almond CWRs	Prescott-Allen and Prescott-Allen (1981)	In the Kopet-Dag Mountains of Turkmen SSR	4?
	Wheat and fruit tree CWRs	Prescott-Allen and Prescott-Allen (1981)	In the Caucasus Mountains (cites Brezhnev 1975)	4?
Sri Lanka	CWRs	FAO (1996c)	CWR inventory part of national PGR program; assessment of 1 PA for *in situ* CWR conservation	1,3
	Oryza, *Solanum* and *Hibiscus* spp.	M. Jayasuriya, pers. comm.	Inventory PAs and attempt to sensitize PA managers to presence of CWRs, info added to PGR dbase (but no fields specifically for CWRs); overlap with Red List taxa unknown	1,3
	CWRs	www.unep.org/gef/resources/resources.htm	Nationwide GEF project	1,3,5,6
Syria	Wheat CWRs	Damania (1996)	Sweida Province (reserve proposed)	3
	Vicia CWRs	Maxted (1995, 1997, 2000)	Ain Dinar, Al Hasakah; Kessab town, Kessab; Qal'at Al Hosn, Homs; Mimas, Djebel Druze proposed as reserves	1,2,3
	CWRs	ICARDA GEF project	(see Jordan)	1,2,3,6-training

Table 1. (*Continued*)

Country	Taxa/Project focus	Reference	Location/Comments	Activity
Turkey	Cereal, pulse CWRs	Maxted (2000)	Kaz Dag, Ceylanpinar Amanos, Mersin GMZs proposed	1,2,3
	Multiple cereal, pulse and tree CWRs	Anonymous (2000)	22 sites, called Genetic Management Zones (GMZs), selected and proposed for protection	1,2,3
	Wheat, barley, chickpea, lentil, chestnut, plum CWRs	Tan (1998)	Sites selected for protection (GMZs) throughout Turkey on existing state-owned lands: 1. Kaz Dag Area of Northwestern Aegean Region; 2. Ceylanpinar of SE Turkey; 3. Mts. at S. Anatolia on the S. part of Anatolian Diagonal	1,2,3
	National Plan for *in situ* conservation of plant genetic diversity (including CWRs); inventory of CWRs	Kaya et al. (1998)	Completed in 1997	1,6-national plan
	Database management system for PGR conservation in Turkey (includes specific fields for *in situ* conservation of CWRs)	Tan and Tan (1998); A. Tan, pers. comm.	National system up and running; includes GIS capability	5
	Vicia spp.	Maxted and Kell (1998)	Describes ecogeographic methodology as applied in Turkey to *Vicia*; recommends sites for protection	1,2,3
	National *in situ* CWR conservation program	A. Tan, pers. comm.	22 GMZs officially accepted; conservation and research programs up and running	1,2,3,4,5
	In situ CWR conservation best practice	V. Heywood, pers. comm.	PDF-B proposal submitted	6-being planned
UK	CWR survey within national PGR survey	Franks (1999)	Countrywide	1
USA	*Vitis rupestris*	Pavek et al. (2000)	7 sites in Wichita Mountains Nat'l. Wildlife Refuge, Ouachita Nat'l. Forest, OK and Clifty Creek Natural Area, MO proposed (4 agreements with PAs established)	2,3,4
	Allium columbianum, *A. geyeri*, *A. fibrillum* CWRs	Becker et al. (1998); ARS News & Information (research by B. Hellier)	Umatilla Nat'l. Forest and Turnbull Nat'l. Wildlife Refuge, WA (no formal *in situ* actions; research continuing)	2,3
	Lathyrus grimsii	Pavek and Garvey (1999) (research by Hannan & Hellier)	Humbolt Nat'l. Forest, NV; (no formal *in situ* actions taken; research underway)	2,3
	Solanum fendleri and *S. jamesii* (potato CWRs)	Becker et al. (1998) (research by Bamberg)	SW US & Texas (no formal *in situ* actions taken; locations well documented and shared with PA managers; info. brochure)	2,3
	Carya spp. (Pecan) CWRs	Pavek and Garvey (1999) (research by Grauke)	Research underway	2
	Capsicum spp. + 23 other CWRs	Tewksbury et al. (1999); Nabhan (1990)	Coronado NF, Tumacacori, AZ 2000 acre site and management plan accepted	1,2,3,4
	National guidelines for *in situ* CWR conservation	Pavek and Garvey (1999) (+*In situ* Subcommittee)	Produced for National Plant Germplasm System (NPGS)	6-Training manual
Uzbekistan	CWRs	www.unep.org/gef/resources/resources.htm	Nationwide GEF project	1,3,5,6
Vietnam	*In situ* CWR conservation project	S. Krugman, pers. comm.	Being planned	6-being planned

Activities: (1) inventory, (2) research, (3) site selection and/or management recommendations, (4) protected area (PA) creation and/or management plan creation/revision, (5) information management, (6) planning and training.

Why *in situ* conservation of CWRs?

The merits of *in situ* and *ex situ* conservation of CWRs have been much debated (Prescott-Allen and Prescott-Allen 1981, 1988; Marshall 1989; Hawkes 1991; Schoen and Brown 1995). Perhaps because *ex situ* conservation developed as the preferred approach to safeguarding crop genetic resources during the 1970s and 1980s when *in situ* conservation of landraces in particular was thought to be impractical, the agricultural community did not begin to embrace *in situ* CWR conservation until the 1990s, despite the fact that influential crop scientists like Frankel (1970) and Jain (1975) had called for its use earlier.

Contributing to this shift was an appreciation that *ex situ* conservation was not succeeding as expected in safeguarding acceptable levels of CWR diversity (Hoyt 1988, p. 26; Davies 1991, pp. 64–65; FAO 1996a). Foremost among the reasons for this are the difficulties and often high costs of capturing, preserving and utilizing genetic variation in CWRs that possess one or more of the following characteristics: dispersed, sometimes small, genetically distinct populations with poorly known genomes, low seed production and/or viability, high maintenance demands of clonal collections, problems in regenerating stored material, and seed recalcitrancy, this latter trait sometimes making conventional storage impractical (Berjak and Pammenter 1997). Natural genetic introgression between crops and their CWRs also stimulated interest in *in situ* conservation (Harlan 1992), as did the nearly cost-free value of the evolutionary processes that generate diversity and much of the breeding value of CWRs. In weighing these points along with what was known about seed viability loss and genetic drift within *ex situ* collections (Hamilton 1994), one can see why *in situ* conservation has today joined *ex situ* conservation as a key element of the integrated tool kit most agricultural scientists feel is needed to conserve CWRs[3].

A brief history of *in situ* CWR conservation

Until the 1970s, CWRs were rarely targeted for conservation by agricultural scientists, perhaps in part because it was felt that CWRs were safe within natural ecosystems (Frankel and Soulé 1987, p. 226) or perhaps also because breeders were still drawing mostly from reservoirs of largely unstudied landraces, easier to use than CWRs in improving crop lines through classical breeding methods (Cubero 1997). However, by the mid-1970s, as awareness of habitat and species declines emerged, agricultural scientists realized that CWRs were no safer than other wild plants in natural settings.

Calls to conserve CWRs intensified during the 1970s and 1980s as the breeding

[3] Both *in situ* and *ex situ* CWR conservation have strengths and weaknesses that can be assessed in terms of time, effort, cost-effectiveness, efficiency, political appropriateness, etc. Good discussions of the types, merits and recommended applications of both are found in Maxted et al. (1997, pp. 24–36) and Prescott-Allen and Prescott-Allen (1981, pp. 11+).

value of CWRs was revealed. Some agricultural researchers such as Frankel (1970) and Jain (1975) included *in situ* CWR conservation in their appeals. Leading international agricultural and conservation organizations began dedicating time and resources to studying the merits of *in situ* CWR conservation (IUCN 1980; IBPGR 1985), and the complementarity of *ex situ* and *in situ* approaches became accepted by a majority of agricultural scientists (Shands 1991). At the same time, CWRs that were rare species or elements of threatened ecosystems became targets of biodiversity conservation programs. However, many of these latter efforts remained unknown to agricultural scientists, despite recognition of the need for cross-sectoral cooperation in CWR conservation (Jain 1975; Prescott-Allen and Prescott-Allen 1981, p. 28).

Scientific publications and meetings dealing with *in situ* CWR conservation increased during the 1980s and 1990s. Development and worldwide endorsement of the Convention on Biological Diversity (CBD) in 1992 and the FAO Global Plan of Action for Plant Genetic Resources in 1996 moved *in situ* CWR conservation into the mainstream of international and national conservation concerns. By signing the CBD and the FAO International Undertaking on Plant Genetic Resources (to be replaced by the International Treaty on Plant Genetic Resources), many countries have now adopted *in situ* CWR conservation as a national priority. Books (Gadgil et al. 1996; Maxted et al. 1997; Zencirci et al. 1998) and national guidelines (Pavek and Garvey 1999) on *in situ* CWR conservation theory and method have appeared, and field projects are underway or being planned. Table 1 presents a worldwide summary of purposeful *in situ* CWR conservation activity, country-by-country, most of which has occurred in the last 10 years.

Six types of activity are recognized here: (1) inventory, (2) research, (3) site selection and/or management recommendations, (4) protected area (PA)[4] creation and/or management plan creation/revision, (5) information management, and (6) planning and training.

Table 1 does not include every *in situ* conservation project in the world seemingly involved in conserving CWRs. For instance, an issue yet to be resolved is the question of what precisely constitutes a crop wild relative[5]. While a core CWR concept roughly glosses to ‘a wild congener or closely related species of a domesticated plant’, the literature and CWR projects have been biased toward wild food crop relatives. Ambiguity remains on the status as ‘crops’ of many forestry, forage, medicinal and ornamental species, especially those recently domesticated or potentially ‘domesticable’, and thus of the status of their wild relatives as CWRs. For these reasons, medicinal, forage, or forestry plant conservation projects that are called something other than CWR projects were mostly excluded from Table 1. An attempt to capture some of this information was made by Thormann et al. (1999),

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[4] The term ‘protected area’ (PA) is used in its broadest sense as ‘‘ . . . a geographically defined area managed through legal or other effective means to protect and maintain biological diversity and natural and associated cultural resources’’ (McNeely 1995, p. 28).

[5] For the purposes of the GEF-supported project, CWRs were defined as ‘‘the progenitors of crops as well as species more or less closely related to them.’’

who reviewed internationally available sources of information relevant to CWR conservation.

Many countries possess PAs containing CWRs that are not identified or managed as CWRs (e.g., Debouck 2000). Similarly, many crop and wild plant databases contain CWR taxa that are not flagged as CWRs. Because we do not consider this activity or information to be purposeful conservation directed specifically toward CWRs, none of these countries, PAs or databases is cited in Table 1.

Discussion: status and trends

Discussion follows on the status and trends within the six recognized *in situ* CWR conservation activities as they occur around the world, drawing examples from Table 1.

Inventory

Inventory is the starting point for *in situ* CWR conservation (Gadgil et al. 1996, p. 5) and it is occurring at international, national, and local levels. Internationally, IPGRI established lists of genera for priority ecogeographic surveys and *in situ* conservation (IBPGR 1985), and a CWR inventory has been compiled for Europe (Heywood and Zohary 1995). International lists motivate country interest and action, stimulate national listing of CWR species, and induce comparisons with existing country or PA inventories (e.g., Italy; Mazzola et al. 1997). However, countries will always want to establish their own CWR lists of taxa that are most relevant to their own crops, floras, and national capacities and priorities. In this regard, Hodgkin (1997) noted that not all CWRs can or should be conserved *in situ*. Many are common species whose populations are not particularly threatened and some are even problematic weeds. He stressed priority setting as a key element of the inventory process.

Several countries have established national CWR lists, usually within their PGR conservation initiatives. The former Soviet Union may have been first to develop a national CWR list (Brezhnev and Korovina 1981), and the former Soviet republics of Armenia and Uzbekistan have maintained and updated these lists. Turkey recently completed a national CWR list. Researchers in Germany (Hammer and Schlosser 1995) and Italy (Hammer et al. 2000) are active in this area.

Other lists have narrower geographic or taxonomic purviews. Some have focused on CWRs within PAs, as Prescott-Allen and Prescott-Allen (1981, p. 22) promoted 20 years ago, others focus on one, or a few CWRs within some other defined geographical area. For example, in collaboration with national and international institutions, the USDA Agricultural Research Service is helping to establish lists and atlases of CWRs in PAs in several South and Central American countries, most notably in Paraguay, Bolivia and Guatemala (K. Williams, personal communication). Sri Lanka has created a list of wild *Oryza* (rice) species in its PAs in order to sensitize their managers to CWR conservation needs (M. Jayasuriya, personal communication).

Academics have inventoried CWRs for their research projects, many of which have conservation overtones. Vaughan and Chang (1992) created a list of *Oryza* (rice) CWRs to survey their presence in southeast Asian PAs, while J. Bamberg of the USDA (personal communication) developed a list of potato CWRs (*Solanum* spp.) for PAs in the southwestern USA. Maxted's list of *Vicia* CWRs (1995) served as a basis for surveying their locations throughout their natural Mediterranean range.

Research

Research has taken many forms involving several disciplines: CWR mapping (Bolivia, Guatemala, Paraguay, USA); ecogeographic surveys (Costa Rica, Ethiopia, Israel, Mauritius, Turkey, USA); CWR policy study (UK); traditional indigenous and peasant ethnobiological investigations (Guatemala, Mexico, USA); CWR monitoring (Israel, Mexico), etc[6].

Ecogeographic surveys are recognized as basic planning tools for *in situ* CWR conservation (Hodgkin and Guarino 1997; Maxted et al. 1997). IPGRI (IBPGR 1985) defines them as the study of the ''distributions of particular species in particular regions and ecosystems; patterns of infra-specific diversity; and relationships between survival and frequency of variation and associated ecological conditions''. During the last 10 years their scope has varied from multi-disciplinary studies of many CWRs of many crops mobilizing major research assets in single countries (Turkey) to narrower studies of one or a few CWRs of a single crop in specific countries or regions (e.g., *Vigna* [azuki bean] in Japan; *Oryza* in Sri Lanka; *Phaseolus* in Costa Rica; *Coffea* in Ethiopia and Mauritius; *Allium*, *Solanum*, and *Vitis* in US PAs). Many ecogeographic projects involving CWRs have been designed to provide basic data for PA site selection and *in situ* CWR management. They thus seem to be fulfilling the role defined for them of guiding a range of *in situ* CWR conservation-related decisions.

Databases are being mined for CWR inventories and mapping projects (Thormann et al. 1999; Guarino et al. 2001). The USDA/Paraguay project is researching herbarium and museum records and other species inventories to determine geographical locations of CWRs in Paraguay and especially in its PAs (K. Williams, personal communication; see also Italy, Mazzola et al. 1997). The objective is to use the data to create or revise management plans within existing PAs but also to recommend sites for new PAs in areas identified as CWR 'hotspots'. Similar work is underway in Bolivia and other South American countries involving potato (*Solanum* spp.) and peanut (*Arachis* spp.) CWRs (L. Guarino, personal communication).

[6] Only examples of research specifically linked to *in situ* CWR conservation are cited. Many CWR taxa have been studied for other reasons, e.g., taxonomic, ecologic, genetic, rare plant conservation, etc. These types of research activities were not reviewed.

Site selection and/or management recommendations

Many sites have been selected around the world for *in situ* CWR conservation in the last 10 years, in almost every case following some form of ecogeographic research. Several CWR projects, like those in Sichuan, China (He et al. 2000) and Paraguay, Guatemala, and Bolivia (K. Williams, personal communication) are still formulating recommendations. CWR management in existing PAs has been investigated in the USA in particular, leading to recommendations for creating or revising PA management plans, including increased monitoring (Pavek and Garvey 1999).

Nevertheless, site selection and related research appear to be under-represented in major regions such as sub-Saharan Africa (outside Ethiopia) and southern South America, Australia, Canada and Japan. Many of the European countries have not yet developed well-defined *in situ* CWR conservation programs but this should begin to be addressed by a ''European crop wild relative diversity assessment and conservation forum'' (B. Laliberté, personal communication) that was funded in 2002 by the European Union. Ingram and Williams (1993, pp. 144+) have shown that if *in situ* CWR conservation efforts are restricted to existing PAs, many world areas rich in CWRs will likely be left uncovered. While many of the regions chosen thus far for research and site selection seem to correspond with centers of domestication, ancient crop diversity or speciation of CWR genera (Armenia, Mexico, Syria, Turkey, Uzbekistan, etc.), others seem to have been left largely unexplored (McNeely 1995).

The size and scope of recommended genetic reserves vary, as do their rates of official acceptance as PAs. Smaller reserves have been proposed to conserve one or a few CWRs within a single genus, while larger ones have been recommended to preserve many CWR genera and species (e.g., Turkey; Anonymous 2000). Most of the sites recommended were selected because of declining CWR diversity or because they harbored concentrations of CWRs that were deemed to merit protection before substantial losses had occurred.

After seven years of study in Turkey, beginning in 1993, 22 Genetic Management Zones (GMZs) have been accepted for official protection (A. Tan, personal communication). Elsewhere, USDA researchers have proposed expanded management attention for *Vitis* (grape), *Allium* (onion), and *Solanum* (potato) CWRs in existing US PAs, with some success. In India, *Citrus indica* has been specifically protected in a Ministry of the Environment Biosphere Reserve. Sites recommended for *in situ* CWR conservation of *Beta* (beet) in Azerbaijan and Iran (Frese et al. 1999), *Coffea* (coffee) in Ethiopia (Gole et al., unpublished), *Oryza* (rice) and *Fagopyrum* (buckwheat) in Nepal (V. Rao and G. Shrestha, personal communication) and *Vicia* in Syria have not as yet seen official action.

Thus, while some recommended sites have achieved protected status in the last decade or have expanded their monitoring and/or management of CWRs, many more recommended sites remain unprotected or unmanaged. Therefore, regardless of how carefully sites are selected, this process alone does not guarantee official action, at least in the near term. Perhaps more time is required for administrative procedures to work themselves through once recommendations are made. But a more likely reason for some of these unfavorable outcomes appears to be weak links between the 'site-selection and/or management-recommendation' processes and the 'official-protected-site and/or management-change-designation' processes. In many cases cited in Table 1, it was not clear to whom the recommendations were made or who ultimately was expected to act on them.

Protected Area (PA) creation and/or management plan creation/revision

Following inventory, ecogeographic research, and site selection and recommendation to create or revise management of a PA, genetic reserve designation and professional management constitute the next steps in many ideal *in situ* CWR conservation scenarios. Official successes have occurred in India, Mexico, Turkey and the USA involving both natural areas and areas with long histories of human management and use.

Most agrobiodiversity conservation projects assume ideally that official protection will benefit CWR preservation (McNeely 1995), but many also recognize that unmanaged or poorly managed PAs are less likely to achieve conservation objectives (Prescott-Allen and Prescott-Allen 1981, pp. 14+). For example, while passive management may be sufficient for many species, for other species more targeted management will be required. For these and related reasons, *in situ* CWR reserve design, placement and management issues have been addressed in recent publications (Hawkes et al. 1997; Maxted et al. 1997; Williams 1997; Maxted 2000).

Outside those successes cited, Table 1 shows that few other CWR reserves have been created and/or CWR management plans created or revised in the last decade. While this is likely due in general to the political and administrative complexities of creating new PAs, the process can also be exacerbated in countries where *in situ* CWR conservation policy has not yet been developed. Management plans prepared to address other conservation objectives can also be slow in changing (Ingram and Williams 1993, p. 143). The Ammiad, Israel site (Safriel et al. 1997, p. 234) usefully illustrates how difficult it can be to protect CWRs officially *in situ*. While much research went into studying this well-known site, and a consensus was reached on the need for its conservation and the creation of a site management plan, for well over 10 years Ammiad has not been managed for CWR conservation nor has it been recommended for or received official protection. Ammiad's continued existence as a CWR study site and reserve appears to depend mostly on the cooperation of the neighboring landowner community.

This introduces the issue of the conservation effectiveness of officially designated PAs in relation to the support, good will, and use of their resources by local human populations. A significant research effort, much of it within the field of ethnobiology, has investigated why legal status alone can be insufficient to assure resource protection within PAs (e.g., Lynch and Alcorn 1994). Several writers have documented indigenous or peasant successes in maintaining and even enhancing biodiversity through application of traditional management principles and practices (Posey 1984; Altieri and Merrick 1987; Oldfield and Alcorn 1987; Meilleur 1994), and a consensus exists that indigenous and peasant peoples must be included in reserve creation when traditional resources or homelands are involved. This awareness is increasingly influencing the policies and actions of both the PGR and the biodiversity conservation communities (McNeely 1995), thanks also to its emphasis within the CBD. Heywood (1999, p. 4) describes this attitude change toward traditional knowledge systems and practices as a ''major conceptual breakthrough'' in the way agrobiodiversity is perceived and protected.

Gary Nabhan and colleagues furnish a good example of indigenous group involvement in a successful PA designation process. Their description of the Tumacacori wild *Capsicum* (chile) reserve in the US Coronado National Forest (Nabhan 1990; Tuxill and Nabhan 1998) reveals a multi-disciplinary, collaborative approach in creating a new PA on government lands. However, other models should be considered for *in situ* CWR conservation where PA creation is less likely. Like for Tumacacori, most of these will draw on cultural research and local human involvement for their success. For instance, small sacred sites with natural vegetation are found in many south Asian countries, and it is common for their plants and animals to have been managed sustainably through indigenous cultural prescription for hundreds of years (Damania 1996, p. 13). Inventorying these sites for CWRs and then managing them within some sort of an informal network also constitutes a potentially viable approach to CWR conservation (Gadgil et al. 1996, pp. 19–20). As this and the chile example illustrate, successful *in situ* CWR conservation will usually be as much a matter of culture as of biology.

Situations where CWRs are weedy elements of agricultural fields or other disturbed areas represent particularly difficult conservation challenges (McNeely 1995, pp. 39–40), and classical PA approaches may be unsuitable. Jain (1975), for example, has stressed that none of the progenitors of major food crops occur as climax vegetation, thus increasing the need to identify conservation solutions for disturbed ecosystems. In this regard, Allem (1997) describes the value of roadsides as potential *in situ* conservation sites, and Debouck (2000, p. 30) concludes that roadsides would present a ''great opportunity for preserving wild relatives in Latin America''. Brush (1991, 1995, 2000) has produced several publications on on-farm conservation of agricultural biodiversity in long-established agroecosystems, mostly addressing *in situ* conservation of farmers' varieties, but he also recognizes the critical value of CWRs in maintaining traditional field system integrity and therefore the need for combining conservation of CWRs and crop diversity *in situ*. Ingram and Williams (1984) and Franks (1999, p. 86) explore the use of international designations within the World Heritage Program or the Man and the Biosphere (MAB) Program to conserve CWRs in areas where ongoing human intervention is essential to their conservation. This approach was adopted by the teosinte (*Zea*/maize CWR) *in situ* conservation project in the Sierra de Manantlan, Mexico, which became a MAB reserve in 1988 (Benz 1988).

Ultimately, the many CWRs that occur in agricultural environments will need to be conserved as part of agricultural production systems. They may benefit from the increasing interest in on-farm conservation of crops, but the number of such programs remains few and their continuing existence is still uncertain (IPGRI 2001). More generally, CWRs are likely to benefit from implementation of the work program on agricultural biodiversity adopted by the Conference of the Parties of the CBD at its 6th meeting. This calls for actions to mitigate negative effects of agriculture on biodiversity and would increase the likely maintenance of crop-associated biodiversity (including CWRs) in agricultural systems.

Information management

Information management (IM) is an essential part of CWR conservation (Ford-Lloyd and Maxted 1997). A PGR IM system has been created in Turkey that includes *in situ* CWR conservation data fields (Tan and Tan 1998). In collaboration with a USDA-ARS project in Paraguay, an existing protected area database in that country was populated with CWR information (K. Williams, personal communication). An international system to manage CWR information does not yet exist. A recently approved (end 2002) Global Environmental Facility (GEF) project ('*In situ* conservation of crop wild relatives through enhanced information management and its field application') recognizes the importance of effective national and international information systems. It is planned to work with five countries (Armenia, Bolivia, Madagascar, Sri Lanka and Uzbekistan) to develop and test national information systems, which could then be adopted by other countries. Together with five international partners (IPGRI, FAO, IUCN, UNEP-WCMC, and BGCI) these countries also plan to develop an international information system as a web-based portal to access CWR information.

Planning and training

Few activities described above have the potential to be successful without relevant planning (Ingram and Williams 1984) and training. Countries that are now planning *in situ* CWR conservation projects in partnership with international agrobiodiversity or biodiversity conservation organizations are identified in Table 1. Once funded, these projects will affect Armenia, Bolivia, Egypt, Jordan, Lebanon, Madagascar, Morocco, Sri Lanka, Turkey, Uzbekistan, Vietnam, and countries of the European Union.

Training is an under-represented topic in CWR publications (but see Hoyt 1988, p. 39). Nevertheless, national partners in ongoing or proposed CWR projects have identified training as a key element to success, especially as it relates to PA and CWR field management and monitoring. The University of Birmingham (UK) and IPGRI promote and offer training opportunities in PGR conservation that includes CWRs (Davies 1991, p. 68). However, no easy-to-consult *in situ* CWR conservation training manual is currently available.

Recommendations

On the basis of the above analysis, the authors offer recommendations[7] here for discussion in hopes of addressing some of the constraints to *in situ* CWR conservation development identified in the status and trends section.

1. A workable, consensus-driven definition of CWR is needed to provide a common language and a bounded meaning to the concept that would clarify discussion and better direct effort. A possible definition would be 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.
2. CWR inventories must continue as a high priority, with guidance and input from international agro-biodiversity and biodiversity conservation organizations. An international list would be useful to organizations that generate massive data sets (e.g., the IUCN Red List of Threatened Plants). Lists at all levels provide the basic targets for directing conservation action, and when CWRs are not flagged in existing databases, using such lists to query databases will be the only way to generate substantial reports on CWRs. Inventories should involve mechanisms for prioritizing conservation action (Maxted and Hawkes 1997).
3. Hawtin and Hodgkin (1997, p. 373) have stressed the importance of revising and then inventorying existing databases to locate natural occurrences of CWRs. Most *in situ* CWR conservation activities are dependent on accurate CWR location information. Good electronic CWR location data exist for many parts of the world, but are usually 'buried' within databases. Significant information could be obtained rapidly and inexpensively by querying these databases once their CWRs are flagged as such. Few relevant databases have done this, and the highest near term CWR IM priority should be to flag CWRs in the major international taxonomic, botanic garden, agro-biodiversity, and biodiversity conservation databases.
4. Once CWRs have been flagged in databases, locating CWRs in existing PAs should be emphasized. Effort should go secondarily to creating and populating CWR fields (location, land ownership, endangerment status, links to *ex situ* collections, etc.), and on digitizing important non-electronic data sets. Location data should be in GIS-compatible lat/long formats for use in multiple data set analyses. Since CWRs are viewed as national assets within country PGR programs, if agreement is reached on the need for a worldwide IM system, an ethical (and perhaps legal) framework acceptable to the countries and institutions involved will be needed. International consultation on objectives, content, form, access and standard protocols for data entry and retrieval would follow.
5. Targeted research is needed to explore the many unresolved questions with respect to how best to identify and manage the populations of CWRs that need to

[7] The recommendations made are the opinions of the authors. They do not necessarily reflect the positions of any institution or organization.

be conserved. This is especially the case for species that occur in agricultural landscapes or are characteristic of disturbed ecosystems.

6. To the degree possible, research and site selection should be guided by gap analyses that integrate data on world centers of crop diversity, centers of crop domestication and centers of speciation of CWR genera with data from regions where *in situ* CWR conservation activities have occurred or are underway. Since the major world areas of CWR diversity have not been systematically identified, it is possible that ongoing research and site selection may be missing important areas of CWR diversity. Ways of more effectively linking research and site selection processes with official protected site designation processes need study. Insights obtained should be applied immediately to planning and implementation of *in situ* CWR conservation projects so that the rate of official designation increases in relation to the number of sites recommended for protection.
7. Organizing *in situ* CWR conservation planning workshops should be a priority. Since *in situ* CWR conservation is cross-sectoral, involves complex policy and administrative elements, and must often consider indigenous and peasant resource management issues, individual researchers and administrators can face daunting challenges in planning and preparing *in situ* CWR conservation projects with realistic chances of success. *In situ* CWR conservation training programs especially for PA personnel are similarly needed, now that the theoretical and methodological groundwork is laid and protected sites exist. Easy-to-consult *in situ* CWR management guidelines for PA personnel and other operators are needed.
8. The presence and the value of CWRs within existing and proposed PAs should be included among the arguments used to stimulate creation of PAs and their management for CWRs. More effort and creativity are needed to publicize the importance of *in situ* CWR conservation and to involve ordinary people in appropriate activities, much as Wilkes (1993, p. 86) recommended for a teosinte *in situ* conservation project in Guatemala. PR should focus on successful outcomes. A web search carried out by one of us uncovered only two articles on *in situ* CWR conservation in the popular media (Anonymous 1998; Sharma 1998), and more articles like these are needed. Innovators like Laghetti et al. (1999) in Italy, and the Armenian PGR web site creators are exploring ways to incorporate *in situ* CWR conservation into eco- and cultural tourism in those countries.
9. Academic, agro-biodiversity, forestry, and biodiversity conservation organizations must coordinate more effectively to define and achieve common CWR conservation objectives. The *in situ* CWR conservation efforts reported here have been increasingly collaborative, but striving to broaden and deepen cooperation must remain a priority. Country-level agricultural and environmental protection administrations must strive to overcome ‘turf wars’ that slow CWR conservation advances.
10. International organizations have assumed strategic, operational, and support functions in developing and facilitating *in situ* CWR conservation projects. Beneficial outcomes have resulted and international organizations must continue

to lead by encouraging national CWR policy development, promoting gap analyses for site selection, organizing and hosting workshops on CWR project planning, devising means of stimulating institutional cooperation, achieving consensus if appropriate on an international CWR information management system and assisting the development of the system, generating PR strategies and materials, and developing training programs for PA personnel along with *in situ* CWR conservation guidelines.

Conclusions

After somewhat of a slow start, *in situ* conservation of crop wild relatives has progressed rapidly during the last decade, and particularly so in a handful of countries. International agreements now recognize its value, method and theory are beginning to develop, on-the-ground projects have been launched, and institutional collaboration is occurring in planning and operations. A first generation of field projects has been or is being completed with some notable successes, and a second generation of projects is underway or being planned. Research and site selection activities have especially flourished, undoubtedly because they are less complex than are protected area creation or management plan revision, activities that have been harder to achieve. Nevertheless, several sites recommended for protection or for management revision in the last decade have been officially designated or are being managed differently, and the *in situ* CWR conservation community has these accomplishments to highlight to decision makers and the general public.

Some of the recommendations we have advanced could be completed quickly and rather inexpensively. With modest revisions to a few major databases, substantial progress can be made locating CWRs around the world simply by using available information more effectively. Increasing the rate of official acceptance of selected sites will be harder. Better planning, training, collaboration, and PR will help. The international agricultural and conservation organizations must continue to play a leadership role in this worldwide effort.

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