CATALOGUING AND PRIORITIZING CROP WILD RELATIVES AS A BASELINE FOR THEIR CONSERVATION AND UTILIZATION

by

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ABSTRACT

The value of wild plant species related to crops (crop wild relatives, or CWR) as sources of traits for pest and disease resistance, tolerance of environmental conditions, yield enhancement, improved nutrition, and a range of other agronomic characteristics, has been recognized since the early 20th century. However, these species are inadequately conserved, which in turn is limiting their utilization potential. In this thesis, based on the published definition of a CWR, a systematic, practical and replicable method for creating a comprehensive CWR checklist and an approach to identifying priority taxa for conservation action are proposed. The process of evaluating the threat status of CWR to inform conservation planning is also elaborated. These methodologies are presented and discussed in the broader context of CWR conservation planning at national and regional scales, and illustrated with China and Europe as case studies. While the CWR checklist methodology results in a large number of included taxa, it provides a comprehensive foundation for conservation planning. The identification of priority taxa as those related to crops of high socio-economic importance, and of those, taxa of greatest utilization potential and/or known to be under threat of genetic erosion, provides a pragmatic means of directing limited conservation resources.

DEDICATION

This thesis is dedicated with love and gratitude to my father, Richard Alexander Kell, and in loving memory of my mother, Muriel Adelaide Kell, née Nairn, and brother, Colin Richard Kell.

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LIST OF ACRONYMS AND ABBREVIATIONS

ACP	African, Caribbean and Pacific (region)
AGRI GEN RES	European Council regulation 1467/1994 (EC, 1994) or 870/2004 (EC, 2004)
AOO	Area of occupancy
ARS	Agricultural Research Service
Bern Convention	Convention on the Conservation of European Wildlife and Natural Habitats
BGCI	Botanic Gardens Conservation International
CAS	Chinese Academy of Sciences
CAAS	Chinese Academy of Agricultural Sciences
CAU	China Agricultural University
CBD	UN Convention on Biological Diversity
CGRFA	UN FAO Commission on Genetic Resources for Food and Agriculture
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CPVO	Community Plant Variety Office
CR	Critically Endangered (IUCN Red List category)
CWR	Crop wild relative(s)
CWR Catalogue	The Crop Wild Relative Catalogue for Europe and the Mediterranean
CWRSG	IUCN SSC Crop Wild Relative Specialist Group
DAFF	Department of Agriculture, Forestry and Fisheries (South Africa)
DD	Data Deficient (IUCN Red List category)
DG	Directorate General (of the EC)
E+Mf	Euro+Med PlantBase filtered (with regard to Chapter 2)
EC	European Commission
ECPGR	European Cooperative Programme for Plant Genetic Resources
EOO	Extent of occurrence
EX	Extinct (IUCN Red List category)

EN	Endangered (IUCN Red List category)
EU	European Union
EURISCO	European Search Catalogue for Plant Genetic Resources
EW	Extinct in the Wild (IUCN Red List category)
FAO	UN Food and Agriculture Organization
GBIF	Global Biodiversity Information Facility
GEF	Global Environment Facility
GENESYS	Global Portal on Plant Genetic Resources
GIS	Geographic information system
GP	Gene Pool (concept)
GPA	FAO Global Plan of Action for Plant Genetic Resources for Food and Agriculture
GRIN	Genetic Resources Information Network
Habitats Directive	Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora
IBCAS	Institute of Botany, Chinese Academy of Sciences
INIBAP	International Network for the Improvement of Banana and Plantain
IPCC	Intergovernmental Panel on Climate Change
IPGRI	International Plant Genetic Resources Institute
IPK	Leibniz Institute of Plant Genetics and Crop Plant Research
ISO	International Organization for Standardization
ITPGRFA	International Treaty on Plant Genetic Resources for Food and Agriculture
IUCN	International Union for the Conservation of Nature
JKI	Julius Kühn-Institut – Federal Research Centre for Cultivated Plants
LC	Least Concern (IUCN Red List category)
MAWPs	Most Appropriate Crop Wild Relative Populations
MEP	Ministry of Environmental Protection (China)
MT	Millions of tons
NA	Not Applicable (IUCN Red List category)

NBAP	National Biodiversity Action Plan
NE	Not Evaluated (IUCN Red List category)
NGO	Non-Governmental Organization
NT	Near Threatened (IUCN Red List category)
PA	Protected Area
PGP	Provisional Gene Pool (concept)
PGR	Plant genetic resources
PGRFA	Plant genetic resources for food and agriculture
POSS	Plant Occurrence and Status Scheme
RE	Regionally Extinct (IUCN Red List category)
RHS	Royal Horticultural Society
SADC	South African Development Community
SAIN	Sustainable Agriculture Innovation Network
SANBI	South African National Biodiversity Institute
SIS	IUCN Species Information Service
SPGRC	South African Development Community Plant Genetic Resources Centre
SSC	IUCN Species Survival Commission
TDWG	Taxonomic Databases Working Group
TG	Taxon Group (concept)
UNEP	United Nations Environment Programme
UN	United Nations
UOB	University of Birmingham
USDA	United States Department of Agriculture
VU	Vulnerable (IUCN Red List category)
WCMC	World Conservation Monitoring Centre
WIEWS	World Information and Early Warning System on Plant Genetic Resources for Food and Agriculture

CHAPTER 1

INTRODUCTION

1.1 The importance of crop wild relatives for crop improvement

Crop wild relatives (CWR) are wild plant species related to crops that are potential sources of traits for the development of new, improved varieties (Maxted *et al.*, 2006). Because of the broad range of habitats in which CWR occur, and their adaptation to a wide range of local environmental conditions, they are an important reservoir of genetic diversity for crop improvement (e.g., see Vaughan, 1994; Hawkes *et al*., 2000; de Wouw *et al*., 2001; Eglinton *et al.*, 2001; Mariac *et al*., 2006; FAO, 2008; Millet *et al*., 2008; Maxted and Kell, 2009). This diversity is particularly important because the process of genetic diversity loss that most crop species bred to meet the uniformity requirements of commercial agriculture have undergone (e.g., see Feldman and Sears, 1981; Eyre-Walker *et al*., 1998; Zohary, 1999; Vollbrecht and Sigmon, 2005; Chung and Singh, 2008; Shepherd *et al*., 2016) can render them highly susceptible to pests, diseases and unexpected environmental conditions, and consequent crop losses (e.g., see Ford-Lloyd and Jackson, 1986; Fowler and Mooney, 1990; Witcombe and Hash, 2000; FAO, 2010; Keneni, 2016). The value of traits derived from CWR has been highlighted by many authors (e.g., Prescott-Allen and Prescott Allen, 1983; Hoyt, 1988; Maxted *et al*., 1997a, 2008, 2012, 2014; Meilleur and Hodgkin, 2004; Hajjar and Hodgkin, 2007; Hodgkin and Hajjar, 2008; Sonnante and Pignone, 2008; Maxted and Kell, 2009; McCouch *et al*., 2013; Vincent *et al*., 2013; Dempewolf *et al*., 2014; Porceddu and Damania, 2015) and their use for the improvement of crops has made a substantial indirect contribution to the world economy (Maxted *et al*., 2008; Maxted and Kell, 2009; Tyack and Dempewolf, 2015).

The Russian agronomist, botanist and geneticist Nikolai Ivanovich Vavilov was instrumental in identifying the genetic relationship between crops and their wild relatives and in promoting the potential of CWR as gene donors for crop improvement in the first half of the 20th century (see Vavilov, 1922, 1926). CWR were subsequently used to improve major crops in the 1940s and 50s, and by the 1960s and 70s, their use had led to some significant improvements (Meilleur and Hodgkin, 2004). Maxted and Kell (2009) reported that CWR have been used increasingly in plant breeding for crop improvement since the 1970s. The authors undertook a review of (published) reported uses of CWR for the improvement of 29 crops and found 234 references citing the actual or potential use of traits from 183 CWR taxa. The breeding objectives in these crops included[1]: a) resistance to pests (e.g., nematodes in sugarbeet – *Beta vulgaris* L. subsp. *vulgaris*, peanut – *Arachis hypogaea* L., and sweet potato – *Ipomoea batatas* (L.) Lam. var. *batatas*; brown plant hopper in rice – *Oryza sativa* L.; and hessian fly in wheat – *Triticum aestivum* L.); b) disease resistance (e.g., powdery mildew and leaf rust in barley – *Hordeum vulgare* L., oat – *Avena sativa* L. and wheat; rust and late leaf spot in peanut; downy mildew in lettuce – *Lactuca sativa* L. and sunflower – *Helianthus annuus* L.; stem rust and fusarium head blight in wheat; yellow dwarf virus in barley; grassy stunt and tungro virus in rice; and bacterial blight in chickpea – *Cicer arietinum* L., common bean – *Phaseolus vulgaris* L. and cotton –

[1] See Maxted and Kell (2009, p. 13–20) for the complete list of examples, including the CWR species used and the reference details.

Gossypium hirsutum L.); c) abiotic stress tolerance (e.g., drought in banana – *Musa acuminata* Colla, chickpea, common bean, oat, rice and soybean – *Glycine max* (L.) Merr.; high temperature in common bean; low temperate in apple – *Malus domestica* (Suckow) Borkh., chickpea and rice; acid sulphate soil and aluminium toxicity in rice; and salinity in common bean, sunflower and wheat); and d) quality improvements (e.g., rice grain characteristics; cassava – *Manihot esculenta* Crantz, pigeon pea – *Cajanus cajan* (L.) Huth, soybean and wheat protein content; inflorescence size, male fertility and dry matter in finger millet – *Eleusine coracana* (L.) Gaertn.; fruit size and shape, and processing ability in tomato – *Solanum lycopersicum* L.; and freezing ability in pea – *Pisum sativum* L.). Based on the number of references collated in that study, the authors concluded that the use of CWR has been particularly prominent in wheat, rice, barley, cassava, peanut, potato, soybean and finger millet—each having ten or more references citing the use of CWR attributed to them (see Maxted and Kell, 2009, p. 12).

The environmental impacts of climate change are causing and will continue to cause significant challenges for the agricultural and horticultural industries and for food and economic security (see Chapters 4 and 5 for further discussion). Based on a review of studies of the impact of climate trends to date on wheat, maize and rice yield in a range of countries across the globe over an average of 29 years as a contribution to the Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change, Porter *et al.* (2014) reported that wheat yields have decreased by an average of almost 2% per decade, maize by between 1% and 2%, with no change in rice. However, although the authors provide evidence that trends vary between regions and between crops, evidence suggests that the overall predicted long-term global trend is for the production of wheat, maize and rice to be negatively affected by climate change at local temperature increases of 2°C above late 20th century levels without adaptation measures (Porter *et al.*, 2014). These are three of the world's major human food crops which provide a substantial proportion of dietary energy worldwide (as much as 30 or even 50% in some subregions) (Kell *et al*., 2015 – Chapter 4). As discussed in Chapter 4, other factors come into play when interpreting the potential impact of climate change on crop productivity. For example, studies based on long-term climate trends do not take account of the potential impacts of extreme weather events on crop production which the IPCC (2012) reported are expected to have a negative effect. In the early years of the 21st century, major economic losses were already being incurred in the agricultural sector—for example, extreme weather events resulting from climate change in 2003 caused an estimated overall uninsured economic loss in the European Union (EU) agriculture sector of €13 billion (Létard *et al*., 2004) (see Kell *et al*., 2015 – Chapter 5). Furthermore, some authors have highlighted that climate change will lead to changes in the occurrence of pests and diseases (e.g., Lane and Jarvis, 2007; FAO, 2011), lending greater uncertainty to the success of crop production. In addition, studies of the impacts of climate change have only been undertaken on a limited number of crops—therefore, the future of productivity for many crops is unknown (Kell *et al*., 2015 – Chapter 4).

To help mitigate these impacts, the seed industry is in need of diverse and novel sources of genetic diversity to produce crop varieties that can withstand changing environmental conditions (e.g., see Jones *et al*., 2003; Duveiller *et al*., 2007; FAO, 2008; Feuillet *et al*., 2008; Lobell *et al*., 2008; Deryng *et al*., 2011; Guarino and Lobell, 2011; Li *et al*., 2011; Luck *et al*., 2011; McCouch *et al*., 2013; Muñoz-Amatriaín *et al*., 2014), and there is some consensus that CWR will become increasingly important to meet this challenge (Zamir, 2001; Vollbrecht and Sigmon, 2005; FAO, 2008, 2010, 2011; Ford-Lloyd *et al*., 2011; Guarino and Lobell, 2011; Kell *et al*., 2012a; Maxted *et al*., 2012, 2014; Ortiz, 2015). Although the use of CWR can present particular challenges for plant breeders because of hybridization barriers and the introgression of unwanted traits into crop material, the application of techniques to help overcome these problems may pave the way to greater use of exotic germplasm in crop improvement (e.g., see Zamir, 2001; Hajjar and Hodgkin, 2007; Dwivedi *et al*., 2008; Feuillet *et al*., 2008; Ford-Lloyd *et al*., 2011; McCouch *et al*., 2013; Walley and Moore, 2015; and further discussion in Kell *et al*., 2017 – Chapter 6). For example, genomics, transcriptomics, next-generation sequencing (NGS), and more recently 'Ecotilling' can be used to understand the genetic basis of desirable traits and thus reduce the number of generations needed to introduce a trait from exotic material, and transgenic techniques (although often controversial) or even genome editing provide options for rapid transformation in crop improvement programmes (Walley and Moore, 2015).

1.2 Advancement in knowledge of CWR diversity, its conservation, and use

At the beginning of the 21st century, relatively little had been systematically recorded about CWR in terms of how many species exist, their relationships to crop species, where they are distributed, to what extent they are already conserved, the threats impacting CWR populations, and to what extent they are utilized for plant breeding research and in crop variety development. During the last c. 15 years, these knowledge gaps have decreased significantly, primarily through a number of key initiatives that have raised the profile of CWR and placed them securely on the international conservation agenda. Notably, the EU-funded project, 'European crop wild relative diversity assessment and conservation forum' (PGR Forum) (2002–2005)[2] brought CWR to the fore and stimulated greater interest in their conservation. Key outcomes of this project included a published definition of a CWR (Maxted *et al*., 2006) and the CWR Catalogue for Europe and the Mediterranean (Kell *et al*., 2005, 2008, Chapter 2)—the first comprehensive published checklist of CWR. In 2007, the Commission on Genetic Resources for Food and Agriculture (CGRFA) of the United Nations Food and Agriculture Organization (FAO) commissioned a background study to inform the establishment of a global network for the *in situ* conservation of CWR (Maxted and Kell, 2009). This work provided a comprehensive overview of the utilization of CWR and strategies for their conservation, and placed emphasis on CWR conservation planning for a selection of globally important crop gene pools.

Other notable projects with a focus on CWR were the GEF-funded project '*In situ* conservation of crop wild relatives through enhanced information management and field application' (2004–2010)[3], in which CWR conservation was initiated in five countries in central and southern Asia, eastern Africa and South America, and from which a manual for *in situ* CWR conservation was published (Hunter and Heywood, 2011); the European Red List of Vascular Plants project (2009–2011)[4], co-funded by the EU and the International Union for the Conservation of Nature (IUCN), which included the first significant effort to assess the Red List status of CWR (Bilz *et al*., 2011;

[2] www.pgrforum.bham.ac.uk/

[3] www.cropwildrelatives.org/resources/expertproject-database/projects/project-list/project-details/?proj=27

[4] http://ec.europa.eu/environment/nature/conservation/species/redlist/index_en.htm

Kell *et al*., 2012b – Chapter 3); the CWR China project, 'Conservation for enhanced utilization of crop wild relative diversity for sustainable development and climate change mitigation'[5], funded by the UK Department for Environment, Food and Rural Affairs (Defra) and Ministry of Agriculture of China (2010–2013), in which conservation planning of China's CWR was initiated (Kell *et al*., 2015 – Chapter 4); and the EU AGRI GEN RES project 'An integrated European *in situ* management work plan: Implementing genetic reserves and on farm concepts' (AEGRO) (2007–2011)[6], in which the focus was placed on CWR conservation planning at crop gene pool level (Kell *et al*., 2012a – Annex 1).

From 2011–2014, the EU-funded project, 'Novel characterization of crop wild relative and landrace resources as a basis for improved crop breeding' (PGR Secure)[7], took forward the conservation concepts and strategies initiated by and developed in the earlier projects, and brought the conservation and user communities together to identify the policy and stakeholder interventions needed to improve the use of CWR (and landrace) germplasm in crop improvement programmes. In 2010, the Crop Trust project, 'Adapting Agriculture to Climate Change: Collecting, Protecting and Preparing Crop Wild Relatives'[8] was initiated, in which a global inventory of CWR in 192 crop gene pools, along with information about CWR–crop relationships and documented actual or potential uses for crop improvement was developed

[5] www.sainonline.org/SAIN-website(English)/pages/Projects/Project%20profile-Conservation%20of%20crop%20wild%20relative%20diversity.html

[6] http://aegro.julius-kuehn.de/aegro/

[7] www.pgrsecure.org/

[8] www.cwrdiversity.org/project/

(the Harlan and de Wet CWR Inventory – Vincent *et al*., 2013), and *in situ* and *ex situ* conservation planning at global level undertaken. Collection of germplasm for *ex situ* conservation, and characterization of material to increase possibilities for its utilization by the plant breeding community was also a major focus of that project. Also of note is the searchable online database, 'Crop Relatives in GRIN Taxonomy' (USDA, ARS, GRIN 2017), which provides access to information about CWR–crop relationships and documented actual or potential uses for crop improvement for a large number of crops, and has been a vital source of information for related databases (e.g., Vincent *et al*., 2013) and for research undertaken under the umbrella of other CWR projects.

In the ACP-EU project, '*In situ* conservation and use of crop wild relatives in three ACP countries of the SADC region' (SADC CWR project) (2014–2016)[9], the methods and approaches to CWR conservation planning developed and widely applied in Europe informed the preparation of National Strategic Action Plans for the Conservation and Sustainable Use of CWR (CWR NSAPs) in the three SADC partner countries, Mauritius (Bissessur *et al.*, 2019), South Africa (Holness *et al.*, 2019) and Zambia (Ng'uni *et al*., 2019). Planning for conservation at regional scale was also undertaken in the context of the SADC CWR project to highlight the value of CWR diversity in the region (Allen *et al*., 2019) and to identify priority populations for conservation action[10]. Other important outputs of that project were a number of freely available tools to assist practitioners in CWR conservation planning (see Magos Brehm *et al*., 2019). More recently, the

[9] www.cropwildrelatives.org/sadc-cwr-project/

[10] www.cropwildrelatives.org/sadc-cwr-project/project-results/conservation-strategies/conservation-planning-for-priority-cwr-in-the-sadc-region/

Darwin Initiative project, ‘Safeguarding Mesoamerican Crop Wild Relatives (2016–2019)[11], has initiated CWR conservation planning in México, Guatemala, Hondurus and El Salvador using systematic conservation planning methods and approaches developed at the National Commission for the Knowledge and Use of Biodiversity (CONABIO), México. The EU Horizon 2020 project, ‘Networking, partnerships and tools to enhance *in situ* conservation of European plant genetic resources’ (Farmer’s Pride) (2017–2020)[12] is the latest project that amongst other activities will take forward the work undertaken in earlier projects to establish a network of sites and stakeholders for *in situ* CWR conservation in the European region.

Through these projects and initiatives, a large pool of knowledge about CWR has been amassed, CWR conservation planning techniques and tools have been developed, capacity in CWR conservation planning has increased, and the profile of CWR enhanced at global level. CWR are now more concretely acknowledged worldwide as a fundamental resource to support food and nutrition security, including through a number of international policies and legislative instruments—notably, the Second Global Plan of Action for Plant Genetic Resources for Food and Agriculture (Second GPA) (FAO, 2011), the Strategic Plan for Biodiversity 2011–2020 (UNEP, 2010a), and the Global Strategy for Plant Conservation 2011–2020 (UNEP, 2010b).

[11] www.psmesoamerica.org/en/

[12] www.farmerspride.eu

1.3 The CWR conservation planning process

Central to this surge in interest in CWR has been the promotion and development of national strategies for their conservation. The premise of national sovereignty over natural resources that underlies all conservation policy and legislation, and specifically for genetic resources has been enshrined in law through the inception of the Convention on Biological Diversity (UN, 1992), naturally means that nations are responsible for the conservation and sustainable use of CWR, as for other wild species. However, while national CWR conservation strategies are essential, they may not collectively ensure the conservation of the most important genetic diversity for world food and economic security, which is dispersed across the globe. This is because national conservation priorities differ and not all countries are, or necessarily will develop conservation strategies specifically for CWR (and if they are, the time-frames for their actions vary considerably). Therefore, when contemplating the conservation of CWR diversity of the most important crops for food and economic security globally, the additional 'layers' of regional and global conservation come into play. The need for this 'holistic' approach to CWR conservation (Heywood *et al*., 2008; Maxted and Kell, 2009; Maxted *et al*., 2012) has now been taken forward with the initiation of regional strategy planning in Europe (Maxted *et al*., 2015; Kell *et al*., 2016 – Chapter 5), the South African Development Community[viii] and Mesoamerica[ix], as well as worldwide (Vincent *et al*., 2013; Castañeda-Álvarez *et al*., 2016; Vincent *et al*., in press). This holistic approach aims to ensure that the full range of CWR diversity is conserved and available for use, and recognizes not only the interdependence of countries and regions on plant genetic resources for food and agriculture (PGRFA), but also the particular value of a their

CWR diversity which may not be found in other parts of the world. For example, CWR diversity in the Euro-Mediterranean region is characterized by a predominance of species related to several cereals and legumes (e.g., wheat, oat, chickpea, lentil – *Lens culinaris* Medik., pea and faba bean – *Vicia faba* L.), fodder and forage crops (e.g., lucerne – *Medicago sativa* L. subsp. *sativa*, white clover – *Trifolium repens* L. and sugarbeet), and many vegetables, fruits, nuts, herbs and oils (e.g., brassicas, lettuce, grape – *Vitis vinifera* L., almond – *Prunus dulcis* (Mill.) D. A. Webb, pistachio – *Pistacia vera* L., sage – *Salvia officinalis* L. and olive – *Olea europaea* L.) (Kell *et al.*, 2008 – Annex 2), while in Central and South America by species related to crops such as maize – *Zea mays* L., potato – *Solanum tuberosum* L., common bean, cassava, sweet potato, tomato, pepper – *Capsicum annuum* L., cotton, avocado – *Persea americana* Mill., cocoa – *Theobroma cacao* L. and vanilla – *Vanilla* Mill. spp. (e.g., see Azurdia *et al*., 2011; Contreras-Toledo *et al*., 2018).

As for all species, CWR conservation planning ideally results in the identification of complementary actions (i.e., both *in situ* and *ex situ*) required to optimize the preservation of genetic diversity. This is achieved through a process of undertaking diversity and conservation gap analyses (i.e., using distribution, environmental, genetic, protected area and gene bank holdings data to determine priority populations and missing conservation actions) for target taxa. The results of these analyses inform decision-making on the actions needed to implement active *in situ* conservation (i.e., population management and monitoring either within or outside existing protected areas) and collection and management of germplasm samples *ex situ* (i.e., in gene banks) of the priority populations. Complementarity between these two conservation approaches is of fundamental importance for two reasons—firstly as a means of insurance for the possible loss of populations *in situ*, and secondly to provide access to germplasm for research and crop improvement.

Two fundamental aspects of conservation planning are the production of taxon checklists and taxon prioritization. Naturally, knowledge of what diversity exists and where it is found is an essential first step in conservation planning. Taxon checklists provide the 'horizontal' baseline for gathering and collating information about individual taxa to create a 'vertical' dimension in a knowledge base. The 'horizontal' (taxonomic) and 'vertical' (biological, ecological, geographic and temporal) data combined are scrutinized to understand the management interventions needed to maintain population and genetic diversity and to inform decision-making. With limited resources available for carrying out active conservation, conservation practitioners and policy-makers are obliged to make decisions about what to conserve in the short term, giving lesser priority to taxa or populations that are not considered (comparatively) to be of immediate conservation concern.

The systematic approach to conservation of plant genetic resources (PGR) first proposed by Maxted *et al*. (1997b), and specifically for national CWR conservation planning by Maxted *et al*. (2007), has now been widely promoted (e.g., see Maxted *et al*., 2013; Magos Brehm *et al*., 2017) and adopted (e.g., Fitzgerald, 2013; Khoury *et al*., 2013; Fielder *et al*., 2015; Phillips *et al*., 2014, 2016; Taylor *et al*., 2017) to determine complementary conservation actions needed for priority CWR populations. While the production of checklists and taxon prioritization would be considered essential in any action to conserve biodiversity, specifically in the case of CWR, the methods require knowledge of crop–CWR relationships and it is this unique characteristic of CWR that lies at the core of this research.

1.4 The definition of crop–CWR relationships

In 1971, Harlan and de Wet published the Gene Pool (GP) concept as a guide for classifying crops and related taxa according to their degree of genetic relatedness and potential for use in conventional plant breeding programmes. The authors classified crop taxa in GP1a and the wild or weedy forms of the crop that hybridize freely with the crop taxa in GP1b, closely related species with which hybridization is possible but may be more difficult in GP2, and species from which gene transfer to the crop is impossible, or requires sophisticated techniques (e.g., embryo rescue, somatic fusion or genetic engineering) in GP3. However, it was not until 35 years later that a formal definition of a CWR was published. Maxted *et al*. (2006, p. 2680) defined a CWR as "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". The authors proposed the Taxon Group (TG) concept as a proxy in the many cases where genetic data are not available to apply Harlan and de Wet's GP concept. The TG concept is based on the intra-generic taxonomic hierarchy and places all taxa in the same genus as a crop in TG4, those in the same subgenus in TG3, and those in the same section or series in TG2. In direct correlation with Harlan and de Wet's GP1a and 1b, crop taxa are classified in TG1a and those in the same species in TG1b. While TG2 and 3 and GP2 and 3 are not necessarily directly correlated, the TG concept provides an alternative to the GP concept when genetic data are not available (Maxted *et al.,* 2006).

While Harlan and de Wet suggested that the secondary gene pool (GP2) might correspond with a taxonomic definition of a genus containing a crop taxon, the concept was proposed as a guide "for placing existing classifications into genetic perspective" (Harlan and de Wet, 1971, p. 513) and in some cases, authors of crop gene pool concepts have classified taxa in the same genus as the crop as belonging to the tertiary gene pool (GP3) (e.g., Hawkes, 1990 for potato; Maxted *et al.*, 1991 and Maxted, 1993 for faba bean; von Bothmer *et al*., 1995 for barley; Stenhouse *et al*., 1997 for sorghum, *Sorghum bicolor* (L.) Moench; and Allem *et al*., 2001 for cassava). Therefore, although the definition of Maxted *et al*. (2006) does not explicitly mention the inclusion of GP3, the generic definition (TG4) includes tertiary wild relatives in some crop gene pools, while in other cases (e.g., cabbage and other brassica crops – *Brassica* spp.; maize; pea; rye – *Secale cereale* L.; sugarbeet; sugarcane – *Saccharum officianarum* L.; and wheat), tertiary (and in some cases secondary) wild relatives are classified in related genera (USDA, ARS GRIN, 2017).

Regardless of the differences in the generic definitions of crop gene pools, the definition of Maxted *et al.* (2006) provides a practical means of defining and classifying crop–CWR relationships, and, on this basis, the possibility to create CWR checklists and assign priority status to taxa according to their degree of relationship to crops. This concept of crop–CWR relationships that is central to this thesis is elaborated further in Chapter 2 in the context of the methodology proposed for creating a CWR checklist, and is inherent in Chapters 4, 5 and 6 in the context of prioritizing CWR for conservation action.

1.5 Research rationale, aim and objectives

The concept for this thesis arose when, in association with the author's professional work in the field of PGR conservation, it became clear that there was a need for research in the specific methods and approaches to establish a baseline for planning systematic conservation of CWR. Characterized by their potential to contribute traits for the improvement of crops, it is their relationship to crop species that distinguishes them from other wild plant taxa. It is this unique characteristic that allows conservation practitioners to define which taxa are CWR in a given geographic area, which crops they are related to, and which taxa should be given priority for conservation action. This research was undertaken to fill a gap in knowledge of how to plan CWR conservation taking into account their relationship to crop species, and to provide methodologies and case studies to guide conservation planners.

Therefore, with the aim of developing and illustrating methods to establish a baseline for CWR conservation actions (and ultimately for their utilization for crop improvement), the objectives of this research were to:

1. Develop a systematic methodology for creating a CWR checklist;
2. Evaluate the threat status of CWR;
3. Elaborate different methods for prioritizing CWR taxa for conservation action at national and regional levels;
4. Propose a logical, pragmatic and generic approach to assigning priority status to CWR taxa that can be applied at any geographic scale.

1.6 Thesis structure and content

A methodology for creating a CWR checklist is presented in Chapter 2 (Kell *et al*., 2018). Illustrated with a case study on the Euro-Mediterranean region, the chapter details the steps taken to undertake a process of matching floristic data (i.e., names of plant taxa that occur within a defined geographical area) with lists of crop genus names (i.e., genus names containing crops, and related genera in the cases of crops such as wheat). The benefits and pitfalls of using this approach are discussed and the methodology is proposed as an appropriate and replicable means of creating a CWR checklist either at national or regional level anywhere in the world.

Chapters 3–5 address the collation and analysis of data required to assign priority status to CWR taxa, and the prioritization process itself. Chapter 3 (Kell *et al*., 2012b) describes the procedure for undertaking Red List assessments of CWR and details what the results reveal about their threat status as well as how they can be interpreted to inform the selection of priority taxa for conservation action. It also gives insight into the threats impacting CWR populations, population trends, and critically, highlights the extent of knowledge of CWR needed to fully understand conservation management needs. The chapter also elaborates the process of selecting the species for assessment, and in this sense presents a means of undertaking *a priori* prioritization (i.e., without knowledge of their threat status), as well as how the results of the assessments and the process itself inform actions needed to conserve CWR diversity.

An example of the application of the methodology for creating a CWR checklist presented in Chapter 2 at national level is summarized in Chapter 4 (Kell *et al*., 2015), and a procedure for identifying priority CWR for conservation action elaborated. The case study presented here for China illustrates how three distinct prioritization criteria can be applied to target CWR taxa in most critical need of conservation interventions: the socio-economic value of the crop to which they are related; their relative threat status; and their potential ease of use or known value in crop improvement programmes. Emphasis is placed on the potential value of national CWR diversity for the improvement of crops that are of paramount importance for food security in other parts of the world, highlighting the interdependency of countries on PGR.

In Chapter 5 (Kell *et al*., 2016), a similar prioritization procedure is presented, but at regional level. In this case study, the rationale for carrying out CWR conservation at a regional scale is elucidated, and the prioritization methodology and results are placed in the broader context of the practical and policy interventions required to conserve high priority CWR at international level in Europe. In Chapter 6 (Kell *et al*., 2017), the various criteria and procedures that have been applied to assign priority status to CWR by different authors are reviewed and critiqued, and a generalized model for undertaking CWR prioritization presented. The approach is proposed as a logical and pragmatic option that reduces the bias and complexity that has been introduced by various practitioners into the process.

The aim, objectives and outputs of the research are précised in Chapter 7, and the advantages and limitations of key elements of the concepts and methods presented in Chapters 2–6 discussed. In this chapter, the processes and their outcomes are also considered in the broader CWR conservation and utilization context, and recommendations given for future work in this area.

Chapters 2–6 are the result of collaborative work in which the author was the lead, and chapters 3–6 comprise work already published. Details of co-author contributions and publisher permissions are provided before each chapter. Chapters 3–6 are included in their published format as they must not be modified. References are therefore listed after each chapter and pagination of the thesis excludes the pages of those published chapters, as stipulated by the University of Birmingham guidelines.

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CHAPTER 2

CREATING A CROP WILD RELATIVE CHECKLIST: A METHODOLOGY AND CASE STUDY ON THE EURO-MEDITERRANEAN REGION

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Declaration of co-author contributions

The concept of matching genus names in Mansfeld's World Database of Agricultural and Horticultural Crops with the taxa in Euro+Med PlantBase to obtain a list of crop wild relatives that occur in Europe was initially proposed by Helmut Knüpffer and discussed by participants at Workshop 1 of the PGR Forum project (the European crop wild relative diversity assessment and conservation forum – EVK2-2001-00192 – www.pgrforum.org), funded under the EC Fifth Framework Programme for Energy, Environment and Sustainable Development) in February 2003, at which all co-authors were present. Shelagh Kell developed the methodology, collated the datasets, undertook the data analyses and wrote the content of the chapter, apart from a substantial portion of the narrative in section 2.2.2.1 describing Euro+Med PlantBase, which Stephen Jury contributed, and the narrative in section 2.2.2.2, contributed by Helmut Knüpffer.

Some of the content of this chapter is based on an earlier publication by the same authors and some of the narrative is the same or similar to narrative in that publication. The publication is annexed to this thesis (Annex 2). The citation of the publication is:

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

The same attributions as stated above for the current chapter also apply to the cited publication. In addition, for that publication, Helmut Knüpffer facilitated access to data in Mansfeld's database and the Schultze-Motel (1966) account, and Stephen Jury facilitated access to data in Euro+Med PlantBase.

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Statements of co-authors

I, Helmut Knüpffer, of the Institute of Plant Genetics and Crop Plant Research, Gatersleben, Germany, confirm that the above declaration of co-author contributions is true and accurate.

I, Stephen Jury, formerly of the University of Reading, UK, confirm that the above declaration of co-author contributions is true and accurate.

I, Nigel Maxted, of the University of Birmingham, UK, confirm that the above declaration of co-author contributions is true and accurate.

I, Brian Ford-Lloyd, Emeritus Professor of the University of Birmingham, UK, confirm that the above declaration of co-author contributions is true and accurate.

2.1 Introduction

Taxon checklists provide the baseline data critical for biodiversity assessment and monitoring, as required by the Convention on Biological Diversity (CBD) (UN, 1992) and the CBD Strategic Plan for Biodiversity 2011–2020 (UNEP, 2010a), including the Aichi Biodiversity Targets, and specifically for plant genetic resources, the Second Global Plan of Action for Plant Genetic Resources for Food and Agriculture (Second GPA) (FAO, 2011), the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) (FAO, 2001), and the Global Strategy for Plant Conservation 2011–2020 (GSPC) (UNEP, 2010b). Taxon checklists are also fundamental for planning and implementing conservation strategies and, specifically for crop wild relative (CWR) taxa, provide the backbone data on which to build knowledge about their current and potential uses as gene donors for crop improvement.

In terms of planning *in situ* conservation, some CWR species may already be included in areas managed for conservation purposes, but their status as CWR may be unknown and they may not be actively monitored and managed. It is evident that relative to the number of crops conserved *ex situ*, the numbers of CWR conserved are few (Maxted *et al*., 2008; Maxted and Kell, 2009; Kell *et al*., 2012 – Chapter 3; Castañeda-Álvarez *et al*., 2016). CWR checklists are therefore needed as a basis for building knowledge about which species are already under some form of protection and/or management *in situ* and *ex situ*, for identifying and closing gaps in their conservation, and for integrating them into existing conservation initiatives.

At the core of the concept for creating a CWR checklist is the 'broad' definition of a CWR as any taxon within the same genus as a crop species (Maxted *et al*., 2006). The authors defined a CWR as "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" (Maxted *et al*., 2006, p. 2680). The authors proposed the Taxon Group (TG) concept as a proxy in the many cases where genetic data are not available to apply the Gene Pool (GP) concept of Harlan and de Wet (1971), which was devised as a guide for classifying crops and related taxa according to their degree of genetic relatedness and potential for use in conventional plant breeding programmes (see Chapter 1, section 1.4). The TG concept is based on the intra-generic taxonomic hierarchy and places all taxa in the same genus as a crop in TG4, those in the same subgenus in TG3, and those in the same section or series in TG2. In direct correlation with Harlan and de Wet's GP1a and 1b, crop taxa are classified in TG1a and those in the same species in TG1b. While TG2 and 3 and GP2 and 3 are not necessarily directly correlated, the TG concept provides an alternative to the GP concept when genetic data are not available (Maxted *et al.,* 2006).

As noted in Chapter 1, although Harlan and de Wet suggested that the secondary gene pool (GP2) might correspond with a taxonomic definition of a genus containing a crop taxon, they also emphasized that the GP concept is a guide "for placing existing classifications into genetic perspective" (Harlan and de Wet, 1971, p. 513). In fact, in some cases, authors of crop gene pool concepts have classified species and sub-specific taxa in the same genus as the crop as belonging to the tertiary gene pool (GP3). This means that because the inclusion of TG4 in the broad definition of a CWR defined here includes all taxa in the same genus as a crop (Maxted *et al*., 2006), the definition includes tertiary wild relatives in some crop gene pools, while in other cases (e.g., cabbage and other brassica crops, maize, papaya, parsnip, pea, pecan, rye, spinach, strawberry, sugarbeet, sugarcane and wheat), tertiary (and in some cases secondary) wild relatives are classified in related genera (USDA, ARS GRIN, 2017). For example, although different gene pool concepts have been defined for wheat, *Triticum aestivum* L. (Maxted and Kell, 2009), it has been proposed that the secondary wild relatives are species in *Aegilops* L. and *Amblyopyrum* Eig, and that the tertiary wild relatives are species in more remote genera, including *Agropyron* Gaertn., *Elymus* L., *Leymus* Hochst., *Secale* L. and *Thinopyrum* Á. Löve (van Slageren, 1994; USDA, ARS GRIN, 2017). Thus, to include tertiary wild relatives of all crop taxa in a CWR checklist, these related genera must also be included.

Maxted *et al*. (2006) emphasize the need to take into account the degree of relatedness of wild relatives to their associated crops to assist in establishing conservation priorities. However, for the purposes of creating a comprehensive CWR checklist using a systematic approach to provide the foundation for conservation planning, the broad definition proposed by the authors, with the addition of related genera to capture tertiary wild relatives for those crop gene pools that extend into related genera, is an appropriate starting point. This concept facilitates a practicable process which in essence involves matching genus names in a floristic checklist of the area concerned with a list of 'crop genera' (i.e., genus names containing crops and related genera in the cases of crops such as wheat), and selecting the taxa within the matching genera from the floristic checklist to create a CWR checklist. While the CWR definition may most commonly be applied to species related to food crops, the concept is equally applicable to species related to fodder and forage crops, and those used in the environmental, industrial, forestry, medicinal, food additive, and amenity plant industries.

In the context of the EC-funded project PGR Forum (see Chapter 1, section 1.2), a systematic approach for creating a comprehensive checklist of CWR was conceived, and the Crop Wild Relative Catalogue for Europe and the Mediterranean (also referred to here as the 'CWR Catalogue', or 'the Catalogue') (Kell *et al*., 2005) was created. At the time of initiating the Catalogue, earlier regional CWR checklists had been proposed by Zeven and Zhukovsky (1975), Heywood and Zohary (1995) and Hammer and Spahillari (1999). However, a systematic approach had not been proposed and applied and previously there had not been a coordinated effort focussing on the production of a comprehensive European CWR checklist.

Kell *et al*. (2008a – Annex 2) presented the concept and an outline of the methodology for creating the CWR Catalogue for Europe and the Mediterranean with a focus on what it revealed about CWR taxonomic diversity in the region. Subsequent to its publication, further assessment was made of the original methodology employed, which resulted in the identification of some refinements to the protocol with regard to the generation of the list of crop genus names, the filtering of occurrence records, and the precise method of dealing with synonymy. This chapter describes the methodology used to create a revised version of the Crop Wild Relative Catalogue for Europe and the Mediterranean (the CWR Catalogue v. 4.0)—a methodology that can be applied in any country or region, given access to the required floristic data in electronic format. The results include an exploration of the number of records in the data sources used to create the Catalogue, as well as the numbers of records the Catalogue contains in terms of taxa and geographic occurrences. Results of analyses of the numbers of taxa in the Catalogue attributed to the three crop genus name list sources are also provided. The benefits of the availability of a broad CWR checklist in terms of conservation planning are discussed and illustrated with examples of ways in which the CWR Catalogue for Europe and the Mediterranean has been used to inform CWR conservation planning in the region. Caveats of the methodology, including the selection of crop genus names and how to deal with the complex issue of synonymy are discussed and the scope for future potential enhancements to the Catalogue considered—for example, the identification of crop–CWR relationships and the addition of economic use categories.

2.2 Methodology

2.2.1 The concept and basic procedure

Figure 2.1 is a simplified model illustrating the concept and basic procedure. The flow chart shows the three sources that are combined to form the crop genus list (i.e., genus names encompassing cultivated taxa and their wild relatives), which is then matched at genus level with a list of taxa found in the country or region (derived from a published Flora or other sources)—in this case a database containing floristic data for Europe and the Mediterranean. The floristic data are then mined for the accepted taxa contained in the matching genera and these are extracted to form the CWR checklist.

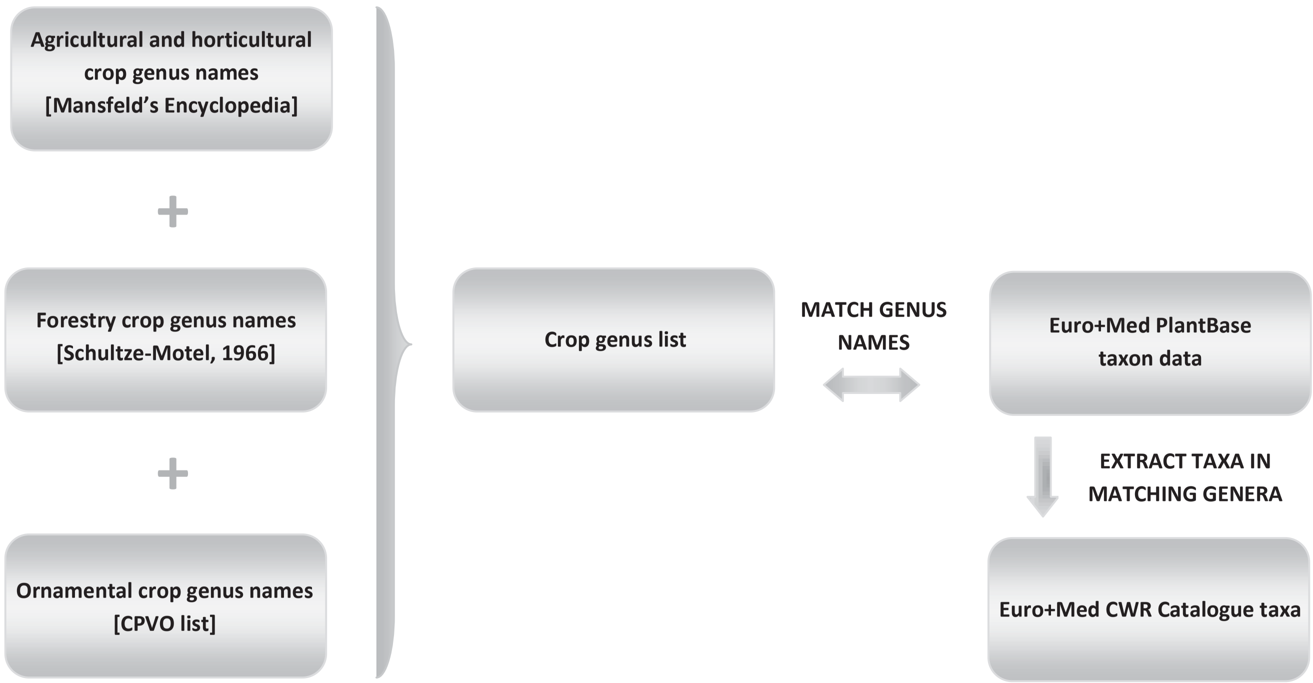

Figure 2.1 A simplified model showing the concept and basic process of creating the CWR Catalogue for Europe and the Mediterranean – the method can be applied in any country or region by replacing the Euro+Med PlantBase taxon data with national or regional floristic data.

2.2.2 Data sources

The CWR Catalogue for Europe and the Mediterranean is primarily derived from two major databases: Euro+Med PlantBase (Euro+Med, 2006–), which provides the taxonomic backbone to the Catalogue, and Mansfeld's World Database of Agricultural and Horticultural Crops (Hanelt and IPK, 2001; http://mansfeld.ipk-gatersleben.de)—referred to here as 'Mansfeld's database'—which is the primary source of crop genus names. Mansfeld's database was used as it is the most comprehensive source of information on plants cultivated worldwide in which the data were accessible in a digitized format suitable for use in the analysis. Genus name lists for forestry taxa were drawn from the publication of Schultze-Motel (1966), 'Enumeration of cultivated forest plant species', and for ornamental plant taxa, from the Community Plant Variety Office (CPVO) (see section 2.2.2.3).

When following this methodology to create a national or regional CWR checklist, practitioners require floristic data (i.e., a list of plant taxa that occur in the area concerned—in this case Euro+Med PlantBase) in tabulated electronic format. Ideally, when a complete floristic checklist (i.e., all known plant taxa in the area) is available in the required format, a comprehensive 'complete CWR checklist' can be created as this provides a basis for planning conservation of the widest range of CWR. However, a 'partial CWR checklist' can also be prepared when the data are not already available electronically, or are only available for part of the flora. In such cases, a 'monographic' approach is used in which a limited number of crop gene pools are included—usually those that are *a priori* considered to be a priority for food, nutrition and economic security. For further information about complete and partial checklists, and the monographic and floristic approaches, see Magos Brehm *et al*. (2017).

A database containing lists of crops and crop genera is under preparation (Kell *et al*., 2019) to facilitate free access to these data for practitioners wishing to create CWR checklists.

2.2.2.1 Euro+Med PlantBase

Euro+Med PlantBase (Euro+Med, 2006–) is an online database and information system for the vascular plants of Europe and the Mediterranean region, providing an up-to-date and critically evaluated consensus taxonomic core for the flora of the region. Originally developed at the University of Reading, UK with funding from the European Union under the Framework 5 Programme, the database comprises names and associated data from *Flora Europaea* (Tutin *et al*. 1964–1980, 1993), the MedChecklist (Greuter *et al*., 1984, 1986, 1989), the Flora of Macaronesia dataset (Hansen and Sunding, 1993), and published Floras from the Euro-Mediterranean region.

Euro+Med PlantBase encompasses all vascular plants of Europe and the Mediterranean region, including ferns and fern allies, and includes native species, naturalized aliens, frequently occurring casuals, frequent and well characterized hybrids, crop weeds, plants that are conspicuously cultivated outdoors (including crops planted on a field scale and street and roadside trees, but not commonly grown park and garden plants). The geographical area covered includes all of Europe[13], the Caucasus, Asiatic Turkey and the East Aegean Islands, Syria, Lebanon, Israel, Jordan, Cyprus, Egypt, Libya, Tunisia, Algeria, Morocco and Macaronesia. The database includes scientific names and authorities, synonyms, occurrences of taxa in countries—and in some cases country subunits, the status of occurrence (i.e., whether the taxon is native, introduced, cultivated or the status is unknown), and a flag to identify taxa endemic to the region, or to one or more countries or territories.

Taxon and occurrence data extracted from Euro+Med PlantBase (Euro+Med, 2006–) were utilized to create the CWR Catalogue v. 4.0. Since 2006, Euro+Med PlantBase has been undergoing a process of revision on a family by family basis and at the time of creation of the CWR Catalogue v. 4.0, around 92% of the database had been updated according to the most recent and prominent taxonomic treatments. The revised dataset (Euro+Med PlantBase Secretariat, Berlin, pers. comm., April 2014) combined with the January 2006 dataset (Euro+Med PlantBase Secretariat, Reading, pers. comm., January 2006) for the unrevised families forms the taxonomic core of the Catalogue, as well as providing one or more geographic reference for each taxon entry in terms of an occurrence in a country and/or subnational geographic area.

[13] The eastern boundary of Europe in Russia and Kazakhstan follows the definition of *Flora Europaea* (Tutin *et al*. 1968-1980; 1993): from the Arctic Ocean along the Kara River to 68°N, thence along the crest of the Ural Mountains (following administrative boundaries) to 58°30'N; thence by an arbitrary straight line to a point 50km east of Sverdlovsk, and by another arbitrary straight line to the head-waters of the Ural River (south of Zlatoust); thence along the Ural River to the Caspian Sea (see map at www.emplantbase.org/information.html).

2.2.2.2 *Mansfeld's World Database of Agricultural and Horticultural Crops*

Mansfeld's database (Hanelt and IPK, 2001; http://mansfeld.ipk-gatersleben.de) contains in excess of 6100 species of agricultural and horticultural cultivated plants worldwide, including cultivated medicinal and aromatic plants but with the exception of ornamental and forestry plants, and cultivars. The database includes algae and fungi, pteridophyta and gymnosperms. Mansfeld's database was the primary source of crop genus names. As the database is extremely comprehensive, it includes most if not all genera containing crops in the groups already mentioned, as well as related genera that include secondary wild relatives (e.g., *Aegilops* in the wheat gene pool), and tertiary wild relatives (e.g., *Elymus* in the wheat gene pool and *Tripsacum* L. in the maize gene pool). In some cases, the related genera also include cultivated taxa—however, the inclusion of *Aegilops* in the database for example is not because it contains a cultivated species but because the genus was previously subsumed in *Triticum* L. and contains species that are important for their role in the evolution of wheat and as gene donors for crop improvement (Hanelt and IPK, 2001; http://mansfeld.ipk-gatersleben.de).

2.2.2.3 *Cultivated forestry and ornamental taxa*

For forestry taxa, a list of genera was extracted from 'Enumeration of cultivated forest plant species' (Schultze-Motel, 1966). For ornamentals, a list of taxa was provided by the Community Plant Variety Office (CPVO)[14], which is the organization responsible for implementing the 'system for the protection of plant variety rights' established by European Community legislation, which allows for intellectual property rights to be granted for plant varieties within

[14] www.cpvo.europa.eu

the EU. This list contains all genera and species for which the CPVO had received an application for Community Plant Variety Rights since it came into operation in 1995 until 04 December 2015 (J. Maison, pers. comm., CPVO, 04 December 2015). As the use of plant taxa in ornamental horticulture is so extensive, the CPVO list was chosen in order to provide a clearly defined limit to the list of ornamental CWR in the Catalogue (see Kell and Maxted, 2003).

2.2.3 Data analysis: application and platform

All data were imported into database tables built in Microsoft Office Access 2007 operated by Microsoft Windows 7. Data analyses were carried out within the same application.

2.2.4 Euro+Med PlantBase data filtering

The taxon and occurrence data in Euro+Med PlantBase (April 2014 dataset) are organized in three main related tables: 1) accepted taxa, 2) non-accepted taxa, and 3) occurrence data. In the January 2006 dataset, the data are organized in two related tables: 1) all taxa, and 2) occurrence data. Initial filtering of the data in these tables was undertaken to select taxon and occurrence records for inclusion in the analysis, as detailed below.

2.2.4.1 Selecting taxa by rank

<u>Selection of taxa from the 2014 dataset</u>

Table 2.1 shows the taxonomic ranks assigned to each taxon entry in the tables of accepted and non-accepted taxa in the April 2014 dataset (in the field 'RankAbbrev' – rank abbreviation). Taxa of the ranks indicated in bold and marked with asterisks were selected (all naturally occurring specific and sub-specific taxa) and the remaining records excluded from the analysis at this stage. Depending on how the floristic data are organized and on the skills of the data analyst,

supra-specific taxa (e.g., families, subgenera, sections and series) may be included in the initial stages of the analysis or added to a CWR checklist once the specific and sub-specific taxa are selected for inclusion. Their exclusion in the initial stage of the analysis may simplify data processing, including matching genus names in the floristic checklist with the list of crop genus names.

Selection of taxa from the 2006 dataset

Naturally occurring taxa within genera that are not included in the 2014 dataset (527 genera) were selected for inclusion in the analysis. Table 2.2 shows the taxonomic ranks assigned to each taxon entry in the January 2006 dataset (in the field 'Rank') at genus level and below. Taxa of the ranks indicated in bold and marked with asterisks were selected for inclusion in the analysis. The taxa in this dataset are organized in one table, 'Taxon' which contains the field 'Status' to tag entries as accepted taxa or synonyms.

Table 2.1 Taxon selection by taxonomic rank – 2014 dataset, showing the ranks included in the two tables containing accepted and non-accepted taxon names (y). Ranks are listed in alphabetical order and selected ranks are shown in bold and marked with asterisks.

Rank abbreviation	Definition	Accepted taxa	Non-accepted taxa
aggr.*	**aggregate**	**y**	**y**
convar.	Convariety[i]	–	y
cl.	class	y	–
coll. sp.*	**collective species[ii]**	y	–
div.	division, or phylum	y	–
f.*	**form**	**y**	**y**
fam.	family	y	y
gen.	genus	y	y
grex	Grex[iii]	–	y
ordo	order	y	y
prol.	Proles[iv]	–	y
race*	**race[v]**	–	**y**
reg.	*regnum*, or kingdom	y	–
sect.	section	y	y
sp.*	**species**	**y**	**y**
subcl.	subclass	y	–
subdiv.	subdivision	y	–
subfam.	subfamily	y	–
subf.*	**subform**	–	**y**
subg.	subgenus	y	y
subsect.	subsection	–	y
subsp.*	**subspecies**	**y**	**y**
subvar.*	**subvariety**	–	**y**
superor.	superorder	y	–
trib.	tribe	–	y
unranked	unranked	–	y
var.*	**variety**	–	**y**

[i] A group of cultivars (cultivated varieties) within a species or inter-specific hybrid.

[ii] 'Coll. sp.' (collective species) is only used to code the ranks of taxa in the genus *Pilosella* (see Bräutigam and Greuter, 2007).

[iii] A horticultural hybrid of orchid.

[iv] An infra-specific category validly used in the past and now only relevant for basionyms (E. Raab-Straube, Berlin, pers. comm., 2014).

[v] A recognizably distinct local intra-specific population.

Table 2.2 Taxon selection by taxonomic rank – 2006 dataset – showing the ranks included in the table containing both accepted and non-accepted taxon names at genus level and below. Ranks are listed in alphabetical order and selected ranks are shown in bold and marked with asterisks.

Rank	Definition
Forma*	**form**
Genus	genus
Sectio	section
Series	series
Species*	**species**
Speciesgroup	**species group**
Subgenus	subgenus
Subsectio	subsection
Subseries	subseries
Subspecies*	**subspecies**
Subvarietas*	**subvariety**
Tax.infrasp.	Infra-specific taxon[i]
Varietas*	**variety**

[i] Contains a number of different sub-specific designations, including 'race' and 'Proles'. However, this rank is not used in the 2014 dataset. Therefore, it was not included in the selection of 2006 taxa.

2.2.4.2 Preparation of occurrence data

Preparation of occurrence data – 2014 dataset

In the 2014 dataset, each record of a taxon occurrence in a geographical unit is coded in the field 'SummaryStatus' in the table of occurrences (Table 2.3). All records were selected for inclusion in the analysis, except for those coded 210 and 310 which are known to have been reported in error.

Preparation of occurrence data – 2006 dataset

In the 2006 dataset, occurrence records are organized in a table containing the status fields: 'Native', 'Introduced', 'Cultivated' and 'StatusUnknown' following the Taxonomic Databases Working Group (TDWG) Standard, 'Plant Occurrence and Status Scheme' (WCMC, 1995) (Table 2.4). Where the status is unknown, records are coded: 'P' (Present), 'S' (Assumed present), 'D' (Doubt about presence), 'E' (Extinct), 'F' (Recorded as present in error), 'A' (Absent).

Table 2.3 Codes used in the field 'SummaryStatus' in Euro+Med PlantBase (April 2014 dataset) and corresponding descriptions.

Summary status codes	Summary status description
120	cultivated
210	introduced: reported in error
220	introduced: presence questionable
240	introduced: doubtfully introduced (perhaps cultivated only)
250	introduced
270	introduced: adventitious (casual)
280	introduced: naturalized
310	native: reported in error
320	native: presence questionable
330	native: formerly native
340	native: doubtfully native
350	native
999	endemic for the Euro-Mediterranean region

Records coded 'P', 'S' 'D' and 'E' under 'status unknown' were selected for the analysis (i.e., filtering out records coded 'F' – recorded as present in error and 'A' – absent). Multiple (up to three) codes can appear against some records (e.g., 'AF' or 'PD'). Where there were code combinations containing only 'F' or 'A', these records were not selected. Records with multiple codes containing 'P', 'S' or 'D' were maintained in the analysis (e.g., 'PA', 'AD', 'PD', 'PE') because they indicate uncertainty about the status of the taxon. All other records were included in the analysis, no matter which combination of codes are used in the 'native', 'introduced' and 'cultivated' fields.

Table 2.4 Codes used in the fields 'Native', 'Introduced', 'Cultivated' and 'StatusUnknown' in Euro+Med PlantBase (Reproduced from Euro+Med PlantBase Secretariat, 2002). Original data standard: WCMC (1995).

Code	Value	Explanation
Native status		
N	Native	The taxon is native (autochthonous) within the area concerned (as contrasted with 'introduced' and 'cultivated' defined below).
S	Assumed to be native	Assumed to be native to the area concerned.
D	Doubtfully native	There is doubt as to whether the status of the plant in the area concerned is native or not.
E	Formerly native (extinct)	The plant is native, doubtfully native or assumed to be native in the area concerned and has become extinct as such.
A	Not native	The plant is definitely not native.
F	Recorded as native in error	The plant has been recorded as native in the area concerned but all such records have been disproved or discounted.
Introduced status		
I	Introduced	The plant has been recorded growing in an area that is outside of its assumed true and normal distribution. This implies evidence that the plant did not formerly occur in the area and also that the plant is either: established and successfully reproducing (either sexually or asexually) or a frequently occurring casual. The plant must not be in cultivation: it does not mean (or include) "Introduced to Cultivation". The means of introduction, whether by man or any natural means is irrelevant and may be unknown.
S	Assumed to be introduced	There is doubt as to whether the Status of the plant in the area concerned is Introduced, as defined above, or not. All records about the introduced status of the plant in the area are in doubt.

Table 2.4 Codes used in the fields 'Native', 'Introduced', 'Cultivated' and 'StatusUnknown' in Euro+Med PlantBase (Reproduced from Euro+Med PlantBase Secretariat, 2002). Original data standard: WCMC (1995).

D	Doubtfully introduced	There is doubt as to whether the Status of the plant in the area concerned is Introduced, as defined above, or not. All records about the introduced status of the plant in the area are in doubt.
E	Formerly introduced (Extinct)	The plant is introduced, doubtfully introduced or assumed to be introduced in the area concerned and has become Extinct as such. The criterion of extinction is that the plant was not found (as an Introduction) after repeated searches of known and likely areas (i.e. sites within the area covered by the record), even though the plant may be extant elsewhere.
A	Not introduced	The plant is definitely not introduced (as defined above) in the area concerned.
F	Recorded as introduced in error	The plant has been recorded as introduced in the area concerned but all of those records have been disproved or discounted. A known fallacious introduced record must have been made, and it must be known that the plant does not occur as an introduction in the area.
Cultivated status		
C	Cultivated	The plant is established in cultivation outdoors in the area concerned. Only plants that are conspicuously cultivated outdoors should be included (includes crops planted on a field-scale and street and roadside trees).
S	Assumed to be cultivated	Assumed to be Cultivated in the area concerned.
D	Doubtfully cultivated	There is doubt as to whether the status of the plant is cultivated or not in the area concerned. All records about the cultivated status of the plant in the area are in doubt.
E	Formerly cultivated (extinct)	The plant was at one time cultivated, doubtfully cultivated or assumed to be cultivated in the area concerned and has become extinct in cultivation in this area, even though it may be extant elsewhere.
A	Not cultivated	The plant is definitely not cultivated (as defined above) in the area concerned.

Table 2.4 Codes used in the fields 'Native', 'Introduced', 'Cultivated' and 'StatusUnknown' in Euro+Med PlantBase (Reproduced from Euro+Med PlantBase Secretariat, 2002). Original data standard: WCMC (1995).

F	Recorded as cultivated in error	The plant has been recorded as Cultivated in the area concerned but all of those records have been disproved or discounted. A known fallacious record of cultivation must have been made, and it must be known that the plant is not cultivated in the area.
Status unknown		
P	Present	The plant is present in the area and meets the criteria for inclusion in Euro+Med PlantBase (i.e. it is either a native species, naturalized alien, frequently occurring casual, frequent and well characterized hybrid, crop weed, or a plant that is conspicuously cultivated outdoors (either a crop planted on a field-scale or street tree but not a commonly grown park or garden plant). Adventives, casuals etc. are not included although noxious weeds (other than those that have become naturalized which will be included for that reason) may be recorded.
S	Assumed Present	It is highly probable that the plant does occur in the area.
D	Doubt about presence	There is doubt about whether the plant presently occurs in the area. This might be because all records are very old, locality details are uncertain, etc.
E	Extinct	The plant was once in the area (P or S) or may once have been in the area (D) but is now extinct in the area.
F	Recorded as present in error	The plant has been recorded as present in the area concerned but the record has been discounted or disproved.
A	Absent	There are no records to suggest that a plant has ever occurred in the area concerned.

In addition to the occurrence status, the field 'WorldDistCompl' is included to flag records that define the global distribution of the taxon (Table 2.5). This flag can be used to ascertain the endemic status of taxa.

Table 2.5 Codes used in the field 'WorldDistCompl' (Reproduced from Euro+Med PlantBase Secretariat, 2002).

Code	Value	Explanation
C	Distribution complete	The taxon is known to occur only within the territory; it is endemic to the territory.
I	Distribution incomplete	The taxon is known not to be endemic to the territory.
U	Not known whether distribution complete	It is not known if the taxon is endemic to the territory.

2.2.4.3 Consolidation of the 2014 and 2006 datasets

The 2014 and 2006 data, which are organized in different formats, were combined into new data tables. For the taxon data, although the coding for the 2006 entries are different to those in the 2014 dataset (e.g., 'species' instead of 'sp.', 'Varietas' instead of 'var.' and 'Forma' instead of 'f.'), it was possible to fit the 2006 data into the 2014 structure so that all data are in the current format. For the occurrence data, a combination of the 2014 and 2006 data structures is necessary to maintain all required fields associated with the 2006 data until such time that the remaining families have been revised and included in the current version of Euro+Med PlantBase, and the next version of the CWR Catalogue produced. For example, the field 'SummaryStatus' is used in the 2014 version, not in the 2006 version, and the field 'StatusUnknown' is used in the 2006 version but not in the 2014 version. The consolidated dataset comprising the filtered taxon and occurrence data is from here on referred to as 'E+Mf'.

2.2.5 Selection of crop genera

Three data sources (described in section 2.2.2) were utilized to create a list of crop genera (the 'crop genus list'): Mansfeld's database (Hanelt and IPK, 2001; http://mansfeld.ipk-gatersleben.de), 'Enumeration of cultivated forest plant species' (Schultze-Motel, 1966), and the

Community Plant Variety Office list of ornamental species (J. Maison, pers. comm., CPVO, 04 December 2015). To capture as wide a range of agricultural and horticultural crop and CWR taxa in the Catalogue as possible, both accepted and synonymic genus names were selected from Mansfeld's database. In this analysis, the term 'synonymic genus names' is used to refer to genera containing species names that are not accepted in a taxonomic treatment. This may include both whole genera that are considered to be synonyms and genera that contain both accepted species names and synonyms. Thus, in cases where a genus name is considered a synonym in Mansfeld's database but is accepted by Euro+Med PlantBase, or where a genus name that contains non-accepted species names in Mansfeld's database contains accepted species names in Euro+Med PlantBase, this genus name is included in the CWR Catalogue in addition to accepted genus names that match (see section 2.2.6 for further details). Only accepted genus names were selected from Schultze-Motel (1966)—because the data were not previously available in electronic format, extraction of synonyms in addition to accepted names was not possible with the available resources. The CPVO does not adopt specific accepted taxonomies, therefore no distinction was made in the ornamental plant dataset between accepted and synonymic genus names—the genus names were thus used as provided by this data source. The crop genus list contains 7238 genera in total, which includes 6914 accepted names and synonyms sourced from Mansfeld's database (see section 2.3.1, Table 2.6).

2.2.6 Genus name matching and extraction of taxa from Euro+Med PlantBase

The genera in the filtered version of Euro+Med PlantBase (E+Mf – see section 2.2.4) corresponding with the crop genus list described in section 2.2.5 were selected. To facilitate this process, the taxon data in E+Mf were analysed independently of the occurrence data. Both accepted and synonymic crop genus names from Mansfeld's database were matched with the accepted genus names from Euro+Med PlantBase to take account of different taxonomies (Fig. 2.2 – 'primary level match'). Thus, where either an accepted genus name or synonym in Mansfeld's database matched an accepted genus name in Euro+Med PlantBase, the genus was included in the Catalogue. For example, the genus *Patellifolia* A.J. Scott, Ford-Lloyd & J.T. Williams is accepted by Euro+Med PlantBase but is a synonym of *Beta* L. in Mansfeld's database. If *Patellifolia* had not been included in the analysis of matching genus names, some taxa from the beet gene pool would have been omitted from the Catalogue. This approach captures the majority of synonyms but is not comprehensive because Euro+Med PlantBase includes further synonyms that are not included in Mansfeld's database. For example, the genus *Vavilovia* Fed. (syn. *Pisum* L.) is accepted in Euro+Med PlantBase but is not included in Mansfeld's database as a synonym. *Vavilovia* contains the species *V. formosa* (Steven) Fedor.—a synonym of *Pisum formosum* (Steven) Alef., which is a close wild relative of garden pea, *Pisum sativum* L. Therefore, to capture the widest range of CWR as possible, the matching process described above was extended to match non-accepted genus names in Euro+Med PlantBase with accepted genus names in Mansfeld's database (i.e., where a synonym in Euro+Med PlantBase matches an accepted name in the crop genus list, the equivalent accepted genus name in

Euro+Med PlantBase was included in the Catalogue) (Fig. 2.2 – 'secondary level match'). As noted in section 2.2.5, only accepted names were included in the forestry crop genus list and there is no distinction between accepted names and synonyms in the ornamental crop genus list. However, the forestry and ornamental crop genus lists were also included in the secondary level matching process to capture synonyms in Euro+Med PlantBase with genus names matching those in the forestry and ornamental lists, and then selecting the equivalent accepted taxa from Euro+Med PlantBase. For example, the genus *Sophora* L. (which is included in the forestry genus list) includes five accepted species and two synonyms in Euro+Med PlantBase—the synonyms occurring in the genus *Cladrastis* Raf. Following this genus name matching process, the accepted taxa within the harmonized genera were selected and the taxon data recombined with the occurrence data in E+Mf to form the CWR Catalogue.

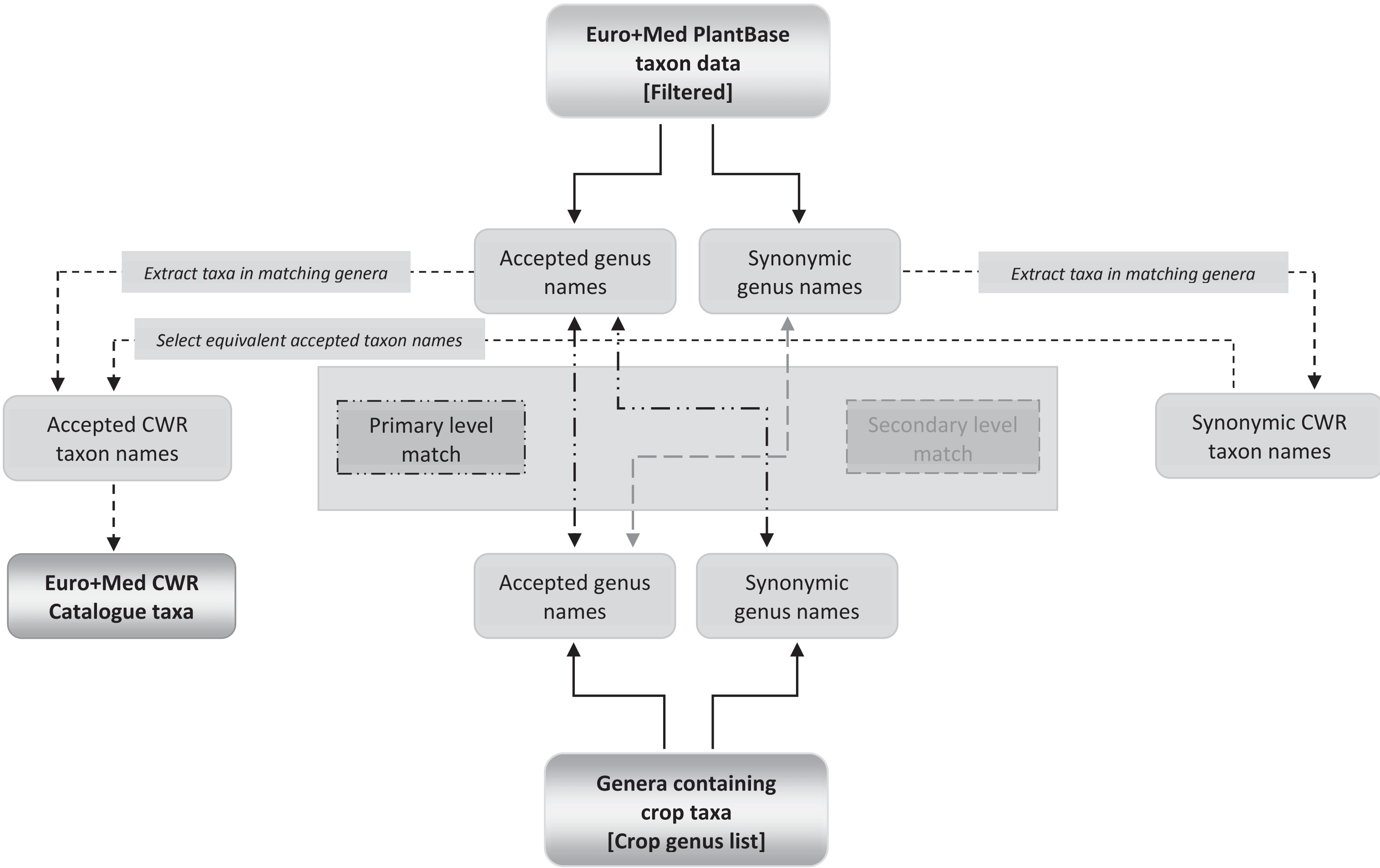

Figure 2.2 The process of matching and extracting taxon names in the creation of the CWR Catalogue. 'Synonymic genus names' refers to genus names containing species names that are not accepted in a taxonomic treatment. This may include both whole genera that are synonyms and genera that contain both accepted species and synonyms.

2.3 Results

2.3.1 Numbers of taxa in the CWR Catalogue data sources

The naturally occurring specific and sub-specific taxa selected from Euro+Med PlantBase for inclusion in the analysis (i.e., prior to data filtering on the basis of occurrence status—see section 2.2.4.1) comprise:

- 29,073 species, 10,803 sub-specific taxa or forms, and 246 aggregates or collective species from the table of accepted taxa in the 2014 dataset;
- 52,593 species, 30,659 sub-specific taxa, forms, subforms or races, and 177 aggregates from the table of non-accepted taxa in the 2014 dataset;
- 2798 accepted species or species groups, 1142 accepted sub-specific taxa or forms, 2544 synonym species or species groups, and 868 synonym sub-specific taxa or forms from the table of accepted and non-accepted taxa in the 2006 dataset.

The 2014 and 2006 taxon datasets combined contain in excess of 31,800 accepted species, more than 11,800 accepted infra-specific taxa, and nearly 78,000 specific and infra-specific synonyms (Table 2.6).

The crop genus list contains 7238 genera. Table 2.6 summarizes the number of genera attributable to each data source. Note that some genera are common to two or more sources—for example, Mansfeld's database contains 63% of the CWR genera sourced from the other crop data sources (forestry and ornamental) combined. When the crop genera are matched with

Euro+Med PlantBase (i.e., to select those taxa that occur in Europe and the Mediterranean), Mansfeld's database is found to contain 76% of the CWR genera sourced from the other crop data sources.

After filtering the occurrence data (see section 2.2.4.2), the number of accepted species names in Euro+Med PlantBase is reduced from 31,806 to 31,291 (Table 2.7).

Table 2.6 CWR Catalogue data sources – summary statistics

Data source	No. of records
Euro+Med PlantBase[i]	
Euro+Med PlantBase: accepted species[ii]	31,806
Euro+Med PlantBase: accepted infra-specific taxa	11,886
Euro+Med PlantBase: synonyms (species)	49,589
Euro+Med PlantBase: synonyms (infra-specific taxa)	28,405
Crop genera	
Agricultural and horticultural crop genera[iii]	6914
Forestry genera[iv]	338
Ornamental genera[v]	612
Total crop genera[vi]	**7238**

[i] Euro+Med PlantBase April 2014 dataset combined with the January 2006 dataset for genera not updated in the April 2014 dataset.
[ii] Including aggregates and collective species.
[iii] Mansfeld's World Database of Agricultural and Horticultural Crops (Hanelt and IPK, 2001; http://mansfeld.ipk-gatersleben.de)—accepted names and synonyms.
[iv] 'Enumeration of cultivated forest plant species' (Schultze-Motel, 1966)—accepted names only.
[v] Community Plant Variety Office (www.cpvo.eu.int) (J. Maison, pers. comm., CPVO, 04 December 2015)—no accepted taxonomy.
[vi] The three groups listed form the crop genus list, containing 7238 genera. Some genera are common to two or more sources.

2.3.2 Numbers of records in the CWR Catalogue

The Catalogue contains 261,191 records of taxon occurrences in the Euro-Mediterranean region[15]. This includes occurrence records in 132 geographical areas, including countries, sub-country units, sub-regions and the region as a whole—the latter coding to allow for those taxa endemic to the region to be identified. Examples of sub-country units are 'Channel Is.' (United Kingdom), 'Corse' (France), 'East Aegean Islands' (Greece), 'Eastern European Russia' (Russian Federation), 'Faial' (Portugal), 'Gomera' (Spain), 'Kriti with Karpathos, Kasos & Gavdhos' (Greece), 'Madeira' (Portugal), 'Novaya Zemlya & Franz-Joseph Land' (Russian Federation), 'São Miguel' (Portugal), 'Svalbard' (Norway), and 'Tenerife' (Spain). Sub-regions include 'Baltic states (Estonia, Latvia, Lithuania) and Kaliningrad region', 'Caucasia (Ab + Ar + Gg + Rf(CS))' (Azerbaijan, Armenia, Georgia and Central–South European Russia), 'Europe', 'Israel-Jordan', 'Lebanon-Syria', and 'Transcaucasia (Azerbaijan, Armenia, and Georgia)'. Occurrences recorded at sub-country and sub-regional levels were maintained in the Catalogue as they may be informative for conservation planning—particularly with regard to ascertaining the global distribution of taxa. Fifty-seven countries fall within the geographic scope of the Catalogue (Table 2.7). Countries were defined following ISO 3166 – Country Codes[16]. However, some geographic areas in Euro+Med PlantBase that cannot be assigned to an ISO classified country were maintained (e.g., 'Former Jugoslavia' and 'Sicily with Malta') to avoid losing any taxon occurrence records.

[15] A map of the geographic scope of Euro+Med PlantBase can be found at: www.emplantbase.org/information.html

[16] https://www.iso.org/iso-3166-country-codes.html

In terms of taxa, 85% of the 31,291 plant species recorded by Euro+Med PlantBase as present or formerly present (extinct) in the region are included in the Catalogue, and these species are found in 1820 genera (Table 2.8). A high proportion of the species in the Catalogue (23,634 – 89%) are recorded with some certainty as native to the region and 14,251 (53%) as endemic.

Table 2.7 Countries included in the CWR Catalogue for Europe and the Mediterranean (defined following ISO 3166 – Country Codes – https://www.iso.org/iso-3166-country-codes.html).

Albania	Georgia	Moldova
Algeria	Germany	Morocco
Andorra	Greece	Netherlands
Armenia	Hungary	Norway
Austria	Iceland	Poland
Azerbaijan	Ireland	Portugal
Belarus	Israel	Romania
Belgium	Italy	Russian Federation
Bosnia-Herzegovina	Jordan	Serbia
Bulgaria	Kazakhstan	Slovakia
Croatia	Latvia	Slovenia
Cyprus	Lebanon	Spain
Czech Republic	Libya	Sweden
Denmark	Liechtenstein	Switzerland
Egypt	Lithuania	Syria
Estonia	Luxembourg	Tunisia
Faroe Islands	Macedonia, The Former Yugoslav Republic of	Turkey
Finland	Malta	Ukraine
France	Montenegro	United Kingdom

Table 2.8 The CWR Catalogue: summary statistics.

Plant taxa present or formerly present in the Euro-Mediterranean region (accepted names)[i]	**No. of taxa**		
	Genera	**Species**[ii]	**Infra-specific taxa**[iii]
Total no. of plant taxa (E+Mf)	2458	31,291	11,702
Agricultural and horticultural taxa (crops and CWR)	1695	25,267	9922
Forestry taxa (crops and CWR)	216	2817	503
Ornamental taxa (crops and CWR)	868	13,846	4159
CWR Catalogue for Europe and the Mediterranean (Total n$^{o.}$ of crop and CWR taxa)	**1820**	**26,704**	**10,327**

[i] The numbers of genera, species and sub-specific taxa in: a) the filtered version of Euro+Med PlantBase (E+Mf) (i.e., before crop genus matching); b) each of the three crop groups (agricultural and horticultural, forestry and ornamental) after matching the crop genus list with E+Mf; and c) the CWR Catalogue.
[ii] Species, species groups, aggregates and collective species.
[iii] Subspecies, varieties and forms.

At least 1100 (55%) of the agricultural and horticultural (Mansfeld) crop genera, 147 (43%) of the forestry genera and 368 (60%) of the ornamental genera are found in the Euro-Mediterranean region. In total, at least 51% of genera in the crop genus list are found in the region (percentage based on the number of accepted genus names in Mansfeld's database combined with the genus names in the forestry and ornamental lists – 2380 genera). These percentages are based on the results of the primary level genus name match only because the additional genera included through the two-way matching process increases these percentages significantly. This is clearly illustrated by the disparity between the number of genera in the ornamental crop genus list (612 – Table 2.6) and the number after carrying out the two-way matching process (868 – Table 2.8).

No less than 2229 (8%) of the species listed in the CWR Catalogue can be considered agricultural and horticultural crops in the Mansfeld sense (see http://mansfeld.ipk-gatersleben.de)—9% of the 25,267 agricultural and horticultural crop and CWR species in the Catalogue. Thus, at least 91% of these species can be considered as wild relatives of agricultural and horticultural crops, while noting that some cultivated species may also occur in their wild form and are thus both crops and CWR. The occurrence data indicate that 1125 species in the Catalogue are cultivated in the region and that of the 2229 agricultural and horticultural crop species listed in the Catalogue, 601 (27%) are not cultivated in the region. These 601 species are therefore likely to comprise cultivated forestry and ornamental species (see section 2.4.3.1 for further discussion).

2.4 Discussion

2.4.1 The Catalogue as a comprehensive resource for CWR conservation planning and utilization

The CWR Catalogue for Europe and the Mediterranean—or any national or regional CWR checklist—provides fundamental baseline data for methodical and efficient conservation planning and is a foundation for recording and communicating information on the actual or potential utilization value of CWR for crop improvement. While many taxa in a CWR checklist may not be priorities for immediate conservation planning and action, either because they are related to crops that are not considered to be of highest socio-economic importance or because they are distantly related and not threatened, once a national or regional CWR conservation strategy is established, additional taxa of less immediate importance may be incorporated into the plan at a later date. Therefore, a CWR checklist is a reference base for conservation planning in the immediate and longer term. In addition, a CWR checklist can be used to assess the representativeness of the taxa in existing conservation initiatives by undertaking cross-matches between the CWR checklist taxa and the taxon lists of such initiatives—for example, see Kell *et al*. (2008a – Annex 2), in which analyses of CWR representation in the IUCN Red List of Threatened Species, EU Habitats Directive, Important Plant Areas and botanic gardens' living collections were carried out. Furthermore, during the process of planning CWR conservation for priority species, knowledge of other CWR taxa that may coexist with those taxa can be used to plan multi-species conservation actions, both *in situ* and *ex situ*.

Since the publication of the CWR Catalogue v. 3.2 (Kell *et al*., 2005, 2008a – Annex 2), the concept and approach presented in this chapter has been promoted in the context of a number of projects with a focus on CWR (including through training programmes) and in several publications—most recently the Interactive Toolkit for Crop Wild Relative Conservation Planning (Magos Brehm *et al*., 2017). The approach has subsequently been applied by a number of conservation practitioners to produce complete or partial national CWR checklists—for example, in Benin (Idohou *et al*., 2013), Zambia (Ng'uni and Munkombwe, 2017) and South Africa (SANBI, ARC and DAFF, 2017). In the Euro-Mediterranean region, national CWR checklists have been developed for a number of countries by utilizing data extracted from the CWR Catalogue and harmonizing the data with the nationally accepted taxonomic classifications (e.g., Portugal – Magos Brehm *et al*., 2008; Cyprus – Phillips *et al*., 2014; United Kingdom – Fielder *et al*., 2015; Czech Republic – Taylor *et al*., 2017; and North Africa – Lala *et al*., 2018). Following the creation of these national checklists, priority taxa have been selected and diversity and conservation gap analyses undertaken to identify populations and sites requiring conservation interventions. In addition to providing the backbones to national CWR checklists in the region, the data in the CWR Catalogue v. 3.2 (Kell *et al*., 2005) were used to inform the Red List assessment of CWR in Europe (Bilz *et al*., 2011; Kell *et al*., 2012 – Chapter 3) and the current version (v. 4.0) provided the foundations for the selection of priority species at regional level (Kell *et al*., 2016 – Chapter 5).

The CWR Catalogue v. 3.2 (Kell *et al*., 2005) was published via the Crop Wild Relative Information System (Kell *et al*., 2008b)—an information management structure for CWR data and searchable online database—as well as on CD-ROM. National datasets were also circulated to the PGR National Focus Points in each country in the European+[17] region, and were made available via the PGR Secure Conservation Helpdesk[18]. In addition, datasets were provided to contacts requesting them by email on an *ad hoc* basis. It is anticipated that the Catalogue v. 4.0 (i.e., the current version) will be published via the Dataverse Project[19], which has been used as an open source data repository for recently produced datasets in the context of the SADC CWR Project[20], including a tool for collating and managing national CWR checklist and inventory data (Thormann *et al*., 2017). This facility allows for different versions of datasets to be published

[17] The countries included in this circulation were the member countries of ECPGR (European Cooperative Programme for Plant Genetic Resources), which includes nations such as Armenia and Israel which are not part of geographic Europe.

[18] www.pgrsecure.org/helpdesk_cwr

[19] https://dataverse.org/

[20] www.cropwildrelatives.org/sadc-cwr-project/

over time and is therefore a suitable platform for publishing the current version and an updated version of the Catalogue in the future (also see section 2.4.3).

2.4.2 Caveats of the methodology

2.4.2.1 The breadth of the Catalogue

The Catalogue contains a high proportion (85%) of the flora of the region. When a similar result was found in early explorations of the data and methodology and after producing the Catalogue v. 3.2 (Kell *et al*., 2005, 2008a – Annex 2), such a high percentage was not anticipated. However, it became clear that combined with a very comprehensive list of genera containing cultivated taxa, the adoption of a broad definition of a CWR results in large numbers of species in a CWR checklist. Add to this the potentially inflated number of species included by taking full account of synonymy at genus level (see section 2.4.2.2) and the overall percentage is increased further. Nonetheless, as already highlighted in section 2.4.1, the systematic approach described in this chapter provides a solid foundation for CWR conservation planning and utilization, both in the immediate and long term. Furthermore, as Kell *et al*. (2017) (Chapter 6) note, while there are particular challenges in using CWR genetic diversity in plant breeding programmes, a wide array of techniques is now available and there is continuing rapid progress in their development and application—therefore, there are increasing options to overcome these challenges and more opportunities to utilize exotic germplasm in the development of new or improved varieties.

Very high percentages of crop and CWR species extracted from the genus name list derived from Mansfeld's database are common to the other two socio-economic groups—that is, 2707

(96%) of the 2817 species in the forestry list and 12,412 (90%) of the 13,846 species in the ornamental list. This is because many crop species have several uses, as do ornamental plants (e.g., medicinal, vegetable). Moreover, there are many species within the same genera as the agricultural and horticultural crop genera that have uses classified within one of the other two socio-economic groups—thus, these groups will share many of the same CWR. Perhaps not surprisingly, the group with the least percentage of species common to the other two groups is the forestry species, with 11% of species common to the agricultural and horticultural crops and 18% common to the ornamental species.

2.4.2.2 The crop genus list

Due to the comprehensiveness of Mansfeld's database, the crop genus list is very large and includes a number of genera that could warrant exclusion due to their relative obscurity in terms of the cultivated species that they encompass. For example, Mansfeld's database only lists one cultivated species in the genus *Acanthophyllum* C.A. Mey.—*A. gypsophiloides* Regel, which is reported to be "occasionally cultivated in Uzbekistan" and is otherwise harvested from the wild "to obtain saponines from the root-stocks" (Hanelt and IPK, 2001; http://mansfeld.ipk-gatersleben.de). The number of genera that could potentially be excluded is 350 (i.e., c. 5% of the crop genus list). This was deduced by matching the list of genera in Mansfeld's database with a list of genera known to contain crops cultivated on a scale to warrant their inclusion in the Catalogue, which was generated by combining the genus names contained in: a) the forestry and ornamental lists (i.e., those generated for this analysis as explained above); b) Annex I of the International Treaty on Plant Genetic Resources for Food and Agriculture (FAO, 2001); c) a list of major and minor food crops according to Groombridge and Jenkins (2002); and d) the list of CWR assessed as a component of the European Red List of Vascular Plants (Bilz *et al*., 2011; Kell *et al*., 2012 – Chapter 3). To decide whether to exclude some or all of these 350 genera, it is necessary to check each one in Mansfeld's database (online) to read the notes on cultivation of all the species listed in the genus in order to find out whether any are cultivated on a sufficiently large scale or are collected from the wild to be cultivated on a small scale, and thus make a judgement on whether the genus should be included. This process is very time-consuming and is somewhat subjective because one researcher may consider that a genus should be excluded, while another may feel it should be included.

These 350 genera encompass 2114 species in the Catalogue. However, an initial review of five of these genera resulted in only one that the lead author would consider excluding (the case of *Acanthophyllum* noted above). While the inclusion of some of these questionable genera does result in the inclusion of some CWR species in the Catalogue that may not strictly warrant inclusion (e.g., five species of *Acanthophyllum* which occur in the Euro-Mediterranean region), the trade-off in terms of the time it would take to check each of the species listed in the 350 genera and make subjective decisions, is warranted. Ultimately it means that the CWR Catalogue is a comprehensive dataset providing the baseline data needed for taxon prioritization and conservation planning in the region.

As detailed in section 2.2.5, only accepted genus names from Schultze-Motel (1966) were used in the analysis and the CPVO does not adopt specific accepted taxonomies, therefore no distinction was made in the ornamental plant dataset between accepted and synonymic genus names. The exclusion of synonymic genus names from the Schultze-Motel account has not had a significant effect on the number of species included in the Catalogue overall, since as already detailed in section 2.4.2.1, 96% of the species in the forestry crop and CWR group are common to the species in the agricultural and horticultural crop and CWR group. The secondary level matching process (see section 2.2.6) between the forestry genus name list and E+Mf adds 101 species to the list of taxa in the forestry group to partially account for synonymy. Similarly, the list of agricultural and horticultural crop and CWR species shares 90% of its taxa with the ornamental group in the Catalogue. Thus, taking into account synonymy in Mansfeld's database captures the majority of species in all groups.

2.4.2.3 Dealing with synonymy

Taking into account synonymy is important to ensure that a national or regional CWR checklist is comprehensive and caters for a wide range of users who may adhere to different taxonomies. The matching process described in section 2.2.6 and depicted in Figure 2.2 captures the widest range of CWR but the approach does present problems—while it is desirable to make a checklist as inclusive as possible, including all synonyms leads to an artificially large number of taxa when matching taxa at genus level. For example, the genus *Centaurea* L. includes *C. cyanus* L. (cornflower), widely cultivated for the cut flower industry, as well as being used as a garden ornamental and as an ingredient in some tea blends, as well as *C. montana* L. and *C. moschata* L., widely cultivated as garden ornamentals. According to Euro+Med PlantBase (Euro+Med, 2006–), *Centaurea* is a large genus with 601 species in the region. These species are included in the Catalogue by undertaking the primary level matching between accepted taxon names in

Euro+Med PlantBase and the crop genus list (Fig. 2.2), *Centaurea* being included in the list of ornamental genera and in the Mansfeld genus list as a synonym.

The first inflation of taxa in the Catalogue arises because the cultivated species *C. cyanus, C. montana* and *C. moschata* are not accepted in Euro+Med PlantBase—the accepted species occurring in the genera *Cyanus* Mill. (*C. cyanus* and *C. moschata*) and *Amberboa* Vaill. Thus, not only are taxa in the genus *Centaurea* included in the Catalogue, but also those in the genera *Cyanus* and *Amberboa* (44 and 7 species respectively). A second inflation of taxa arises by undertaking the secondary level matching when a further 89 species in the genus *Psephellus* Cass. that occur in the region are included because they are the accepted names of *Centaurea* spp. that are not accepted in Euro+Med PlantBase. However, the matching method ensures that all CWR taxa are included, is relatively straightforward and replicable in any country or region, and results in a fully comprehensive checklist.

An alternative approach to reduce the number of taxa in a CWR checklist would involve starting the process with a list of cultivated taxa (species and sub-specific taxa), identifying the accepted taxon names of those cultivated taxa according to the floristic treatment being used as the basis of the CWR checklist (in this case, Euro+Med PlantBase), and extracting all taxa within the same genera to create the CWR checklist. However, this approach would be highly complex (either at regional or national level) due to the large number of cultivated taxa worldwide, the large number of synonyms of those taxa, and the fact that there is not currently a comprehensive list of crop taxa and their synonyms readily available in electronic format. Furthermore, changes in the classifications of cultivated taxa could imply a revision of the checklist being required, whereas matching at genus level using the two-way process described here provides a more flexible baseline dataset in terms of capturing a broad range of taxa from the start.

It is also worth noting that although the secondary level matching process adds a large number of genera to the Catalogue (615), relatively few species are added (1744), with 377 of these genera only adding one species each to the Catalogue, 199 between two and nine species (653 species in total), 22 between 10 and 19 species (293 species in total), and 12 genera adding between 21 and 89 species each (421 species in total). The species added by undertaking the secondary level match account for less than 6.5% of the species in the Catalogue, which contains 26,704 accepted species in total (see Table 2.8).

Taxonomic uncertainty is of course an ongoing problem for conservationists—it is for this reason that it is necessary to adopt an accepted taxonomy in all conservation endeavours. However, in the case of providing access to a wide range of users of information, where should the line be drawn? As already noted, in Europe and the Mediterranean, if genus name matches are carried out between: 1) accepted names and synonyms in the crop genus list and accepted names in Euro+Med PlantBase, and 2) accepted names in the crop genus list (Mansfeld and forestry genera only) matched with synonyms in Euro+Med PlantBase and their accepted name equivalents selected for inclusion in the Catalogue, this results in a list of species accounting for around 85% of the Euro-Mediterranean flora. While this inclusive and comprehensive approach provides the best access to CWR information, it cannot be considered a true picture of the real number of CWR in the region as the number of taxa is artificially inflated. However, for the purposes of providing a comprehensive information system accessible to as wide a range of users as possible, including the second level matching is appropriate and advisable when creating any CWR checklist.

2.4.2.4 Uncertainty in the occurrence data

When filtering the Euro+Med PlantBase data to select taxon occurrences for inclusion in the Catalogue (see section 2.2.4.2), records described with uncertainty about their presence (i.e., 'presence questionable' in the April 2014 dataset, and those with or containing the codes 'S' – 'Assumed present' and 'D' – Doubt about presence in the 'Status unknown' field in the January 2006 dataset) were included. This ensures that when the statuses are confirmed, if a taxon is present it is already included, and if it is absent or recorded as present in error, these records can be removed. If occurrence records with the codes indicating uncertainty about their presence in the region had not been included in the analysis, the number of species in the Catalogue would have reduced from 26,704 to 25,067 (i.e., 6%)—quite a substantial reduction if these taxa are later recorded as absent or recorded as present in error.

2.4.3 Enhancements to the Catalogue

2.4.3.1 Identification of crop taxa and crop–CWR relationships

Since the purpose of the CWR Catalogue (or any CWR checklist) is to provide baseline data for conserving and utilizing these taxa for crop improvement, knowing which taxa are cultivated and the relationships between them and the related wild species would clearly be advantageous. Identifying cultivated species in the Catalogue is not straightforward because definitions vary from one data source to another and if synonymy is taken into account, taxon selection not only becomes complex, but the list of cultivated species may become artificially large (Kell *et al*., 2008a – Annex 2). Further, a taxon may be both cultivated and occur in the wild.

Kell *et al*. (2005) attempted to identify cultivated species and tag them in the online version of the CWR Catalogue v. 3.2 (for a full explanation of the process, see Kell *et al*. 2008a – Annex 2). This included: a) all taxa coded 'C' (Cultivated)[21], 'S' (Assumed to be cultivated) and 'D' (Doubtfully cultivated) in the occurrence status field 'Cultivated'; and b) species names in Mansfeld's World Database of Agricultural and Horticultural Crops (Hanelt and IPK, 2001; http://mansfeld.ipk-gatersleben.de), 'Enumeration of cultivated forest plant species' (Schultze-Motel, 1966) and the CPVO ornamental list (T. Kwakkenbos, pers. comm., CPVO, 2003) matching species listed in the Catalogue. To capture as wide a range of crop species as possible, matching between synonymic species in Mansfeld's database and species in the Catalogue was carried out (Kell *et al*., 2008a – Annex 2).

In the current analysis, species listed in Mansfeld's database were matched with those in the Catalogue (taking account of the two-way matching process) to ascertain the number of species that may be considered as agricultural and horticultural crops in the Mansfeld sense (see section 2.3.2). Mansfeld's database is inclusive of a very wide range of cultivated species—for example, in addition to food, fodder, forage, medicinal, aromatic and industrial crops, plants cultivated for soil improvement, sand dune fixation, hedging, grafting stock, shade and support

[21] This includes plants that are conspicuously cultivated outdoors, such as crops planted on a field scale and street and roadside trees (Euro+Med PlantBase Secretariat, 2002) – see Table 2.4.

are also included (Kell *et al*., 2008a – Annex 2). Thus, this selection includes 'crops' in a broad sense.

Kell *et al*. (2008a – Annex 2) noted that because the data contained in the Schultze-Motel (1966) account were not available in electronic format, cultivated forestry species were selected by manually cross-checking the subset of species in the Catalogue generated by undertaking the genus name matching process with the forestry genus name list, with those listed in the Schultze-Motel account. In the current analysis it was not possible to repeat this process or explore other options due to time restrictions. Therefore, the identification of a list of cultivated forestry species that could be made available in electronic format to facilitate a comprehensive process of tagging these species in the Catalogue would be a valuable enhancement.

As also noted by Kell *et al*. (2008a – Annex 2), the list of species used to tag the cultivated ornamental species in the Catalogue was not representative of the extensive number of species utilized in the ornamental plant industry. This is because: a) the ornamental genera from the CPVO varieties list were deliberately chosen to keep the ornamental component of the Catalogue to a reasonable minimum, since the use of plant species in the ornamental industry is extremely wide-ranging; and b) the CPVO does not use a standard nomenclatural system and many varieties are listed without inclusion of the specific epithet (Kell *et al*., 2008a – Annex 2). As noted by the authors, a better coverage of cultivated ornamental species could be provided by matching the species in the Catalogue with a more comprehensive database such as the

Royal Horticultural Society (RHS) Horticultural Database[22]. This avenue was explored before undertaking the current analysis but the RHS database manager was at that time unable to assist by providing access to the data in offline electronic format.

Recording the relationships between cultivated and wild species in the Catalogue would be possible for around 200 food and beverage crops for which the Gene Pool or Taxon Group concepts have been applied and recorded (see Vincent *et al*., 2013; USDA, ARS, GRIN, 2017). However, not only would this process be complex and time-consuming due to issues of synonymy, but it would effectively be duplicating effort. A more practical and sustainable approach would be to explore options for making the CWR Catalogue available as a searchable online database and providing links from the included taxa to the two sources cited above. At present, to identify these relationships for taxa listed in national CWR checklists (either those extracted from the CWR Catalogue or newly created), online searches of these two databases can be undertaken and taxon lists can be downloaded for the required country. However, using this approach involves harmonization of the taxon names with the accepted floristic taxonomies of the country, and, due to differing country of occurrence records in different sources, some taxa may be missing or additional taxa may be included when cross-checked with the national Flora or floristic checklist of that country.

As noted in section 2.2.4.1, supra-specific taxa such as families, subgenera, sections and series may be included in a CWR checklist if the data are available. The inclusion of subgenera,

[22] http://apps.rhs.org.uk/horticulturaldatabase/

sections and series is of particular interest as it would enable the classification of taxa according to the Taxon Group concept for those that have not previously been classified in Gene Pools or Taxon Groups. In the case of the CWR Catalogue for Europe and the Mediterranean, the classification of taxa in sections is available for 118 genera (6.5% of the genera in the Catalogue), in series for seven, and in subgenera for 58. The classification of taxa into subgenera and sections is available for 22 genera, and for subgenera and series for three. Further analysis would be required to establish the value of adding these taxonomic ranks to the Catalogue.

2.4.3.2 Adding use categories

Another enhancement of the Catalogue could be made by assigning use categories to the crop taxa, as well as the indirect use categories to the wild relatives as implied by their relationships to crops. This option was explored by accessing data in GRIN Taxonomy for Plants[23] (J. Wiersema, pers. comm., Beltsville, August 2009), which include economic use categories for all included taxa. However, GRIN Taxonomy for Plants is structured in a way that does not facilitate an automated matching process between use categories and taxa, since the cultivated status and use categories of taxa are related with the geographic (countries of occurrence) data. As there is no link between the cultivated status tag and categories of use, when there is more than one use category recorded (e.g., food and medicinal), it is not possible to distinguish whether the taxon is cultivated for food or medicinal purposes—it could be cultivated for both purposes or one use could be through direct harvesting of plants or plant material from the wild.

[23] Searchable at https://npgsweb.ars-grin.gov/gringlobal/taxon/abouttaxonomy.aspx

As suggested in section 2.4.3.1, a pragmatic solution would be to explore options for making the CWR Catalogue available as a searchable online database and providing links from the included taxa to GRIN Taxonomy for Plants, as well as to other relevant online databases such as Mansfeld's World Database of Agricultural and Horticultural Crops (Hanelt and IPK, 2001; http://mansfeld.ipk-gatersleben.de) and the IUCN Red List of Threatened Species[24].

2.5 Conclusion

The production of a CWR checklist is the essential first step in the process of undertaking systematic CWR conservation planning. CWR checklists provide the baseline data needed to understand the extent of taxon diversity that exists in countries (and in some cases, sub-country units) and regions, the foundations for recording ecogeographic data associated with the taxa, and for taxon prioritization and subsequent diversity and conservation gap analyses. The methodology presented in this chapter for creating the CWR Catalogue for Europe and the Mediterranean v. 4.0 results in a comprehensive checklist of CWR taxa related to a broad range of crops. The approach is methodical, practical, and replicable in any country or region, and provides a resource for both immediate and longer term conservation planning.

Creation of the Catalogue following the two-way matching process described in this chapter resulted in the inclusion of 85% of the species that occur in the region. Taking into account issues of synonymy, the inclusion of some genera which could warrant exclusion, as well as uncertainty in the occurrence data (see section 2.4.2), this is probably a slightly artificially large

[24] www.iucnredlist.org/

number of species. Therefore, for the purposes of argument, we may conclude that c. 80% of the flora of the region can broadly be considered as PGR of current or potential use (including both crops and CWR), with the caveat that the Catalogue includes a comprehensive list of genera containing a broad range of cultivated species and that many included species are distantly related to those crops.

More important than the number of species contained in the Catalogue (or any CWR checklist) is how the data are put to use. As elaborated in section 2.4.1, the Catalogue and other CWR checklists have been central in the CWR conservation planning process, from defining which wild relatives occur in the geographic area of the checklist, to informing Red Listing of CWR taxa, to evaluating the extent of CWR taxon diversity represented in existing conservation initiatives, to prioritization of taxa for conservation action.

As discussed in section 2.4.3, there is scope for enhancements to the CWR Catalogue in terms of defining crop taxa, the categories of use of those taxa and by inference the indirect use categories of their wild relatives, and the relationships between the cultivated and wild taxa according to the Gene Pool and Taxon Group concepts. Appropriate methods of achieving these enhancements need to be explored and resources made available to implement them. Ideally, a means of linking the relevant datasets using appropriate internet protocols should be explored as this would avoid duplicating data recording and storage, provide greater clarity regarding the sources of data used to create these enhancements (giving exposure and credit to the data providers), provide an open source information management structure available to all, and a framework for the addition of other datasets in the future.

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CHAPTER 3

EUROPEAN CROP WILD RELATIVE THREAT ASSESSMENT: KNOWLEDGE GAINED AND LESSONS LEARNT

Shelagh Kell, Nigel Maxted and Melanie Bilz

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Declaration of co-author contributions

Shelagh Kell generated the datasets from IUCN's Species Information Service (SIS) in which the Red List assessment data are collated and stored, undertook the data analyses, produced the tables and figures, and wrote the content of the chapter. Nigel Maxted commented on, and provided suggestions for edits to the manuscript. Melanie Bilz collaborated in the production of the European CWR Red List assessments as the Project Coordinator of the European Red List of Vascular Plants project. Shelagh Kell took overall responsibility for coordinating the production of the CWR Red List assessments as a contribution to that project. The work included selecting the species for assessment, obtaining and entering data to SIS, liaising with taxon experts (many of whom are authors and co-authors of the assessments), assessing and contributing to the assessments, and editing the content of the assessments to IUCN data consistency standards.

Some of the content of this chapter is based on an earlier publication involving the same authors and some of the narrative is the same or similar to narrative in that publication. The citation of the publication is:

> Bilz, M., Kell, S.P., Maxted, N. and Lansdown, R.V. (2011) *European Red List of Vascular Plants*. Luxembourg: Publications Office of the European Union. 130 pp. http://ec.europa.eu/environment/nature/conservation/species/redlist/downloads/European_vascular_plants.pdf

For that publication, Shelagh Kell generated the datasets from SIS, undertook the data analyses, produced the tables and figures, and wrote the content of section 4, 'Crop wild relatives – species selection and results' in the standard format required according to the publication series. Shelagh Kell and Nigel Maxted contributed significantly to the content of section 6, 'Discussion'. Melanie Bilz had overall responsibility for collating the content of the publication in the standard format required according to the publication series.

Shelagh Kell

13 January 2018

Statements of co-authors

I, Nigel Maxted, of the University of Birmingham, UK, confirm that the above declaration of co-author contributions is true and accurate.

I, Melanie Bilz, of the Technische Universität Berlin, Institut für Landschaftsarchitektur und Umweltplanung, Fachgebiet Landschaftsplanung und Landschaftsentwicklung, Germany (previously of the IUCN Species Programme), confirm that the above declaration of co-author contributions is true and accurate.

Correction

Section 28.2.3, page 222 – The first sentence of the last paragraph should read: "This preliminary selection of 18 crops or crop groups are found within 19 genera within which there are 279 species recorded as native to Europe" (the word 'species' is missing in the published chapter).

28 European Crop Wild Relative Threat Assessment: Knowledge Gained and Lessons Learnt

S.P. Kell, N. Maxted and M. Bilz

28.1 Introduction

The IUCN Red List Categories and Criteria (IUCN, 2001) have been widely applied to assess the relative risk of extinction (or threatened status) of vascular plant species and the resulting Red List assessments have been published in the IUCN Red List of Threatened Species, as well as in national Red Lists. The 2010 IUCN Red List of Threatened Species includes 12,510 vascular plants, of which 8487 (68%) are classified as threatened, 1128 (9%) as Near Threatened, 1846 (15%) as Least Concern and the remainder as Data Deficient or Lower Risk/conservation dependent (IUCN, 2010). We do not know how many of these species are crop wild relatives (CWR), but an analysis of the 2004 IUCN Red List of Threatened Species revealed that of the CWR that occur in Europe and the Mediterranean, only 161 species were included and of these, only one (*Olea europaea* subsp. *cerasiformis*) is a wild relative of a major food crop and 16 are wild relatives of minor food crops – all of them being tree species (Kell *et al.*, 2008). Analysis of the 2006 IUCN Red List of Threatened Species showed that the overall number of wild relatives from the Euro-Mediterranean region had increased to 223 but that still only one wild relative of a major food crop was included and only 19 of minor food crops – all but one of these (*Allium rouyi*) being tree species.

One reason for the lack of CWR taxa included in the IUCN Red List of Threatened Species is that many of the plant taxa listed in the 1997 IUCN Red List of Threatened Plants have not yet been evaluated against the revised Red List Criteria (IUCN, 2001) – re-evaluation of the CWR included would be beneficial, as well as a thorough review of CWR included in national Red Lists (Kell *et al.*, 2008). The latter recommendation has been partially addressed by a recent initiative of Botanic Gardens Conservation International (BGCI), who developed a consolidated list of 1917 European threatened plant taxa based mainly on national Red Lists and species distribution data (Sharrock and Jones, 2009). Of the taxa included, 112 are CWR species found in 32 genera, including eight wild relatives of major food crops (*Brassica* and *Hordeum* spp.) and 50 wild relatives of minor food crops (*Allium*, *Avena*, *Beta*, *Brassica*, *Daucus*, *Fragaria*, *Lactuca*, *Pisum*, *Prunus*, *Pyrus* and *Vicia* spp.).

As noted by Heywood (2009), the lack of an up-to-date regional Red List not only means we do not know how many plants

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are threatened in Europe, but also that it has been a 'serious obstacle' to tackling some of the targets of the Global Strategy for Plant Conservation. A recent initiative of the International Union for the Conservation of Nature and Natural Resources (IUCN) and the European Commission set out to begin to redress this by undertaking regional Red List assessments of 2000 vascular plant species as a component of the first published European Red List (see http://ec.europa.eu/environment/nature/conservation/species/redlist/). Three plant groups were selected for inclusion in this initiative – CWR, aquatic plants and policy species (i.e. species listed in the annexes of the Habitats Directive, Bern Convention, CITES and the EU Wildlife Trade Regulation). As a contribution to the 2000 species to be assessed, regional Red List assessments of 591 CWR species were undertaken both for Europe and for the geographical area defined by the 27 EU member states.

This chapter summarizes the procedure used to select the CWR species for inclusion in the European Red List and the process and results of undertaking the regional assessments using the IUCN Red List Categories and Criteria (IUCN, 2001).

28.2 Selection of CWR Species for Assessment

Due of the large number of CWR species present in Europe, a clear process of target taxon selection was needed to maximize impact in terms of raising awareness about the importance of European CWR and their threatened status; therefore, wild relatives of a list of priority crops were selected based primarily on food and economic security in Europe. Species were selected from the CWR Catalogue for Europe and the Mediterranean (the CWR Catalogue) (Kell *et al.*, 2005), which contains taxon and distribution data from Euro+Med PlantBase (2006). At the time of production of the species list, the taxonomic and distribution data in Euro+Med PlantBase (www.emplantbase.org/home.html) had been revised for several families; including three of the largest families – Compositae, Poaceae and Rosaceae.[1] These revised data were combined with the 2006 dataset for the remaining families to form the basis for species selection, as well as the taxonomic standard for the CWR list. The taxon selection process (Kell *et al.*, in prep.) is outlined below in five steps.

28.2.1 Step 1: CWR native to Europe

The IUCN Red List Categories and Criteria should only be applied to wild populations inside their natural range, or to populations resulting from benign introductions[2] (IUCN, 2001); therefore, the first step in the target taxon selection procedure was to select CWR native to Europe. In the unrevised (2006) Euro+Med PlantBase dataset, each occurrence record is either recorded as 'Status Unknown' or if the status is known, a coding system is used in three fields – 'native', 'introduced' and 'cultivated'. For these records, taxon occurrences recorded in the 'native' field as 'native', 'assumed to be native' or 'doubtfully native' were selected as well as those recorded as 'formerly native (extinct)' (see Table 28.1).[3] In the revised (2009) dataset, a new field is used ('Summary Status') to record the status of each taxon occurrence. For these data, all occurrences recorded as 'native', 'native: doubtfully native', 'native: formerly native' and 'native: presence questionable' were selected. The list of CWR native to Europe contains 19,345 species; this includes CWR of agricultural and horticultural crops, forestry species, ornamentals, and medicinal and aromatic plants.

28.2.2 Step 2: CWR of human and animal food crops

Data from three primary sources were used to select a list of priority crop genera containing wild relatives native to Europe – the

Table 28.1 Codes for recording native status in Euro+Med PlantBase (Euro+Med PlantBase Secretariat, 2002).

Code	Value	Explanation
N	Native	The taxon is native (autochthonous) within the area concerned (as contrasted with 'introduced' and 'cultivated' defined below).
S	Assumed to be native	Assumed to be native to the area concerned.
D	Doubtfully native	There is doubt as to whether the status of the plant in the area concerned is native or not.
E	Formerly native (extinct)	The plant is native, doubtfully native or assumed to be native in the area concerned and has become extinct as such.
A	Not native	The plant is definitely not native.
F	Recorded as native in error	The plant has been recorded as native in the area concerned but all such records have been disproved or discounted.

CWR Catalogue for Europe and the Mediterranean (Kell *et al.*, 2005), GRIN Taxonomy for Plants (USDA, ARS, National Genetic Resources Program, 2009) and Mansfeld's World Database of Agricultural and Horticultural Crops (Hanelt and IPK Gatersleben, 2001; IPK Gatersleben, 2003). Genera containing cultivated taxa used for human and animal food were initially selected as priority groups. Within the human food crop group, cultivated taxa with the use types 'cereals', 'fruits', 'nuts', 'oil/fat', 'pseudocereals', 'pulses', 'seeds', 'starch', 'sugar' and 'vegetables' were selected.[4] This selection excludes beverage bases, gums/mucilages and any taxa identified as being of direct use potential (i.e. not as gene donors). The animal food crop group includes forage and fodder crops. This list contains 262 genera, within which there are 7324 CWR species native to Europe. Of these, 5955 are wild relatives of human food crops (found in 185 genera) and 2332 are wild relatives of forage crops (found in 146 genera); 955 species are wild relatives of both food and forage crops – these species are found in 62 genera. Although these species were selected on the basis of their potential as gene donors to human and animal food crops, some genera also include taxa cultivated for other purposes (e.g. medicinal, ornamental); therefore, the CWR assessed may have wider value as gene donors beyond food crops.

28.2.3 Step 3: CWR of high priority human food crops

The list of CWR of human and animal food crops encompasses a large number of species (7324) and it was therefore necessary to narrow down this list further by selecting the highest priority species. The first step was to select CWR of a number of human food crops that are particularly important to Europe in terms of production quantity and/or value. In terms of production quantity, there are 18 crops or crop groups of which Europe produced an average of >1 Mt in the 5 years from 2003 to 2007 that have CWR native to Europe that may be important for crop improvement: wheat, sugarbeet, barley, grapes, rapeseed, apples, oats, cabbages (and other brassicas), rye, olives, carrots and turnips, onions, peaches and nectarines, peas, lettuce and chicory, pears, plums and sloes, and strawberries (Fig. 28.1). Note that there are other economically important crops excluded from this list (e.g. potato) that have wild relatives in Europe, but they are very distant wild relatives – the centre of diversity of the potato gene pool being in South America – and are therefore not considered a priority in terms of their potential as gene donors for crop improvement. Figure 28.2 shows the average value of crops or crop groups produced in Europe over 5 years from 2004 to 2008 that have CWR native to Europe which may be important

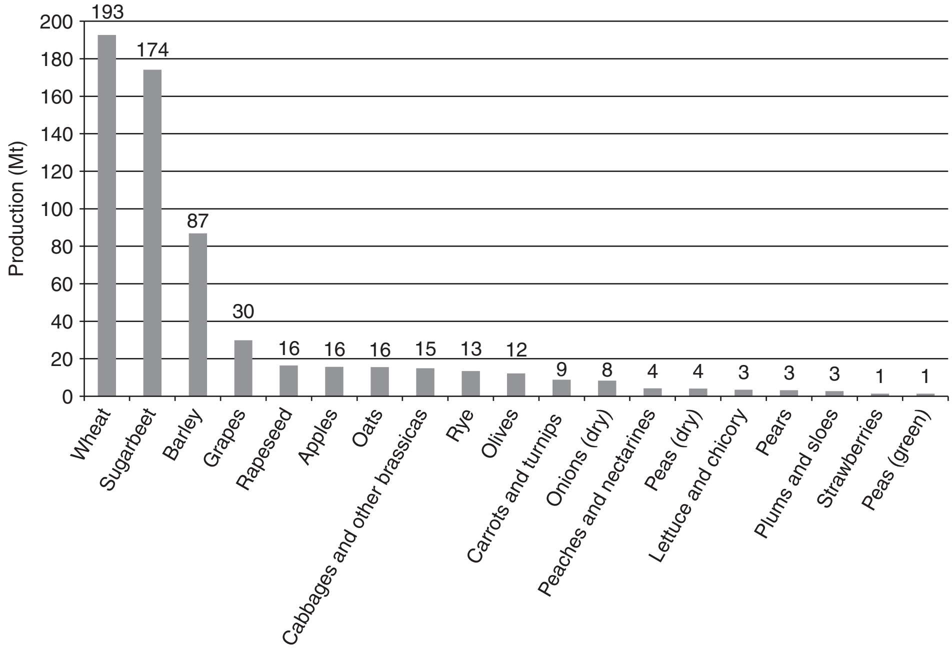

Fig. 28.1. Crops/crop groups of which Europe produced an average of >1 Mt in five years from 2003 to 2007 that have CWR native to Europe which may be important for crop improvement (Kell *et al.*, in prep). Data source: FAOSTAT (FAO, 2009).

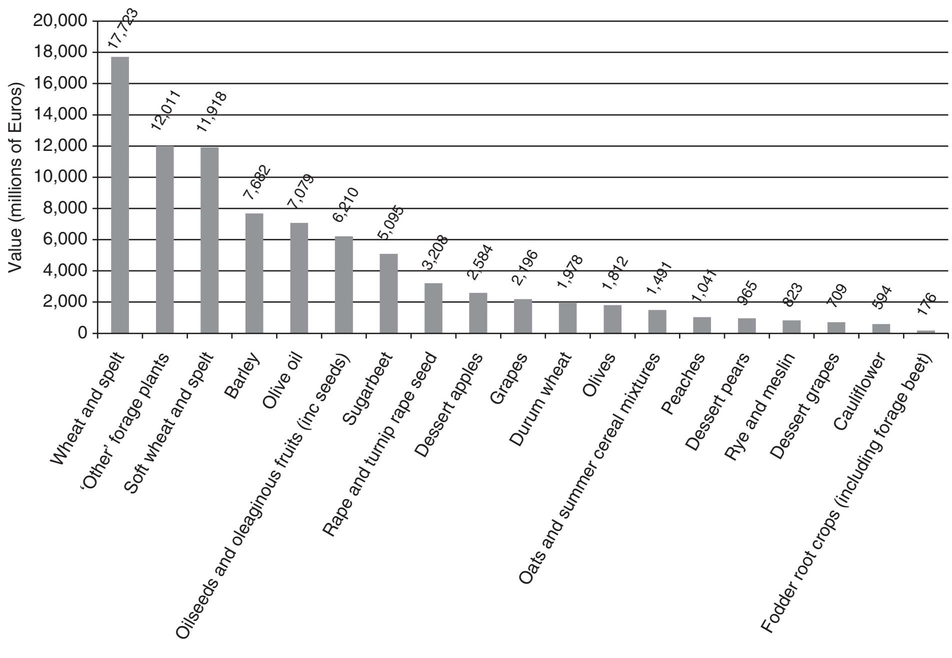

Fig. 28.2. The average value (millions of Euros) of crops/crop groups produced in Europe over 5 years from 2004 to 2008 that have CWR native to Europe which may be important for crop improvement (Kell *et al.*, in prep). Data source: Eurostat (European Communities, 1995–2009).

for crop improvement. All of the crops or crop groups included in this analysis are also included in the priority list of human food crops based on production quantity.

This preliminary selection of 18 crops or crop groups are found within 19 genera within which there are 279 recorded as native to Europe. All the species within this group were included in the European Red List due to their high potential economic importance as gene donors to human food crops.

28.2.4 Step 4: CWR of animal food crops

The production quantity and economic value data that are available for human food crops are not readily available for animal food crops on an individual crop basis; therefore, it is not possible to prioritize animal food crops according to these criteria. However, of the 279 CWR species identified in the high priority human food CWR group, 106 are wild relatives of forage and/or fodder crops, as well as human food crops; therefore, CWR of a number of animal food crops are included in this list.

28.2.5 Step 5: CWR of other human and animal food crops

To add to the high priority list of 279 species described above, Annex I of the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) was also used as the basis for species selection. This is a list of Plant Genetic Resources for Food and Agriculture (PGRFA) established according to criteria of food security and interdependence and includes 78 genera containing human or animal food crops. Fifty-nine of these genera contain taxa that are native to Europe, some of which are already included in the high priority CWR list defined above.

Annex I of the ITPGRFA is divided into two lists: (i) human food crops; and (ii) forages. The human food crop list mainly lists entire genera because the CWR of these crops are recognized as being important for food security. The forage list only includes specific species because (i) the crops are mainly selections from populations of wild species and the CWR are less likely to be used for crop improvement; and (ii) many of the forage genera contain a very large number of species; for example, *Festuca* contains 204 species native to Europe.

Additional human food crop genera listed in Annex I of the ITPGRFA that were included in the list of CWR to be assessed are: *Asparagus* – 21 species, brassica complex (*Armoracia*, *Barbarea*, *Camelina*, *Crambe*, *Diplotaxis*, *Eruca*, *Isatis*, *Lepidium*, *Raphanus*, *Rorippa* and *Sinapis*)[5] – 121 species, *Cicer* – four species, *Lathyrus* – 18 species (only those in Gene Pools (GP) 1b and 2 and Taxon Groups (TG) 1b and 2 – see Maxted *et al.*, 2006), *Lens* – five species, wheat complex (*Agropyron* and *Elymus*)[6] – 17 species, and *Vicia* – 20 species (GP1b, TG1b, GP2, TG2 and four species for which data were readily available). *Lathyrus* and *Vicia* species were limited to the close wild relatives only, due to the large number of species included in these genera.

Fifty-two of the forage species listed in Annex I of the ITPGRFA are native to Europe. These were all included for assessment as their continued existence in the wild is important for the future of these crops; thus, knowing their conservation status in the wild is important to inform conservation planning. In addition, all *Medicago* species native to Europe were included on the basis of data availability.

This selection resulted in a list of 596 species; however, some of these were removed as they are hybrids which are generally not included in the IUCN Red List. Later in the project, some additional species were added by experts at a European CWR Red List workshop; these included five species in the genus *Sinapidendron*, which is related to brassica crops and endemic to the Madeira archipelago, and some recently described species of *Crambe* endemic to the Canary Islands. The final list of CWR species for assessment comprised 591 species in 25 crop gene pools/groups (Kell *et al.*, in prep.) (Table 28.2),

Table 28.2. Overview of the list of CWR species selected for inclusion in the European Red List.

Crop gene pool/group	Genus (or genera)	Total no. of species in gene pool/group[a]	No. of species assessed[b] (% of gene pool/group)
Brassica complex	*Armoracia*, *Barbarea*, *Brassica*, *Camelina*, *Crambe*, *Diplotaxis*, *Eruca*, *Isatis*, *Lepidium*, *Raphanus*, *Rorippa*, *Sinapidendron*, *Sinapis*	506	142 (28%)
Onion, leek, garlic etc.	*Allium*	750	118 (16%)
Legume forages	*Astragalus*, *Hedysarum*, *Lotus*, *Lupinus*, *Medicago*, *Melilotus*, *Onobrychis*, *Ornithopus*, *Securigera*, *Trifolium*	3469	93 (3%)
Wheat	*Aegilops*, *Agropyron*, *Elymus*, *Triticum*	213	36 (17%)
Lettuce	*Lactuca*	130	27 (21%)
Faba bean/vetch	*Vicia*	160	23 (14%)
Asparagus	*Asparagus*	120	19 (16%)
Grass pea	*Lathyrus*	160	19 (12%)
Stone fruits and almond	*Prunus*	200	16 (8%)
Grass forages	*Agrostis*, *Alopecurus*, *Arrhenatherum*, *Festuca*, *Lolium*, *Phalaris*, *Phleum*, *Poa*	1210	14 (1%)
Oat	*Avena*	25	13 (52%)
Carrot	*Daucus*	22	12 (55%)
Pear	*Pyrus*	15	11 (73%)
Cultivated beets	*Beta*, *Patellifolia*	13	10 (77%)
Barley	*Hordeum*	32	8 (25%)
Lentil	*Lens*	5	5 (100%)
Apple	*Malus*	40	5 (13%)
Chickpea	*Cicer*	44	4 (9%)
Chicory	*Cichorium*	6	3 (50%)
Strawberry	*Fragaria*	330	3 (1%)
Rye	*Secale*	3	3 (100%)
Other forages	*Atriplex*, *Salsola*	380	2 (1%)
Garden pea	*Pisum*	3	2 (67%)
Olive	*Olea*	33	2 (6%)
Grape	*Vitis*	65	1 (2%)
Total		7933	591 (7%)

[a]Data primarily sourced from Mabberley (2008).
[b]Including species assessed as Not Applicable.

188 of which are endemic to Europe. Although it is possible to apply the IUCN Red List Categories and Criteria at subspecific level, all assessments were undertaken at species level as stipulated by the contractual arrangements of the project.

28.3 The Red List Assessment Process

Assessment of the threatened status of species using the IUCN Red List Categories and Criteria (IUCN, 2001) is essentially a two-step process:

1. Data of seven types are collated and documented: (i) taxonomic; (ii) distribution; (iii) population; (iv) habitat and ecology; (v) use and trade; (vi) threats; and (vii) conservation actions (Box 28.1). These data are gathered from a number of sources, including taxon experts, published and grey literature, databases and websites.
2. The taxon is evaluated against the IUCN Red List Criteria and the Red List Category is selected.

There are five main Red List Criteria: (A) population reduction, (B) geographic range, (C) small population size and decline, (D) very small or restricted population and (E) quantitative analysis indicating the probability of extinction. Each main criterion includes a number of sub-criteria against which the species is evaluated. If the species meets the criteria in at least one of the main classes, it is assigned one of the threatened categories, Critically Endangered (CR), Endangered (EN) or Vulnerable (VU). If the species meets the criteria in more than one main class, it is assigned the highest category of threat but the less threatened category according to the other criterion or criteria is also documented. If the species does not meet any of the criteria A–E needed to evaluate it as threatened, another category is selected; these are Extinct (EX), Extinct in the Wild (EW), Regionally Extinct (RE), Near Threatened (NT), Least Concern (LC), Data Deficient (DD) or Not Applicable (NA) (for definitions of the categories, see IUCN, 2001).

The two criteria primarily used to assess the European CWR species as threatened were B (geographic range) and D (very small or restricted population) because detailed population data were rarely available to apply Criterion A or C, and quantitative data did not exist to apply Criterion E. The majority of threatened species were assessed under Criterion B which is based on the extent of occurrence (EOO) and/or area of occupancy (AOO) of the species (see IUCN, 2001 for definitions). To assess a species as threatened using Criterion B, two of three sub-criteria must be met:

1. The population is severely fragmented and/or it occurs in a small number of highly threatened locations.
2. There is a continuing decline in the EOO, AOO, area, extent and/or quality of habitat, number of locations or subpopulations, or number of mature individuals.
3. There are extreme fluctuations in the EOO, AOO, number of locations or subpopulations, or number of mature individuals.

Sub-criteria 1 and 2 were used most frequently and under sub-criterion 2, many assessments were based on a decline in the area, extent and/or quality of habitat (sub-criterion 2(iii)) because it is often possible to infer that a species' habitat is declining due to the reported threats, even if an assessor does not have first-hand experience from visiting the sites.

Following data collation, application of criteria and selection of the Red List Category, the rationale to justify the assessment is documented, highlighting the key issues to support the assessment and explaining why the species qualifies for the assigned category, and finally, the assessor and contributor names are added. Each assessment is edited to data consistency standards and then reviewed and evaluated by at least two experts – the names of the reviewers are also published with the assessment.

The data and the selected category are entered into IUCN's Species Information Service (SIS – an online information management system for documenting species accounts and Red List assessments). All data sources are fully referenced and when the assessments are published, they present an account that summarizes the taxonomy and nomenclature of the species, where it occurs, what the trends are in population size, what the species' habitat and ecological requirements are, what threats it faces, the Red List status, and current or needed conservation actions.

The assessment process involved the collaboration of more than 70 experts who have good knowledge of the national flora of their country and/or of a particular taxonomic group. A key part in the process was

Box 28.1 Summary of data types collated to undertake the European Red List assessments

Taxonomy

- Nomenclature (taxon name, authority, synonyms etc.).
- Recent taxonomic changes, any current taxonomic doubts or debates about the validity or identity of the species, or issues of synonymy.
- A note of any subspecific taxa.
- Crop(s) the species is related to (common and scientific names) and information on the degree of relationship of the wild relative to the crop (where known) using the Gene Pool concept (Harlan and de Wet, 1971) or Taxon Group concept (Maxted *et al.*, 2006).

Distribution and occurrence

- A summary of the current information available for the geographic range of the species within Europe. If the species has part of its natural distribution range outside Europe, a brief note of its global distribution is also included.
- Country occurrences (and sub-national unit(s) where applicable) recorded using built-in descriptors in SIS. Only occurrences within the species' native European range were recorded, or cases where the origin or presence is uncertain.
- A map showing the distribution of the species.

Population

- A summary of the information available for size and trend (i.e. increasing, decreasing or stable) of the European population of the species. If the population is severely fragmented, this was also recorded.
- Information about sizes and trends of subpopulations or populations of subspecific taxa, or trends in particular areas of the species' European range were also included when available.
- Where no quantitative information on population sizes or trends were available, if possible it was noted whether the species is common, abundant, or rare, etc. If there really was no information at all about the population, this was noted.

Habitats and ecology

- A summary account of the suitable habitats and ecological requirements of the species, highlighting any potential traits that may be of interest for crop improvement (e.g. drought resistance, salt tolerance).
- Comments on the area, extent and/or quality of habitat; in particular, whether the habitat is thought to be stable or declining.
- The habitat(s) in which the species occurs are also documented using IUCN's Habitats Classification Scheme.

Use and trade

- A summary account of the information available for any utilization and/or trade of the taxon (local, national and international trade).
- A note of any known or potential uses of the species as a gene donor for crop improvement.

Threats

- Major threats that have affected the species in the past, those that are affecting the species now, or those that are likely to affect the species in the future.
- The main reason for the threat, the scale of the threat, and the stress this places on the species are also recorded where the information is available.
- Threats are also documented using IUCN's Threats Classification Scheme.

Conservation

- Conservation actions currently in place (if any) and realistic actions needed to mitigate the threats causing declines (if any). This includes information on both *in situ* and *ex situ* conservation measures.
- Conservation actions are also documented using IUCN's Conservation Actions Classification Scheme.

a 5-day Red List workshop involving 26 experts and a team of facilitators, during which many of the assessments were drafted. The remaining work was undertaken through email correspondence and completion and editing of the assessments was undertaken mainly by three members of staff of the coordinating institutes.

28.4 The Threatened Status of European CWR

Out of the 591 CWR species for which regional assessments were carried out, 19 were assessed as Not Applicable (NA)[7] as they were either considered by experts not to be native to Europe (i.e. they were introduced after AD 1500) or only had a marginal distribution in the region. One species, *Allium jubatum*, which is native to Asiatic Turkey and Bulgaria, was assessed as RE – according to Mathew (1996), it has not been found in Bulgaria since its original collection in 1844. Of the remaining 571 species assessed, 313 (55%) were assessed as LC, 166 (29%) as DD, 26 (5%) as NT, 22 (4%) as VU, 25 (4%) as EN and 19 (3%) as CR (Fig. 28.3).

28.4.1 Threatened and Near Threatened species

Figure 28.4 shows that of the 25 crop gene pools/groups for which the European CWR were assessed, at least 14 contain regionally and/or globally threatened (CR, EN or VU) or Near Threatened (NT)[8] species (92 species in total, of which 65 are endemic to Europe), the highest number occurring in the brassica complex which in total contains 137 species native to and with a significant proportion of the global population in Europe. At least 8–50% of the species assessed in each of these crop gene pools/groups are threatened or NT (Fig. 28.5) and these percentages are likely to increase when the Data Deficient species are re-evaluated. Note that none of the crop gene pools/groups are endemic to Europe; therefore, this is not a comparison of the threatened status between entire crop gene pools/

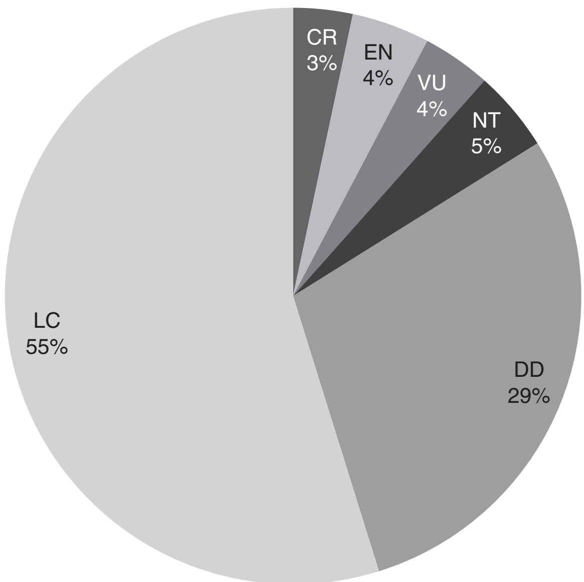

Fig. 28.3. IUCN Red List categories assigned to 571 European CWR (regional assessments). (LC=Least Concern; DD=Data Deficient; NT=Near Threatened; VU=Vulnerable; EN=Endangered; CR=Critically Endangered.)

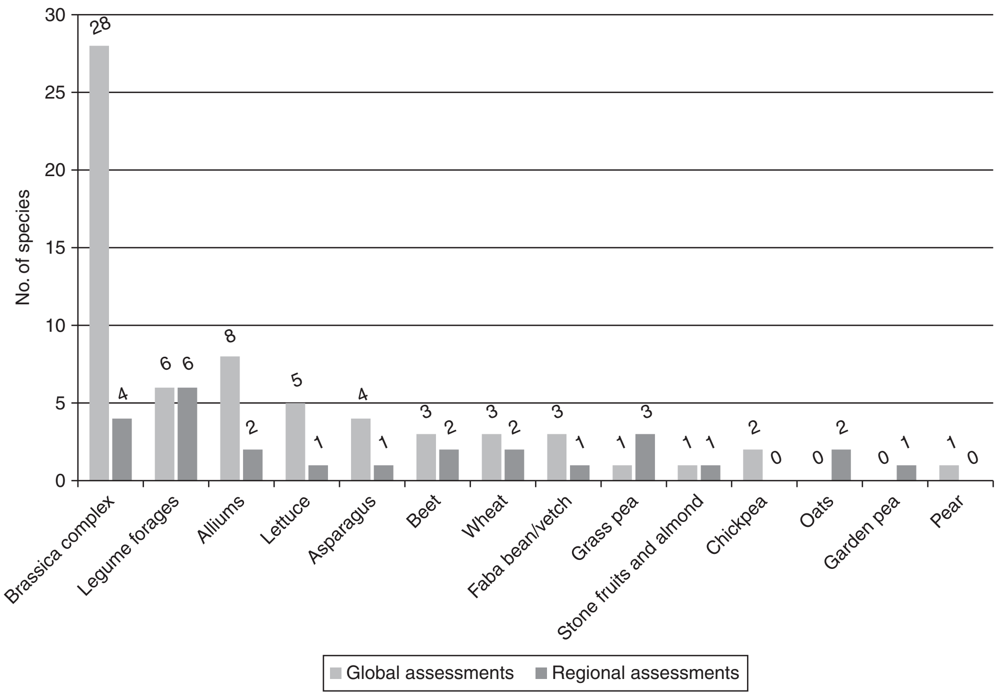

Fig. 28.4. The numbers of globally and regionally threatened (CR, EN or VU) or Near Threatened (NT) species, out of the sample assessed in 14 crop gene pools/groups.

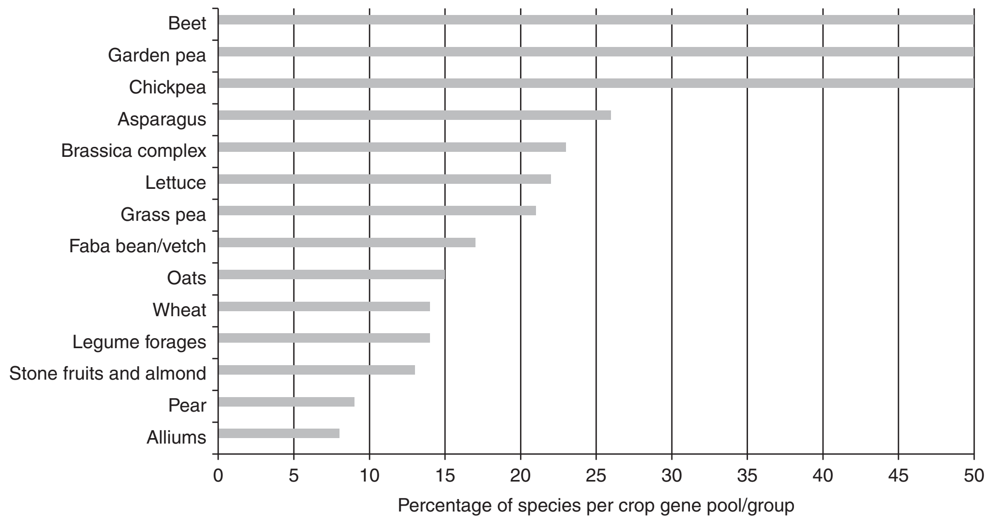

Fig. 28.5. The percentages of globally and regionally threatened (CR, EN or VU) or Near Threatened (NT) species, out of the sample assessed in 14 crop gene pools/groups, excluding species assessed as Not Applicable.

groups because only species that are native to Europe were assessed and the species that are not endemic to Europe were regionally (not globally) assessed. Further, not all species native to Europe were assessed in each genus – for the legume forages, only species listed in Annex I of the ITPGRFA were assessed and due to the large numbers of species in *Vicia* and *Lathyrus*, only species in GP1b, TG1b, GP2, TG2 (i.e. the closest wild relatives) were assessed. An additional five species of *Vicia* were also assessed for which data were readily available. However, these results provide an indication of the crop gene pools or complexes that are under greatest threat of extinction in Europe.

It is particularly notable that half of the species assessed in the beet gene pool (five species) are threatened – three globally (*Beta patula* and *Patellifolia webbiana* (CR) and *B. nana* (VU)) and two regionally (*B. adanensis* (VU) and *B. macrocarpa* (EN)). The centre of diversity of the beet gene pool is in Europe, with 10 out of the 13 species native to Europe (two of which are single country endemics); therefore, we know that at least 30% of the gene pool (in terms of taxonomic diversity) is threatened with extinction. Beet is a highly important crop for the European economy; the wild relatives have already been used extensively for crop improvement and further genetic diversity may be needed from the wild populations in the future. Therefore, it is clear that urgent attention needs to be paid to the conservation of these species. The brassica complex is also of particular concern as 27% (137) of the species are native to Europe and more than 18% (25) of these are threatened (24 globally), with a further 5% (7) considered to be Near Threatened. The threatened status of the lettuce, wheat and allium gene pools are also of considerable concern because, like beet and brassica crops, these are also highly economically important crops in Europe which have a relatively large proportion of their gene pools native to the region.

We cannot assume that the percentage of threatened species in a gene pool is equivalent to the percentage of threatened genetic diversity; however, in the absence of genetic data to prove otherwise, we have to take the precautionary approach and assume that in percentage terms, the risk of extinction to genetic diversity at least equates to the risk of extinction to taxonomic diversity. In fact, Maxted *et al.* (1997a) and Maxted (2003) pointed out that while it is difficult, if not impossible, to quantify the loss of genetic diversity within CWR species, it must be faster than the loss of species, because there will be some genetic erosion (loss of genetic diversity) from the species that remain extant and complete loss of genetic diversity from those that become extinct, given that both extant and extinct species face the same threats. Therefore, if we assume that genetic diversity is strongly correlated with occurrences of species at particular localities and that some of those occurrences are threatened, then we may validly infer that the percentage of threatened species in a gene pool could signify a greater level of threat to overall genetic diversity in the gene pool than to taxonomic diversity.

Table 28.3 shows the countries with the highest to lowest numbers of regionally and globally threatened or NT species. As would be expected, the highest numbers of species are found in the countries of southern and eastern Europe which are known to have large floras and thus a large number of CWR species. It is notable that many of the threatened and NT species are endemic to the Canary Islands and to the Madeira and Azores archipelagos, as well as to Sicily – this is of course no surprise, since not only do these islands have a high degree of endemism, but many island habitats are highly degraded, fragmented and fragile (Kell *et al.*, 2008).

28.4.2 Least Concern species

It is striking that more than half of the species assessed were evaluated as LC. However, this statistic should be interpreted with great caution as a LC assessment does not necessarily mean that a species or subpopulations of that species do not

Table 28.3. European countries containing regionally and globally threatened or Near Threatened CWR species (out of 591 species assessed).

Country	No. of species	No. endemic to Europe (national endemics)	National endemic species (Red List category)
Spain (including the Balearic and Canary Islands)	33	27 (24)	*Allium melananthum* (NT), *A. pardoi* (VU), *A. pyrenaicum* (VU), *Asparagus arborescens* (VU), *A. fallax* (EN), *A. plocamoides* (VU), *Cicer canariense* (EN), *Crambe arborea* (VU), *C. feuillei* (CR), *C. gomerae* (VU), *C. laevigata* (EN), *C. microcarpa* (EN), *C. pritzelii* (EN), *C. scaberrima* (VU), *C. scoparia* (EN), *C. sventenii* (CR), *C. tamadabensis* (CR), *C. wildpretii* (CR), *Diplotaxis siettiana* (CR), *Lactuca singularis* (VU), *Medicago citrina* (CR), *Patellifolia webbiana* (CR), *Prunus ramburii* (VU), *Rorippa valdes-bermejoi* (CR)
Portugal (including the Azores and Madeira archipelagos)	19	15 (12)	*Beta patula* (CR), *Crambe fruticosa* (NT), *Diplotaxis vicentina* (CR), *Lactuca watsoniana* (EN), *Sinapidendron angustifolium* (CR), *S. frutescens* (EN), *S. gymnocalyx* (NT), *S. rupestre* (CR), *S. sempervivifolium* (EN), *Vicia capreolata* (EN), *V. costae* (CR), *V. ferreirensis* (CR)
Ukraine (including Crimea)	17	7 (5)	*Agropyron cimmericum* (EN), *A. dasyanthum* (EN), *Allium pervestitum* (EN), *Lepidium turczaninowii* (CR), *Medicago saxatilis* (EN)
Greece	12	5 (5)	*Beta nana* (VU), *Cicer graecum* (EN), *Lactuca alpestris* (NT), *Medicago heyniana* (NT), *M. strasseri* (NT)
Italy (including Sardinia and Sicily)	11	6 (5)	*Brassica glabrescens* (VU), *B. macrocarpa* (CR), *B. rupestris* (NT), *B. villosa* (NT), *Lathyrus odoratus* (NT)
Cyprus	11	4 (4)	*Allium exaltatum* (VU), *Brassica hilarionis* (EN), *Lactuca cyprica* (NT), *L. tetrantha* (VU)
France (including Corsica)	6	1 (1)	*Allium corsicum* (CR)
Russian Federation (European part)	5	1 (0)	–
Malta	3	1 (1)	*Allium lojaconoi* (NT)
Serbia	3	1 (0)	–
Montenegro	2	0	–
Romania	2	1 (0)	–
Slovenia	2	1 (0)	–
Turkey (European part)	2	0	–
Croatia	2	1 (0)	–
Bulgaria	2	0	–
The former Yugoslav Republic of Macedonia	2	0	–
Moldova	1	1 (0)	–
Albania	1	0	–
Hungary	1	1 (1)	*Pyrus magyarica* (CR)
Germany	1	0	–
Bosnia and Herzegovina	1	0	–

warrant conservation action. In interpreting this result, there are two important issues that need to be taken into account – the first relates to the application of the Red List Criteria and potential subjectivity of the process, and the second relates to the issue of taxonomic versus genetic diversity assessment, as explained below.

The criteria for assessing a species as threatened (i.e. CR, EN or VU) are rigorous; therefore, when these criteria are not met, an assessor has the choice of assessing the species as NT, LC or DD. According to IUCN guidelines, DD assessments should be avoided when possible; therefore, the assessor is forced to lean towards either a NT or LC assessment. Strong justification is needed to assess a species as NT and where insufficient knowledge has resulted in the threatened criteria not being fulfilled it is also highly likely that an NT assessment could not be justified on the basis of a lack of sufficient knowledge. Therefore, the assessor must either decide to evaluate the species as DD or LC. It is often difficult to make a judgement as to whether there really is insufficient knowledge and the species should be assessed as DD or whether it is in fact an LC species. This decision can be highly subjective depending on the views and attitude of the individual undertaking the assessment – some may be more inclined to take a precautionary approach than others.

Many of the species assessed as LC are relatively widespread in Europe, occurring in several countries; however, some have a relatively narrow distribution and are assessed as LC because despite their restricted range, they do not meet the threatened criteria. The latter group of species is likely to mainly comprise national endemics and may already be included in national conservation plans. However, if they are not already adequately conserved, both *in situ* and *ex situ*, the LC assessment should be carefully interpreted as it does not necessarily mean that the species is not in need of conservation action – at minimum, population monitoring is likely to be needed.

We should also be very careful about interpreting an LC assessment for those species that are relatively widely distributed in Europe – it could be assumed that these species are secure and require no conservation action; however, there are two strong counter arguments. One is that although it is possible to apply the Red List Categories and Criteria (IUCN, 2001) to individual subpopulations,[9] the system does not include genetic diversity within and between subpopulations as a criterion for assessment – it is based on population size and geographic range. As the goal of CWR conservation is to maximize the conservation of genetic diversity, it is vital that sufficient subpopulations are conserved, both *in situ* and *ex situ*, to provide an adequate sample of total genetic diversity. Genetic diversity knowledge is lacking for the majority of species as sampling and analysis is resource intensive; therefore, it is necessary to ensure that as wide a range of ecogeographic diversity is sampled and conserved as possible – ecogeographic diversity being used as a proxy for genetic diversity (see Kell *et al.*, Chapter 2, this volume). This means that conservation of even the most widespread species should be of concern, both at regional and national levels. The second counter-argument is that many of the species regionally assessed (or globally assessed if endemic to Europe) as LC are threatened at national level – further analysis is needed to ascertain exactly how many, but based on information documented during the Red Listing process, we estimate that it could be a third or more. Therefore, for the same reason outlined above, these species should be of conservation concern, not only nationally, but also regionally, in order to ensure that the maximum intraspecific genetic diversity is conserved throughout the species' range.

28.4.3 Data Deficient species

The relatively high percentage of species assessed as DD is attributable to two main factors: (i) insufficient knowledge of the species to apply the Red List Criteria; and (ii) resource and time limitations resulting in gaps in data collection and/or application of the criteria. In many cases, knowledge of the species' distribution was available, but there was little, if any information about the population size, structure or trend. General knowledge about the habitats of the species, where known, could often be used to make inferences about threats to the species, but this is not enough to make a reasoned judgement about the threatened status of a species. It is clear that more work needs to be done to improve our knowledge of the threatened and conservation status of these species.

28.5 Threats to European CWR and Population Trends

For 49% (279) of the species assessed, 31 threats were reported, the most frequent being 'livestock farming and ranching', 'tourism and recreation areas' and 'housing and urban areas' (Fig. 28.6). The IUCN threat descriptor, 'livestock farming and ranching' includes the subordinate descriptors 'agro-industry grazing, ranching or farming', 'small-holder grazing, ranching or farming', 'nomadic grazing' and 'scale unknown/unrecorded'. It is important to note that due to the imprecise nature of these descriptors, the significance of the frequency at which this threat was reported should be interpreted with care. It would be erroneous to conclude that farming *per se* is a threat to CWR diversity; in fact, farmed areas (including arable land and pasture) are one of the primary habitats of CWR species. It is unsustainable farming practices, such as severe overgrazing, conversion of land to monocultures and the heavy application of fertilizers, herbicides and pesticides that are the major threats to CWR that grow in agricultural areas. This includes grazing in semi-natural habitats such as Mediterranean maquis.

Of the species assessed, 26% are reported to have no known past or ongoing

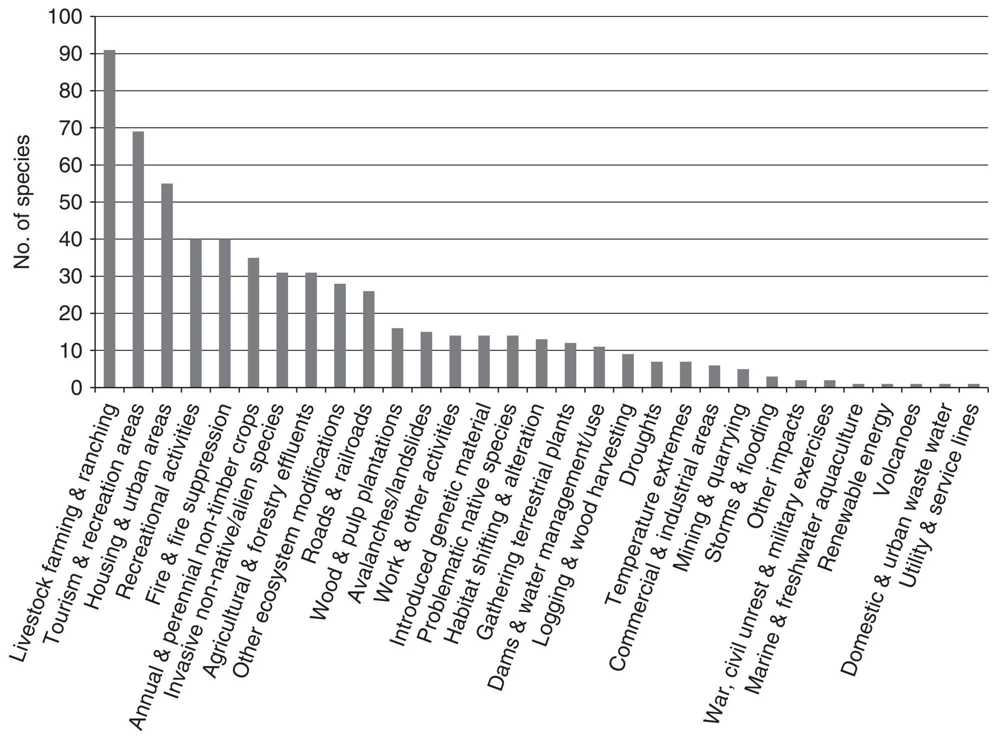

Fig. 28.6. Threats reported to affect 279 of the European CWR species assessed, showing the number of species for which each one was recorded.

threats and are not expected to face any major threats in the foreseeable future. The majority of these were assessed as LC, with only six assessed as DD. For 25% of the species assessed, the threats are unknown – the majority of these species were assessed as DD, but 32 were evaluated as LC.

The majority of threats (nearly 68%) reported were recorded as 'ongoing', but for 27% of the time the threat trend was recorded as 'unknown'. For 15 species, threats were reported as being likely to have an impact in the future, while for the same number of species, the threats were reported to have had an impact in the past and were either thought likely to return (nine species) or unlikely to return (six species).

Figure 28.7 shows the 22 most common habitats in which the species occur. In addition to these, there were another 35 habitat types recorded for nine species or less. The habitat was recorded as unknown for 45 species and 'other' types of habitat were recorded for 19 species. It is difficult to make inferences about threats to particular habitats because threats and habitat types are linked to a species (i.e. the entire European range of the species) and are therefore not directly related. However, it is possible to make some assumptions about the most threatened habitats by looking at the number of threats impacting species found in those habitats (Table 28.4). These data should be interpreted with caution as the greater number of threats shown against the habitat types may be partly attributable to the larger number of species recorded in those habitats.

For 221 of the 571 species assessed, the population trend was reported to be 'stable', for 62 species 'decreasing' and for 13 species 'increasing' – the population trend for 275 species was recorded as 'unknown' (Fig. 28.8). Of the 92 species assessed as threatened or NT, 48 are reported to have a decreasing population trend and 21 are thought to be stable – for 23 of these species, the population trend is unknown (Table 28.5). It is clear that the 48 species assessed as threatened or NT with a decreasing population trend should be flagged up as an urgent priority for conservation action – particularly those endemic to Europe. Those with unknown population trends should have monitoring programmes put in place immediately and the species reported to be stable should also be closely monitored to ensure that potential changes in the trend can be reported.

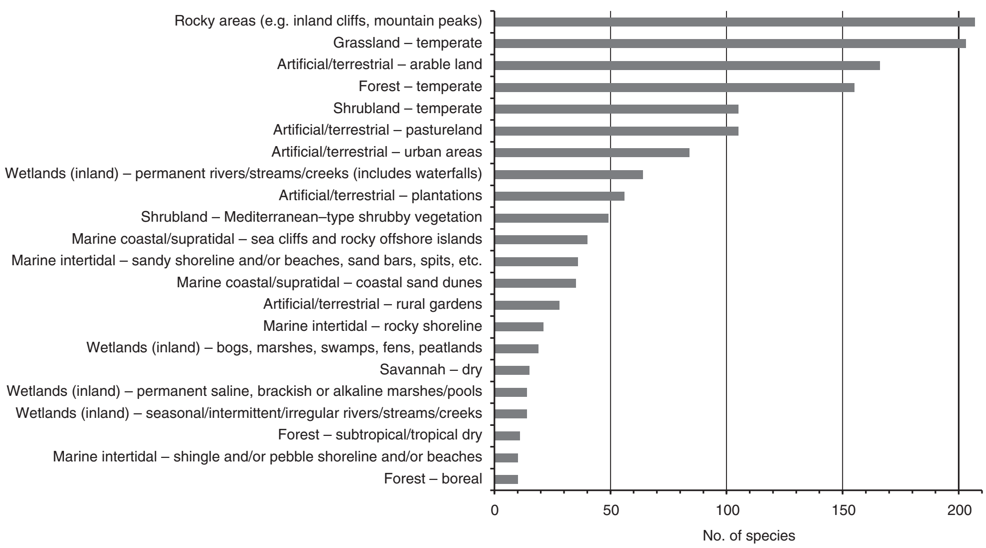

Fig. 28.7. Habitat types recorded for ten species or more.

Table 28.4. The number of threats impacting CWR species found in 45 habitat types recorded for 521 species.

Habitat type	No. of threats
Rocky areas (eg. inland cliffs, mountain peaks)	24
Grassland – Temperate	24
Shrubland – Temperate	23
Wetlands (inland) – Permanent Rivers/Streams/Creeks (includes waterfalls)	22
Forest – Temperate	22
Shrubland – Mediterranean-type Shrubby Vegetation	21
Artificial/Terrestrial – Arable Land	20
Artificial/Terrestrial – Urban Areas	19
Artificial/Terrestrial – Pastureland	19
Marine Coastal/Supratidal – Coastal Sand Dunes	18
Marine Coastal/Supratidal – Sea Cliffs and Rocky Offshore Islands	18
Forest – Subtropical/Tropical Dry	16
Artificial/Terrestrial – Plantations	16
Wetlands (inland) – Permanent Saline, Brackish or Alkaline Marshes/Pools	12
Marine Intertidal – Rocky Shoreline	12
Marine Intertidal – Sandy Shoreline and/or Beaches, Sand Bars, Spits, etc.	11
Forest – Subtropical/Tropical Moist Montane	11
Wetlands (inland) – Bogs, Marshes, Swamps, Fens, Peatlands	11
Shrubland – Subtropical/Tropical Dry	10
Artificial/Terrestrial – Rural Gardens	10
Wetlands (inland) – Seasonal/Intermittent/Irregular Rivers/Streams/Creeks	9
Forest – Boreal	9
Marine Intertidal – Salt Marshes (Emergent Grasses)	9
Shrubland – Boreal	9
Wetlands (inland) – Permanent Freshwater Lakes (over 8 ha)	8
Wetlands (inland) – Seasonal/Intermittent Freshwater Marshes/Pools (under 8 ha)	7
Savanna – Dry	6
Marine Intertidal – Shingle and/or Pebble Shoreline and/or Beaches	6
Marine Intertidal – Mud Flats and Salt Flats	6
Wetlands (inland) – Permanent Freshwater Marshes/Pools (under 8 ha)	5
Marine Coastal/Supratidal – Coastal Brackish/Saline Lagoons/Marine Lakes	5
Wetlands (inland) – Permanent Saline, Brackish or Alkaline Lakes	4
Desert – Temperate	4
Wetlands (inland) – Alpine Wetlands (includes temporary waters from snowmelt)	3
Artificial/Aquatic – Canals and Drainage Channels, Ditches	3
Grassland – Subtropical/Tropical Dry	3
Grassland – Subtropical/Tropical High Altitude	2
Wetlands (inland) – Seasonal/Intermittent Freshwater Lakes (over 8 ha)	2
Shrubland – Subtropical/Tropical High Altitude	2
Wetlands (inland) – Seasonal/Intermittent Saline, Brackish or Alkaline Marshes/Pools	2
Artificial/Aquatic – Ponds (below 8 ha)	2
Wetlands (inland) – Freshwater Springs and Oases	1
Wetlands (inland) – Shrub Dominated Wetlands	1
Artificial/Aquatic – Seasonally Flooded Agricultural Land	1
Artificial/Aquatic – Irrigated Land (includes irrigation channels)	1

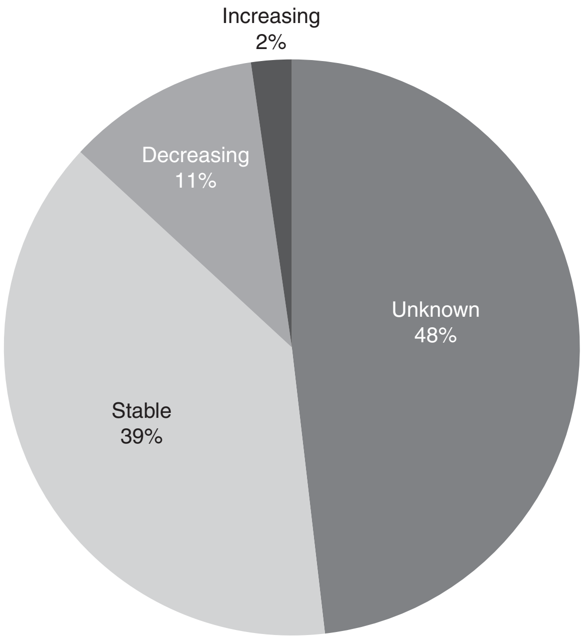

Fig. 28.8. Population trends recorded for 571 species.

Table 28.5. Globally and regionally threatened or Near Threatened CWR species (out of 591 species assessed) and population trends; species endemic to Europe are shown in bold.

Species	Red List status	Population trend[a]
Allium corsicum	CR	↓
Beta patula	CR	?
Brassica macrocarpa	CR	→
Crambe feuillei	CR	↓
Crambe sventenii	CR	↓
Crambe tamadabensis	CR	→
Crambe wildpretii	CR	↓
Diplotaxis siettiana	CR	?
Diplotaxis vicentina	CR	?
Lepidium turczaninowii	CR	↓
Medicago citrina	CR	↓
Medicago fischeriana	CR	↓
Patellifolia webbiana	CR	?
Pyrus magyarica	CR	→
Rorippa valdes-bermejoi	CR	↓
Sinapidendron angustifolium	CR	?
Sinapidendron rupestre	CR	→
Vicia costae	CR	↓
Vicia ferreirensis	CR	↓
Aegilops tauschii	EN	?
Agropyron cimmericum	EN	↓
Agropyron dasyanthum	EN	?
Allium pervestitum	EN	?
Asparagus fallax	EN	↓

Continued

Table 28.5. Continued.

Species	Red List status	Population trend[a]
Asparagus nesiotes	EN	↓
Avena insularis	EN	?
Avena murphyi	EN	↓
Barbarea lepuznica	EN	↓
Beta macrocarpa	EN	↓
Brassica hilarionis	EN	↓
Cicer canariense	EN	↓
Cicer graecum	EN	↓
Crambe laevigata	EN	↓
Crambe microcarpa	EN	↓
Crambe pritzelii	EN	↓
Crambe scoparia	EN	?
Lactuca watsoniana	EN	↓
Lathyrus cassius	EN	↓
Medicago cretacea	EN	↓
Medicago rupestris	EN	↓
Medicago saxatilis	EN	↓
Sinapidendron frutescens	EN	?
Sinapidendron sempervivifolium	EN	?
Vicia capreolata	EN	↓
Aegilops bicornis	VU	↓
Allium exaltatum	VU	↓
Allium pardoi	VU	↓
Allium pyrenaicum	VU	→
Allium schmitzii	VU	↓
Asparagus arborescens	VU	↓
Asparagus pastorianus	VU	↓
Asparagus plocamoides	VU	↓
Beta adanensis	VU	↓
Beta nana	VU	→
Brassica glabrescens	VU	↓
Crambe arborea	VU	→
Crambe aspera	VU	↓
Crambe gomerae	VU	→
Crambe scaberrima	VU	→
Isatis platyloba	VU	↓
Lactuca singularis	VU	↓
Lactuca tetrantha	VU	↓
Medicago glandulosa	VU	↓
Medicago kotovii	VU	↓
Prunus lusitanica	VU	↓
Prunus ramburii	VU	↓
Agropyron tanaiticum	NT	?
Allium albiflorum	NT	?
Allium convallarioides	NT	?
Allium lojaconoi	NT	→
Allium melananthum	NT	?
Brassica insularis	NT	→
Brassica rupestris	NT	→
Brassica villosa	NT	→
Crambe fruticosa	NT	→
Diplotaxis siifolia	NT	?

Continued

Table 28.5. Continued.

Species	Red List status	Population trend[a]
Lactuca alpestris	NT	?
Lactuca cyprica	NT	→
Lactuca triquetra	NT	→
Lathyrus amphicarpos	NT	↓
Lathyrus odoratus	NT	↓
Lathyrus rotundifolius	NT	→
Medicago cancellata	NT	↓
Medicago heyniana	NT	?
Medicago hypogaea	NT	→
Medicago pironae	NT	?
Medicago strasseri	NT	?
Pisum fulvum	NT	→
Rorippa prolifera	NT	?
Sinapidendron gymnocalyx	NT	?
Trifolium argutum	NT	→
Vicia barbazitae	NT	→

[a] ↓ = decreasing; ? = unknown; → = stable

28.6 Conservation Actions and Research Needs

Detailed information about conservation actions in place for each species assessed (primarily the species' *in situ* and *ex situ* conservation status) is recorded in a text field in SIS. There are fields in the database to record whether a species occurs within a protected area (PA) and whether it is conserved *ex situ*, but these data are not reliable and informative enough for analytical purposes. This is because the fact that a species occurs in a PA does not necessarily mean that the population is actively conserved – on the contrary, we know already that many CWR do occur in PAs but that they are only passively conserved as they are not the primary conservation targets of the sites (Maxted *et al.*, 1997b); this means that these populations are not actively managed or monitored and therefore may be in decline, yet this fact is unknown to the PA manager. Further, checking a box to say that a species is conserved *ex situ* tells us nothing about the number of samples conserved, where they were collected (to truly reflect inherent patterns of genetic diversity) and from what source; therefore, it would be misleading to use this data field as an indication of the *ex situ* conservation status of a species. However, using data extracted from EURISCO (2010), it was possible to obtain an indication of the *ex situ* conservation status of the species assessed. Further, it is possible to record conservation and research actions needed in SIS; therefore, we can make inferences from these sources about the adequacy of current conservation measures in place.

Germplasm accessions that are recorded by gene banks as being of wild or weedy origin are reported by EURISCO for 273 of the 571 species assessed (nearly 48%) and these are found in 23 of the 25 crop gene pools/groups included for assessment. This does not mean that there are not gene bank holdings of the other species because not all gene banks contribute data to EURISCO and not all accessions reported are necessarily tagged as being of wild or weedy origin. Further, germplasm holdings in botanic gardens such as those located in the Canary Islands and Madeira are not reported via EURISCO and these are known to conserve accessions of a number of the CWR species assessed. However, a very high proportion of European gene banks do now provide holdings data to EURISCO; therefore, we can reasonably assume that there are large gaps in the *ex situ* conservation of some of the highest priority CWR in Europe.

Furthermore, most species are represented by very few accessions, are reported by only one gene bank, and have been collected from only a small part of the species' range.

Conservation actions needed were recorded for 483 of the species assessed (Fig. 28.10). The most commonly recorded conservation needs were *ex situ* conservation

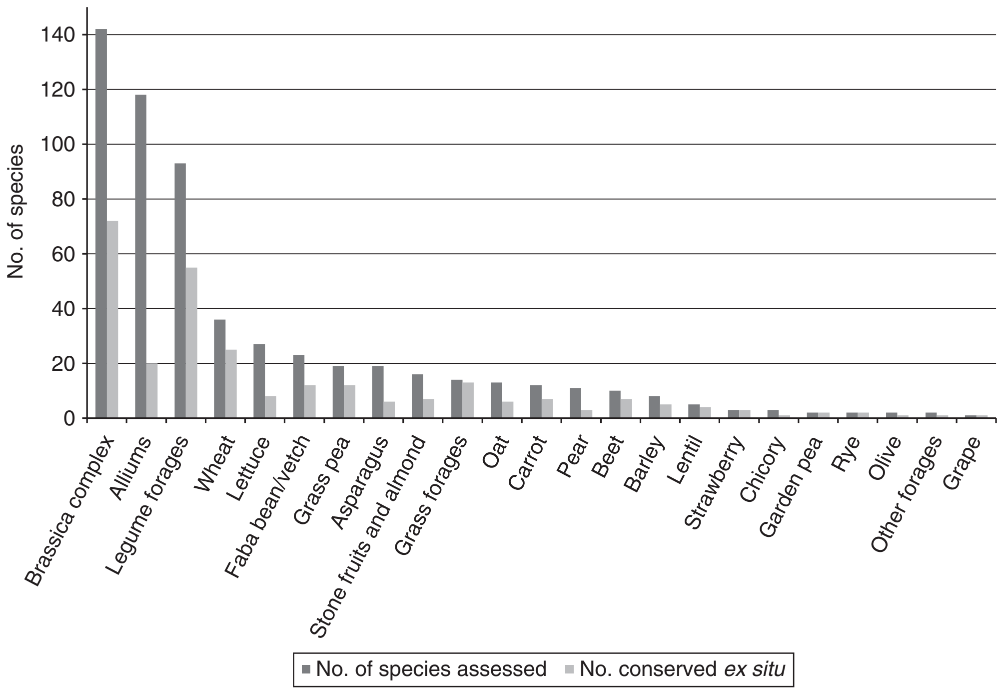

Fig. 28.9. The number of CWR species assessed in each crop gene pool/group compared with the number of species reported by EURISCO (2010) as having wild or weedy accessions in European gene banks.

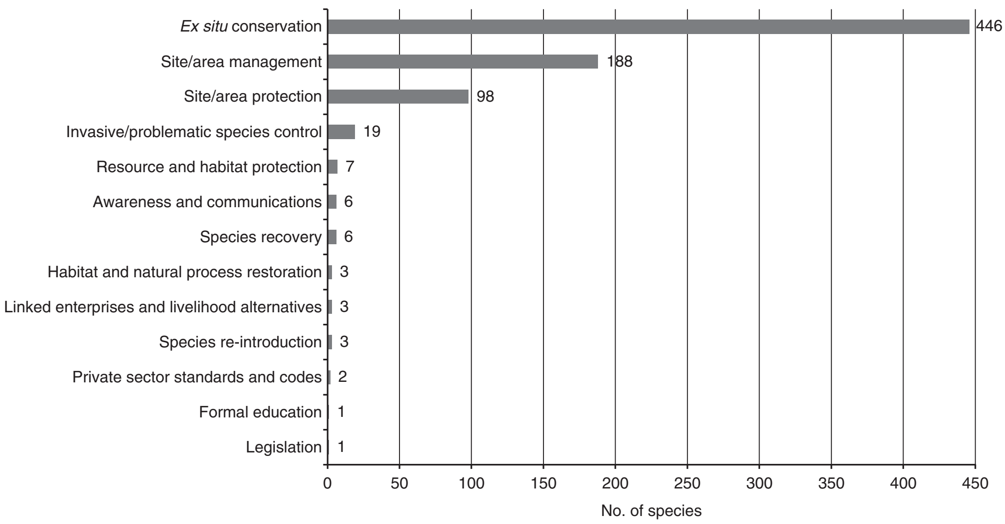

Fig. 28.10. Conservation actions needed for 483 species.

(which was recorded for 446 species – more than 78% of the 571 species assessed), site management (which was noted for 33% of the species) and site protection (17% of species). Research needs recorded included population size, distribution and trends (356 species), threats (163 species), habitat trends (73 species), life history and ecology (69 species) and taxonomy (35 species). It is clear from these results that much needs to be done not only to conserve European CWR, but also to improve our knowledge to enable conservation planning.

28.7 Conclusions and Recommendations

A sample of high priority European CWR species have been regionally assessed using the IUCN Red List Categories and Criteria (IUCN, 2001). These assessments have been published in the first European Red List and those that are endemic to Europe (188 species) have been published in the IUCN Red List of Threatened Species. This is the first time that a concerted effort has been made to carry out Red List assessment specifically for CWR as a group of plants and therefore it represents a significant breakthrough, not only in conservation planning for CWR but also in increasing awareness of their importance and the need for conservation action.

The results of this initiative show that a significant proportion of the species assessed are threatened or are likely to become threatened in the near future and that some crop gene pools or crop groups, such as the cultivated beets, are particularly at risk – these species should be subject to immediate conservation gap analysis and concerted actions. More than half of the species assessed are categorized as Least Concern but many of these are nationally threatened and even for those species that are relatively common and widespread in Europe, there is a need to conserve representative samples from throughout their range (both *in situ* and *ex situ*), to ensure that the widest possible range of genetic diversity is conserved and available for use in crop improvement programmes. A thorough review of the species evaluated as Least Concern should be undertaken to highlight those in most urgent need of conservation attention and those that require monitoring; data recorded on population trends, conservation and research needs and national threatened status can be used to aid priority-setting. Many species were assessed as Data Deficient – re-evaluation of these species is required when resources are available.

An analysis of the threats affecting CWR populations in Europe clearly show that concerted action is needed to alleviate the causal factors, the most commonly reported threats being livestock farming, development for tourism and recreation, and new housing and urban areas; however, with an increasing human population placing pressure on land and resource use, this presents an enormous challenge. An immediate priority should be the establishment of genetic reserves for the highest priority species (see Kell *et al.*, Chapter 2, this volume) with complementary back-up in *ex situ* collections. *In situ* management plans for these species need to address the threats present at the site, such as excessive grazing by livestock. On-farm management may present an option for CWR populations that grow in agro-environments (see Maxted *et al.*, 1997b, 2011).

In addition to the knowledge gained on the threatened status of European CWR species, a positive outcome of this initiative is that a significant quantity of datum has been collated that is not only useful for conservation planning but serves as a baseline for future assessment. Further, a large group of specialists with expert knowledge of wild plant species has received training in IUCN Red Listing and professional collaboration has been fostered within this network. At the same time, undertaking this initiative presented some challenges, including dealing with issues of data quality and consistency, problems associated with information management (data recording and standards), communicating with a network of experts dispersed in many different countries, and the potential subjectivity of the process. It is important to stress that Red Listing depends heavily on the voluntary contributions of experts who have the knowledge and access to information needed to carry out the assessments; however, the demand on their professional time means that they cannot always contribute as much as they might like to Red Listing. Therefore, for future projects of this kind it would be beneficial to allocate funding to acknowledge the contributions of experts (even if it is a nominal amount) because their knowledge is fundamental to the success of such a project.

This initiative should not be viewed as an end in itself but as a springboard for future work in this area. Specifically, we recommend that as a priority, the Crop Wild Relative Specialist Group (CWRSG) of the Species Survival Commission of IUCN coordinates the collation of Red List assessments of national endemic CWR species (both within and outside Europe) for submission to the IUCN Red List of Threatened Species (recognizing that adequate resources will be required). This will have a significant impact by increasing awareness of the importance of CWR, their threatened status and the need for conservation action.

Finally, the application of the IUCN Red List Categories and Criteria to this sample of European CWR species has reinforced the need for the development of an additional means of assessment that takes into account intra-specific genetic diversity. Although the existing system can be used to assess subpopulations of a species (in addition to subspecies and varieties) and has been successfully used in this manner for several mammals (see for example: www.iucnredlist.org/apps/redlist/details/2468/0), the assessment is still based on population size (i.e. the number of mature individuals) and/or geographic range, rather than the genetic diversity (i.e. allelic richness, evenness and/or uniqueness) within and between those subpopulations. It is rarely the case that all subpopulations of a species contain an equal proportion of genetic diversity; therefore, when the aim (as for CWR conservation) is to maximize both inter- and intra-specific genetic diversity to ensure that the widest pool of genes is available for use in crop improvement programmes, the risk of extinction for a species must consider both within and between subpopulation genetic diversity. Indeed, the goal of wild plant species conservation in general should take account of intra-specific genetic diversity as it is the maintenance of this diversity, both within and between subpopulations, that ensures overall population stability. We therefore recommend that genetic diversity is taken into account in the assessment process, either to complement or extend the applicability of the existing system.

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Notes

[1] In February 2011, a major revision of Euro+Med PlantBase was published; the changes made to the families other than Compositae, Poaceae and Roasaceae are not reflected in the list of CWR species selected for inclusion in the European Red List.

[2] A benign introduction is defined as ‘an attempt to establish a species, for the purpose of conservation, outside its recorded distribution, but within an appropriate habitat and eco-geographical area. This is a feasible conservation tool only when there is no remaining area left within a species’ historic range’ (IUCN, 1998).

[3] The field for recording native status primarily contains only one code for each occurrence, but in some cases, multiple codes are used. For example, some records are coded ‘DN’, ‘NE’ or ‘NS’. Again, this indicates a degree of uncertainty in the data and to take an inclusive approach, all records containing combinations of codes N, S, D and E were included.

[4] Subclasses of food types used in GRIN Taxonomy for Plants (USDA, ARS, National Genetic Resources Program, 2009), which is adapted from the Economic Botany Data Standard (Cook, 1995).

[5] *Brassica* spp. are included in the high priority human food crop list.

[6] *Triticum*, *Aegilops* and *Secale* spp. are included in the high priority human food crop list.

[7] A species is classified as NA when a very small proportion (usually ca. 1% or less) of its global population occurs in the region of the assessment or because it is not a wild population or not within its natural range in the region, or because it is a vagrant.

[8] A taxon is Near Threatened when it has been evaluated against the criteria but does not qualify for Critically Endangered, Endangered or Vulnerable now, but is close to qualifying for or is likely to qualify for a threatened category in the near future (IUCN, 2001).
[9] The IUCN Red List Categories and Criteria have been applied to a number of mammal species at subpopulation level but no subpopulation assessments of plant species have been published to date.

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CHAPTER 4

CHINA'S CROP WILD RELATIVES: DIVERSITY FOR AGRICULTURE AND FOOD SECURITY

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Bin Chen facilitated access to data in the China Checklist of Higher Plants and Haining Qin facilitated access to the data in the China Red List – Higher Plants Volume. Shelagh Kell and Bin Chen collaborated on the production of the CWR China Checklist. Shelagh Kell undertook all other data analyses, produced the tables, figures and supplementary data, and wrote the content of the paper. Haining Qin, Brian Ford-Lloyd, Wei Wei and Nigel Maxted provided comments and suggestions on the draft manuscript. The research was undertaken in the context of the collaborative project 'Conservation for enhanced utilization of crop wild relative diversity for sustainable development and climate change mitigation' (CWR China) (see acknowledgements at the end of the paper). All co-authors collaborated in this project and were involved in discussions during project meetings and workshops.

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Statements of co-authors

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I, Bin Chen, of the Shanghai Chenshan Botanical Gardens, China (formerly of the Institute of Botany, Chinese Academy of Sciences), confirm that the above declaration of co-author contributions is true and accurate.

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I, Brian Ford-Lloyd, Emeritus Professor of the University of Birmingham, UK, confirm that the above declaration of co-author contributions is true and accurate.

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China's crop wild relatives: Diversity for agriculture and food security

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ABSTRACT

The potentially devastating impacts of climate change on crop production and food security are now widely acknowledged. An important component of efforts to mitigate these impacts is the production of new varieties of crops which will be able to thrive in more extreme and changeable environmental conditions. There is therefore an urgent need to find new sources of genetic diversity for crop improvement. Wild plant species closely related to crops (crop wild relatives) contain vital sources of such genes, yet these resources themselves are threatened by the effects of climate change, as well as by a range of other human-induced pressures and socio-economic changes. The flora of China comprises more than 20,000 native higher plant species, a proportion of which have known or potential value as gene donors for crop improvement. However, until now, the full range of these valuable crop wild relative species had not been identified. In this paper we present a methodology for creating a checklist of, and prioritizing China's crop wild relatives, and reveal that 871 native species are related to crops that are of particularly high socio-economic importance in China—including rice, wheat, soybean, potato, sweet potato, millet and yam—crops which are also of notably high value for food and economic security in other parts of the world. Within this list we have identified species that are in particular need of conservation assessment based on their relative Red List status and potential for use in crop improvement programs. Endemic species that have particularly high economic value potential in China and that are under severe threat of genetic erosion and thus in need of urgent conservation action include wild relatives of tea (*Camellia fangchengensis* S. Yun Liang et Y.C. Zhong and *C. grandibracteata* H.T. Chang et F.L. Yu), apple (*e.g.*, *Malus honanensis* Rehder, *M. ombrophila* Hand.-Mazz. and *M. toringoides* (Rehder) Hughes), and pear (*Pyrus pseudopashia* T.T. Yu). We provide recommendations for developing a systematic and comprehensive national CWR conservation strategy for China, highlighting the challenges and requirements of taking the strategy forward to the implementation phase.
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1. Introduction

1.1. The value of crop wild relatives for climate change mitigation

Crop wild relatives (CWR) are species closely related to crops that have the potential to contribute traits for crop improvement (Maxted et al., 2006). They have been used increasingly in plant breeding since the early 20th century and have provided vital genetic diversity for crop improvement—for example, to confer resistance to pests and diseases, improve tolerance to environmental conditions such as extreme temperatures, drought and flooding, and to improve nutrition, flavor, color, texture and handling qualities (Maxted and Kell, 2009). CWR have contributed significantly to the agricultural and horticultural industries, and to the world economy (Maxted and Kell, 2009; Maxted et al., 2008) and have long been recognized as a critical resource with a vital role in food security and economic stability (Hajjar and Hodgkin, 2007; Hoyt, 1988; Maxted et al., 1997a, 2012, 2014; McCouch et al., 2013; Meilleur and Hodgkin, 2004; Prescott-Allen and Prescott Allen, 1986; Stolton et al., 2006).

Today, crop production is significantly affected by the impacts of climate change and the future holds much uncertainty in terms of productivity both in the short and long term. In the Fifth Assessment Report of the Intergovernmental Panel on Climate

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Change (IPCC, 2014), Porter et al. (2014) note that climate trends over the past 50 years have had a negative impact on wheat and maize production in some regions and an overall negative impact on aggregate global production of these two crops. Impacts have been minor on rice and soybean yields, both in major production regions and globally and increasing temperatures have had a beneficial impact on crop production in some high latitude regions (Porter et al., 2014), including northeast China (Chen et al., 2010). Reported small or beneficial impacts of climate trends should however be interpreted with care. For example, Hijioka et al. (2014) cite a study of the response of rice yields to climate change in the period 1981–2005 in China (Zhang et al., 2010) which showed positive correlation between yield and temperature in tandem with increased solar radiation. However, in some localities lower yields were correlated with higher temperatures, with yield increases being positively correlated with rainfall.

Critically, projected impacts of climate change on rice production in China indicate that increasing temperatures will result in lower yields due to shorter growing periods (Hijioka et al., 2014). The authors also report (citing Wassmann et al., 2009a,b) that current temperatures are approaching critical levels in terms of increasing heat stress during the susceptible developmental stages of the rice plant. A study showing reduced rice yields throughout Asia under different climate change scenarios concluded that one of the most vulnerable regions is eastern China (Masutomi et al., 2009). On the other hand, Hijioka et al. (2014) highlight that winter wheat yields in China are projected to increase throughout the 21st century in the Huang-Huai-Hai Plain, China's most productive wheat growing region (Thomson et al., 2006), and in the North China Plain (Tao and Zhang, 2013). However, in the latter region, maize yields are projected to substantially decrease (Tao et al., 2009).

The studies cited above relate to long-term climate trends and do not take account of the potential impacts of extreme climate events on crop production which the IPCC (2012) reported are expected to have a negative effect. For example, rice crop yields may be lower in response to extreme rises in temperatures (Mohammed and Tarpley, 2009; Tian et al., 2010) and crop production can also be negatively impacted by periods of high rainfall causing flooding (Handmer et al., 2012). An additional potential pressure on agriculture in China is insufficient water caused by demand for non-agricultural uses (Xiong et al., 2010, cited in Hijioka et al., 2014).

While reported potential future increases in crop production in some areas for some major crops is positive, the overall trend is for climate change impacts to negatively affect crop production, as well as introducing higher levels of uncertainty with regard to the stability of environmental conditions. Climate change will also lead to changes in the occurrence of crop pests and diseases, as well as in production areas (Lane and Jarvis, 2007; FAO, 2011). Furthermore, studies of the impacts of climate change have only been undertaken on a limited number of crops. Therefore, the future of productivity for many crops is unknown. The potential ramifications are far-reaching, impacting the entire value chain, from farmers to consumers. Major crop losses may lead to local food and economic insecurity, as well as impacting global food supplies and market values. China is a major producer and exporter of several staple crops, including rice, wheat and maize. The potential for substantial decreases in productivity and even severe crop losses will not only impact on China's food and economic security but may potentially have a marked effect in other regions as well.

One option for mitigating the impacts of climate change on food production is to develop crop varieties with increased resistance to elevated temperatures, drought, pests and diseases (Easterling et al., 2007). The authors comment that the many climate change adaptation studies on wheat, rice and maize crops indicate that this option alone, or combined with other adaptations such as changes in planting times and locations and improved water management, has the potential to provide an average of 10% increase in yield across all regions, all crops and different temperature regimes. The cultivation of high temperature tolerant varieties of maize in the North China Plain for example, combined with adaptations in planting regimes, could have a significant increase in yields, while no adaptation interventions may result in yield reductions of up to 19% (Tao and Zhang, 2010). In a meta-analysis of projected crop yields in a range of climate change and adaptation scenarios, Challinor et al. (2014) concluded that the development of new cultivars was the most effective modification. Indeed, the development of new crop varieties is at the top of a list of technological adaptation options presented by Noble et al. (2014). Plant breeders are therefore in need of diverse and novel sources of genetic diversity to produce new crop varieties able to cope with the impacts of changing growing conditions (Deryng et al., 2011; Duveiller et al., 2007; FAO, 2008; Feuillet et al., 2008; Guarino and Lobell, 2011; Jones et al., 2003; Li et al., 2011; Luck et al., 2011; McCouch et al., 2013; Muñoz-Amatriaín et al., 2014). Due to the breadth of genetic diversity inherent in CWR populations, which are adapted to a wide range of environmental conditions, they are likely to become increasingly important as sources of genetic diversity to produce crop varieties able to cope in the altered environmental conditions induced by climate change (FAO, 2008, 2010, 2011; Ford-Lloyd et al., 2011; Guarino and Lobell, 2011; Kell et al., 2012a; Maxted et al., 2012; Vollbrecht and Sigmon, 2005; Zamir, 2001), especially in the light of enhanced gene discovery and breeding techniques, as well as improved knowledge of the use of exotic germplasm in breeding programs (Dwivedi et al., 2008; Feuillet et al., 2008; Hajjar and Hodgkin, 2007; Lobell et al., 2008; McCouch et al., 2013; Zamir, 2001). CWR are therefore a fundamental component of plant genetic resources for food and agriculture (PGRFA) and may contribute significantly to future food security.

1.2. Threats to crop wild relatives and current conservation status

CWR species occur in a wide range of habitats, including high altitude steppe, forests, riversides, coastal beaches and cliffs, crop and pasturelands, orchards, roadsides and urban areas. Some are relatively common and widespread but many have limited distributions and habitat niches. Like other wild species, CWR are subject to an increasing range of threats in their native habitats (FAO, 1996, 1998, 2010, 2011; Maxted et al., 2008, 2012, 2015), including deforestation, logging, plantation agriculture and forestry, agricultural industrialization, desertification, urbanization, mining and quarrying, invasive species and climate change (Bilz et al., 2011; Kell et al., 2012b; Maxted and Kell, 2009; Maxted et al., 2014). Many wild relatives of major crops are found in disturbed, pre-climax communities—the habitats most affected by increasing levels of anthropogenic change and destruction (Jain, 1975). Compared to other wild species found in more stable climax communities, CWR are therefore likely to be disproportionately and adversely impacted by environmental change (Maxted and Kell, 2009). In a study of the Red List status of CWR in Europe, the most frequently reported threat was unsustainable farming practices, such as severe overgrazing, conversion of land to monocultures and the heavy application of fertilizers, herbicides and pesticides (Kell et al., 2012b). In China the main threat to wild plant species (and thus also CWR) is habitat loss and degradation, with agro-forestry impacting 29% of affected threatened species, infrastructure development impacting 12%, and the remaining 59% being impacted by harvesting or other forms of habitat loss and degradation (Qin et al., 2013).

The value of CWR and the requirement for greater conservation efforts are recognized in a number of global policy instruments, including the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) (FAO, 2001) and the Second Global Plan of Action for Plant Genetic Resources for Food and Agriculture (GPA) (FAO, 2011). The importance of CWR is also underlined in the CBD Strategic Plan (CBD, 2010a) and Global Strategy for Plant Conservation 2011–2020 (CBD, 2010b). For several decades, the focus has been on the *ex situ* conservation of PGRFA in gene banks. However, few *ex situ* conservation programs have focused intentionally on the active conservation of CWR as a resource for crop improvement and future food security. An analysis of European gene bank collections data stored in EURISCO (http://eurisco.ecpgr.org) revealed that only 4% of accessions are of wild species (Dias and Gaiji, 2005) and while this has more recently been estimated at 7% (S. Dias, pers. comm., Rome, 2013), the breadth of coverage of crop gene pools is limited (Kell et al., 2008, 2012b). Further, Kell et al. (2012b) found that most European priority CWR species are represented by very few *ex situ* accessions, are reported by only one gene bank, and have been collected from only a small part of the species' range. At global level, FAO (2010), based on data provided by WIEWS (http://apps3.fao.org/wiews/wiews.jsp) reported that in 2009, 18% of accessions in germplasm collections were of wild species and that this was an increase of 3% since 1996. However, this increase was comparable with the increase in numbers of research/breeding materials and landrace accessions so may simply represent an increase in the number of accessions reported overall or a general increase in the size of collections of all types of germplasm. Further, the percentage of accessions alone is not an adequate indication of the *ex situ* conservation status of CWR. Information on the number of species, crop gene pool coverage and the genetic representativeness of the collections is needed in order to undertake a comprehensive assessment. A recent initiative (see CWR and Climate Change, 2013; Dempewolf et al., 2014) aims to redress the requirement for systematic *ex situ* CWR conservation by identifying global priority CWR, developing and implementing an *ex situ* conservation action plan for priority species, and promoting the use of the conserved diversity in crop improvement programs.

While the *ex situ* conservation of CWR germplasm is essential for research and utilization purposes, it does not allow for continued evolution of populations and potential genetic adaptation to changing environmental conditions. Maxted et al. (1997b) reported a shift in emphasis to PGRFA conservation *in situ* in the 1980s but it is only since the early 2000s that the need for *in situ* CWR conservation has been formally recognized, most notably in the ITPGRFA (FAO, 2001) and GPA (FAO, 2011), with the GPA specifically highlighting *in situ* conservation and management of CWR as a 'priority activity'. Methods for systematic *in situ* CWR conservation planning have developed rapidly since the turn of the century and there are now a set of commonly agreed and widely tested scientific concepts and techniques (Maxted et al., 2015) for which practical implementation guidelines and support is available (*e.g.*, see JKI, 2007–2013; Maxted et al., 2013; UOB, 2011–2014). Progress has been made in systematic national CWR conservation strategy planning in Europe, the Middle East and the Americas, as well as some advances in the Caucasus, Madagascar and northern Africa, and the momentum is increasing with projects now focusing on southern Africa and Central America. At global level, the FAO Commission on Genetic Resources for Food and Agriculture (CGRFA) commissioned a background study on the establishment of a global network for *in situ* conservation of CWR (Maxted and Kell, 2009) and recently held a Technical Workshop to take forward the development of an *in situ* conservation network in a broader PGRFA context (FAO, 2013). Despite the good progress made in some parts of the world, the transition from CWR conservation planning to practice presents an ongoing challenge involving a complex range of socio-economic and political factors (Maxted et al., 2015). One of the greatest hurdles is bringing together the PGRFA and environmental conservation communities which have historically operated in isolation of one another (Maxted and Kell, 2009; Maxted et al., 1997c, 2008, 2015). At governmental level this involves fostering communication and collaboration between agricultural and environmental departments and agencies because both have responsibility for conservation of wild plant diversity that may be of value for agriculture.

1.3. China's flora – a reservoir of diversity for crop improvement

China has a flora containing in excess of 35,000 higher plant species (Qin and Wang, 2013), a proportion of which have known or potential value as gene donors for crop improvement. These include native wild relatives of food crops such as rice, wheat, soybean, sorghum, banana, apple, citrus fruits, grape, stonefruits and millet. The many examples of the use of CWR species native to China for crop improvement include: *Glycine soja* Siebold & Zucc. which has been utilized to confer traits to soybean (*G. max* (L.) Merr.) for cold tolerance and early ripening (Budin, 1973; Sun et al., 1997; Zhao and Gai, 2006), and to improve protein content (Diers et al., 1992; Sebolt et al., 2000) and yield (Concibido et al., 2003); *Malus baccata* (L.) Borkh. used to transfer cold tolerance in apple, *M. domestica* Borkh. (Cummins and Aldwinckle, 1979); *Musa balbisiana* Colla and *M. basjoo* Siebold & Zucc. ex Iinuma for abiotic stress resistance (including drought and cold tolerance) in banana, *M. acuminata* Colla (INIBAP/IPGRI, 2006); *Oryza rufipogon* Griff. to transfer traits to rice (*O. sativa* L.) for yield improvement (Brar and Khush, 1997; Lee et al., 2004, 2005; Liang et al., 2004; Marri et al., 2005; Moncada et al., 2001; Septiningsih et al., 2003; Thomson et al., 2003; Tian et al., 2006; Xiao et al., 1996, 1998), aluminium toxicity tolerance (Nguyen et al., 2003) and drought resistance (Zhang et al., 2006); *Sorghum propinquum* (Kunth) Hitchc. for yield improvement and early maturity in sorghum, *S. bicolor* (L.) Moench (Hajjar and Hodgkin, 2007); *Aegilops tauschii* Coss. for drought tolerance (Gororo et al., 2002) and yield improvement (Pestsova et al., 2006; Valkoun, 2001) in wheat, *Triticum aestivum* L., as well as a range of other agronomic traits (see Maxted and Kell, 2009); and *Vitis amurensis* Rupr. for cold resistance in grape, *V. vinifera* L. (Golodriga and Souyatinou, 1981). Vincent et al. (2013) recently reported the creation of a global inventory of priority CWR taxa based on the likely ease of CWR use by breeders or past evidence of breeders' use and found that China is the country with the highest number of taxa (222) related to a list of 173 human food crops that have the most immediate use potential. China is also one of the ten most important countries for further *ex situ* collecting and is third globally in terms of the value of native CWR diversity for food security (Vincent et al., 2013).

The flora of China is one of the richest in the world (Wang et al., 1995). The country covers nearly 7% of the world's land mass and spans five temperate and tropical climatic zones from north to south (Wang et al., 1995). China's diverse topography encompasses a wide array of habitat types—including mountains, deep gorges, high plateaux, hills, basins and plains—which have influenced the distribution of species and vegetation types (Davis et al., 1986; Wang et al., 1995). Many mountainous areas of China have distinctive floras (Wang et al., 1995) and more than half of the country's seed plant species are endemic (Huang et al., 2011). This floristic richness and diversity represents a vast natural reservoir of genetic diversity with potential to contribute to the production of new crop varieties adapted to grow and yield in rapidly changing climate change-induced environmental conditions.

Systematic efforts to identify China's CWR and plan for their complementary (*in situ* and *ex situ*) conservation have now been initiated under the umbrella of the UK–China Sustainable Agriculture Innovation Network (SAIN) (www.sainonline.org/english.html). In this paper we describe the process of identifying and prioritizing China's CWR and provide an annotated checklist of priority CWR taxa (the CWR China Inventory), highlighting those of particular conservation concern and the areas of China which are likely to be the focus of the most intensive conservation action, subject to more detailed diversity and gap analyses.

2. Data and methods

2.1. Generating a checklist of China's crops and CWR

A checklist of crops and CWR that occur in China (the CWR China Checklist) was generated using a methodology previously developed and applied to produce the CWR Catalogue for Europe and the Mediterranean (Kell et al., 2005, 2008). In essence, the method involves three steps: (1) draw up a list of genus names containing cultivated taxa to produce a list of 'crop genera'; (2) match the crop genera with the genus names in the floristic inventory of the area under study; and (3) extract the taxa from the floristic inventory that are within the matching genera identified under step 2 to produce the CWR checklist (Fig. 1 – based on Kell et al., 2008). The resulting list includes both cultivated and wild plant taxa to provide the links between wild species and the crop(s) they are related to and recognizing that a taxon may exist in both cultivated and wild forms. This method is based on a broad definition of a CWR—any taxon in the same genus as a crop (Taxon Groups 1–4 – see Maxted et al., 2006), or in the case of some crop complexes (*e.g.*, wheat), closely related genera—and provides a practical means of creating an initial CWR checklist, especially when floristic data are available in electronic format. It also recognizes that while taxa that are most closely related to crops are easier to utilize in conventional plant breeding programs, there are many examples of the use of traits from more distantly related taxa for crop improvement and of remote taxa that have been evaluated and contain traits of potential interest (Maxted and Kell, 2009; Vincent et al., 2013). As noted in Section 1.1, these more distantly related taxa may not have immediate utilization potential but many are likely to contain genetic diversity that will be of use for future crop adaptation. Therefore, in this paper we use the term crop 'gene pool' in a broad sense to include all taxa within the same genus as the crop taxon or in closely related genera where relevant, while recognizing that in the case of some crop genera (*e.g.*, the large genera *Solanum* L. and *Vicia* L.), there are many taxa that are distantly related to the one or more crop species in those genera. For this reason, in this study we also identify the closest wild relatives of the priority crops, or taxa that are more distantly related that have been successfully utilized in crop improvement programs or that have been evaluated and have shown promise for crop improvement (see Sections 2.2 and 3.4, and Supplementary data).

The CWR China Checklist was created using two data sources: for the flora of China, the China Checklist of Higher Plants (Qin et al., 2009), and for the list of genera containing cultivated taxa, the crop genus name list generated during the production of the CWR Catalogue for Europe and the Mediterranean (Kell et al., 2005). The latter list was generated using data extracted from Mansfeld's World Database of Agricultural and Horticultural Crops (http://mansfeld.ipk-gatersleben.de; Hanelt and IPK, 2001); Enumeration of Cultivated Forest Plant Species (Schultze-Motel, 1966); and the Community Plant Variety Office list of licensed plant varieties in Europe (Kwakkenbos, 2003, pers. comm.) (see Kell et al., 2008).

2.2. Selecting China's priority CWR species

Prioritization is a fundamental part of the conservation planning process. Due to the limited resources available for PGRFA conservation, priority species and populations need to be identified to direct

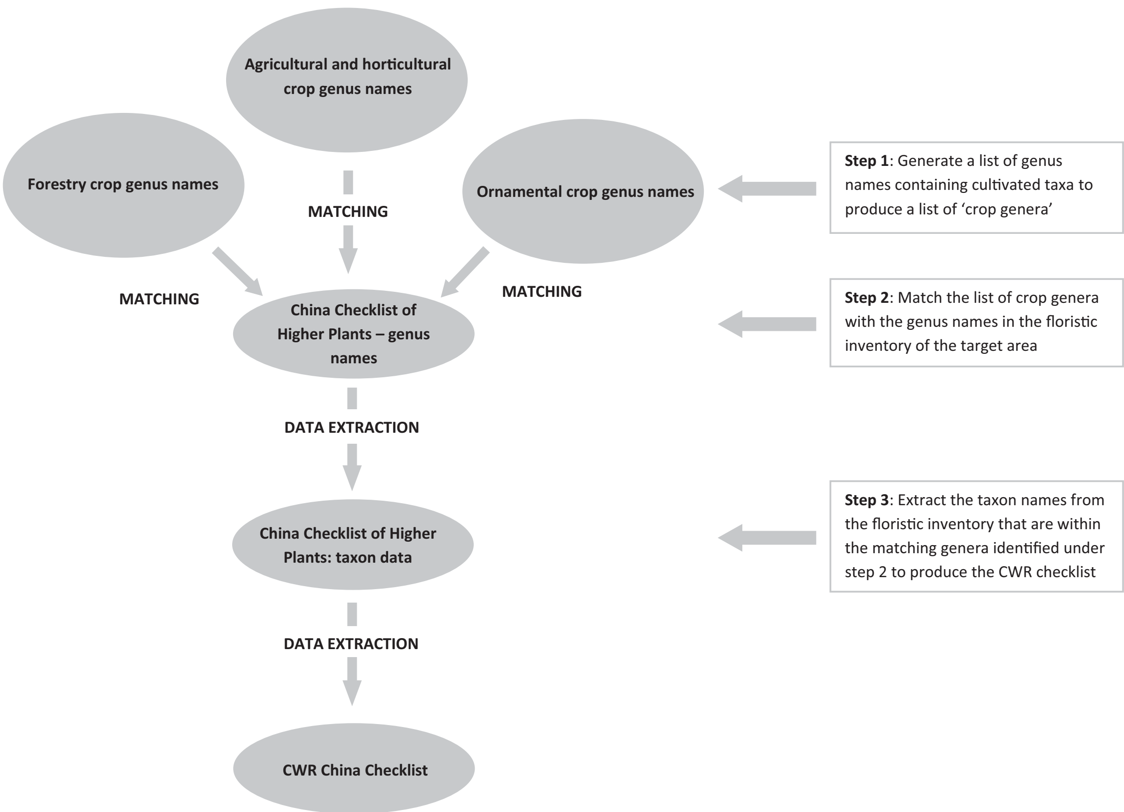

Fig. 1. Methodology for generating the CWR China Checklist.

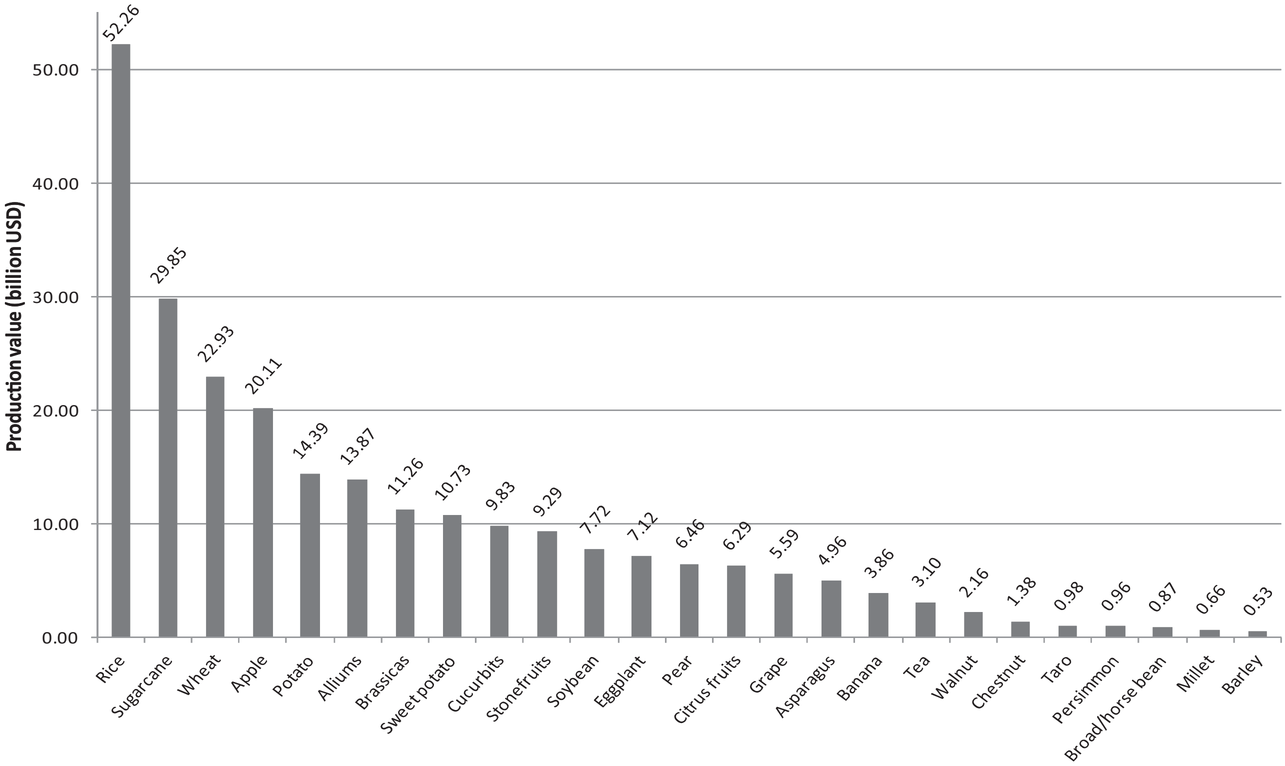

Fig. 2. Human food crops/crop groups with an average annual production value of more than US$500 million in China in the period 2002–2011 that have native wild relatives. Data source: FAO (2014).

funding where it is most needed. There are a variety of prioritization measures that can be applied (Maxted et al., 1997d), but three main criteria are of greatest relevance when assigning priorities to CWR species in the context of conservation planning: (i) the socio-economic value[1] of the crop to which they are related (Ford-Lloyd et al., 2008); (ii) their relative threat status (Ford-Lloyd et al., 2008; Maxted and Kell, 2009); and (iii) their potential ease of use or known value in crop improvement programs (Maxted and Kell, 2009; Maxted et al., 2012). In general, priority is given to native species. However, depending on how long they have been present, some introduced CWR populations may harbor important genetic diversity, especially because many taxa are able to adapt rapidly to new environments (Ford-Lloyd et al., 2014).

To select China's priority CWR, firstly, using an entirely novel approach, FAO crop production statistics (FAO, 2014) were consulted to obtain annual production values of human food crops cultivated in China over the ten year period 2002–2011[2]. Human food crops with an average annual value of more than US$500 million over this period that have CWR native to China were identified and the native wild relatives of these crops selected from the CWR China Checklist to create a list of nationally important CWR based on the economic importance of the associated crops. The global values of human food crops in terms of average annual energy supply per capita over the ten year period 2000–2009 was calculated from FAO food supply statistics (FAO, 2014) for the major sub-regions of the world to highlight crops of particular global value for food security[3]. China's native wild relatives of these crops that were not already included in the list based on national economic importance were added to form the base priority list of taxa to include in the CWR China Inventory. Secondly, the China Red List of Biodiversity – Higher Plants Volume (MEP and CAS, 2013) was used to identify threatened and Near Threatened taxa in the base priority list, as well as those endemic to China. Using occurrence data in the China Checklist of Higher Plants (Qin et al., 2009), provinces containing regionally and globally threatened or Near Threatened CWR were identified. Thirdly, by consulting data available on the degree of relationship between the crop species and the wild relatives in the crop gene pool and/or the known value of CWR in crop improvement programs (Vincent et al., 2013), taxa in the base priority list that are likely to have greater use value for crop improvement were identified. Lists of priority CWR at each of these three levels were compiled to create the CWR China Inventory with the purpose of providing the foundations for national CWR conservation planning in China.

3. Results and discussion

3.1. Overview of the CWR China Checklist

The CWR China Checklist contains 24,499 crop and CWR species accounting for around 70% of the flora of China. This large number of species is expected as similar results were found for Europe and the Mediterranean region. The reasons for this are: (a) the use of a broad definition of a crop (including all types of cultivated taxa from food crops to those used for industrial, environmental and medicinal purposes); (b) the application of a broad definition of a CWR (i.e., any taxon within the same genus as a crop or in the case of some crop gene pools, such as wheat and brassicas, taxa within closely related genera); and (c) the inclusion of both native and introduced taxa, as well as those that are cultivated (Kell et al., 2008). Identifying the number of native, introduced and cultivated CWR species in China is not straightforward as occurrence records

[1] The term 'socio-economic value' as used in this paper refers to value to society both in terms of supporting economic growth and ensuring food security.
[2] The production value data used were the most recent available at the time of undertaking the analysis.
[3] The energy supply data used were the most recent available at the time of undertaking the analysis.

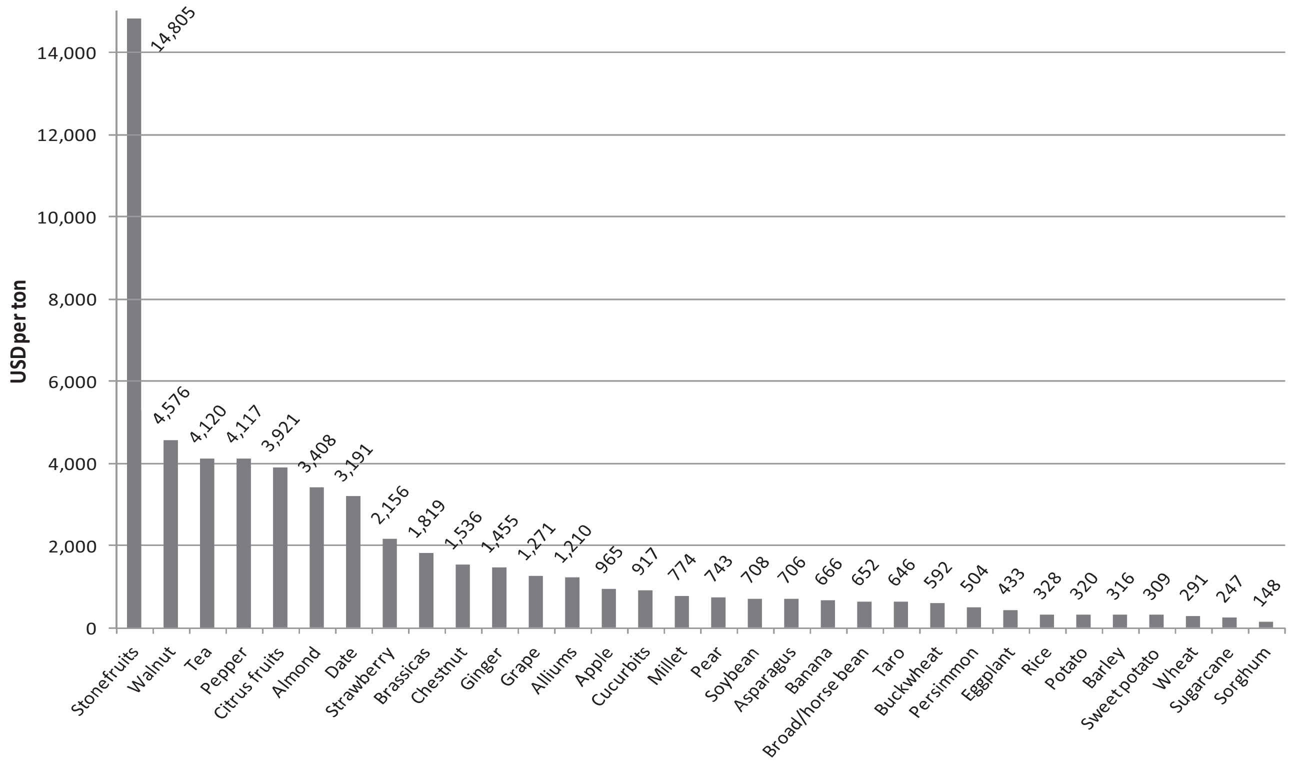

Fig. 3. Average annual value per ton of human food crops/crop groups cultivated in China that have native wild relatives, measured over the three year period 2009–2011. Data source: FAO (2014).

are not coded using the Plant Occurrence and Status Scheme (WCMC, 1995) in the China Checklist of Higher Plants (Qin et al., 2009). However, an indication of the number of native species can be obtained by matching the species in the CWR China Checklist with those in the China Red List of Plants which only includes native species that occur in their wild form (although excluding poisonous plants and weeds). This reveals that at least 20,500 species in the CWR China Checklist are native and occur in the wild. A match between the Checklist and a list of cultivated species extracted from Mansfeld's World Database of Agricultural and Horticultural Crops shows that 2262 species are known to be cultivated worldwide. This excludes species cultivated for forestry and ornamental uses and the number of cultivated species in the CWR China Checklist is therefore likely to be significantly higher.

3.2. CWR prioritization stage one: socio-economically important crops

National conservation planning for PGRFA demands careful prioritization to identify species that are of potential socio-economic importance to the nation. Wild relatives of crops that are socio-economically important for a country are likely to gain greatest attention due to their importance for the national economy and for food security. Focusing on crops of highest socio-economic value provides an important motivation for the establishment of a national PGRFA conservation management framework which can be enhanced in the future with the addition of species which are less economically important to the country as a whole but which are important for local food and economic security. Further, species in major economic groups of cultivated taxa other than human and animal food may also be considered for inclusion in the national CWR conservation strategy in the future: namely, food additives (*e.g.*, flavorings, sweeteners, stabilizers, thickening agents and colorings); materials (*e.g.*, fiber, timber, resins and industrial oils); fuels; social (*e.g.*, tobacco); medicines; and environmental (*e.g.*, ornamentals and plants used for erosion control and soil improvement) (Maxted et al., 2015). It is also worth noting that some genera containing human and animal food crops also include taxa cultivated for other purposes, which may for example include crops used for biofuel or for ornamental or medicinal purposes.

The initial prioritization of China's CWR is based on human food crops due to their importance for nutrition and food security. Fig. 2 shows the 25 human food crops or crop groups[4] with an average annual production value of more than US$500 million in China over the period 2002–2011 that have native wild relatives[5]. The broad gene pools of these crops of particularly high national economic importance combined contain 837 CWR species native

[4] Cucurbits: cucumber, gherkin, melon and melonseed. Brassicas: rapeseed, cabbage, cauliflower, broccoli and other brassicas. Alliums: onion, garlic, leek and shallot. Citrus fruits: orange, grapefruit, pomelo, lemon, lime, tangerine, mandarin, clementine, satsuma and other unspecified citrus fruits. Stonefruits: peach, nectarine, plum, sloe, apricot, cherry and other unspecified stonefruits. Chestnut: Chinese, European and Japanese chestnut.

[5] At least eight species may be reported in FAO crop production data under the general category 'millet', including Japanese millet (*Echinochloa esculenta* (A. Braun) H. Scholz), white millet (*Echinochloa frumentacea* Link), finger millet (*Eleusine coracana* (L.) Gaertn.), teff (*Eragrostis tef* (Zucc.) Trotter), common millet (*Panicum miliaceum* L.), kodo millet (*Paspalum scrobiculatum* L.), pearl millet (*Pennisetum glaucum* (L.) R. Br.) and foxtail millet (*Setaria italica* (L.) P. Beauv.). All but two of these species (teff and kodo millet) are reported by eFloras (2008) to be cultivated in China. The origins of the wild *Echinochloa* species that occur in China are uncertain and the only wild relative of finger millet native to China is *Eleusine indica* which is a pantropical invasive annual weed that occurs in tropical and subtropical areas of the country in disturbed places and roadsides (eFloras, 2008). Therefore, CWR in the genera *Panicum*, *Pennisetum* and *Setaria* are included in the list of priority CWR based on national economic importance.

[6] Native status ascertained from species included in the China Red List (MEP and CAS, 2013) or for species not included in the Red List, GRIN Taxonomy for Plants (USDA, ARS, National Genetic Resources Program, 2014) and the Flora of China (eFloras, 2008). For a small number of species which are not included in the China Red List or GRIN Taxonomy for Plants and the native status is not explicit in the Flora of China, the native status is uncertain and requires clarification.

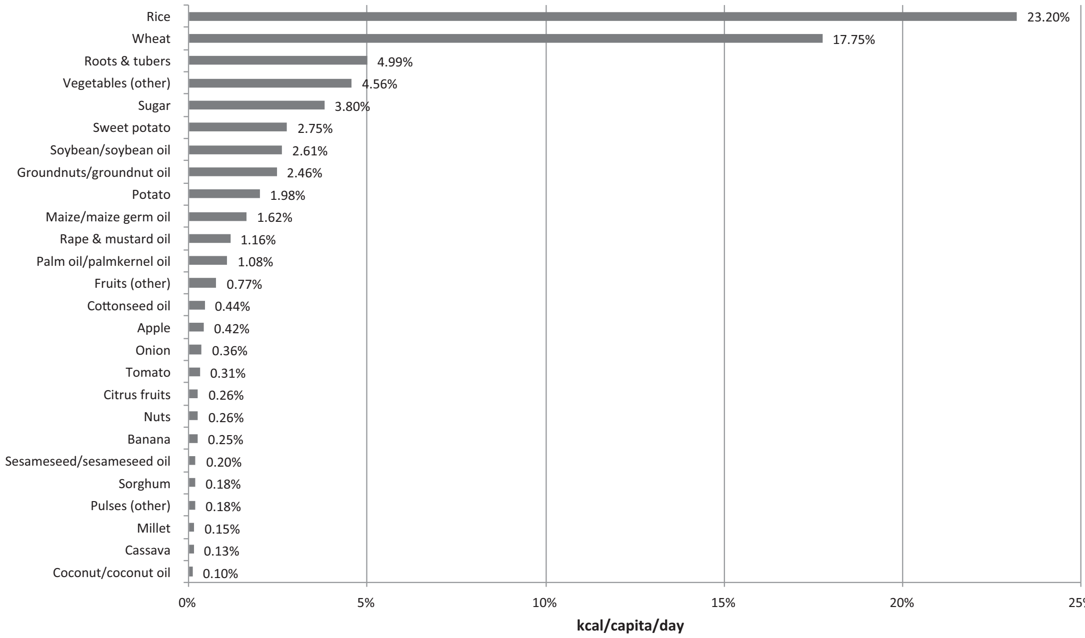

Fig. 4. Average annual contributions of human food crops/crop groups consumed in China to dietary energy (kilocalories) per capita per day of 0.1% or more over the period 2000–2009. Data source: FAO (2014).

to China[6]. Although the monetary value of crops measured per ton varies considerably between crops (*e.g.*, see Fig. 3), production quantity is always linked fully or partially to overall economic value measured as a product of price x production quantity (*e.g.*, Kell et al., 2012b for Europe; H. Fielder, University of Birmingham, pers. comm., 2014 for the UK; J. Magos Brehm, University of Birmingham, pers. comm., 2014 for Portugal), although this depends on the scale of the analysis, the type of crops included (*e.g.*, food crops versus ornamental crops), and the selected cut-off point for the selection of priority crops. For example, Fig. 3 shows that the average per ton value of date (*Phoenix dactylifera* L.) in China over the three year period 2009–2011 was US$3191—more than 12 times the average value of sugarcane over the same period. However, when measuring overall economic value, the high quantity of sugarcane produced in China compared with that of date means that sugarcane has a significantly higher value to the national economy if production quantities remain relatively stable at current levels.

Many crops that are of high economic value in China are also important for food security. Fig. 4 shows the value of human food crops/crop groups consumed in China in terms of food supply expressed as average annual contributions to dietary energy (kilocalories) per capita per day of 0.1% or more in the period 2000–2009. The importance of rice and wheat is starkly obvious and the results of the analysis indicate that most if not all of the other crops of particularly high economic value in China are important as plant-derived energy sources.[7]

Although the priority for most countries is to conserve resources that are of greatest potential socio-economic value to the nation, it is important to consider the value of genetic resources in a broader geographic sense since no country is self-sufficient in food supply. The interdependence among countries for food supplies and plant genetic resources has long been acknowledged (*e.g.*, see FAO, 1998, 2001) and as emphasized by Khoury et al. (2014) is now ever more important due to increased homogeneity of staple human food crops across the world. Thus, most countries indirectly depend on genes from wild relatives native to other parts of the world as well as on their own native genetic resources. For example, broad/horse bean, eggplant and potato are economically important crops in China but the closest wild relatives of these crops are found in other parts of the world (primarily the Fertile Crescent for broad/horse bean and Central and South America for eggplant and potato). Further, the impacts of climate change are likely to increase the interdependence of countries on PGRFA due to the need for greater adaptation in crops (FAO, 2011). The decision as to which additional crop gene pools to prioritize for inclusion in a national CWR conservation strategy that are not of high economic value to the nation could be based on crop import statistics (i.e., selecting crops that are important for national food security but not cultivated or only grown on a small scale nationally). However, this is a complex approach and does not take account of national genetic resources that may be of greater value in other parts of the world (*i.e.*, for the improvement of crops important for food security in other regions but not nationally). Another option would be to include all crops listed in Annex I of the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) (FAO, 2001), which is a list of PGRFA established primarily according to criteria of food security and interdependence. Thirteen of the 25 nationally important crops/crop groups already identified are listed in Annex I of the Treaty: apple, asparagus, barley, banana, brassicas, broad bean, citrus fruits, eggplant, pearl millet, potato, rice, sweet potato and wheat. However, the inclusion of all the listed crops would not only inflate the list of priority species beyond a reasonable number for immediate conservation action, but would also be difficult to justify to national authorities since China is not a signatory to the Treaty. Therefore, a pragmatic approach is to include native wild relatives of crops that are considered to be of major global importance for food security.

FAO (1998) emphasized the need to conserve the diversity of the relatively small number of crops that are important for global food security, defining these as crops which “supply more than 5% of plant-derived energy intake at the sub-regional level” (FAO, 1998, p. 15). These are wheat, rice, maize, millet, sorghum, potato, soybean, sugarcane, sweet potato, cassava, beans (*Phaseolus* L. spp.) and banana/plantain (*Musa* L. spp.). The global food security value

[7] Crop groupings in FAO food supply statistics differ from those in production statistics.

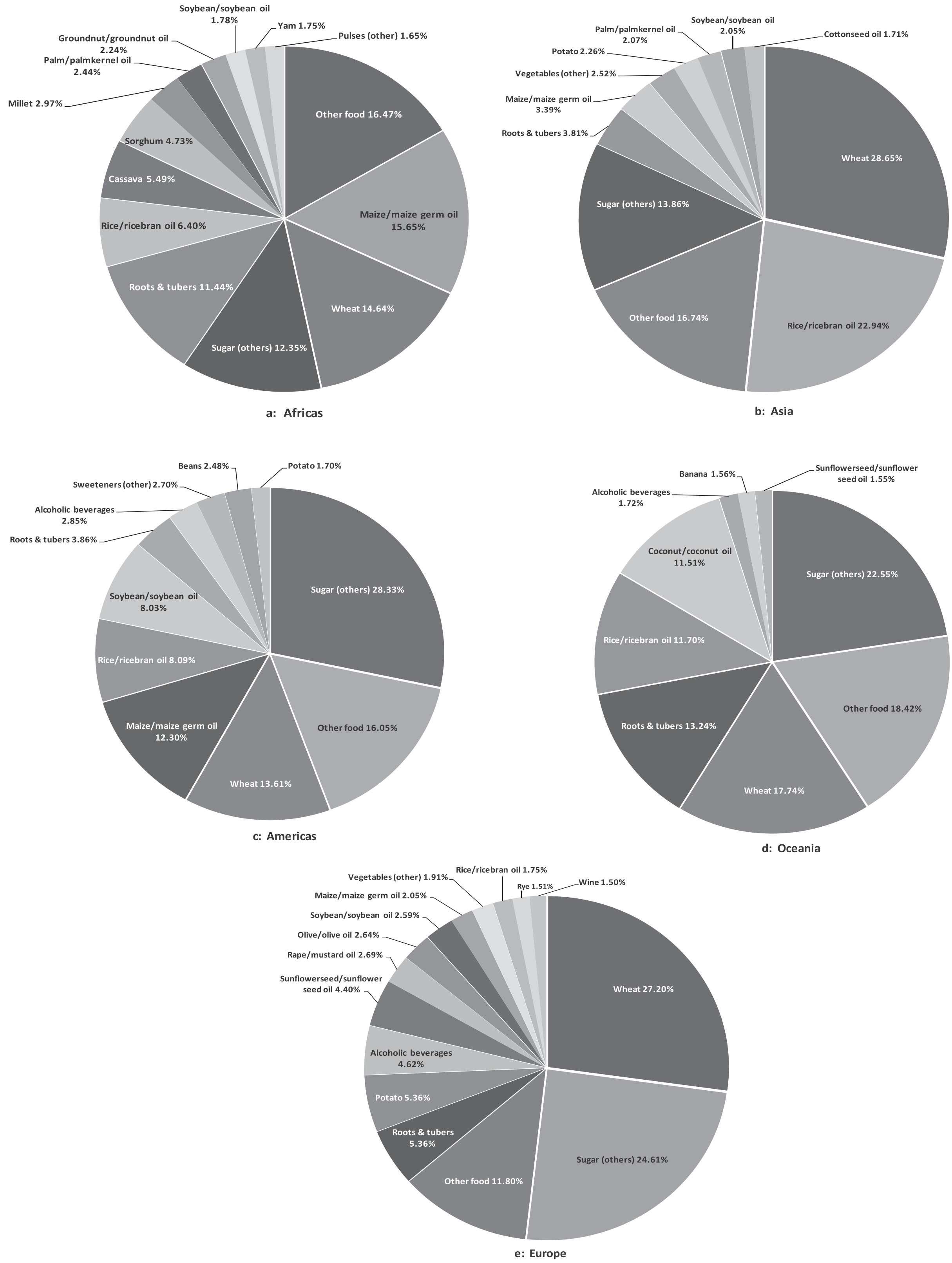

Fig. 5. a–e Average annual contributions of human food crops/crop groups to dietary energy (kilocalories) per capita per day of 1.5% or more over the period 2000–2009 in five major world regions. Data source: FAO (2014). The category 'other food' is an aggregation of crop commodities that each supply less than 1.5% of dietary energy. Categories such as 'rice/rice bran oil' and 'soybean/soybean oil' are grouped because they are derived from the same crop. One or other, or both forms may be consumed in any given region. The category 'sugar (others)' may include sugar sourced from sugarcane, sugar beet and a number of other crop species.

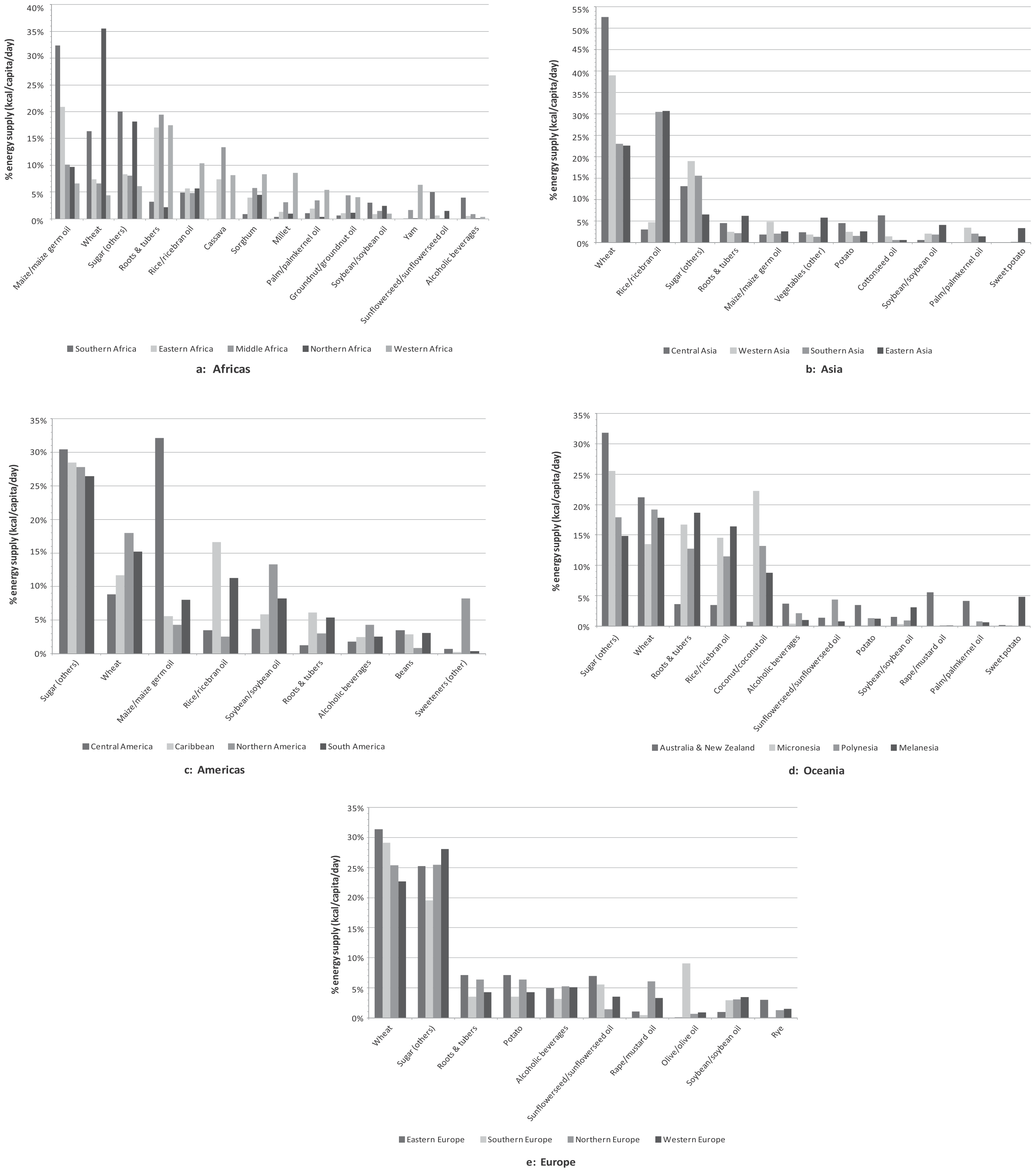

Fig. 6. a–e Average annual contributions of human food crops/crop groups to dietary energy (kilocalories) per capita per day of 3% or more over the period 2000–2009 in 21 major world sub-regions. Data source: FAO (2014). Categories such as 'rice/rice bran oil' and 'soybean/soybean oil' are grouped because they are derived from the same crop. One or other, or both forms may be consumed in any given sub-region. The category 'sugar (others)' may include sugar sourced from sugarcane, sugar beet and a number of other crop species.

of most of these crops remains critically high, as evidenced by an analysis of plant-derived energy supply in the major world regions (Figs. 5a–e) and sub-regions (Figs. 6a–e) over the ten year period 2000–2009. However, banana and plantain have on average provided less than 3% of plant-derived dietary energy in all sub-regions during this period, with the greatest contribution being 2.5% in Micronesia. The contribution of sugarcane is difficult to measure as sugar in food supply systems is primarily reported

Table 1
National and global crops/crop groups of high socio-economic importance with native wild relatives in China. The genera containing the crops and their wild relatives, the number of species in the broad gene pool (including crops), and the number and percentage of CWR species native to China[a] are shown.

Crop/crop group	Crop genus (or genera)	Total no. of species in the broad crop gene pool[b]	No. of species native to China	Percentage of species native to China
Taro	*Colocasia*	8	5	62
Grape	*Vitis*	79	38	48
Tea	*Camellia*	250	100	40
Apple	*Malus*	62	23	37
Olive	*Olea*	35	13	37
Chestnut[c]	*Castanea*	9	3	33
Wheat	*Aegilops, Agropyron, Elymus, Leymus, Triticum*	368[d]	119	32
Citrus fruits[e]	*Citrus*	33	10	30
Soybean	*Glycine*	16	4	25
Sugarcane	*Saccharum*	36	9	25
Stonefruits[f]	*Armeniaca, Cerasus, Prunus*[g]	259[h]	60	23
Barley	*Hordeum*	43	8	19
Walnut	*Juglans*	21	4	19
Pear	*Pyrus*	69	13	19
Rice	*Oryza*	18	3	17
Broad/horse bean	*Vicia*	232	38[i]	16
Alliums[j]	*Allium*	910	132	14
Banana	*Musa, Ensete*	78[k]	11	14
Asparagus	*Asparagus*	211	28	13
Brassicas[l]	*Armoracia,Barbarea, Brassica, Camelina, Crambe, Diplotaxis, Eruca, Isatis, Lepidium, Raphanus, Rorippa, Sinapidendron, Sinapis*	575[m]	49[n]	8
Yam	*Dioscorea*	613	49	8
Persimmon	*Diospyros*	725	61	8
Common millet, pearl millet, foxtail millet[o]	*Panicum, Pennisetum, Setaria*	629[p]	36	6
Sorghum	*Sorghum*	31	2	6
Sweet potato	*Ipomoea*	448	21	5
Cucurbits[q]	*Cucumis*	51	2	4
Eggplant, potato	*Solanum*	1199	30[r]	2
	TOTALS	7008	871	12%

[a] Native status ascertained from species included in the China Red List (MEP and CAS, 2013) or for species not included in the Red List, GRIN Taxonomy for Plants (USDA, ARS, National Genetic Resources Program, 2014) and the Flora of China (eFloras, 2008). For a small number of species which are not included in the China Red List or GRIN Taxonomy for Plants and the native status is not explicit in the Flora of China, the native status is uncertain and requires clarification.
[b] All species in the same genus as the crop(s) or in closely related genera. Numbers are derived from accepted species names in The Plant List (2013)
[c] Chinese, European and Japanese chestnut.
[d] *Aegilops* – 25; *Agropyron* – 26; *Elymus* – 234; *Leymus* – 55; *Triticum* – 28
[e] Orange, grapefruit, pomelo, lemon, lime, tangerine, mandarin, clementine, satsuma and other unspecified citrus fruits.
[f] Peach, nectarine, plum, sloe, apricot, cherry and other unspecified stonefruits.
[g] Taxa in the genera *Amygdalus*, *Armeniaca*, *Cerasus* and *Prunus* are recognized in the China Checklist of Higher Plants (Qin et al., 2009) and China Red List (MEP and CAS, 2013). However, *Amygdalus* is not listed in Table 1 as the genus is not accepted in The Plant List and GRIN Taxonomy for Plants (USDA, ARS, National Genetic Resources Program, 2014). It is however included in the analysis as a synonym of *Prunus*.
[h] *Armeniaca* – 1; *Cerasus* – 4; *Prunus* – 254
[i] All *Vicia* species native to China are distantly related to broad/horse bean.
[j] Onion, garlic, leek and shallot.
[k] *Ensete* – 8; *Musa* – 70
[l] Rapeseed, cabbage, cauliflower, broccoli and other brassicas.
[m] *Armoracia* – 3; *Barbarea*– 29; *Brassica* – 39; *Camelina* – 8; *Crambe* – 39; *Diplotaxis* – 35; *Eruca* – 3; *Isatis* – 80; *Lepidium* – 234; *Raphanus* – 4; *Rorippa* – 91; *Sinapidendron* – 4; *Sinapis* – 6
[n] The genera *Armoracia* and *Sinapidendron* do not contain CWR native to China. *Sinapidendron* is endemic to the islands of Madeira, Portugal.
[o] Common millet, pearl millet and foxtail millet are treated as a crop group in this study because FAO crop production data do not distinguish between the various millet crop species. Wild relatives of teff and kodo millet occur in China but these are not included as priority species as the crops are not nationally important and their specific contribution to food security is not reported in FAO food supply statistics. Also see footnote 4.
[p] *Panicum* – 442; *Pennisetum* – 83; *Setaria* – 104
[q] Cucumber, gherkin, melon and melonseed.
[r] All *Solanum* species native to China are distantly related to eggplant and potato.

according to the type of processed product (*e.g.*, raw, refined, centrifugal) rather than by crop species. Therefore, the category 'sugar (others)' (as distinct from the category 'sugarcane' which alone contributes a maximum of 1.5% to plant-derived dietary energy in southern Asia and less than 1% in all other regions) may include products derived from a number of crop species, including sugarcane.

Perhaps more important are the crops of high dietary energy value highlighted in the sub-regional analysis that are not included in the FAO (1998) list of globally important major food crops, namely various oil crops: cottonseed (*Gossypium hirsutum* L.), mustard (*Brassica* L. and *Sinapis* L. spp.), palm (*Elaeis guineensis* Jacq.), olive (*Olea europaea* L.), rape (*B. napus* L.) and sunflower (*Helianthus annuus* L.), as well as yam and rye. Further analysis is needed to understand the significance of these crops in today's human diet and trends in their consumption in recent years. However, regardless of their place in our diet and of their contribution to health and nutrition, they are clearly crops of modern global socio-economic importance.

Based on the results of this analysis, the following crops are of particular global importance in terms of their direct contribution to food security on the premise that they provide 3% or more of plant-derived dietary energy supply in one or more sub-regions (in alphabetical order): beans (*Phaseolus vulgaris* L.), cassava (*Manihot esculenta* Crantz), coconut (*Cocos nucifera* L.), cotton (*Gossypium hirsutum* L.), groundnut (*Arachis hypogaea* L.), maize (*Zea perennis* (Hitchc.) Reeves & Mangelsd.), millet (*Echinochloa esculenta* (A. Braun) H. Scholz, *Eleusine coracana* (L.) Gaertn., *Eragrostis tef*

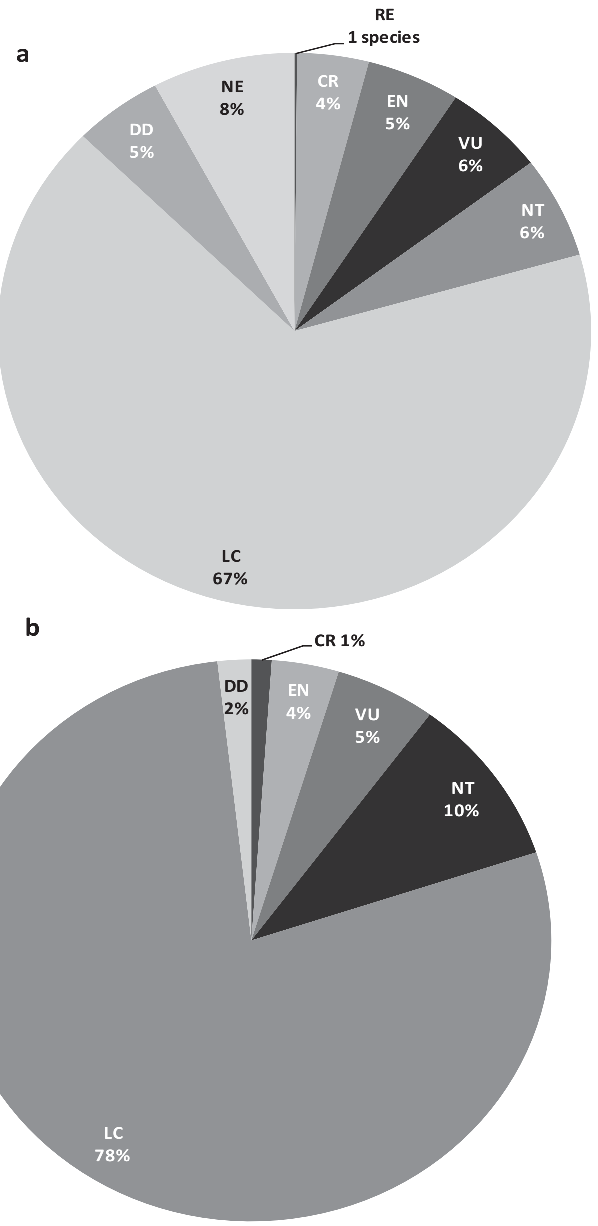

Fig. 7. a and b The Red List status of priority CWR in China. Fig. 7a shows the status of 744 species. Fig. 7b shows the status of 276 infraspecific taxa in 127 species. RE – Regionally Extinct; CR – Critically Endangered; EN – Endangered; VU – Vulnerable; NT – Near Threatened; LC – Least Concern; DD – Data Deficient; NE – Not Evaluated.

(Zucc.) Trotter, *Panicum miliaceum* L., *Paspalum scrobiculatum* L., *Pennisetum glaucum* (L.) R. Br. and *Setaria italica* (L.) P. Beauv.), mustard seed (*Brassica nigra* (L.) K. Koch and *Sinapis alba* L.), oil palm (*Elaeis guineensis* Jacq.), olive (*Olea europaea* L.), potato (*Solanum tuberosum* L.), rapeseed (*B. napus* L.), rice (*Oryza sativa* L.), rye (*Secale cereale* L.), sorghum (*Sorghum bicolor* (L.) Moench), soybean (*Glycine max* (L.) Merr.), sunflower (*Helianthus annuus* L.), sweet potato (*Ipomoea batatas* (L.) Lam.), wheat (*Triticum* L. spp.) and yam (*Dioscorea alata* L.). Eleven of these crops have native wild relatives in China: millet, mustard seed, olive, potato, rapeseed, rice, sorghum, soybean, sweet potato, wheat and yam. Therefore, wild relatives of olive, sorghum and yam that are native to China were added to the base list of priority species (*i.e.*, those related to crops/crop groups of national socio-economic importance) since this list already captures native wild relatives in China of all other crops of major importance for food security in one or more sub-regions of the world. This is a clear indication of the global importance of China's CWR genetic resources. The resulting list of species which forms the basis of the CWR China Inventory are related to 28 crops or crop groups spanning 48 genera, 46 of which contain 871 CWR species native to China, representing 12% of the species in these (broad) gene pools[8] worldwide (Table 1). Notably, a quarter or more of the CWR species in the gene pools of taro, grape, tea, apple, olive, chestnut, wheat, citrus fruits, soybean and sugarcane are native to China,[9] making them particularly important for national conservation attention.

3.3. CWR prioritization stage two: relative Red List status

A Red List of the higher plants of China has recently been published (MEP and CAS, 2013) and enables further prioritization of China's priority CWR on the basis of their Red List status. Figs. 7a and b show the Red List status of the CWR prioritized on the basis of their relationship to socio-economically important crops in China and worldwide. Fig. 7a shows the Red List status of 744 of the priority species. The other 127 species were assessed at infraspecific level (subspecies, varieties and forms) and the percentages shown in Fig. 7b are proportions of 276 infraspecific taxa. Results show that 152 species (19% of the species assessed) and 55 infraspecific taxa in a further 42 species (5% of the species assessed) are threatened (Critically Endangered, Endangered or Vulnerable) or Near Threatened (NT) (see Supplementary data). Seven percent (58) of the priority species (8% assessed at species level – Fig. 7a) have not yet been assessed and are therefore classified as Not Evaluated (NE). As already noted in this section, the China Red List excludes some poisonous plants and weeds. It is likely that some of these 58 species fall into this category, although further investigation is needed to validate this assumption. IUCN (2001) stress that until an assessment is made, taxa listed as Data Deficient and Not Evaluated should not be treated as if they are not threatened and that it may be appropriate to give them the same degree of attention as threatened taxa until their status can be assessed.

The comparative Red List status of a group of CWR taxa can be used to prioritize for conservation planning. Threatened and Near Threatened taxa are obvious candidates for monitoring and conservation management. However, this does not negate the need for conservation planning of taxa categorized as Least Concern. As stressed by Kell et al. (2012b), the rigorousness of the IUCN Red List criteria coupled with the potential subjectivity of the Red List assessment process, can lead to a large number of taxa being categorized as Least Concern. Some of these taxa are widespread, occurring in a number of provinces in China while others have restricted ranges. Distribution data in the China Checklist of Higher Plants (Qin et al., 2009) indicate that 99 of the priority CWR species in China evaluated as Least Concern occur in 10–29 provinces, 139 in 5–9, 196 in 2–4 and 169 in only one. At minimum, populations of restricted range taxa categorized as Least Concern should be monitored. Further, although it is possible to apply the IUCN Red List Categories and Criteria (IUCN, 2001) to individual subpopulations, the system does not include genetic diversity within and between subpopulations as a criterion for assessment—rather, it is based on population size and geographic range (Kell et al., 2012b). The authors note that as the goal of CWR conservation is to maximize the conservation of genetic diversity,

[8] Including crop species.

[9] Native status ascertained from species included in the China Red List (MEP and CAS, 2013) or for species not included in the Red List, GRIN Taxonomy for Plants (USDA, ARS, National Genetic Resources Program, 2014) and the Flora of China (eFloras, 2008). For a small number of species which are not included in the China Red List or GRIN Taxonomy for Plants and the native status is not explicit in the Flora of China, the native status is uncertain and requires clarification.

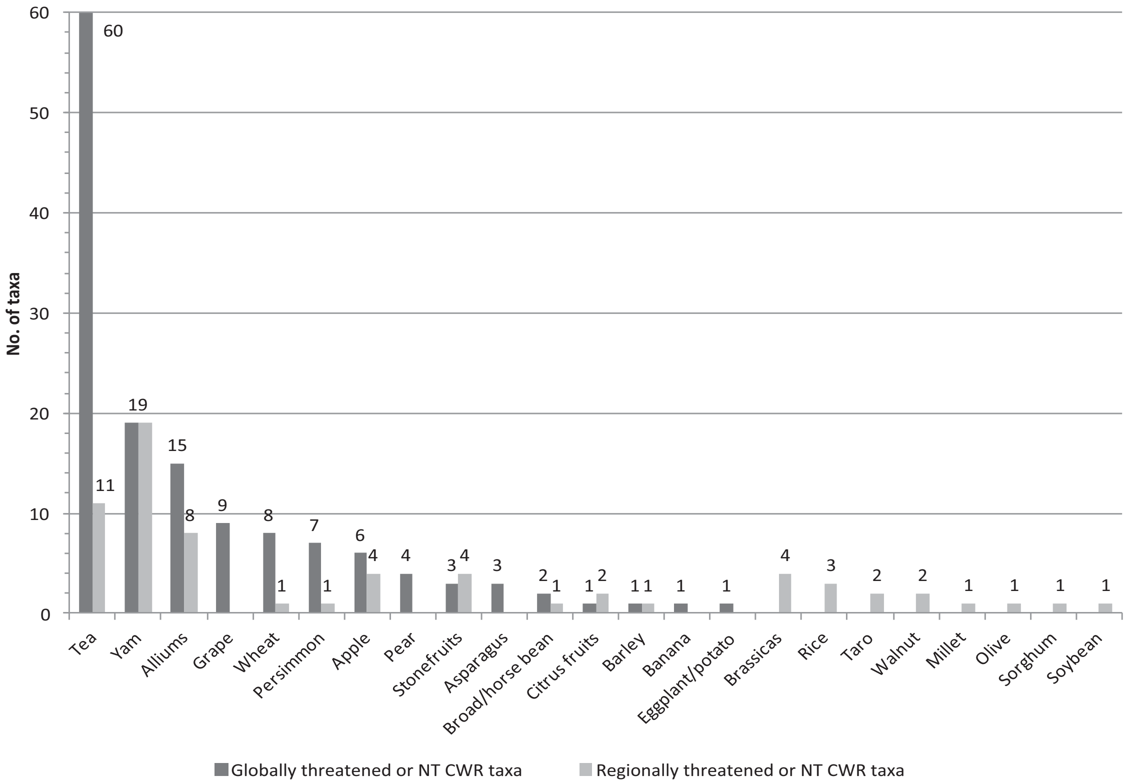

Fig. 8. The numbers of globally and regionally threatened or Near Threatened CWR taxa (152 species and 55 subspecies or varieties in a further 42 species) in 24 priority crop gene pools/groups in China. Eggplant and potato are combined as they are both *Solanum* species.

sufficient subpopulations must be conserved to ensure an adequate sample of total genetic diversity is available for utilization. Therefore, even the most widespread species should be included in conservation action plans.

Fig. 8 shows the numbers of globally and regionally threatened (CR, EN or VU) or Near Threatened (NT) taxa[10] (152 species and 55 subspecies or varieties in a further 42 species) in 24 of the 28 priority crop gene pools/groups with native wild relatives in China. The remaining four crops/crop groups either do not have threatened or Near Threatened taxa native to China (cucurbits, sugarcane and sweet potato[11]) or are Not Evaluated (chestnut). The gene pools of 16 crops/crop groups contain globally threatened or Near Threatened taxa, including tea, grape, apple, citrus fruits and wheat. As already noted in this section, these five crop gene pools/groups have a high proportion of native CWR species in China. They are therefore a high priority for national conservation action. Table 2 shows the provinces in China in which the 152 regionally and globally threatened or Near Threatened CWR species in 23 priority crop gene pools/groups (as shown in Fig. 7 except for millet[12]) are distributed. For this analysis, it was not possible to identify the distribution of threatened or Near Threatened infraspecific taxa since the distribution data are linked to the China Checklist of Higher Plants (Qin et al., 2009), not to the China Red List (MEP and CAS, 2013) and the nomenclature has not yet been harmonized between the two databases. One hundred priority CWR species are globally threatened or Near Threatened, 65 of which occur in only one of 18 provinces. Provinces with notably high levels of endemism are Yunnan, Guangxi, Sichuan, Hainan and Guangdong.

3.4. CWR prioritization stage three: utilization potential

Relative Red List status alone can be used as a prioritization criterion to guide CWR conservation efforts. However, some threatened and Near Threatened taxa may not be closely related to priority crops nor have currently known actual or potential use in crop improvement programs. While any taxon in a crop gene pool, whether closely or more distantly related may have future but currently unknown value for crop improvement, most plant breeders turn to more closely related taxa in breeding programs because they are more easily introgressed using conventional breeding techniques. More distantly related taxa that have been utilized successfully in plant breeding for crop improvement or shown promise for potential use are also of interest. Therefore, as noted in Section 2.2, the potential ease of use or known value in crop improvement programs of CWR taxa can also be used as a prioritization criterion.

An analysis primarily based on data in the Harlan and de Wet Crop Wild Relative Inventory (Vincent et al., 2013) revealed that 126 (14%) of the 871 CWR species in the CWR China Inventory are either relatively closely related[13] to the priority crops/crop groups or more distantly related but with documented actual or potential uses (see Supplementary data). These 126 species are related to 23 of China's 28 priority crops/crop groups (all except chestnut, taro, broad/horse bean, eggplant and potato). Twenty-three of

[10] Globally threatened or NT taxa are endemic to China. Regionally threatened or NT taxa are those assessed at national level but not endemic to China.

[11] One sweet potato CWR is evaluated as Data Deficient.

[12] Millet is not included in this analysis because all but one taxon related to the three cultivated millets included in the analysis are evaluated as Least Concern or Data Deficient. This taxon is a relative of foxtail millet—*Setaria viridis* subsp. *pachystachys* (Steud.) Tzvelev)—which is evaluated as Near Threatened.

[13] Species in Gene Pools 1b or 2, Taxon Groups 1b, 2 or 3, or Provisional Gene Pools 1b or 2. For details of these concepts see Maxted et al. (2006) and Vincent et al. (2013).

Table 2
Provinces in China containing regionally and globally threatened or Near Threatened CWR species in 24 priority crop gene pools/groups.

Province	No. of species	No. endemic to China (provincial endemics)	Provincial endemic species (Red List category)
Yunnan	61	33 (21)	*Allium chienchuanense* (CR), *A. siphonanthum* (EN), *Asparagus mairei* (EN), *A. subscandens* (VU), *Camellia candida* (EN), *C. crassipes* (VU), *C. cupiformis* (CR), *C. fascicularis* (CR), *C. grandibracteata* (VU), *C. hekouensis* (CR), *C. pachyandra* (VU), *C. szemaoensis* (VU), *Dioscorea banzhuana* (CR), *D. biformifolia* (CR), *D. menglaensis* (EN), *D. nitens* (CR), *D. sinoparviflora* (EN), *Diospyros anisocalyx* (EN), *D. nigricortex* (VU), *Solanum deflexicarpum* (VU), *Vitis mengziensis* (CR)
Sichuan	31	19 (8)	*Allium aciphyllum* (NT), *A. guanxianense* (NT), *Camellia elongata* (EN), *C. punctata* (VU), *C. szechuanensis* (VU), *C. villicarpa* (VU), *Diospyros sutchuensis* (CR), *Elymus sinosubmuticus* (VU)
Guangxi	31	17 (9)	*Camellia chrysanthoides* (EN), *C. fangchengensis* (CR), *C. impressinervis* (CR), *C. leptophylla* (EN), *C. longipedicellata* (EN), *C. micrantha* (EN), *C. pilosperma* (CR), *C. pubifurfuracea* (EN), *C. pubipetala* (EN)
Guangdong	22	12 (3)	*Camellia azalea* (CR), *C. melliana* (EN), *Vitis ruyuanensis* (VU)
Guizhou	20	12 (1)	*Camellia luteoflora* (VU)
Zhejiang	11	7 (1)	*Vitis wenchowensis* (EN)
Hunan	12	7 (0)	–
Hainan	11	6 (5)	*Camellia amplexifolia* (EN), *C. parviflora* (EN), *C. xanthochroma* (VU), *Diospyros corallina* (VU), *D. inflata* (EN)
Jiangxi	10	6 (0)	–
Fujian	13	5 (1)	*Armeniaca zhengheensis* (CR)
Hubei	8	5 (0)	–
Xizang	16	4 (2)	*Dioscorea xizangensis* (CR), *Elymus curtiaristatus* (NT)
Shaanxi	6	4 (2)	*Vicia taipaica* (NT), *Vitis bashanica* (CR)
Hebei	5	4 (2)	*Allium chiwui* (EN), *Elymus serpentinus* (NT)
Qinghai	5	4 (2)	*Elymus alpinus* (NT), *E. angustispiculatus* (NT)
Gansu	6	4 (0)	–
Henan	4	3 (0)	–
Xinjiang	13	2 (2)	*Allium juldusicola* (NT), *A. pevtzovii* (NT)
Chongqing	2	2 (2)	*Armeniaca hypotrichodes* (EN), *Elymus puberulus* (NT)
Inner Mongolia	6	2 (1)	*Elymus villifer* (EN)
Shandong	3	2 (1)	*Allium brevidentatum* (NT)
Hong Kong	2	2 (0)	–
Taiwan	6	1 (1)	*Musa insularimontana* (CR)
Taihang	1	1 (1)	*Pyrus taihangshanensis* (VU)
Anhui	6	1 (0)	–
Ningxia	4	1 (0)	–
Shanxi	2	1 (0)	–
Heilongjiang	1	0	–
Jiangsu	1	0	–
Jilin	1	0	–
Shanghai	1	0	–

these species (related to rice, soybean, sorghum, yam, tea, citrus fruits, stonefruits, apple, pear, walnut and alliums) are threatened or Near Threatened, six of which (related to tea, apple and pear) are endemic to China. A further three species are closely related to Chinese, European and Japanese chestnut (*Castanea* Mill. spp.) (USDA, ARS, National Genetic Resources Program, 2014) (see Supplementary data). These species are currently categorized as Not Evaluated in China. The relationships between wild *Colocasia* Schott species and taro (*Colocasia esculenta* (L.) Schott ex Schott & Endl.) have not yet been established. Therefore, using the precautionary approach, all *Colocasia* species native to China should be prioritized for conservation assessment, especially given that these species account for more than 62% of the taro gene pool. The Gene Pool or Taxon Group concept of persimmon (*Diospyros kaki* Thunb.) requires investigation to identify the closely related CWR or those more distantly related of current known potential use. However, two taxa in Taxon Group 1b (the same species as the crop) are recognized in the China Checklist of Higher Plants: *D. kaki* var. *macrantha* Makino and *D. kaki* var. *bicolor* Hand.-Mazz. Both are endemic to China and evaluated as Least Concern. According to Vincent et al. (2013), CWR identified in the current study as native to China which are related to eggplant and potato (*Solanum* spp.), and pearl millet (*Pennisetum* Rich. spp.), are either not closely related to the crop or have no known documented actual or potential use in crop improvement programs. Although this does not necessarily mean that CWR taxa in these crop gene pools are not of potential future value, the need to direct limited conservation resources where they are most needed means that the highest priority taxa should be afforded a higher priority in national CWR conservation planning.

The purpose of identifying the highest priority crop gene pools in China and those that contain threatened or Near Threatened taxa and/or taxa of greatest potential use for crop improvement, is to produce a list of high priority taxa to inform national CWR conservation planning. Ideally, all 871 species related to China's priority crops/crop groups should be included in the conservation planning process. This would be possible given access to good quality distribution data for these species. For example, conservation planning using complementarity analysis (*e.g.*, Maxted et al., 2007; Phillips et al., 2013) or ecogeographic diversity analysis (*e.g.*, Parra-Quijano et al., 2008, 2011, 2012a,b; Rubio Teso et al., 2014) can be undertaken for a large number of species once the distribution data are edited, standardized and organized according to the requirements of the applicable software programs. However, depending on the availability of distribution data, expertise and financial resources for conservation planning, a reduced list of priority CWR species based on their relative Red List status and/or potential for use in crop improvement may be more desirable and practical. Furthermore, when making conservation proposals to the relevant national authorities, a shorter list of priority species may be more realistic in order to attract the necessary financial support to initiate the national CWR conservation strategy. Therefore, a pragmatic solution is the provision of a list containing all 871 priority CWR species (the CWR China Inventory) that can be ranked according to relative Red List status, current known potential for use in crop improvement programs, and endemism, and the ranking can then be used as the foundation for further national CWR conservation planning (see Supplementary data).

4. Conclusion

Crop wild relatives are an important source of diversity for crop improvement and are likely to become increasingly important for adapting crops so that they can yield under a range of increasingly detrimental abiotic and biotic stresses, as well as under more frequent and extreme climatic fluctuations. However, like the crops themselves, wild relative populations are threatened by climate change, as well as a range of other pressures affecting wild plant species in their native habitats. The importance of CWR and the need for greater conservation efforts has been acknowledged in a number of global policy instruments and knowledge of CWR diversity, as well as methods for planning its conservation, has increased rapidly since the beginning of the century.

The rich flora of China contains CWR diversity that is not only of potential use for national food and economic security, but also for global food security, since a number of globally important crop gene pools contain wild species native to China. In this paper we have presented a method for identifying and prioritizing China's CWR and produced an annotated list of 871 of the highest priority species in the gene pools of 28 socio-economically important crops/crop groups (the CWR China Inventory) as a baseline for future conservation planning. At least 17% of these species are classified as threatened (Critically Endangered, Endangered or Vulnerable) or Near Threatened and a further 5% of species contain threatened or Near Threatened infraspecific taxa, which is comparable with the 16% of priority European CWR that have been evaluated as threatened or Near Threatened (Bilz et al., 2011; Kell et al., 2012b). Assessment of the *in situ* and *ex situ* conservation status of these taxa is an urgent priority, particularly for the 16 crop gene pools/groups that contain globally threatened or Near Threatened taxa, including tea, grape, apple, citrus fruits and wheat. Our results highlight Yunnan, Guangxi, Sichuan, Hainan and Guangdong as the provinces containing the highest numbers of these endemic threatened and Near Threatened species. However, while relatively large percentages of taxa have been categorized as Least Concern (57% at species level and a further 13% of species at infraspecific level), this should not lead to the conclusion that most priority CWR are not in need of conservation action. Ecogeographically representative samples still need to be conserved both *in situ* and *ex situ* to ensure that the genetic diversity of these populations is preserved and available for utilization. Fifty-eight (7%) of the 871 priority species have not yet been evaluated against the IUCN Red List criteria. Although many of these may be widespread weedy species or poisonous plants that were excluded from the China Red List, we recommend that they are added to the Red List as Not Evaluated due to their importance as CWR and that their Red List status is ascertained to ensure that the full suite of information about China's priority CWR is available for future conservation planning.

On the supported assumption that the majority of plant breeders continue to use close wild relatives in crop improvement programs, we have also highlighted 126 species that have the greatest current documented potential for trait transfer, as well as those that are more distantly related but have known documented actual or potential value. These species constitute 14% of the CWR China Inventory and occur in 23 of the 28 priority crop/crop group gene pools. Twenty-three are threatened or Near Threatened, six of which (related to tea, apple and pear) are endemic to China. All 126 species should be the focus of *in situ* and *ex situ* conservation gap analyses, including those evaluated as Least Concern.

CWR conservation in China presents perhaps a greater challenge than many other countries, simply due to the sheer size of the country. From a planning perspective, the only potential barrier is access to occurrence data of sufficient quality for all priority CWR species throughout their range. Once the necessary data are collated, diversity and gap analyses can be undertaken using techniques that have been widely tested and successfully applied in the preparation of national CWR conservation strategies in other countries (*e.g.*, Maxted et al., 2007; Phillips et al., 2013; Rubio Teso et al., 2014). While we know that a national CWR conservation strategy for China can be developed on paper, making the transition from planning to practice presents a greater challenge. The implementation of a comprehensive complementary conservation strategy will involve policy amendment, close collaboration between the relevant actors, and a dialogue with the plant breeding sector and other interested user communities. Experience in Europe has highlighted the need to bring all stakeholders on board at the start of the conservation planning process, including government representatives from the agricultural and environmental ministries, gene bank and protected area managers, plant breeders and researchers, as well as other potential user groups such as agro-NGOs.

China has remarkable wild plant diversity and this includes relatives of nationally and globally important crops. Many of these species will be of value for future food and economic security. There is therefore an urgent need to raise awareness of their value—in particular to promote their importance at policy level—and to undertake systematic CWR conservation planning as a first step towards securing this vast reservoir of diversity for agriculture and food security.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.agee.2015.02.012.

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CHAPTER 5

EUROPE'S CROP WILD RELATIVE DIVERSITY: FROM CONSERVATION PLANNING TO CONSERVATION ACTION

Shelagh Kell, Brian Ford-Lloyd and Nigel Maxted

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A description of the methods and results of data analyses undertaken to select priority crop wild relative species at regional level (see section 11.2.2, starting on page 129 of the PDF document that follows) are provided as supplementary material, since these details were not included in the published chapter.

Declaration of co-author contributions

Shelagh Kell collated the data, undertook the data analyses, produced the tables and figures presented as supplementary material in this thesis, and wrote the content of the chapter. Brian Ford-Lloyd and Nigel Maxted have been the senior collaborators in this and associated work for c. 15 years.

The content of this chapter and of the supplementary material in this thesis is based on an oral presentation given by Shelagh Kell at the conference, 'Enhanced genepool utilization – Capturing wild relative and landrace diversity for crop improvement' in June 2014. The citation of the presentation is:

> Kell, S., Iriondo, J., Magos Brehm, J., Ford-Lloyd, B.V., Harris, C. and Maxted, N. (2014) *Europe's Crop Wild Relatives: From Conservation Planning to Conservation Action*. Conference paper given at 'Enhanced genepool utilization – Capturing wild relative and landrace diversity for crop improvement', NIAB Innovation Farm, Cambridge, UK, 16–20 June 2014. www.pgrsecure.bham.ac.uk/sites/default/files/documents/public/conference_presentations/Kell_etal.pdf

Shelagh Kell collated the data, undertook the data analyses, produced the tables and figures, and wrote the content of the presentation. Brian Ford-Lloyd and Nigel Maxted have been senior collaborators in this and associated work in CWR conservation planning for c. 15 years. José Iriondo and Joana Magos Brehm have also been close collaborators in associated work in CWR conservation planning for around the same time period. Claire Harris undertook some analyses associated with the development of the European CWR conservation strategy as part of her under-graduate research at the University of Birmingham. Although the results of those analyses are not included in the presentation or in the chapter presented here, her contribution to the work in general is acknowledged with co-authorship of the presentation.

Some of the content of this chapter is also drawn from the following publication:

> Maxted, N., Avagyan, A. Frese, L., Iriondo, J.M., Magos Brehm, J., Singer, A. and Kell, S.P. (2015) *ECPGR Concept for* In Situ *Conservation of Crop Wild Relatives in Europe*. Wild Species Conservation in Genetic Reserves Working Group, European Cooperative Programme for Plant Genetic Resources, Rome, Italy. www.ecpgr.cgiar.org/fileadmin/templates/ecpgr.org/upload/WG_UPLOADS_PHASE_IX/WILD_SPECIES/Concept_for_in__situ_conservation_of_CWR_in_Europe.pdf
>
> And the associated background document:
>
> Maxted, N., Avagyan, A. Frese, L., Iriondo, J.M., Kell, S.P., Magos Brehm, J. and Singer, A. (2013) *Preserving Diversity:* In Situ *Conservation of Crop Wild Relatives in Europe – the Background Document*. Rome, Italy: *In Situ* and On-farm Conservation Network, European Cooperative Programme for Plant Genetic Resources. www.pgrsecure.bham.ac.uk/documents/background_document.pdf

Some of the narrative in this chapter is the same or similar to narrative in the above cited publications. Shelagh Kell produced the first draft of the first cited publication as a summary of the associated background document. Sections of the text in both documents were contributed by Shelagh Kell and significant input was provided by Lothar Frese, José Iriondo and Joana Magos Brehm to both documents. Nigel Maxted was the lead author of both works. Alvina Avagyan and Alon Singer provided minor input to both documents.

Shelagh Kell

14 January 2018

Statements of co-authors

I, Brian Ford-Lloyd, Emeritus Professor of the University of Birmingham, UK, confirm that the above declaration of co-author contributions is true and accurate.

I, Nigel Maxted, of the University of Birmingham, UK, confirm that the above declaration of co-author contributions is true and accurate.

I, Lothar Frese, of the Julius Kühn-Institut, Germany, confirm that the above declaration of co-author contributions is true and accurate.

I, José Iriondo, Professor of the Universidad Rey Juan Carlos, Spain, confirm that the above declaration of co-author contributions is true and accurate.

I, Joana Magos Brehm, Honorary Research Fellow of the University of Birmingham, UK, confirm that the above declaration of co-author contributions is true and accurate.

11 Europe's Crop Wild Relative Diversity: From Conservation Planning to Conservation Action

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11.1 Introduction

11.1.1 The value of Europe's crop wild relative diversity

Europe has a wealth of native and endemic diversity of wild species related to crops of regional and global socio-economic importance. Heywood and Zohary (1995) drew attention to the significance of crop wild relative (CWR) diversity in the region, highlighting the 'rich wild gene pools' (p. 375) of several cereals, food legumes, fruit crops and vegetables, as well as aromatic plants, ornamentals and forestry crops. Examples include the native wild relative diversity of oats (*Avena sativa* L.), sugarbeet (*Beta vulgaris* L.), carrot (*Daucus carota* L.), apple (*Malus domestica* Borkh.), annual meadow grass (*Festuca pratensis* Huds.), perennial rye grass (*Lolium perenne* L.) and white clover (*Trifolium repens* L.). Many minor crop species have significant wild relative diversity in the region, including asparagus (*Asparagus officinalis* L.), lettuce (*Lactuca sativa* L.), sage (*Salvia officinalis* L.), raspberries and blackberries (*Rubus* spp.), as well as herbs and aromatic plants such as mints (*Mentha* spp.) and chives (*Allium* spp.) (Maxted *et al.*, 2008). Europe is also an important region for forest genetic resources, such as pine, poplar and sweet cherry (*Pinus*, *Populus* and *Prunus* spp.), and ornamental plants, such as sweet pea (*Lathyrus odoratus*), sweet pinks (*Dianthus* spp.) and violets (*Viola* spp.) (Kell *et al.*, 2008). The recent creation of the Harlan and de Wet inventory of globally important CWR taxa (www.cwrdiversity.org/checklist/) and the associated geographic analysis of their distribution (Vincent *et al.*, 2013) indicated that southern Europe was globally significant in terms of its richness of species related to economically important crops.

Today, agricultural production is challenged by climate change. Although food production in Europe is likely to be less affected by climate change in the first half of the 21st century than some other regions of the world (IPCC, 2007), an increase in extreme weather events due to climate change can have far-reaching impacts. For example, in 2003, temperatures reached 6°C above long-term averages and there were rainfall shortages of up to 300 mm (Trenberth *et al.*, 2007). These extreme climatic changes resulted in estimated economic losses in the European Union (EU) agriculture sector of €13 billion (Létard *et al.*, 2004). In a review of the implications of climate change for food plant production in Europe, Kovats *et al.* (2014) highlight the significant negative effects of summer heatwaves and drought on grain yields, particularly in southern Europe. In an examination of climate change impacts on crop production under different

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climate change scenarios, the authors underline the fact that while negative impacts on crop yields in central and northern Europe will likely be less significant than in the south of the region, increased climatic variability could have marked effects in the north and greater crop damage could result from insect pests and pathogens in response to rising temperatures.

One option for mitigating the impacts of climate change on food production is to develop crop varieties with increased resistance to heat shock, drought, pests and diseases (Easterling *et al.*, 2007). The authors observe that the many climate change adaptation studies on wheat, rice and maize crops indicate that this option alone, or combined with other adaptations such as changes in planting times and locations and improved water management, has the potential to provide an average of 10% increase in yield across all regions, all crops and different temperate regimes. Kovats *et al.* (2014) also drew attention to the fact that at 'the high range of the projected temperature changes, only plant breeding aimed at increasing yield potential jointly with drought resistance and adjusted agronomic practices may reduce risks of yield shortfall'. Given the problem of increased climate variability, the authors also emphasize the need for greater use of between- (as well as within-) species genetic diversity in farming systems. This places even greater emphasis on the need to conserve a broad range of plant genetic diversity both within and between species in order to provide options for the adaptation of a wide range of crop species as an insurance against climate variability.

Plant breeders and farmers are therefore in need of a continuous supply of diverse and novel sources of genetic diversity to produce new crop varieties able to cope with the impacts of changing growing conditions (Hawkes *et al.*, 2000; FAO, 2008; Feuillet *et al.*, 2008; Maxted *et al.*, 2012, 2014, 2015). Due to the breadth of genetic diversity inherent in CWR populations, which are adapted to a wide range of environmental conditions and constantly changing in response to biotic and abiotic pressures (Maxted and Kell, 2009; Kell *et al.*, 2012a), they are likely to become increasingly important as sources of genetic diversity to produce crop varieties able to cope in the altered environmental conditions induced by climate change (FAO, 2008; Feuillet *et al.*, 2008; Maxted and Kell, 2009; Kell *et al.*, 2012a; Maxted *et al.*, 2012, 2013, 2014, 2015). CWRs are therefore a fundamental component of plant genetic resources for food and agriculture (PGRFA) and may contribute significantly to future food security (FAO, 2008; Maxted and Kell, 2009; Maxted *et al.*, 2011, 2012, 2014, 2015; Kell *et al.*, 2012a).

11.1.2 What do we know about European CWR diversity?

Kell *et al.* (2005) created the first comprehensive catalogue of CWRs for Europe and the Mediterranean using a broad definition of a CWR (i.e. any species in the same genus or closely related genera to any type of cultivated plant species), and found that approximately 80% of the flora of the region consisted of crops and their wild relatives. Further analysis revealed that more than 15,000 species were native to Europe, of which at least half were endemic (Kell *et al.*, 2008). The authors found that four countries contained more than 20% of the species in the Euro-Mediterranean region: Turkey, Spain, Italy and France, which was consistent with the overall proportions of the flora of the region that occurred in these countries. However, per unit area, Greece had the highest concentration of CWR diversity in the region. A high percentage of CWR species occurred on the EU's oceanic islands, such as the Canary Islands (Spain) and the Azores (Portugal), but also other islands such as Sicily (Italy) and Malta, and Corsica (France). For example, around 10% of the crop and CWR taxa of the Spanish territories occurred in the Canary Islands – taxa that were not found in mainland Spain (Kell *et al.*, 2008). This is not surprising, since islands exhibit high levels of endemism due to their isolation from continental areas, so they are natural reservoirs of unique genetic diversity (Dulloo *et al.*, 2002).

In the most comprehensive assessment of the Red List status of CWRs to date, 572 European species in 25 economically important crop genepools/groups were assessed (Bilz *et al.*, 2011; Kell *et al.*, 2012b). The results of this study showed that at least 11.5% (66) of the species were threatened, with 3.3% (19) of them being Critically Endangered (CR), 4.4% (22) Endangered (EN) and 3.8% (25) Vulnerable (VU). A further 4.5% (26) of the species were classified as Near

Threatened and one species (*Allium jubatum* J.F. Macbr.) was Regionally Extinct. The remaining species were regionally assessed as Data Deficient (DD) (29%) or Least Concern (LC) (54.7%). However, of the species assessed as LC, around one-third were threatened at national level (Kell *et al.*, 2012b). The same authors reported that of the 25 crop genepools/groups for which the European CWRs were assessed, at least 14 contained regionally and/or globally threatened (CR, EN or VU) or Near Threatened (NT) species (92 species in total, of which 65 were endemic to Europe), the highest number occurring in the brassica complex, which in total contained 137 species native to and with a significant proportion of the global population in Europe. At least 8–50% of the species assessed in each of these crop genepools/groups are threatened or NT, and these percentages are likely to increase when the DD species are re-evaluated. Crop genepools/groups of particular concern in terms of the percentage of regionally threatened wild species are brassica, beet, lettuce, wheat and allium (Kell *et al.*, 2012b).

Kell *et al.* (2012b) also analysed the factors threatening CWR diversity and reported 31 distinct threats – the most frequent being 'livestock farming and ranching', 'tourism and recreation areas' and 'housing and urban areas'. However, the authors note that we should not conclude that farming *per se* is threatening CWR diversity – in fact, farmed areas (including arable land and pasture) are one of the primary habitats of CWR species. It is unsustainable farming practices, such as severe overgrazing, conversion of land to monocultures and the heavy application of fertilizers and herbicides that are the major threats to CWRs that grow in agricultural areas (Kell *et al.*, 2012b). Although there is sufficient evidence that CWR diversity is threatened by climate change (Maxted *et al.*, 2014), IUCN Red List assessments do not reflect this directly, as the impacts are often less direct and so cannot be attributed unequivocally to climate change. What is actually noted is overgrazing, increased threat from fires or competition from alien species, each of which may have at its foundation changes in the biotic or abiotic environment themselves attributable to climate change (Kell *et al.*, 2012b).

Given their value and threatened status, it might be expected that CWRs would have been the focus of specific, systematic conservation efforts, but this is far from the case, either in Europe or elsewhere (Hoyt, 1988; Maxted *et al.*, 1997a, 2011, 2013, 2015; Maxted, 2003; FAO, 2010; Kell *et al.*, 2012a). For example, based on data available via EURISCO, only around 9% of total germplasm accessions in genebanks are of wild origin (Dias *et al.*, 2012). Further, the ratio of the number of accessions of cultivated species to wild species is striking at 12:1, with an average of 167 for each cultivated species and 14 for each wild species. This may be explained in part by breeders' historic focus on the exploitation of genetic diversity existing within crops, but it is still surprising given that most diversity in crop genepools is located in the related wild species (Maxted *et al.*, 2008). The situation is even less satisfactory for *in situ* CWR conservation. Recently, a set of standards for genetic reserve *in situ* CWR conservation was established, but it is thought that no European protected areas currently meet these standards and only a few claim to be actively conserving CWR diversity *in situ* (Anikster *et al.*, 1997; Tan and Tan, 2002; Avagyan, 2008; Pinheiro de Carvalho *et al.*, 2012).

Although CWRs have been used by plant breeders to broaden crop breeding pools since the early 20th century, the conservation of CWRs has only been addressed by policy makers relatively recently. However, no mechanisms currently exist to organize technically coordinated, effective and efficient *in situ* conservation actions for CWRs across political borders in Europe; therefore, a systematic regional approach to *in situ* CWR genetic diversity conservation is required (Maxted, 2003, Maxted *et al.*, 2013, 2015). Critically, the same authors note that while there has been some embryonic but growing interest in the conservation of CWRs by the nature conservation community, collaboration between the environmental and agricultural sectors at all geographic levels still needs to be improved – a situation that seems to have changed little since the need for an integrated, multidisciplinary approach to CWR conservation was highlighted by Heywood (1997).

11.1.3 Progress in implementing national CWR conservation strategies in Europe

The concept of developing national CWR conservation strategies proposed by Maxted *et al.* (2007) to help ensure more systematic CWR conservation has been widely adopted by the international PGRFA community as the standard framework for national CWR conservation planning. However, although some CWR taxa may have been included incidentally in national biodiversity strategies and action plans, national conservation strategies specifically for CWRs have yet to be developed in most European countries. The EU-funded Seventh Framework Programme PGR Secure project (2011–2014; www.pgrsecure.org) provided the opportunity to extend the national strategy approach to a significant number of European countries, and has resulted in a sea change in CWR conservation in the region. National strategy development was supported with project funding in Finland, Italy, Spain and the UK, with additional funding allocated for the provision of technical support for the development of strategies in Albania, Bulgaria, Cyprus, Czech Republic and Norway. Substantial project resources were also committed to provide training and ongoing web-based and individual expert support to national PGR programmes throughout Europe (see Kell *et al.*, 2012c, and www.pgrsecure.org/helpdesk), which have resulted in the initiation of national strategies in a number of other countries, including Greece, Lithuania, Sweden and Turkey.

The development of national CWR conservation strategies in several European countries throughout the region has provided an opportunity to test the national strategy planning model and analyse variation in its application between countries. Initial comparisons indicate close correlation between countries with regard to the choice of prioritization criteria, as well as approaches to diversity and gap analyses, although there is some variation in the application of the criteria, as well as in the level and scope of the diversity analyses undertaken – the latter which may be guided largely by the availability of technical expertise and resources (see Iriondo *et al.*, Chapter 14, this volume, 2016). What is clear at this stage is that while much progress has been made in planning CWR conservation, few countries have actually implemented the strategy – *in situ* and *ex situ* conservation actions specifically for national CWR resources are in place in only a few rare cases and on an *ad hoc* basis.

A critical issue that has been highlighted by a number of European national PGR programmes is the lack of clarity with regard to the coordinating/implementing body responsible for CWR conservation. CWRs often fall in the 'gaps' between the remits of the environmental protection (or nature conservation) agencies and the agricultural administration agencies (Maxted *et al.*, 2008). *In situ* populations of CWRs require protection and active conservation in the same way as other wild species, but the focus of nature conservation agencies tends to be on habitat and rare or threatened species conservation. Incidentally, some of these species may be CWRs and some target habitats may contain CWRs, but the *in situ* conservation of priority national CWR diversity is rarely (in all but a few cases) a specific objective (Maxted, 2003). In terms of *ex situ* PGRFA (including CWRs) conservation, this is mainly the responsibility of the agricultural sector. However, *ex situ* conservation of European CWR diversity is currently inadequate because the focus of PGRFA conservation has historically been mainly on the collection and conservation of crop germplasm (Maxted *et al.*, 2008). Furthermore, some national programmes have reported a lack of coordination, or even competition, between the environment protection agencies and agricultural administration when it comes to developing a policy on CWR conservation and management.

It is clear that the lack of national policy dedicated to CWR conservation and use is undermining progress in practical implementation of the CWR conservation needs identified in national CWR conservation strategy documents. The development of regional policy on CWR conservation is needed to obligate member states to fill the CWR conservation 'gaps' and take action to implement national CWR conservation priorities, thus driving forward CWR conservation across the region (Maxted *et al.*, 2013, 2015).

11.2 A Regional Approach to CWR Conservation in Europe

11.2.1 Why a regional CWR conservation strategy?

A national approach to CWR conservation (see Maxted *et al.*, 2007, 2013) is important because it is the responsibility of individual nations to conserve genetic resources within their jurisdiction, and they are required by the Second Global

Plan of Action (GPA) for Plant Genetic Resources for Food and Agriculture, the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) and the Convention on Biological Diversity (CBD) to report on their activities. However, national priorities vary between nations and are likely to be distinct from regional priorities. For example, some countries only assign priority to CWRs of nationally important crops and not to those of regionally important crops that may occur in their country, or some prioritize only endemic CWR taxa. Thus, some populations of regionally important CWRs are not included in national strategies. Conversely, some nationally important taxa are not considered a priority at the regional level; therefore, by producing a regional list of priority taxa based on national priorities, taxa that are not in need of immediate conservation action throughout their entire range would be included and resources misspent. This point was illustrated by Maxted *et al.* (1997b) with the example of *Vicia bithynica* L. It is native throughout central and southern Europe and the Mediterranean Basin, but the extreme north-western edge of its distribution is the south coast of Britain, where the species is found at a few localities, all of which are threatened by increased levels of tourism and natural coastal erosion. Here, the populations are being genetically eroded and the species may, in the near future, even become extinct in the UK. However, it is thriving in its centre of diversity and is clearly not threatened at the international level. Therefore, while *in situ* conservation of *V. bithynica* is a priority in the UK, it is not a priority at the regional level.

In addition to national strategies, a Europe-wide CWR conservation strategy is thus needed to: (i) ensure that regionally important CWR resources are targeted for conservation action across their full range; (ii) ensure that resources are not allocated incorrectly to conservation of taxa that are nationally but not regionally important; and (iii) provide a framework for directing European policy on the conservation of PGRFA. Furthermore, in a context of limited resources assigned to CWR conservation by nations and European institutions, the development of a regional CWR conservation strategy may enable a more efficient way of conserving CWR resources than simply having the sum of the national strategies of the European countries.

The national and regional approaches to CWR conservation in Europe may be considered as top-down and bottom-up, respectively, but what is critical is that the two approaches are not viewed as independent of one another – rather, that they are harmonized and implemented in a coordinated way towards an integrated European CWR conservation strategy (Maxted *et al.*, 2013, 2015).

11.2.2 Developing the regional strategy

Baseline taxon data

The baseline taxon data for the Europe-wide CWR conservation strategy is provided by the *Crop Wild Relative Catalogue for Europe and the Mediterranean* (the CWR Catalogue), originally published by Kell *et al.* (2005) as an output of the EU-funded Framework 5 project, PGR Forum (www.pgrforum.org). An outline of the methodology for creating the CWR Catalogue and the results of data analysis can be found in Kell *et al.* (2008).

The CWR Catalogue provides an overview of the breadth of crop and CWR diversity in the European region and the baseline data for conservation planning at the regional scale. Further, national CWR checklists have been extracted and provided to each European country for use in the national PGR programmes to form the basis of national checklists, inventories and, subsequently, national CWR conservation strategies and action plans. However, for the development of a Europe-wide CWR conservation strategy, it is necessary to select regional priority species – those with the greatest potential to contribute to food and economic security in the region.

Selection of priority CWR species at the regional level

The role of prioritization in the conservation planning process is widely recognized. Three main criteria are of greatest relevance when assigning priorities to CWR species in the context of conservation planning:

1. The socio-economic value of the crop to which they are related (Ford-Lloyd *et al.*, 2008).
2. Their potential ease of use or known value in crop improvement programmes (Maxted and Kell, 2009; Maxted *et al.*, 2012).

3. Their relative threatened status (Ford-Lloyd *et al.*, 2008; Maxted and Kell, 2009).

In general, priority is likely to be given to native species. However, depending on how long they have been present, some introduced CWR populations may harbour important genetic diversity, especially because many taxa are able to adapt rapidly to new environments (Ford-Lloyd *et al.*, 2014). Therefore, introduced populations may be considered for inclusion in CWR conservation plans once the policy to support the initial strategy is in place and actions implemented.

In 2009, European CWR species were prioritized on the basis of their socio-economic importance and native status in Europe in the context of the production of a European Red List (Bilz *et al.*, 2011; Kell *et al.*, 2012b). The initial selection was limited to the native wild relatives of food and forage/fodder crops, due to their importance for food security. Within these major groups, crop genepools were selected on the basis of (i) production quantity and economic value in the region averaged over a 5-year period, and/or (ii) their inclusion in Annex I of the ITPGRFA – a list of PGRFA established according to criteria of food security and interdependence which includes 78 genera containing human or animal food crops, 59 of which contain food CWRs or wild populations of forage/fodder species native to Europe. Species in the same genera as the priority crops or in closely related genera were selected, and this resulted in a list of 591 CWR species in 58 genera and 25 crop genepools/crop groups.[1] The Red List assessment of the initial list of 591 priority CWR species provided a snapshot of the threat status of CWRs in Europe. However, the list was produced several years ago and required updating in line with the latest production quantity and economic value statistics, revised taxonomic classifications and some new prioritization concepts developed recently in the context of prioritizing China's CWRs (Kell *et al.*, 2015). To this end, the following steps were taken to redefine Europe's priority CWRs:

1. FAO crop production statistics (FAO, 2014) were consulted to obtain the annual production values of human food crops cultivated in Europe over the 10-year period 2002–2011. Human food crops with an average annual value of more than US$500 million over this period that have CWRs native to Europe were identified and the native wild relatives of these crops selected from the CWR Catalogue for Europe and the Mediterranean, to create a base list of regionally important CWRs based on the economic importance of the associated crops. The regional value of human food crops in terms of average annual energy supply per capita over the 10-year period 2000–2009 was calculated from FAO food supply statistics (FAO, 2014) for Europe, to highlight crops of particular regional value for food security.

2. By consulting the data available on the degree of relationship between the crop species and the wild relatives in the crop genepool and/or the known value of CWRs in crop improvement programmes (Vincent *et al.*, 2013), taxa in the base priority list that are likely to have greater use value for crop improvement were identified.

3. The European Red List of Vascular Plants (Bilz *et al.*, 2011) was used to identify threatened and Near Threatened taxa in the base priority list, and those endemic to Europe were identified based on data in the CWR Catalogue for Europe and the Mediterranean. Using occurrence data in the CWR Catalogue for Europe and the Mediterranean, countries containing regionally and globally threatened or Near Threatened CWRs were identified.

4. Lists of priority CWRs at each of these three levels were compiled to create the European CWR Inventory, with the purpose of providing the foundations for regional CWR conservation planning in Europe.

Using this prioritization approach, the species selected on the basis of criteria 1 and 2 combined are considered priorities for regional conservation planning, regardless of their regional (for native species) or global (for endemic species) Red List status. While some of these species are relatively widespread and not threatened at the taxon level, individual populations not only may be threatened but also may contain unique genetic diversity that could be valuable for crop improvement (Kell *et al.*, 2012b). An example is *Beta vulgaris* subsp. *maritima*, a primary wild relative of cultivated beets, which grows in coastal areas and is widely distributed across much of Europe. If the Red List status of this taxon (which is Least Concern) was applied as a prioritization criterion, it might be overlooked in conservation planning at the regional scale. However, one of the main objectives of *in situ* CWR conservation is the maintenance of the optimum amount of genetic diversity of a genepool in nature, which is prerequisite for the evolutionary processes that generate novel genetic variation (Kell *et al*., 2012b). On this basis, ten candidate populations of *B. vulgaris* subsp. *maritima* have been proposed for *in situ* conservation management because they are known to harbour genetic variation for traits useful for plant breeding (Kell *et al*., 2012a).

The European CWR Inventory as a basis for regional conservation planning

The purpose of identifying the highest priority crop genepools in Europe and those that contain taxa of greatest potential use for crop improvement and/or threatened or Near Threatened taxa is to produce a list of high-priority taxa to inform regional CWR conservation planning. On the basis of the process described above, 192 CWR species native to Europe were identified as the highest priority taxa requiring immediate conservation status assessment and complementary conservation planning. The initial results of diversity and gap analyses have revealed that the responsibility for conserving these priority species is Europe-wide, with some 30 countries containing native, wild populations of 20 or more species. Alarmingly, less than half of the species are represented in genebank collections, and of these, around 50% are represented by only eight accessions or less (Kell *et al*., 2014).

11.3 An Integrated European CWR Conservation Strategy

The integrated European CWR conservation strategy brings together the national and regional approaches to maximize the active conservation of priority populations of CWR taxa throughout the region (Fig. 11.1). In summary, the concept (which has been endorsed by the Steering Committee of the European Cooperative for Plant Genetic resources (ECPGR) – see Maxted *et al*., 2015) is as follows (Maxted *et al*., 2013, 2015):

1. **National CWR conservation strategy:** each country has its own national CWR conservation strategy implemented through *in situ* and *ex situ* activities undertaken by national agencies.
2. **Regional CWR conservation strategy:** this comprises a regional network of *in situ* CWR conservation populations backed up by germplasm collection and *ex situ* management, without consideration of national borders. A regional expert authority (e.g. the ECPGR Wild Species Conservation in Genetic Reserves Working Group) provides leadership on the identification of conservation targets, oversees the technical aspects of the implementation of the strategy and provides support to the relevant national agencies responsible for the realization of the identified targets.
3. **Integrated European CWR conservation strategy:** the two distinct strategic levels are married into one coherent integrated whole:
    - *National–regional integration:* priority national populations are nominated by the national PGR coordinator for inclusion in the integrated European CWR conservation strategy for formal recognition as part of the European network of priority *in situ* CWR populations.
    - *Regional–national integration:* individual CWR conservation populations identified in the regional CWR conservation strategy are implemented at the national level as detailed in 2 above.

Critically, while the focus of *in situ* CWR conservation has historically been on the designation of genetic reserves, this concept proposes a paradigm shift away from the conservation of sites to the designation of priority CWR conservation populations (most appropriate crop wild relative populations – MAWPs). This new concept is appropriate given that: (i) many CWR populations occur outside of formally designated protected areas; (ii) environmental change in response to future climate scenarios is expected to cause range shifts in some species and a great deal of uncertainty with regard to the stability and suitability of the sites in which they occur; and (iii) if in extreme circumstances *in situ* conservation is unfeasible, greater emphasis can be placed on *ex situ* conservation and the possible introduction of populations to more stable localities. This change also reflects the reality of *in situ* conservation – in designating a genetic reserve for CWR conservation, it was not the site itself that

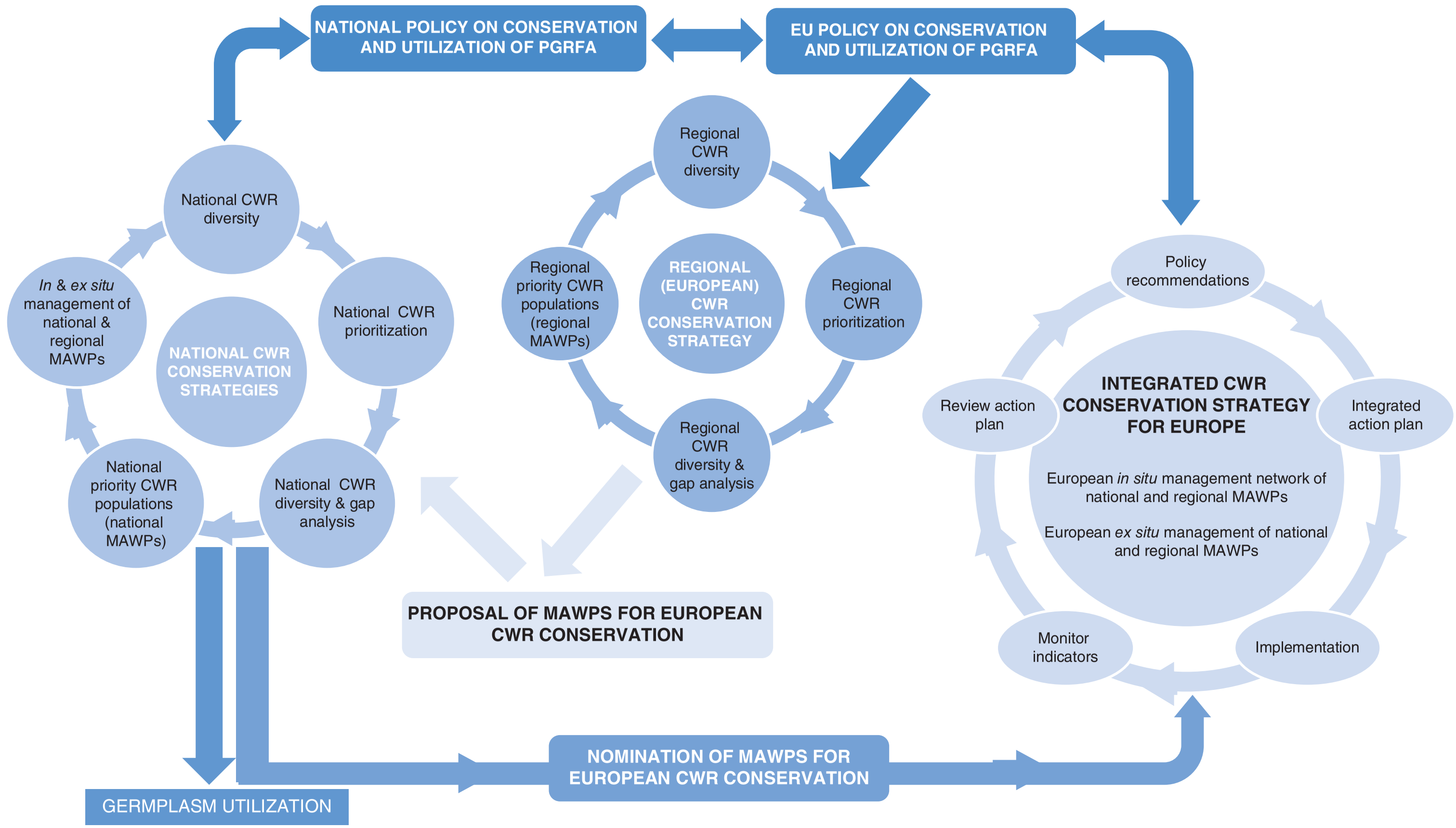

Fig. 11.1. Schematic representation of the concept for *in situ* conservation of CWRs in Europe. (From Maxted *et al*., 2013, 2015). *Note*: MAWPs = most appropriate crop wild relative populations.

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was being conserved but the populations of the target taxa within that locality, so it was more accurate to actually refer to the populations themselves rather than the site.

As well as ensuring the conservation of national CWR diversity, the national network of MAWPs may also contribute to the European (regional) network of MAWPs if they contain CWR diversity of regional importance. In turn, the European network of MAWPs may also contribute to the global network if they contain CWR diversity of global importance. Thus, some national MAWPs, particularly those in Vavilov centres of diversity (Vavilov, 1926), may also be designated as MAWPs of international importance and be part of the regional and global networks. Conversely, it is logical that each MAWP included in the regional or global network is also nominated as part of a country's national CWR diversity network. As a result of the integration of national and regional strategies, there are likely to be cases where a number of site designations or target populations for *ex situ* conservation might duplicate conservation efforts. In this case, it may be necessary to eliminate the redundancy of multiple countries proposing similar conservation targets, with a corresponding increase in efficiency in the process (Maxted *et al.*, 2013).

The integrated European CWR conservation strategy will require periodic review and updating according to future developments in CWR conservation and utilization science and practice, as well as regional agrobiodiversity conservation policy. For example, while the initial focus is on the highest priority crop genepools to support the European agricultural industry and food security, in the future the strategy may be developed to include a wider range of socio-economically important crop genepools, particularly when a number of national CWR conservation strategies are available for review and comparison and in which particular crop genepools may be highlighted as priorities across the region. In this regard, the planning and implementation of the initial strategy can act as a blueprint for the inclusion of further crop genepools in the future. Continual long-term monitoring of the implementation of the integrated strategy will also be required to highlight aspects requiring adaptation in the future. Triennial national reports and a 10-year review cycle have been proposed (Maxted *et al.*, 2013).

11.4 A New Policy Paradigm for CWR Conservation in Europe

A critical aspect of the strategy is the integration of national and regional CWR conservation actions. This requires the inclusion of regional priority species in national CWR conservation planning. European nations should have an obligation to monitor/conserve populations of these species, whether nationally threatened or not. This approach will require a regional authoritative body to oversee its implementation; therefore, the practicalities of implementing this integration need to be addressed and incorporated into European policy on agrobiodiversity conservation. As no European legislation with a focus on CWR conservation currently exists, there is at present no means of enforcing this obligation on EU member states or those European countries not currently within the EU. Emphasis therefore needs to be placed on the development of a clear regional policy on CWR conservation with buy-in from national PGR programmes throughout the region. For the regionally important CWR species that are included in Annex I of the ITPGRFA, the Treaty may be used as leverage for obligating European nation states to actively conserve CWR genetic resources within their jurisdiction. However, as the Treaty does not cover all European priority crop genepools, it is vital that EU legislation with a specific focus on CWRs is developed.

This legislation could be achieved using a combination of approaches. First, a specific EU Directive on PGRs could be enacted that would contemplate the protection of priority CWR populations within existing European biodiversity protection infrastructures. Second, the inclusion of priority CWRs (if not already included) in the annexes of the EU Habitats Directive would place an obligation on EU member states to conserve populations of the species within their jurisdiction. However, since the species for inclusion in the Habitats Directive have to be proposed by nation states, buy-in on regional policy with respect to CWR conservation is needed from the onset of discussions in this area. A possible complication in terms of changes to the Habitats Directive is that its falls under the remit of the European Commission (EC) Directorate General (DG) for Environment, while PGRFA issues fall under the remit of the EC DG for Agriculture and Rural Development. As already highlighted, CWRs frequently fall in a 'responsibility gap' between environment and agriculture agencies, both at national and regional levels – it is critical that this issue is resolved and the gap closed.

In terms of policy in support of CWR conservation in Europe, there are a number of other issues to consider, including how to ensure the success of conservation actions that depend on cross-border cooperation and the need for a central coordinating body to collect reports on the implementation of the integrated strategy. These policy-related issues will require discussion between the relevant actors (e.g. the EC, European Environment Agency and ECPGR) once the technical aspects of the integrated European CWR conservation strategy have been developed, agreed and finalized.

Acknowledgements

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Note

[1] In this context, the term 'crop group' is used to refer to genera containing multiple crops (e.g. onion, leek, garlic, etc., in the genus *Allium*), crop complexes such as the brassica complex, which contains multiple crops within multiple genera, or crops grouped according to their category of use (e.g. legume forages), as listed in Annex I of the ITPGRFA.

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CHAPTER 5 – SUPPLEMENTARY MATERIAL

METHODOLOGY AND RESULTS OF THE SELECTION OF PRIORITY CROP WILD RELATIVE SPECIES AT REGIONAL LEVEL IN EUROPE

The content presented here is supplementary to Chapter 5 – Kell *et al*. (2016). The material comprises a description of the methods and results of data analyses undertaken to select priority crop wild relative species at regional level (see section 11.2.2, starting on page 129 of the preceding PDF document), since these details were not included in the published chapter.

S5.1 Summary of the methodology

As summarized by Kell *et al*. (2016, p. 130) (Chapter 5), following the three main prioritization criteria (the socio-economic value of crops, the potential ease of use or known value of wild relatives in crop improvement programmes, and their relative threat status), three steps were taken to identify Europe's priority crop wild relatives (CWR):

1. FAO crop production statistics (FAO, 2014) were consulted to obtain annual production values of human food crops cultivated in Europe over a ten year period and those with an average annual value of more than US$500 million that have CWR native to Europe were identified. The native wild relatives of these crops were selected from the CWR Catalogue for Europe and the Mediterranean v. 4.0 (the CWR Catalogue) (see Kell *et al*., 2018a – Chapter 2) to create a base list of regionally important CWR based on the economic importance of the associated crops. The regional value of human food crops in terms of average annual energy supply per capita over a ten year period were calculated from FAO food supply statistics (FAO, 2014) for Europe to highlight crops of particular regional value for food security.
2. By consulting data available on the degree of relationship between the crop species and the wild relatives in the crop gene pool and/or the known value of CWR in crop improvement programmes (Vincent *et al*., 2013), taxa in the base priority list that are likely to have greater use value for crop improvement were identified.

3. The European Red List of Vascular Plants (Bilz *et al.*, 2011) was used to identify threatened and Near Threatened taxa in the base priority list, and those endemic to Europe were identified based on data in the CWR Catalogue.

Further details and results of these steps are presented in section S5.2.

S5.2 A step by step description of the methodology and results

S5.2.1 Step 1: Selection of crops of high socio-economic importance

FAO crop production statistics (FAO, 2014) were consulted to obtain annual production values of human food crops cultivated in Europe over the ten year period 2002–2011. Crops or crop groups with an average annual value of more than US$500 million over this period that have significant native wild relative taxonomic diversity in the region were identified (Figure S5.1, Table S5.1), and the native wild relatives of these crops selected from the CWR Catalogue to create a base list of regionally important CWR based on the economic importance of the associated crops. Some crops (e.g., watermelon) have native wild relatives in the region but there are few occurrences and they are on the edge of their range, so are not included as a priority for Europe. Only two *Solanum* L. species are included as all species in that genus that are native to Europe are distantly related to potato, and only two are in the tertiary gene pool of eggplant and endemic to the Canary Islands. Only two *Lathyrus* L. species are included as all *Lathyrus* species native to Europe are distantly related to pea (*Pisum sativum* L.), and only two species (*L. clymenum* and *L. ochrus*) have known potential for improvement of the crop (Vincent *et al.*, 2013). The broad gene pools of these crops of particularly high regional economic importance combined contain 568 CWR species and 273 subspecies native to Europe.

The regional value of human food crops in terms of average annual energy supply per capita over the ten year period 2000–2009 were calculated from FAO food supply statistics (FAO, 2014) for Europe to highlight crops of particular regional value for food security (Figs. S5.2 and S5.3). Figure S5.2 shows the value of human food crops/crop groups consumed in Europe in terms of food supply expressed as average annual contributions to dietary energy (kilocalories) per capita per day of 0.1% or more in the period 2000–2009. The importance of wheat and sugar is starkly obvious and although the crop groupings in the FAO food supply statistics differ from those in the production statistics, the results indicate that most if not all of the other crops of particularly high economic value in Europe are important as plant-derived energy sources. A cursory probe into FAO food supply statistics revealed that wheat, rye and root/tuber crops are also notable sources of plant-derived protein in the region.

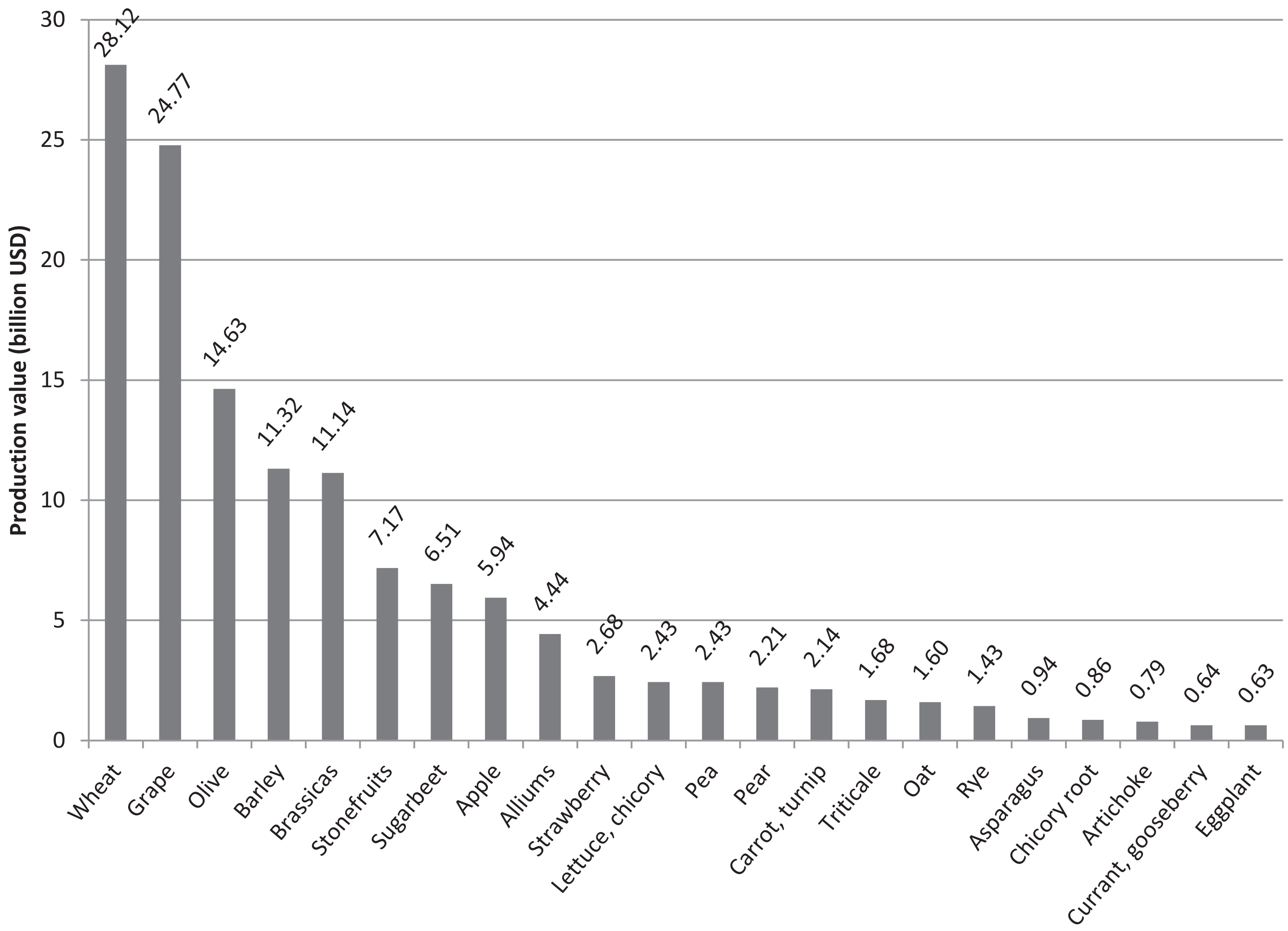

Figure S5.1 Human food crops/crop groups with an average annual production value of more than US$500 million in Europe in the period 2002–2011 that have significant native wild relative taxonomic diversity in the region (reproduced from Kell *et al.*, 2014). Data source: FAO (2014).

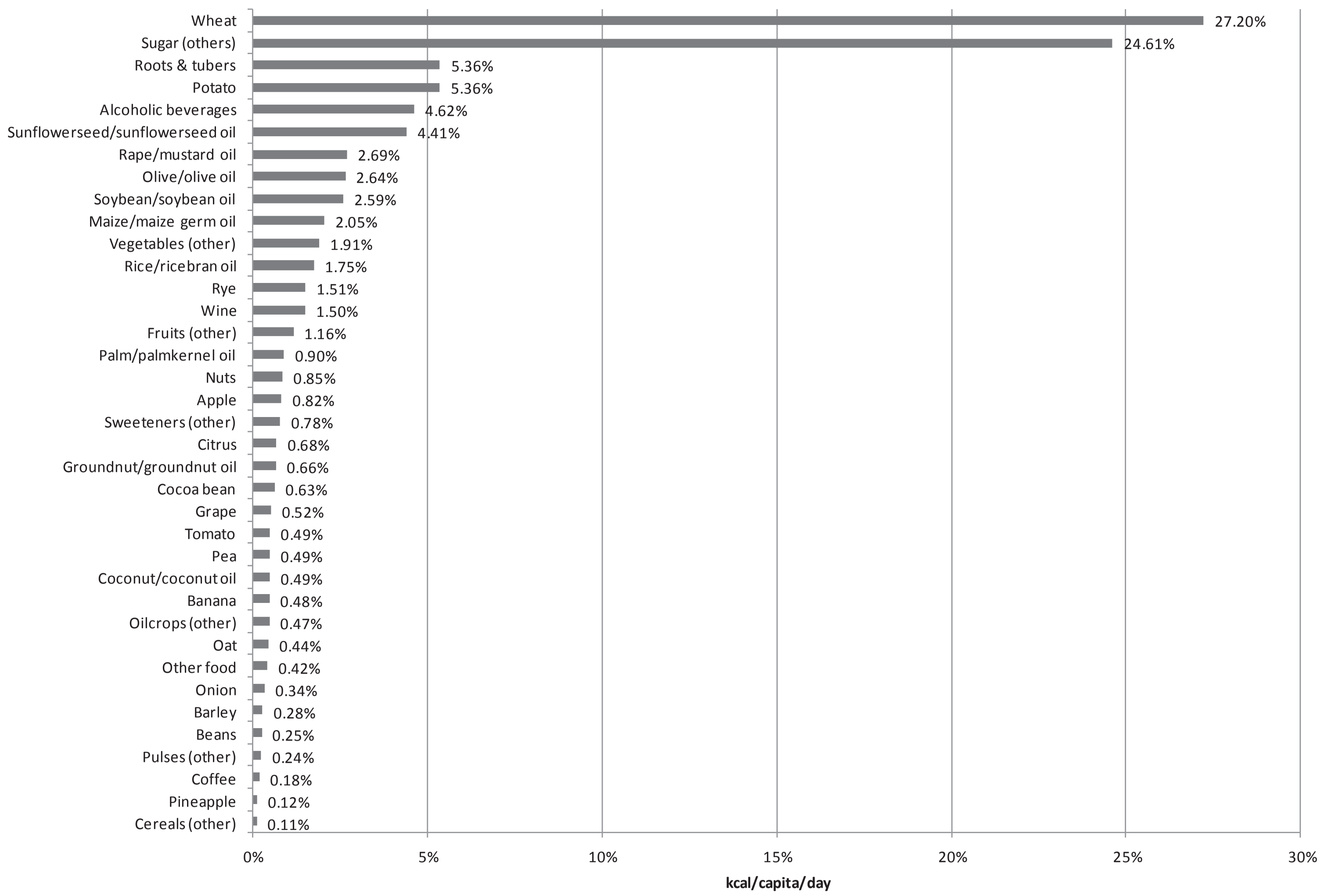

Figure S5.2 Average annual contributions of human food crops/crop groups consumed in Europe to dietary energy (kilocalories, or kcal) per capita per day of 0.1% or more over the period 2000–2009. Data source: FAO (2014).

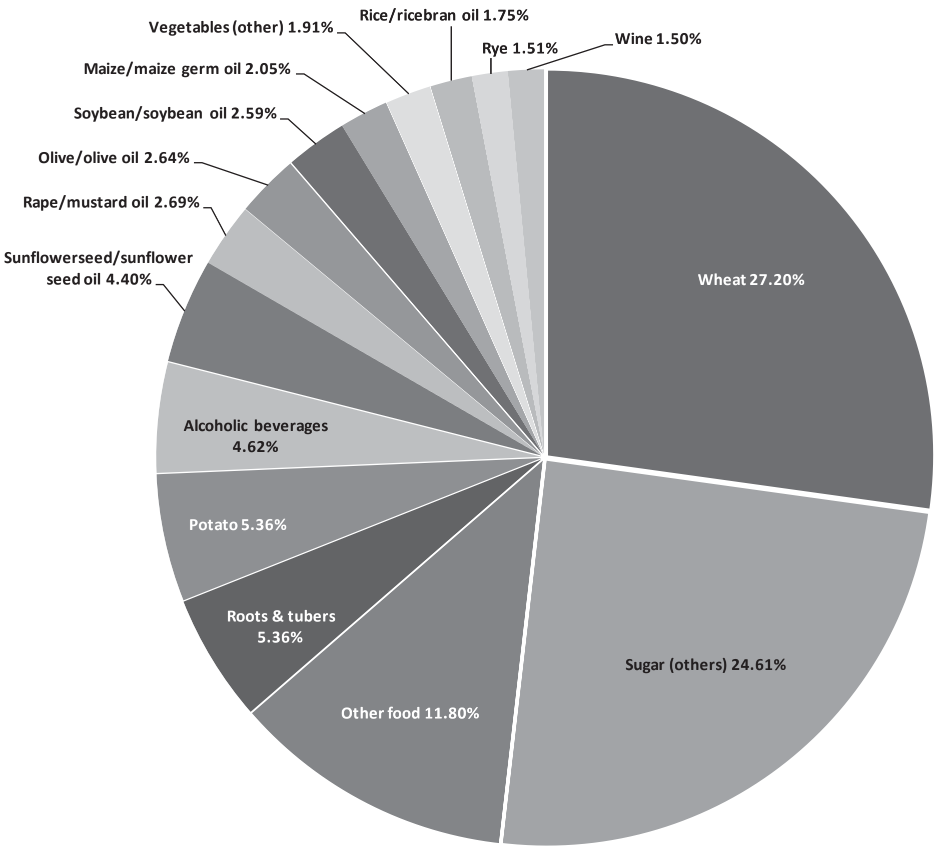

Figure S5.3 Average annual contributions of human food crops/crop groups to dietary energy (kilocalories) per capita per day of 1.5% or more over the period 2000–2009 in Europe (reproduced from Kell *et al*., 2014). Data source: FAO (2014). The category 'other food' is an aggregation of crop commodities that each supply less than 1.5% of dietary energy[25]. Categories such as 'rice/rice bran oil' and 'soybean/soybean oil' are grouped because they are derived from the same crop. One or other, or both forms may be consumed in the region. The category 'sugar (others)' may include sugar sourced from sugarcane, sugarbeet and a number of other crop species.

[25] Other food crop commodities: Apple; banana; barley; beans (phaseolus); beverages (other); cereals (other); citrus fruits; cocoa bean; coconut/coconut oil; coffee; cottonseed oil; date; fruits (other); grape; groundnut/groundnut oil; millet; nuts; oat; oilcrops (other); onion; palm/palmkernel oil; pea; pepper; pimento; pineapple; plantain; pulses (other); sesameseed/sesameseed oil; spices (other); sweet potato; sweeteners (other); tea; tomato.

As highlighted by Kell *et al*. (2015) (Chapter 4) and Khoury *et al*. (2016), most countries depend indirectly on plant genetic resources (PGR) from other parts of the world. An examination of the average annual contributions of human food crops/crop groups to dietary energy (kilocalories) per capita per day of 1.5% or more over the period 2000–2009 in the region (Figure S5.3) shows that Europe is highly dependent on potato, sunflower seed, soybean, maize and rice. These crop gene pools have primary regions of diversity in Central and South America (maize and potato), North America (sunflower seed), East Asia (rice and soybean), Southeast Asia and West and Central Africa (rice) (Khoury *et al*., 2016). Acknowledging this inter-dependency of countries and regions on PGR, the value of genetic diversity in European CWR populations for countries outside the region was also taken into consideration. Out of a list of crops of particular global importance in terms of their direct contribution to food security on the premise that they provide 3% or more of plant-derived dietary energy supply in one or more other sub-regions (see Kell *et al*., 2015 – Chapter 4), those with native wild relative diversity in Europe are mustard seed (*Brassica nigra* (L.) K. Koch and *Sinapis alba* L.), rapeseed (*B. napus* L.) and wheat (*Triticum aestivum* L.). The base list of priority species (i.e., those related to crops/crop groups of regional socio-economic importance) already captures native wild relatives in Europe of these crops of major importance for food security in one or more other sub-regions of the world.

Table S5.1 Human food crops/crop groups of high socio-economic value that have significant native wild relative taxonomic diversity in Europe.

Alliums[i]	Carrot	Lettuce	Stonefruits[iii]
Apple	Chicory	Oat	Strawberry
Artichoke	Currant	Olive	Sugarbeet
Asparagus	Eggplant	Pea	Triticale
Barley	Gooseberry	Pear	Wheat
Brassicas[ii]	Grape	Rye	

[i] Onion, garlic, leek, shallot and other alliaceous crops.
[ii] Rapeseed, cabbage, cauliflower, broccoli and other brassicas.
[iii] Peach, nectarine, plum, sloe, apricot, cherry and other stonefruits.

S5.2.2 Step 2: Selection of taxa with greatest value for crop improvement

By consulting data available on the degree of relationship between the crop species and the wild relatives in the crop gene pool and/or the known value of CWR in crop improvement programmes (Vincent *et al*., 2013) (see Chapter 1, section 1.2), taxa in the base priority list that are likely to have greater use value for crop improvement were identified. The taxa selected were those classified by Vincent *et al*. (2013) as belonging to: a) Gene Pools (GPs) 1b or 2; or b) Provisional Gene Pools (PGPs) 1b or 2; or c) Taxon Groups (TGs) 1b, 2 or 3; or d) taxa in GP3 or TG4 for which there is documented evidence of their confirmed or potential use[26]. This resulted in a list of 150 species (26% of the base priority list) and 47 subspecies (the latter in 20 species) (17% of the base priority list) that: a) are relatively closely related to the most socio-economically important food crops/crop groups in Europe; and/or b) have known uses or have shown promise for use in food crop improvement programmes. These high priority taxa span 33

[26] For details of these concepts see Maxted *et al*. (2006) and Vincent *et al*. (2013), as well as Chapter 1, section 1.4 and Chapter 2, section 2.1.

genera and are related to 22 of Europe's 23 priority crops/crop groups (all except eggplant) (Figure S5.1, Table S5.1). They are regionally important and therefore immediate priorities for regional conservation planning (i.e., taking into account their entire range in Europe). At least nineteen species (related to alliums, brassicas, oat, pea, stonefruits, sugarbeet, triticale and wheat) are threatened or Near Threatened, 12 of which (related to brassicas, oat, stonefruits, sugarbeet, triticale and wheat) are endemic to Europe.

S5.2.3 Step 3: Addition of regionally and globally threatened species

While it would be desirable to target all of the 568 most socio-economically important CWR species for regional conservation planning, in the short term it is unlikely to be feasible to include this many species in the regional conservation strategy due to resource limitations. More than 60% are distantly related to socio-economically important crops and there is currently no published evidence of their known or potential use for crop improvement. Further, a proportion of these species are relatively widespread in Europe. There is therefore currently insufficient justification for the inclusion of all these species in the regional conservation strategy. However, although they may not be known to be of immediate value for crop improvement, future characterization of populations may reveal traits of interest, particularly taking into account the potential genetic adaptation of populations in response to the impacts of climate change. While the introgression of traits from these species may not be possible using conventional plant breeding techniques, the increasingly widespread use of transgenic procedures strengthens their potential value for crop improvement and provides justification for focusing conservation efforts on them (see Chapter 1, section 1.1 and Chapter 6). Therefore, taking a pragmatic approach, in addition to the 150 species selected on the basis of prioritization criteria 1 and 2, of the remaining 376 species, those known to be under a relatively high degree of threat (i.e., Critically Endangered – CR, Endangered – EN, Vulnerable – VU, or Near Threatened – NT) according to Bilz *et al.* (2011) (also see Kell *et al.*, 2012 – Chapter 3) were identified (42 species). The potential value of these species combined with their regional or global threat status provides justification for their inclusion in the regional CWR conservation strategy.

S5.3 Summary of the results

Carrying out the three steps described in sections S5.2.1–S5.2.3 to select priority species based on their: a) relationship to crops of high socio-economic importance, b) known or potential utilization value, and c) threat status, resulted in a list of 192 CWR species native to Europe which are of particularly high priority for conservation action (Table S5.2, Figs. S5.4 and S5.5). Lists of priority CWR at each of these three levels were compiled to create the European CWR Inventory with the purpose of providing the foundations for regional CWR conservation planning in Europe (Kell *et al*., 2019).

Table S5.2 Numbers of priority CWR taxa for conservation planning in Europe.

Prioritization step	**No. of taxa**	
	Species	**Infra-specific taxa**
1. Native wild relatives of crops of high socio-economic importance (the 'base list')	568	273
2. Taxa in the base list with greatest value for crop improvement	150	47
3. Taxa in the base list (in addition to those with greatest value for crop improvement) that are threatened or Near Threatened	42	–

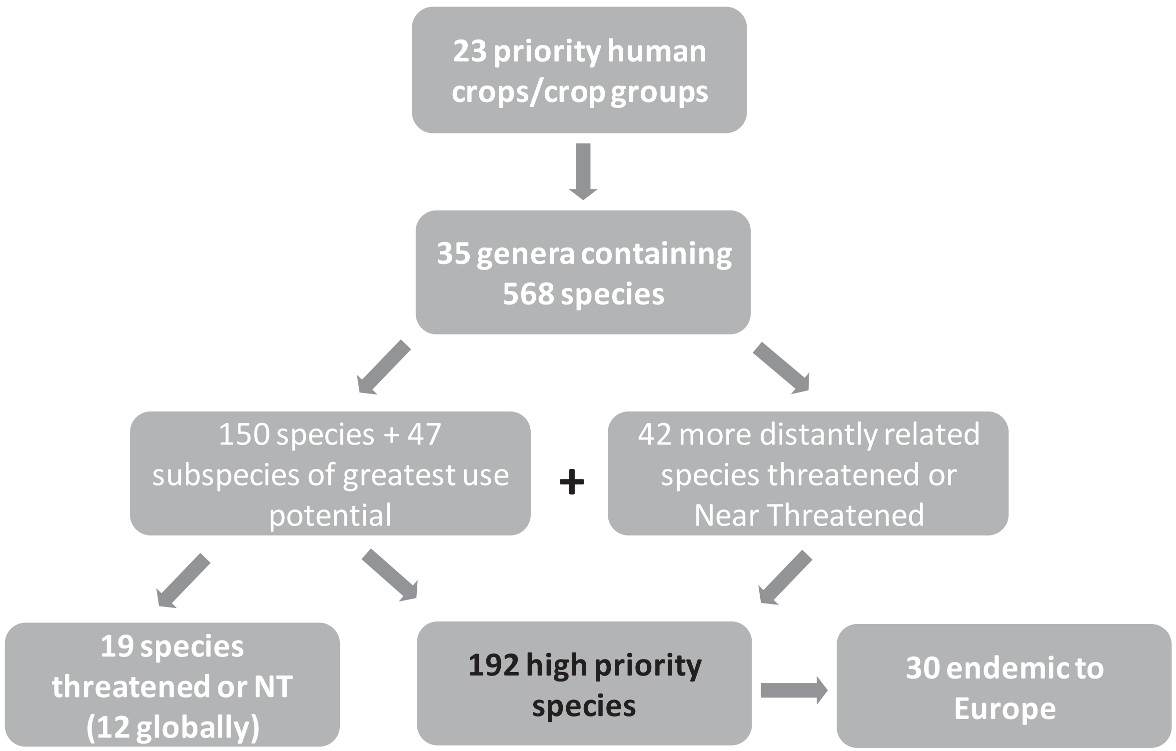

Figure S5.4 Flow chart illustrating the process and results of selecting priority CWR at regional level in Europe (reproduced from Kell *et al*., 2014).

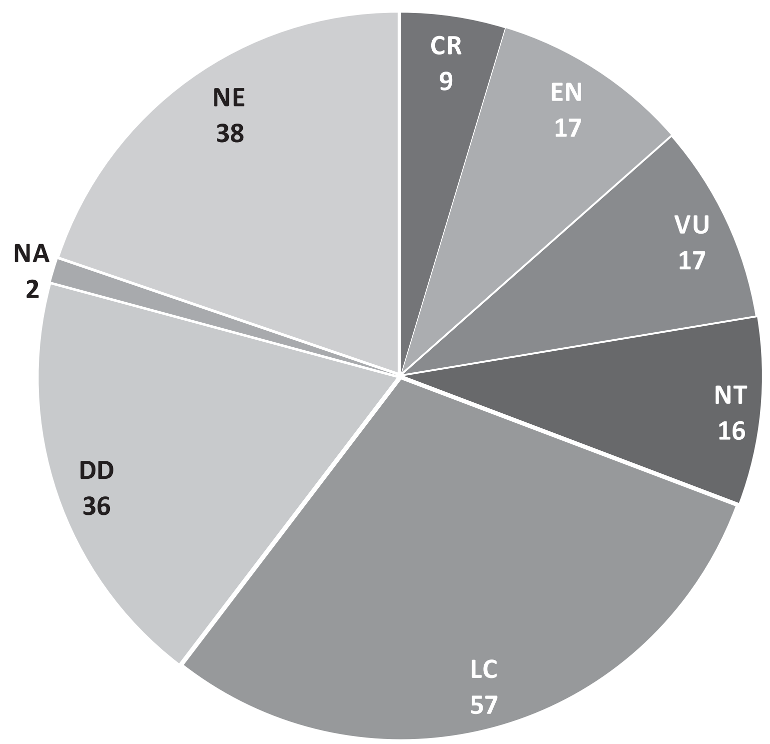

Figure S5.5 The Red List status of 192 high priority CWR in Europe (reproduced from Kell *et al.*, 2014). The categories are as defined by IUCN (2001)[27].

[27]CR – Critically Endangered; EN – Endangered; VU – Vulnerable; NT – Near Threatened; LC – Least Concern; DD – Data Deficient; NA – Not Applicable; NE – Not Evaluated.

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CHAPTER 6

BROADENING THE BASE, NARROWING THE TASK: PRIORITIZING CROP WILD RELATIVE TAXA FOR CONSERVATION ACTION

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Declaration of co-author contributions

Shelagh Kell wrote the content of the paper and produced the tables and figure. Brian Ford-Lloyd, Joana Magos Brehm, José Iriondo and Nigel Maxted provided comments on the draft manuscript. All co-authors have contributed to discussions and previous work on prioritization of CWR in the context of a number of collaborative projects over a period of c. 15 years.

Shelagh Kell

13 January 2018

Statements of co-authors

I, Brian Ford-Lloyd, Emeritus Professor of the University of Birmingham, UK, confirm that the above declaration of co-author contributions is true and accurate.

I, Joana Magos Brehm, Honorary Research Fellow of the University of Birmingham, UK, confirm that the above declaration of co-author contributions is true and accurate.

I, José Iriondo, Professor of the Universidad Rey Juan Carlos, Spain, confirm that the above declaration of co-author contributions is true and accurate.

I, Nigel Maxted, of the University of Birmingham, UK, confirm that the above declaration of co-author contributions is true and accurate.

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RESEARCH

Broadening the Base, Narrowing the Task: Prioritizing Crop Wild Relative Taxa for Conservation Action

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ABSTRACT

A broad definition of a crop wild relative is any taxon within the same genus as a crop species, or in the case of some crop genepools, other closely related genera. Given the large number of species cultivated for human and animal food, and medicinal, ornamental, environmental, and industrial purposes, the number of taxa related to these crops is inevitably vast, one estimate being >58,000 species globally. Limited resources for conservation management demands careful planning so that taxa in most urgent need of conservation are given priority. Various prioritization criteria have been used to target wild taxa for conservation action; however, in the case of crop wild relatives, a specific approach is needed to take account of their particular value as potential sources of traits for crop improvement. A surge in conservation planning for crop wild relatives since the turn of the century has resulted in a wide range of different crop wild relative prioritization criteria and methods being applied. This paper reviews those criteria and methods and presents a harmonized, logical, and pragmatic means of assigning priority status to crop wild relative taxa on the basis of three main criteria: (i) the socioeconomic value of crops, (ii) the relative potential value of the wild relatives of socioeconomically valuable crops for variety improvement, and (iii) the relative threat status of the wild relatives of socioeconomically valuable crops.

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Abbreviations: CWR, crop wild relative(s); GP, Gene Pool; IUCN, International Union for the Conservation of Nature; PGR, plant genetic resources; PGRFA, plant genetic resources for food and agriculture; SADC, South African Development Community; SPGRC, South African Development Community Plant Genetic Resources Centre; TG, Taxon Group.

THE value of traits derived from crop wild relative (CWR) populations for use in the development of new crop varieties is well documented (e.g., see Hoyt, 1988; Maxted et al., 1997a, 2008, 2012, 2014; Meilleur and Hodgkin, 2004; Hajjar and Hodgkin, 2007; Maxted and Kell, 2009; McCouch et al., 2013; Vincent et al., 2013; Dempewolf et al., 2014), and many researchers and plant breeders recognize the future potential value of CWR diversity, particularly as a source of traits to adapt crop species to the variable and uncertain environmental conditions associated with climate change. There are particular challenges for the plant breeding community in using CWR genetic diversity in breeding programs—for example, overcoming hybridization barriers between species and the problem of linkage drag. However, the wide array of techniques now available (including the use of biotechnological tools), and rapid progress in their continuing development and application, provides increasing options to overcome these challenges, thus opening opportunities for the greater utilization of exotic germplasm in the development of new or improved varieties.

As a prerequisite to the utilization of CWR in crop improvement programs, germplasm needs to be (i) conserved,

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(ii) characterized, and (iii) made available to the plant breeding research and development communities. These are three major challenges that the conservation and plant breeding communities continue to face and which require concerted action at national, regional, and global levels (Maxted et al., 2008, 2012, 2015, 2016; Maxted and Kell, 2009; McCouch et al., 2013; Dempewolf et al., 2014). Since the turn of this century, a number of notable initiatives have raised the profile of CWR and put them firmly on the international conservation agenda; however, conservationists and policymakers are faced with the difficult challenge of how to conserve the vast numbers of CWR taxa and the genetic diversity they contain. If we consider a broad definition of a CWR as any taxon classified in the same genus as a crop species (Maxted et al., 2006), or in the case of some crops, other closely related genera (e.g., the genepool of bread wheat, *Triticum aestivum* L. subsp. *aestivum* encompasses not only taxa in the genus *Triticum* but also in the genera *Aegilops* L., *Agropyron* Gaertn., *Amblyopyrum* Eig, *Elytrigia* Desv., *Leymus* Hochst. and *Elymus* L.), the gross global number of crop and CWR species may account for >58,000 (~21%) of the world's known flowering plant species (Maxted and Kell, 2009; Maxted et al., 2012), and this is disregarding the thousands of subspecific CWR taxa that may contain unique genetic diversity. Clearly it is not feasible to consider conservation interventions for such a large number of taxa; therefore, those in most urgent need of conservation need to be afforded priority for immediate attention.

Many different criteria can be used to prioritize species for conservation action, including socioeconomic use, taxonomic uniqueness, cultural value, endemicity, rarity, intrinsic biological vulnerability, threat of genetic erosion, current conservation status, ecogeographic distinctiveness, and distribution (Maxted et al., 1997b; Heywood and Dulloo, 2005). A wide range of approaches to applying species prioritization criteria have been employed, including scoring and ranking schemes and rule-based systems (reviewed by Magos Brehm et al., 2010). In the case of CWR, however, a specific approach is needed to take account of their particular value as potential sources of traits for crop improvement. A surge in CWR conservation planning since the beginning of the century has resulted in a range of prioritization approaches being applied by different authors of various complexities, depending on the context. In this paper we review the approaches that have been taken to date and consider the question, "which CWR taxa should pragmatically be targeted for immediate conservation action?" We present a harmonized, logical, and efficient means of assigning priority status to CWR taxa that can be applied nationally and regionally as part of a holistic global CWR conservation strategy on the basis of three main criteria: (i) the socioeconomic value of crops, (ii) the potential value of the wild relatives of socioeconomically valuable crops for variety improvement, and (iii) the threat status of the wild relatives of socioeconomically valuable crops. Regardless of the context and scope of the conservation action, these criteria are the most relevant for prioritization of CWR taxa, and in the last 15 yr of concerted action on CWR conservation planning have been widely promoted and consistently applied as the primary basis of taxon selection.

THE CRITERIA EXPLAINED

Criterion 1: The Socioeconomic Value of Crops

The relative socioeconomic value of crops (i.e., their value to society, both in terms of ensuring food and nutrition security and supporting sustainable economic growth) is the most important and fundamental criterion when assigning conservation priority to CWR. The rationale for conserving CWR diversity is to maintain and provide access to it for crop improvement, and while it would be desirable to conserve wild species related to all crops, this option is not realistic at any geographic scale of conservation action. Thus, CWR taxa related to priority crops (i.e., those that are considered to be of highest socioeconomic value) should be given precedence for conservation action because these are the crops with greatest value to human society for food and economic security. Furthermore, because the transfer of traits from CWR to these crops is likely to have significant socioeconomic impact and the cost of prebreeding is more likely to be offset by the additional value of the introgressed traits, the conserved CWR diversity is more likely to be used. The selection of priority crops should therefore logically be the first step in the CWR prioritization process, or if taking a "parallel" approach to prioritization (see explanation provided below), the application of this criterion should be afforded significant weight in the scoring process.

This criterion is founded on the basis of the definition of a CWR proposed by Maxted et al. (2006), which has been widely accepted and adopted by those working in the field of CWR conservation planning worldwide. A CWR taxon is defined by its "indirect use derived from its relatively close genetic relationship to a crop" (Maxted et al., 2006, p. 2680) and, as noted by the authors, includes any taxon within the same genus as a crop taxon. On this basis, it is relatively simple with access to floristic data (i.e., flora checklists) to create complete or partial checklists of CWR (a complete checklist being a list of wild taxa related to crops of all types, and a partial checklist being a list of wild taxa related only to selected crop types, such as human food or forage), and to select those taxa related to the highest priority crops.

The selection of priority crops varies according to geographic scale and the context of the conservation action. For example, whereas the conservation of wild relatives of major food crops such as bread wheat, maize (*Zea mays* L.), and rice (*Oryza sativa* L.) is a priority for global food security, at the regional or national level, minor crops such as cassava (*Manihot esculenta* Crantz), millets [e.g., finger millet, *Eleusine coracana* (L.) Gaertn. and foxtail millet, *Setaria italica* (L.) P. Beauv.], and sweet potato [*Ipomoea batatas* (L.) Lam. var. *batatas*] may be a higher priority. In general, of the main crop use categories (human food, animal food, food additives, materials, fuels, social uses, medicines, and environmental uses; Wiersema and León, 2013), human food crops are of the highest priority due their importance for nutrition and food security (Kell et al., 2015b), and thus their fundamental role in sustaining human life. Crops of high economic value are also of uppermost priority (Kell et al., 2012a) due to their importance for sustainable economic growth, as well as providing important motivation for the establishment of national conservation and sustainable use management plans for plant genetic resources for food and agriculture (PGRFA) (Kell et al., 2015b). There are therefore two main subcriteria on which to base the selection of priority crops: (i) crops of high importance for nutrition and food security, and (ii) crops of high importance due to their economic value. On the basis of these two subcriteria, when planning CWR conservation and sustainable use strategies at the national or regional level, crops in any use category may be afforded priority, depending on the inherent floristic diversity of the country or region and economic value of the CWR diversity within its borders. For example, forage and fodder crops are of particular importance in the Nordic subregion of Europe (Fitzgerald, 2016), where there are fewer human food CWR. At the global level, food security is paramount when considering the selection of priority CWR taxa for active conservation. Thus, wild relatives of human food crops are of critical importance for conservation action at this broad worldwide scale.

The selection of priority crops can be based on a number of crop value statistics (e.g., related to food supply and economic value), which are publicly available via FAOSTAT (www.fao.org/faostat/), the online database of FAO's Statistics Division, as well as by consulting the statistical databases of government agencies, which are publicly available in some countries, and those of regional administrations such as EuroStat (EU, 1995–2016), provided by the European Commission. Value statistics are not available for all crops, but this does not mean that the crops for which these data are not available are unimportant. Other indicators of socioeconomic value can be used to assign relative value to crops—for example, on the bases of (i) expert knowledge of the local, national, or regional socioeconomic value of crops (e.g., for particular nutritional qualities, local market value, or cultural importance); (ii) the number of varieties of a crop cultivated in a country or region; and (iii) the number of accessions of crops held in national or regional genebanks. However, not only do these indicators introduce a degree of subjectivity to the analysis, practitioners should be careful when ranking their importance with respect to other crops, since direct comparisons cannot be made using different indicators. When possible, consultation with the plant breeding community is also important when selecting priority crops, although this approach usually takes only national or regional priorities into account, overlooking the potential value of a nation's or region's CWR diversity for the improvement of crops that are economically valuable in other countries or regions.

Criterion 2: The Potential Value of Wild Relatives for Variety Improvement

In light of recent rapid developments in gene discovery and transfer techniques, it can be argued that all wild species are potential gene donors to crops. However, the use of biotechnology to transfer genes between distantly related species (transgenesis) remains a controversial issue, and the cultivation of crop varieties developed using transgenic techniques is not universally accepted. In addition, biotechnological techniques may work well when considering traits that are regulated by one or few genes but may be more problematic when dealing with traits regulated by many genes or when the genes being transferred are pleiotropic. In the latter case, the transfer of genes from distantly related species may cause the disruption of coadapted gene complexes. Further, the use of biotechnology in plant breeding remains relatively expensive and technically challenging, and the tools and technical knowledge are not available to all plant breeders working on all crops. Therefore, the use of conventional breeding techniques for interspecies gene transfer between closely related species is likely to remain the global norm (Maxted and Kell, 2009; Maxted et al., 2012). In cases where the technology is available, cisgenesis, which involves the use of biotechnology to transfer genes from the same or closely related sexually compatible species, may become more widely accepted as the urgency to speed up the production of new crop varieties to respond to global change gains greater understanding in society. As a general rule, there is therefore a strong argument to assign high priority to the conservation of the wild relatives that are most closely related to crop taxa.

The Gene Pool (GP) concept of Harlan and de Wet (1971) provides the best means of identifying the closest wild relatives, which are taxa in GP1b (wild or weedy forms of the crop that hybridize freely with the crop taxon, also known as "primary" wild relatives) and GP2 (less closely related species with which hybridization is possible but may be more difficult, also known as "secondary" wild relatives). However, GP concepts have only been published for a relatively small number of crops (Maxted et al., 2006)—mainly major food crops such as bread wheat, maize, and rice, or those that are of particular regional economic importance such as sugarbeet (*Beta vulgaris* L. subsp. *vulgaris*) in Europe.

In the absence of this knowledge, taxonomic classifications can be used as a proxy measure for the degree of genetic relationship and therefore the likely interfertility of a taxon to the crop (Maxted et al., 2006). The Taxon Group (TG) concept (Maxted et al., 2006) uses taxonomic distance as a proxy for genetic distance, the assumption being that subspecies or botanical varieties in the same species as the crop (primary wild relatives in TG1b) and taxa in the same series or section as the crop (secondary wild relatives in TG2) are likely to be more easily used than more remote taxa in conventional plant breeding. Although taxonomic distance and genetic distance do not always concur, the concept offers a viable alternative to assessing the degree of relationship of the wild relatives to the crop (and thus potential crossing ability) in the absence of genetic data (Maxted et al., 2006). In cases where the GP concept has not been ascertained and for genera that have not been subdivided into sections and series, the best available information on genetic and/or taxonomic diversity has to be used to make reasoned assumptions about the most closely related taxa, and thus potential crossing ability. For example, in a study conducted by Maxted and Kell (2009), the classification of wild relatives of finger millet into primary, secondary, and tertiary groups was made on the basis of a review of published results of various genetic studies performed on *Eleusine* taxa because a GP classification had not previously been published and the TG concept could not be applied because the genepool contains only nine species, eight of which are in the genus *Eleusine*, which is not subdivided into subgenera, sections, or series. Vincent et al. (2013) later referred to classifications such as this as Provisional GP concepts.

While primary and secondary CWR are of high conservation priority, this does not negate the need to assign conservation priority to taxa in GP3 or TGs 3 and 4 ("tertiary" wild relatives). In this regard, there are two specific considerations when applying Criterion 2 in CWR conservation planning. First, taxa that have already been used in plant breeding or that are known to contain traits of interest for crop improvement (increasing the likelihood of them being used in the future) should be given high priority status (Maxted and Kell, 2009). Examples include the tertiary wild relatives of sugarbeet (*Patellifolia* A.J. Scott et al. spp.), which are donors of beet cyst nematode (*Heterodera schachtii* Schmidt) resistance (now successfully used in sugarbeet production worldwide) and other resistance traits (Prescott-Allen and Prescott-Allen, 1986), and *Hordeum chilense* Roem. & Schult., a tertiary wild relative of barley (*H. vulgare* L. subsp. *vulgare*) that has a number of characteristics of interest for breeding (in particular, resistance to barley leaf rust, caused by *Puccinia hordei* G.H. Otth) and has potential for use in wheat and triticale improvement (Martín and Cabrera, 2005). Second, the particular value of the most closely related species applies to the majority of crops but may be of less importance when prioritizing species related to crops that hybridize relatively freely with their tertiary wild relatives or are routinely bred using advanced techniques. For example, cassava hybridizes naturally with many of the wild species in the genepool and a number of species in GP3 have already been used in breeding programs (Maxted and Kell, 2009), and virtually any wild relative of potato (*Solanum tuberosum* L.) can be utilized in improvement of the crop using ploidy manipulation or somatic fusion to overcome crossing barriers (Bradshaw et al., 2006).

Although narrowing down conservation action to a limited number of CWR taxa is a necessary part of conservation planning, all CWR (regardless of their position in the crop genepool) may be important as gene donors in the future—many taxa remain uncharacterized and the transfer of traits for crop improvement may be facilitated by new breeding techniques (as well as existing techniques that are not yet universally accepted, as mentioned above). Therefore, tertiary wild relatives with no currently known specific use potential should not be overlooked in conservation planning, especially considering that many of these taxa could become more restricted and threatened in the future, particularly in response to climate change. Importantly, species in this category that are known or suspected to be under threat of genetic erosion should be afforded conservation priority (see Criterion 3 below). Further, when the required data are readily available to include a larger number of CWR in diversity and gap analyses to identify populations and sites of conservation priority than have been afforded high priority conservation status, additional tertiary taxa may be targeted for conservation because they coexist with the high priority taxa.

Due to recent concerted efforts in determining and documenting the relationships between taxa in food crop genepools (Maxted and Kell, 2009; Vincent et al., 2013; USDA, ARS, GRIN, 2017), data on the classification of the wild relatives of a wide range of crops into primary, secondary, and tertiary groups are now freely available to aid CWR conservation planning worldwide via the Harlan and de Wet CWR Inventory (Vincent et al., 2013; www.cwrdiversity.org/checklist) and the Germplasm Resources Information Network (USDA, ARS, GRIN, 2017; https://npgsweb.ars-grin.gov/gringlobal/taxon/taxonomysearchcwr.aspx).

As for Criterion 1, consultation with the plant breeding community is worthwhile when selecting priority CWR taxa on the basis of their use potential, especially to gain the support of the user community for their conservation. However, this approach has the same caveat as previously stated: (i) it introduces a degree of subjectivity in the process because not all plant breeders can practically be consulted, and (ii) it usually takes only national or regional priorities into account, overlooking the potential value of a nation's or region's CWR diversity for the improvement of crops that are economically valuable in other countries or regions.

Nonetheless, if consultation with plant breeders is viewed as an additional step in the process (i.e., adding species to the priority list rather than removing them), it is certainly of great value in the CWR conservation planning process.

Criterion 3: The Threat Status of Wild Relatives of Priority Crops

The degree to which species are under threat, relative to other species, is a fundamental criterion for conservation planning. In the case of CWR taxa, however, this criterion should ideally not take precedence over Criteria 1 and 2 unless resources for conservation planning and/or implementation necessarily limit the number of taxa that can be included in the priority list—for example, in cases where the mandate for the conservation requires focus only on a small number of species, or when distribution data are not readily available for all species that would ordinarily be prioritized, including those closely related but with relatively wide distributions. Assigning greatest weight to Criteria 1 and 2 in the CWR conservation planning process increases opportunities to conserve a broad range of genetic diversity of taxa with the most use potential for food and economic security. Following the process of applying the three criteria conceptualized in Fig. 1, CWR taxa of greatest use potential *and* those considered to be worthy of special conservation attention due to their relative threat status (whether closely or distantly related to priority crops) can be prioritized for conservation assessment and possible action, bearing in mind that many threatened species may already be under some level of conservation management because they are listed in legislative instruments such as National Biodiversity Action Plans (NBAPs) or regional conservation initiatives such as the EU Habitats Directive (EU, 1998–2016).

Attributing relative threat status to CWR is no different to any other wild taxa. The primary and most obvious means of achieving this is to categorize taxa according to their Red List status, either based on existing assessments published in national and regional Red Lists, as well as the International Union for the Conservation of Nature (IUCN) Red List of Threatened Species (www.iucnredlist.org), or by undertaking new assessments. Systematic Red List assessment of CWR is now becoming more commonplace through a number of initiatives, particularly under the auspices of the Crop Wild Relative Specialist Group (CWRSG, www.cwrsg.org) of the IUCN Species Survival Commission, which is taking the lead in Red Listing of CWR and has published global assessments for a number of priority CWR in the IUCN Red List of Threatened Species, as well as regional assessments of priority CWR

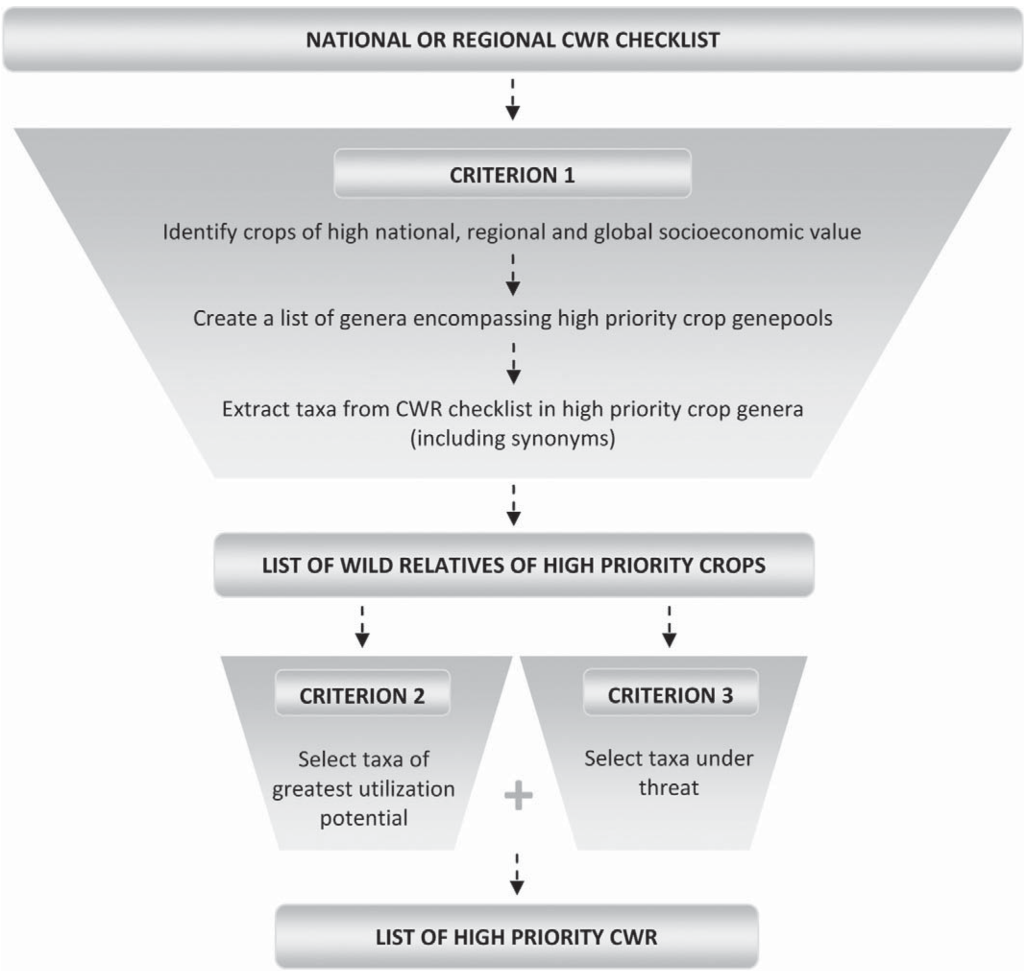

Fig. 1. Conceptual diagram showing a harmonized, logical, and pragmatic approach to crop wild relative prioritization based on three main criteria, which results in a list of taxa that are of greatest use potential for crop improvement and/or considered to be worthy of special conservation attention due to their relative threat status.

in Europe (Bilz et al., 2011). Although Red List assessment of CWR at the national level has not generally been systematically undertaken, some CWR species are included in national Red Lists because of their importance as threatened species per se, rather than as CWR.

If CWR taxa have not been Red Listed, it does not mean that they are not under threat. If a published assessment is not available, a proxy for relative threat may be applied in the prioritization process by categorizing taxa according to their comparative distribution (Ford-Lloyd et al., 2008, 2009) and/or based on knowledge of threats to a species' primary habitat. The comparative distribution of taxa can be seen as an indicator of the relative degree of threat when actual threats to populations or the habitats in which they are found are unknown, on the assumption that the overall populations (i.e., all subpopulations counted together) of taxa with more limited distributions are more likely to be negatively affected by the stresses caused by potential threatening factors. Using this approach, taxa with relatively limited distribution ranges can be afforded higher priority status than those that are more widely distributed. However, this measure should be applied with caution. First, although a taxon may be recorded as occurring in several countries, without knowledge of the actual distribution within those countries, we do not know how widely distributed the taxon actually is across its range. Second, because the aim of CWR conservation is to maximize conservation of infraspecific diversity, populations of taxa that are known to occur both inside and outside the country or region of the CWR conservation action should be actively conserved across their range. Another approach is to use the concept of "taxon vulnerability" (Maxted et al., 2004). In the absence of sufficient data to undertake Red List assessments of African *Vigna* L. spp., the authors combined measures of rarity, breadth of distribution, absolute numbers of ex situ representation, relative ex situ coverage from the breadth of diversity, utility, and extinction assessment to generate an estimate of vulnerability to extinction of each CWR in the study. This approach does, however, include elements of gap analysis (ex situ) in the selection of priority taxa, a step ideally undertaken after taxon prioritization to avoid excluding important taxa in conservation planning.

Importantly, the status of a taxon as endemic should not be confused with its relative distribution. A taxon may be endemic to a country but widely distributed and not threatened, whereas other nonendemic taxa may have narrow ranges and may be threatened. Further, at the regional level, a taxon that is endemic to a small island cannot be compared with one that is endemic to a large continental country. Therefore, although it is understandable that countries and regions assign conservation priority to endemic taxa because of their inherent value to the country as unique national resources, emphasis should be placed on the actual relative distribution of taxa, not to their endemic status per se.

Critically, when prioritizing CWR based on their Red List status, it is not necessarily the case that a species that has been evaluated as Least Concern using the IUCN Red List Categories and Criteria (IUCN, 2012a) is not in need of conservation action. Kell et al. (2012a) argued that three important issues need to be taken into account when interpreting a Least Concern assessment. First, the IUCN Red List assessment process does not take into account genetic diversity within and between populations, only population size and geographic range. As the goal is to maximize the conservation of CWR genetic diversity, it is vital that sufficient populations are actively managed both in situ and ex situ to provide an adequate sample of total genetic diversity (Ford-Lloyd and Maxted, 1993; Maxted et al., 2008, 2012, 2015, 2016; Maxted and Kell, 2009; Kell et al., 2012b). Second, the criteria for assessing a species as threatened (i.e., Critically Endangered, Endangered, or Vulnerable) are very robust, and for species that do not meet the required thresholds, assessors must choose between Near Threatened, Data Deficient, or Least Concern—a choice that is highly subjective. Third, although the regional Red List status of many CWR is likely to be Least Concern, many of these species may be nationally threatened. In Europe, Kell et al. (2012a) estimated that this applies to as many as one third of the species regionally assessed as Least Concern.

When including Red List assessments in the CWR prioritization process, practitioners should also be careful to distinguish between national, regional, and global assessments (note that in this sense "regional" refers to a geographic region such as Europe, not to a regional Red List assessment sensu IUCN [2012b], which includes national assessments), because the Red List status of taxa at these different geographic scales carries different weight depending on the scope of the conservation action. For example, when prioritizing CWR taxa as part of the national CWR conservation strategy planning process, the national Red List Status of species is clearly of upmost importance because prioritization is being undertaken at the national level. National endemic species that are assessed as threatened or Near Threatened are also regionally and globally threatened or Near Threatened, so highlighting this can add weight to the argument for their conservation, even if the regional and global assessments have not been published. On the other hand, for species that are assessed as nationally threatened, Near Threatened, Data Deficient, or Not Evaluated but are not endemic, including their regional and/or global Red List status will not help the cause for their national conservation if they are evaluated as Least Concern at those geographic scales. In a few cases, however, the regional and/or global Red List assessments of non-national endemic species are important to consider in the national prioritization process. For example, in Europe, species regionally and globally assessed as threatened or Near Threatened that occur in more than one country include: *Allium schmitzii* Cout. (Vulnerable) and *Asparagus nesiotes* Svent. (Endangered) (native to Portugal and Spain) (Santos Guerra et al., 2011a, 2011b); *Barbarea lepuznica* Nyár. (Endangered) (native to Romania and Serbia) (Strajeru and Stevanović, 2011); and *Medicago pironae* Vis. (Near Threatened) (native to Croatia, Italy, and Slovenia) (Branca and Donnini, 2011).

A Note about CWR Prioritization and Occurrence Status

Although it is generally accepted that the three criteria presented above are most relevant when prioritizing CWR taxa in the conservation planning process, some authors apply the additional criterion "occurrence status," which in its simplest terms defines whether a taxon is native or introduced to the geographic area delineated in the conservation action, although there are several occurrence status categories defined in the Plant Occurrence and Status Scheme (POSS) (WCMC, 1995). In general, taxa that are considered to be native are afforded conservation priority in any type of biodiversity conservation action plan, although archaeophytes—taxa that have been introduced to an area in ancient times (commonly considered to be before 1500 AD)—are frequently also considered to be of priority. However, since some taxa are able to adapt rapidly to new environments (Ford-Lloyd et al., 2014), populations of neophytes (taxa introduced to an area after 1500 AD) can offer important and unique genetic diversity. Even if they arrive in their non-native habitat with a narrow genetic base, they are likely to rapidly evolve to their new environment and may contain unique diversity not present in the source population.

CWR PRIORITIZATION AT THREE GEOGRAPHIC SCALES

A holistic global approach to CWR conservation involving action at the national, regional, and global levels has been promoted by Iriondo et al. (2008), Maxted et al. (2008, 2012, 2013, 2015, 2016), and Maxted and Kell (2009) and is enshrined in the Convention on Biological Diversity (UN, 1992), the International Treaty on Plant Genetic Resources for Food and Agriculture (International Treaty on PGRFA) (FAO, 2001), and the Second Global Plan of Action on Plant Genetic Resources for Food and Agriculture (FAO, 2012). In recent years, much progress has been made in planning CWR conservation at each of these three geographic scales. To inform ongoing developments, particularly in national CWR conservation planning, it is both relevant and timely to review approaches to CWR prioritization that have been undertaken to date and to highlight some common issues arising in the process.

National Approaches to CWR Prioritization

Due to the sovereign rights of nations over the management and use of the genetic resources within their political borders, the responsibility to conserve those resources also lies at the national level. Therefore, national CWR conservation strategies, which aim for the systematic conservation of priority CWR genetic diversity in situ and ex situ, are fundamental to the effective global conservation of these resources. The surge in projects and research focusing on the conservation of CWR diversity in recent years has resulted in significant progress in the development of national CWR conservation strategies, particularly in the European region, which has been a hub of developments in CWR conservation practice for the last 15 yr. In Europe, a coordinated approach to CWR conservation is being implemented through the auspices of the European Cooperative Programme for Plant Genetic Resources (ECPGR, www.ecpgr.cgiar.org), which has adopted an integrated approach to CWR conservation in the region (Maxted et al., 2015). Three notable projects funded by the EU between 2002 and 2014 (PGR Forum, www.pgrforum.bham.ac.uk; AEGRO, http://aegro.julius-kuehn.de/aegro; and PGR Secure, www.pgrsecure.org) have provided the framework within which knowledge on CWR diversity and planning for its conservation has increased exponentially and enabled concerted efforts in conservation planning (as well as the beginnings of its implementation) in the region based on a range of commonly agreed on and widely tested scientific concepts and techniques. Through the project PGR Secure, training in CWR conservation planning methods (including prioritization) has been provided across the region to build capacity and encourage action at the national level.

Iriondo et al. (2016) and Labokas (2016) reviewed progress in national CWR conservation planning in 26 countries in Europe, Western and Central Asia, and North America, providing useful comparisons between the prioritization methods employed. Notably, both authors highlighted criteria that countries have used which they consider to be supplemental to the three main criteria presented in this paper: (i) stakeholder priorities (especially those of plant breeders), (ii) use categories, (iii) CWR of crops listed in Annex I of the International Treaty on PGRFA, (iv) relative distribution, (v) endemic status (national and regional), (vi) geographical or regional responsibility for certain taxa with restricted worldwide distributions, (vii) rarity of the habitat in which the species grow, (viii) relative abundance, (ix) status in surrounding countries, (x) species listed in the annexes of the EU Habitats Directive, (xi) national protection status, (xii) expected effects of climate change on distribution, (xiii) occurrence status, (xiv) the center of diversity of the crop genepool, and (xv) ex situ and in situ conservation status. In addition, Hunter and Heywood (2011) reviewed the CWR prioritization criteria applied in Armenia, Bolivia, Madagascar, Sri Lanka, and Uzbekistan, noting that the countries "adopted different sets of criteria based on the knowledge, experience, and interests of those involved in the exercise" (p. 130). In addition to the criteria listed above, the following criteria were used: (i) state of knowledge and availability of information, (ii) degree of genetic erosion, (iii) multiple or combined value, (iv) traditional use, and (v) use by local people as a food source.

Untangling this array of different prioritization criteria applied by countries as part of the national CWR conservation strategy planning process is important to assist in future national efforts, both in systematically applying CWR prioritization criteria and in reporting on the methods used. In Table 1, we address each criterion listed above in turn, commenting on those that can be considered integral to or as subcriteria of the three main CWR prioritization criteria presented in this paper, and on their relevance and value for CWR conservation planning. Labokas (2016) also highlighted the categories of crop use that were considered important in the prioritization process, noting that three countries (Norway, Portugal, and Sweden) prioritized taxa related to crops in six use categories: human food, animal food, forestry, medicinal and aromatic, industrial, and ornamental. This emphasizes the point made above that when planning CWR conservation and sustainable use strategies at the national level, crops in any use category may be afforded priority, depending on the inherent floristic diversity of the country and the economic value of the CWR diversity within its borders.

In terms of the methods used in applying the prioritization criteria, there are two primary approaches: (i) the serial method, in which one criterion is applied after another, sequentially reducing the number of taxa to a priority subset; and (ii) the parallel method, in which taxa are scored for all criteria, ranked according to their total scores, and then selected on the basis of their placement in categories according to one or more "cut-off" scores (Maxted et al., 1997b). Sometimes a combination of these two methods may be applied. Both methods are valid but have limitations and potential pitfalls. Using the serial method, the order in which the criteria are applied effectively affords weight to each, and the resulting priority taxon list therefore reflects this weighting. For example, selecting taxa related to priority crops (Criterion 1), followed by selection of a subset based on relative threat status (Criterion 3), results in many taxa that may be of high value for crop improvement being excluded. The same result would occur by selecting taxa based on their relative threat status (Criterion 3), followed by the value of the selected taxa according to the crops to which they are related. Therefore, when using the serial method of applying the criteria, Criterion 1 should always be the first one applied to ensure that the most important taxa are included in terms of their potential to contribute traits to the most socioeconomically valuable crops, and the practical likelihood that trait introgression from CWR is likely to be applied for that crop. After the application of this criterion, the recommended approach is to apply Criterion 2 to identify the first subset of priority taxa, then to apply Criterion 3 to the remaining taxa, thus producing a list of priority taxa that are either of greatest use potential or considered to be worthy of conservation action because they are under threat of genetic erosion, regardless of their current known or potential value for crop improvement. This method is illustrated in Fig. 1.

Using the parallel method, all taxa in a national CWR checklist (whether complete or partial) are scored for each criterion and ranked according to their total scores to identify priority taxa. This approach can be quite robust if very carefully planned and executed. However, there are two major potential pitfalls. First, the decision has to be made whether to afford equal weight to each of the criteria. Experience has shown that some countries tend to lend greater weight to relative threat status than to the socioeconomic value of the related crop or use potential for crop improvement, an approach that results in many taxa that may be of high value for crop improvement being excluded from the priority list. This problem may be compounded by including several subcriteria (as described in Table 1). Giving equal weight to these subcriteria effectively results in unintentionally affording greater weight to one of the three main criteria (usually Criterion 3, because most of the subcriteria being applied relate to relative threat status). Second, the scoring system used is always subjective because it depends on the opinions of the practitioner undertaking the prioritization—although this subjectivity can be reduced to some extent through a process of review and validation involving national stakeholders, experts, and based on previous studies. One solution proposed to reduce bias and subjectivity is to apply a number of different methods to the same set of species and then select the top 50 species in each of the methods to ensure that the priority species identified are those common to most methods (Magos Brehm et al., 2010). However, this approach involves a significant amount of researcher time and may not be possible in most circumstances.

In addition to these pitfalls, the work involved in scoring a large number of species is arduous and time consuming, whereas the more simple serial approach described in this paper can be relatively rapidly achieved by running queries on the base dataset. We therefore conclude that, while there is no single right or wrong way of undertaking CWR prioritization, the approach summarized in Fig. 1 is the simplest and most applicable approach to ensure that all important taxa are included in the priority list and to reduce potential for bias towards relative threat status over the potential value of taxa for the improvement

Table 1. Crop wild relative (CWR) prioritization criteria reported by Hunter and Heywood (2011), Iriondo et al. (2016), and Labokas (2016), with a commentary on their placement within the framework of the three main criteria presented in this paper, as well as on their value in the CWR prioritization process.

Criteria	Supplemental to the three main prioritization criteria?	Placement within the framework of the three main prioritization criteria	Value for prioritizing CWR taxa
Stakeholder priorities, especially those of plant breeders.	No	This can be considered as a subcriterion of both Criteria 1 and 2 because stakeholder priorities can be considered when selecting high priority crops and CWR taxa with the greatest use potential.	Caution should be exercised in assigning weight to this subcriterion because it is unlikely that all relevant stakeholders can practically be consulted and stakeholder priorities are unlikely to take account of the potential socioeconomic value of CWR outside the geographic scope of the conservation action.
Use categories	No	This is integral to Criterion 1, socioeconomic value of crops.	Criterion 1, to which "use categories" belongs, is the most important and fundamental of the three CWR prioritization criteria.
CWR of crops listed in Annex I of the International Treaty on Plant Genetic Resources for Food and Agriculture (International Treaty on PGRFA)	No	This can be considered as a subcriterion of Criterion 1, socioeconomic value of crops, because Annex I of the International Treaty on PGRFA is a list of crops considered important for global food security and interdependence.	Caution should be exercised in assigning weight to this subcriterion because the list is not exhaustive and excludes some crops that are of economic importance in some regions and countries. Nonetheless, it can be valuable to include this subcriterion as justification for CWR conservation due to the obligations of Contracting Parties to implement the provisions of the Treaty.
Multiple or combined value	No	This can be considered as a subcriterion of both Criteria 1 and 2 because multiple values can be taken into account when selecting high priority crop and CWR taxa (some crop species have multiple values and some CWR taxa are related to more than one crop).	Caution should be exercised in assigning weight to this subcriterion because species with multiple use values should not necessarily be given precedence over those with only one use value that is of high socioeconomic importance.
Relative distribution	No	This can be considered as a subcriterion of Criterion 3, relative threat status, because it is based on the premise that the narrower a species' range, the more likely it is to be subject to genetic erosion.	The value assigned to this subcriterion is applicable to any wild species and thus is important for CWR conservation planning. However, caution should be exercised in applying this subcriterion because assigning significant weight to it can result in more widespread CWR taxa being ignored in conservation planning.
Endemic status (national and regional)	No	This can be considered as a subcriterion of Criterion 3, relative threat status, because it is based on the premise that the narrower a species' range, the more likely it is to be subject to genetic erosion.	The value assigned to this subcriterion is applicable to any wild species and thus is important for CWR conservation planning. However, caution should be exercised in applying this subcriterion because assigning significant weight to it can result in more widespread CWR taxa being ignored in conservation planning.
Geographical or regional responsibility for certain taxa with restricted worldwide distribution	No	This can be considered as a subcriterion of Criterion 3, relative threat status, because it is based on the premise that the narrower a species' range, the more likely it is to be subject to genetic erosion.	The value assigned to this subcriterion is applicable to any wild species and thus is important for CWR conservation planning. However, caution should be exercised in applying this subcriterion because assigning significant weight to it can result in more widespread CWR taxa being ignored in conservation planning.
Rarity of the habitat(s) in which a species grows	No	This can be considered a subcriterion of Criterion 3, relative threat status, because it implies that species that occur in rare habitats may be under threat of genetic erosion.	As a subcriterion of Criterion 3, this measure can be important for prioritizing CWR taxa that may be threatened but have not been Red Listed. However, caution should be exercised in applying this subcriterion because assigning significant weight to it can result in more widespread CWR taxa being ignored in conservation planning.

Table 1. Continued.

Criteria	Supplemental to the three main prioritization criteria?	Placement within the framework of the three main prioritization criteria	Value for prioritizing CWR taxa
Relative abundance	No	This can be considered a subcriterion of Criterion 3, relative threat status, because it implies that species with small overall population sizes may be under threat of genetic erosion.	As a subcriterion of Criterion 3, this measure can be important for prioritizing CWR taxa that may be threatened but have not been Red Listed. However, caution should be exercised in applying this subcriterion because assigning significant weight to it can result in more widespread CWR taxa being ignored in conservation planning.
Status in surrounding countries	No	This can be considered a subcriterion of Criterion 3, relative threat status, because it implies knowledge of the threat status of subpopulations in neighboring countries.	As a subcriterion of Criterion 3, this measure can be important for prioritizing CWR taxa that may be threatened. However, caution should be exercised in applying this subcriterion because assigning significant weight to it can result in more widespread CWR taxa being ignored in conservation planning.
Degree of genetic erosion	No	This can be considered a subcriterion of Criterion 3, relative threat status, because "genetic erosion" is a term commonly used in relation to taxa and populations under threat of extinction.	As a subcriterion of Criterion 3, this measure can be important for prioritizing CWR taxa that may be threatened but have not been Red Listed. However, caution should be exercised in applying this subcriterion because assigning significant weight to it can result in more widespread CWR taxa being ignored in conservation planning.
Species listed in the annexes of the EU Habitats Directive	No	This can be considered a subcriterion of Criterion 3, relative threat status, because the species listed in the annexes of this EU legislative instrument are those considered to be endangered, vulnerable, rare, or endemic and requiring particular attention (due to known threats impacting the species) (EU, 1998–2016).	This subcriterion should not be afforded significant weight in planning CWR conservation because the Directive does not take into account the particular value of CWR and the species are already subject to conservation measures. Nonetheless, it can be valuable to include this subcriterion as justification for CWR conservation due to the obligations of EU Member States to implement the provisions of the Directive.
National protection status	No	This can be considered a subcriterion of Criterion 3, relative threat status, because the species listed in national legislative instruments are generally those considered to be rare, threatened, or of particular national importance due to their endemic status.	This subcriterion should not be afforded significant weight in planning CWR conservation because it does not take into account the particular value of CWR and the species are already subject to conservation measures. Nonetheless, it can be valuable to include this subcriterion as justification for CWR conservation due to the obligations of national biodiversity conservation agencies to implement the provisions of national legislation.
Expected effects of climate change on distribution	No	This can be considered a subcriterion of Criterion 3, relative threat status, because it implies that results of climate change modeling indicate that taxa may be under greater or lesser threat of genetic erosion under projected climate change scenarios.	As a subcriterion of Criterion 3, this measure is important for prioritizing CWR taxa that may be threatened in the future based on results of climate change modeling. However, it is more likely to apply to the later stage of CWR conservation planning in which specific populations are targeted for conservation action after conducting diversity and gap analyses.
Occurrence status	Yes	Not applicable	The criterion should not be afforded the same weight as the three main CWR prioritization criteria because it is applicable to any wild species.
The center of diversity of the crop gene pool	Yes	Not applicable	The criterion should not be afforded the same weight as the three main CWR prioritization criteria because CWR populations in the margins of the range of crop gene pool taxa may contain unique and important genetic diversity.
State of knowledge and availability of information	Yes	Not applicable	This criterion should not influence the selection of priority CWR taxa. If there is a paucity of information on priority taxa, the need to collect more information should be highlighted in the conservation plan.

Table 1. Continued.

Criteria	Supplemental to the three main prioritization criteria?	Placement within the framework of the three main prioritization criteria	Value for prioritizing CWR taxa
Ex situ and in situ conservation status	Not applicable. This does not apply to prioritization at taxon level.	Not applicable	Assessing conservation status is undertaken after the selection of priority taxa. Regardless of a CWR taxon's conservation status, it should remain in the priority list based on its value as a gene donor for crop improvement. This is also taking into account that its conservation status may change in the future.
Traditional use	Not applicable. This criterion does not apply to prioritization of CWR taxa.	Not applicable	Traditional use (including use by local people as a food source) refers to the direct use of wild plants (i.e., by harvesting plant parts or whole plants from the wild), such as for food, medicine, materials, and ceremonial uses. The criterion may be used as a supplement to CWR prioritization to add weight to the need for CWR taxon conservation or to highlight traditional uses as a threat to populations. However, it is not in itself a criterion for prioritizing CWR taxa.
Use by local people as a food source	Not applicable. This criterion does not apply to prioritization of CWR taxa.	Not applicable	Traditional use (including use by local people as a food source) refers to the direct use of wild plants (i.e., by harvesting plant parts or whole plants from the wild), such as for food, medicine, materials, and ceremonial uses. The criterion may be used as a supplement to CWR prioritization to add weight to the need for CWR taxon conservation or to highlight traditional uses as a threat to populations. However, it is not in itself a criterion for prioritizing CWR taxa.

of socioeconomically valuable crops. Having made this point, practitioners must make a pragmatic decision on the best approach, which may be influenced by a number of factors including: (i) the particular nature of the conservation action (e.g., different national authorities may require or prefer a specific approach or may specify a maximum number of taxa that can be considered for conservation action), (ii) the number of taxa in the base list (e.g., if starting from a complete checklist of thousands of taxa related to crops in all the main use categories, the task of scoring all taxa may prohibit taking the parallel approach), and (iii) the availability of data (there may be significant gaps in the information required to score all taxa in a checklist across all criteria, and in such cases, the parallel approach would not be appropriate).

Whichever approach is chosen, the number of priority taxa resulting from the exercise should not unduly influence the process. Although it is important to acknowledge that conservation agencies are forced to direct limited resources for conservation action where they are most needed and thus may be alarmed if presented a list of 200 priority taxa as opposed to only 20, the rationale for maintaining a priority list, regardless of the number of taxa included, is twofold. First, systematic conservation planning methods using advanced geographic information system (GIS) techniques aim to maximize CWR diversity conservation through action targeted at the minimum number of populations and sites. Second, if necessary, a priority taxon list can itself be prioritized to identify the highest priority taxa in most urgent need of conservation attention, while the remaining taxa may be considered for active conservation intervention at a later date.

In addition to the sources cited in this paper, there are a number of published case studies detailing the national CWR conservation strategy planning process, which practitioners can consult to help inform the choice of prioritization approach. A compilation is published by Bioversity International at www.cropwildrelatives.org/inventories-and-strategies/. Importantly, to ensure the uptake of conservation recommendations arising from the national CWR conservation strategy planning process, the relevant national stakeholders, including the national authorities that are responsible for wild plant species conservation and conservation of PGRFA, should be involved in the prioritization process. One option is through the organization of workshops in which the practitioner undertaking the prioritization can explain the options to national stakeholders and seek their agreement on the approach to be taken, after which the procedure and resulting list of priority taxa can be validated, either through a subsequent workshop (a process which was undergone in Jordan; Magos Brehm et al., 2016) or through correspondence.

CWR Prioritization at Regional Level

The rationale for a regional approach to CWR conservation (and thus a regional approach to CWR prioritization) lies first in the recognition of the importance of a region's PGR and their common value to the region as a whole, with each region tending to be characterized by having CWR related to different crops [e.g., sunflower, *Helianthus annuus* L. in North America, maize in Central America, potato in South America, sugarbeet in Europe, cowpea, *Vigna unguiculata* (L.) Walp. in East Africa, grape, *Vitis vinifera* L. in West Asia, and rice in East Asia). Second, because such resources are not restricted to national borders, their conservation is the shared responsibility of the countries in which the populations occur. Third, only taking a national approach to CWR conservation does not systematically address the conservation of CWR diversity throughout a region due to differing national priorities and the pace at which nations are able to develop national CWR conservation strategies, with some countries already being advanced in the process and others having not yet started. In addition, the identification of regionally important populations or sites of CWR diversity may lend weight to the urgency of those countries in which they occur to enact conservation, recognizing the regional (and potentially global) importance of the resources. Further, the existence of regional administrative bodies adds to the justification for taking a regional approach to PGR conservation because, in some cases, associated legislative instruments such as regional biodiversity conservation action plans are already in place and may act as frameworks and provide the impetus for CWR conservation action in the region.

An approach involving the integration of national and regional CWR conservation strategies is encapsulated by Maxted et al. (2015) and, as mentioned above, is being taken forward in Europe under the auspices of the regional network for PGR conservation, the ECPGR. Taking a lead from the European integrated initiative, a similar approach is currently in the planning phase in the South African Development Community (SADC) region in the context of the SADC Crop Wild Relatives Project (www.cropwildrelatives.org/sadc-cwr-project). In both regions, a similar approach to the prioritization of the region's CWR diversity has been undertaken following the method illustrated in Fig. 1, but with some variation in the process due to the comparative availability of data to apply the prioritization criteria and sensitivity related to the mandate of the bodies responsible for PGRFA conservation in the region.

In Europe, Kell et al. (2014) selected a preliminary list of high priority CWR species for regional conservation planning by: (i) identifying priority human food crops (or crop groups, such as brassicas, alliums, and stonefruits; Kell et al., 2015b) based on their production value and contribution to dietary energy in the region (Criterion 1); (ii) extracting taxa from the regional CWR checklist (Kell et al., 2005) in the genera of the priority crop genepools; and (iii) selecting taxa from the list created under step ii that either have the greatest use potential for crop improvement based on Vincent et al. (2013) (Criterion 2) or are threatened or Near Threatened (Criterion 3). In this case, the application of Criterion 3, "relative threat status," was possible because most species related to the highest priority crops or crop groups identified for the region had already been Red Listed at the regional level (Bilz et al., 2011; www.iucnredlist.org/initiatives/europe).

A similar approach was taken to prioritize CWR taxa in the SADC region (Kell et al., 2015a), although the process differed because there is no regional floristic checklist available to create a regional CWR checklist and no regional Red List. Further, in addition to using FAOSTAT crop production value and contribution to dietary energy statistics (www.fao.org/faostat/) to identify priority crops or crop groups in the region, there was strong justification to include taxa related to additional crops included in the base collection of the regional genebank managed by the SADC Plant Genetic Resources Centre (SPGRC) due to their clear importance for nutrition and food security in the region. Thus, the application of Criterion 1 involved the compilation of priority crops or crop groups from two sources: FAOSTAT and the SPGRC base collection database. A partial CWR checklist for the region was created by identifying CWR in the genepools of the priority crops or crop groups using taxon and geographic (countries of occurrence) data from GRIN Taxonomy for Plants and Vincent et al. (2013). From this list, a subset of high priority CWR taxa were selected on the basis of their use potential (Criterion 2) using the same sources. For the additional priority crops included from the SPGRC base collection for which GP classifications were not available, online and literature searches were conducted to ascertain which taxa related to those crops can be considered of greatest use potential, in some cases including wild populations of the crop species themselves. Criterion 3 was not applied because, as already noted, there is no regional Red List available for the SADC region. The application of a proxy for relative threat status based on relative distribution was not considered to be of value because, as previously noted, the aim of CWR conservation is to maximize conservation of infraspecific diversity—thus, populations of taxa that are known to occur both inside and outside the region should be actively conserved across their range. Thus, in the SADC region, the list of high priority CWR taxa is based only on the application of Criteria 1 and 2.

An important consideration when prioritizing CWR taxa at either the national or regional level is to not only consider the value of CWR diversity to a country or region, but also its value to other countries and regions.

For example, in Europe, there is significant native wild relative diversity of crops of particular global importance in terms of their direct contribution to food security in other regions. These include mustard seed [*Brassica nigra* (L.) K. Koch and *Sinapis alba* L.], rapeseed (*B. napus* L.), wheat, sugarbeet, some roots and tubers, and other vegetable crops. In the SADC region, crops of particular global importance that have CWR in the region include millets, rice, and sorghum, *Sorghum bicolor* (L.) Moench. Likewise, both regions depend on PGR from other regions, including potato, sunflower seed, soybean, maize, and rice in Europe, and beans (*Phaseolus* L. spp.), cassava, maize, soybean, and wheat in the SADC region. Taking a national example, in an analysis of priority CWR taxa in China, Kell et al. (2015b) identified 20 crops (or crop groups) of global importance due to their contribution to food security, based on their value as major sources of plant-derived dietary energy supply in one or more subregions of the world. The authors highlighted that, out of 11 of these crops or crop groups that have native wild relatives in China, eight are important to the nation due to their production and/or dietary energy value, while the remaining three are important for their dietary energy value in other regions (olive, *Olea europaea* L. in Europe and sorghum and yam, *Dioscorea alata* L. in Africa). These examples illustrate the interdependence of countries and regions on PGR and serve to highlight the potential regional and/or global value of CWR diversity, providing strong justification for prioritizing the conservation of CWR taxa that may not be valuable as potential gene sources for the improvement of socioeconomically important crops in the country or region developing the CWR conservation strategy, but which may be of value in other parts of the world.

Prioritizing CWR Taxa at Global Level

The rationale for a global approach to CWR prioritization is clear. Crop wild relative populations contain valuable traits for adapting crops to meet the needs of the increasing human population under the pressure of a rapidly changing climate. They are a reservoir of genetic diversity adapted to a wide range of environmental conditions that plant breeders are increasingly likely to need to create new varieties able to cope under the duress of exceptional and uncertain abiotic conditions, as well as for adaptation to future biotic stresses (Zamir, 2001; Vollbrecht and Sigmon, 2005; FAO, 2008, 2010, 2012; Ford-Lloyd et al., 2011; Guarino and Lobell, 2011; Kell et al., 2012b; Maxted et al., 2012). The production of new crop varieties has been highlighted by the Intergovernmental Panel on Climate Change (IPCC) as a critical intervention to mitigate the impacts of climate change (e.g., see Easterling et al., 2007; Tao and Zhang, 2010; Challinor et al., 2014; Noble et al., 2014)—therefore, to underpin global food security, CWR require systematic conservation action (Maxted et al., 2008, 2012, 2015, 2016; Maxted and Kell, 2009; McCouch et al., 2013; Vincent et al., 2013; Dempewolf et al., 2014).

In a study commissioned by the FAO Commission on Genetic Resources for Food and Agriculture (CGRFA), Maxted and Kell (2009) initiated research on CWR of 14 globally important food crops reported by FAO (1997) to supply >5% of the plant-derived energy intake in one or more subregions of the world, as a starting point for the establishment of a global network of CWR genetic reserves. For each crop, the global, regional, and local importance was elaborated, genepool classifications defined, distribution and center of diversity outlined, known or potential uses of their CWR reviewed, and recommendations put forward for the conservation of the highest priority species based on their utilization potential and relative threat status.

Following the work of Maxted and Kell (2009), Vincent et al. (2013) produced the Harlan and de Wet CWR Inventory (www.cwrdiversity.org/checklist), which contains information on the GP, TG, or Provisional GP concepts and known actual or potential use of species related to 173 food crops. Global priority crops for inclusion in the Inventory were identified as those listed in Annex I of the International Treaty on PGRFA, combined with the major and minor food crops listed by Groombridge and Jenkins (2002). In addition, after identifying the genera encompassing the genepools of these crops, because many of the genera contain multiple crop species, Vincent et al. (2013) consulted Manfeld's World Database of Agricultural and Horticultural Crops (Hanelt and IPK, 2001) to ensure that all crop species within these genera were included. Following the methodology of Maxted and Kell (2009), the priority wild relatives of the 173 food crops were identified as those in GPs (or Provisional GPs) 1b and 2 or TGs 1b, 2, and 3 (CWR within the same subgenus as the crop) and more distantly related taxa that are documented to have been previously used for crop improvement or that have shown promise for crop improvement, resulting in a global priority list of CWR comprising 1392 species (Vincent et al., 2013).

The prioritization methodology of Vincent et al. (2013) served to identify priority CWR of a wide range of crops that are undoubtedly important for nutrition and food security in many parts of the world. However, in identifying native CWR diversity in China of global importance, Kell et al. (2015b) argued that the inclusion of wild relatives of crops listed in Annex I of the International Treaty on PGRFA would not only inflate the number of taxa in the list of priority CWR of China beyond a reasonable number to attract sufficient resources for their conservation, but that, because China is not signatory to the International Treaty on PGRFA, basing the selection of priority CWR on this legal instrument was not appropriate and would be difficult to justify to the relevant national authorities. Taking the lead from FAO

(1997), the authors proposed a shortlist of 20 crops (or crop groups, such as millets) "of particular global importance in terms of their direct contribution to food security on the premise that they provide 3% or more of plant-derived dietary energy supply in one or more subregions" (Kell et al., 2015b, p. 147). A counter argument to prioritizing this subset of food crops is that it is limited only to those crops that contribute the most calories to human diets and does not take account of the nutritional needs of the human population, particularly bearing in mind that six are oil crops (cottonseed, *Gossypium hirsutum* L., mustard, palm, *Elaeis guineensis* Jacq., olive, rape, *Brassica napus* L., and sunflower), which have limited nutritional value. However, global statistics on the nutritional value of food crops are not currently available to prioritize them objectively for their nutritional qualities, and as the authors note, "regardless of their place in our diet and of their contribution to health and nutrition, they are clearly crops of modern global socioeconomic importance" (Kell et al., 2015b, p. 147). In addition, taking a global holistic approach to CWR conservation by integrating national and regional strategies with a global strategy, CWR prioritization at the national and regional levels will most likely capture wild relatives of a broad range of crops, including minor crops of particular nutritional value at the national and subregional levels. In conclusion, while the Harlan and de Wet CWR Inventory is a highly valuable and comprehensive source of information on global food CWR diversity, its universal use in establishing conservation priorities for CWR taxa should not be taken for granted. Rather, practitioners should use it selectively as a resource for CWR prioritization based on clearly defined objective criteria.

CONCLUSIONS

To effectively conserve CWR diversity for its actual and potential use, there is an urgent need for comprehensive and systematic CWR conservation strategies to be implemented worldwide, integrating national, regional, and global approaches to maximize conservation of the full range of important CWR genetic resources. Taxon prioritization is a fundamental step in conservation planning, and with the vast number of CWR taxa that exist, a harmonized, logical, and pragmatic means of assigning priority status is needed that can be applied nationally, regionally, and globally as part of a holistic global CWR conservation strategy. In this paper, we have presented an approach based on three main criteria and reviewed their practical application at the national, regional, and global scales to highlight the strengths and commonalities of this approach, as well as to untangle some common misconceptions when applying CWR prioritization criteria. Based on experience in and knowledge of CWR prioritization practice over recent years, and particularly on the results of the analysis presented in Table 1, we reiterate the three criteria here with greater clarity regarding the potential subcriteria that are frequently used in the prioritization process to provide clearer guidance on their application in the future (Table 2). While acknowledging that the precise method chosen depends on several factors and that there is no one definitive way of undertaking CWR prioritization, we recommend that practitioners consider the approach presented in Fig. 1. It is logical and relatively simple to apply, both at the national and regional levels, and reduces the potential for introducing unintentional bias in the selection of priority CWR taxa for conservation action, particularly towards relative threat status over the potential value of taxa for the improvement of socioeconomically valuable crops.

Conflict of Interest

We, the authors, declare that we have no conflicts of interest.

Table 2. The three main crop wild relative prioritization criteria defined and associated subcriteria that have been applied by different countries.

Main criterion	Associated subcriteria
1 The socioeconomic value of crops	1. Stakeholder priorities (e.g., plant breeders and researchers) 2. Crops listed in Annex I of the International Treaty on Plant Genetic Resources for Food and Agriculture 3. Multiple or combined value
2 The potential value of the wild relatives of socioeconomically valuable crops for variety improvement	1. Stakeholder priorities (e.g., plant breeders and researchers) 2. Multiple or combined value
3 The threat status of the wild relatives of socioeconomically valuable crops	1. Relative distribution 2. Endemic status (national and regional) 3. Geographical or regional responsibility for certain taxa with restricted worldwide distribution 4. Rarity of the habitat in which the species grow 5. Relative abundance 6. Status in surrounding countries 7. Degree of genetic erosion 8. Species listed in the annexes of the EU Habitats Directive 9. National protection status 10. Expected effects of climate change on distribution

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CHAPTER 7

DISCUSSION AND CONCLUSION

7.1 Synopsis of research aim, objectives and outputs

With the aim of developing methods to establish a baseline for CWR conservation action and ultimately for their utilization for crop improvement, and as part of a systematic approach to CWR conservation planning, the objectives of this research were to: i) develop a systematic methodology for creating a CWR checklist; ii) evaluate the threat status of CWR; iii) elaborate methods for prioritizing CWR taxa for conservation action at national and regional levels; and iv) propose a logical, pragmatic and generic approach to assigning priority status to CWR taxa. A systematic and replicable method of creating a CWR checklist was developed and illustrated with a case study for the Euro-Mediterranean region (Chapter 2 – Kell *et al*., 2018) and for China (Chapter 4 – Kell *et al*., 2015); Red List assessments of a large sample of CWR were undertaken and the data analysed to understand their threat status (Chapter 3 – Kell *et al*., 2012a); methods of prioritizing CWR taxa for conservation action at national and regional levels were elaborated with case studies on China (Chapter 4 – Kell *et al*., 2015) and Europe (Chapter 5 – Kell *et al*., 2016); and a generic approach to prioritizing CWR taxa that can be applied at national or regional level was proposed (Chapter 6 – Kell *et al*., 2017).

7.2 Appraisal of methods and outcomes

7.2.1 Creating a crop wild relative checklist

The methodology for creating a CWR checklist presented in Chapter 2 (Kell *et al*., 2018) is systematic and replicable in that it is based on a logical process of matching the names of taxa (at genus level) that are found in a country or region (derived from a published Flora or other sources) with a list of crop genus names—the latter dataset a resource that will be freely available for use by practitioners wishing to adopt the same approach (Kell *et al*., 2019a). Clearly, the availability of floristic data in electronic format greatly facilitates this process, particularly because of the complications of dealing with issues of synonymy (see Chapter 2, sections 2.2.6 and 2.4.2.3). Nonetheless, manual matching is possible—for example, in Benin, Idohou *et al*. (2013) undertook a process of manual matching between a list of genera containing crops cultivated in the country and genera in relevant published Floras, and extracted the taxa in the matching genera, since national floristic data are not available in electronic format in that country.

The methodology presented in this thesis results in a fully comprehensive checklist of wild relatives of the area concerned. This arises from the use of a list of crop genus names that was generated from a source that is inclusive of a wide range of cultivated species, combined with the application of a broad definition of a CWR. Thus, the checklist not only includes taxa closely related to crops (i.e., those in the primary gene pool—the same species as the crop), but also those that are more distantly related (i.e., those in the secondary or tertiary gene pools). While this method inevitably leads to the inclusion of a high percentage of the flora, it provides a clear understanding of the full range of crop and CWR diversity in the area and a solid basis for CWR conservation planning (see Chapter 2, section 2.4.1).

As discussed in Chapter 2, section 2.4.2.3, an alternative approach to create a CWR checklist could be to start the process with a list of cultivated taxa, identify the accepted taxon names of those taxa according to the floristic treatment being used as the basis of the checklist, and extract all taxa within the same genera. This would reduce the number of taxa in the checklist by undertaking the 'secondary level match' at genus level as proposed in this chapter, and could be useful to *a priori* eliminate species cultivated on a very minor scale. To make such an approach available to any practitioner creating a CWR checklist, a) a comprehensive list of cultivated taxa and their synonyms would have to be generated and published as an open source dataset, and b) an easily replicable methodology for generating the checklist would have to be developed and promoted.

Other approaches could be to only include closely related wild taxa and/or use a reduced list of *a priori* prioritized crop genera (e.g., Ng'uni and Munkombwe, 2017, for Zambia). The author does not advocate the creation of a CWR checklist that only includes close wild relatives because: a) many taxa in related species (and even genera) have been utilized for crop improvement (e.g., see Hajjar and Hodgkin, 2007; Maxted and Kell, 2009; Maxted *et al*., 2012); b) it is widely agreed that plant breeders are likely to need to search for traits in the wider gene pool to produce new crop varieties tolerant of altered abiotic conditions and resistant to new strains of pests and diseases (e.g., see McCouch, 2004; Feuillet *et al*., 2008; Maxted and Kell, 2009; Olesen *et al*., 2011; Rötter *et al*., 2011; Maxted *et al*., 2012; 2014; Ventrella *et al*., 2012;

McCouch *et al*., 2013; Challinor, *et al*. 2014; Kovats *et al*., 2014; Noble *et al*., 2014; Ebert and Schafleitner, 2015; Ortiz, 2015; Porceddu and Damania, 2015); and c) options for transferring genes from these sources are becoming increasingly widely available (e.g., see Zamir, 2001; Hajjar and Hodgkin, 2007; Dwivedi *et al*., 2008; Feuillet *et al*., 2008; Sonnante and Pignone, 2008; Ford-Lloyd *et al*., 2011; McCouch *et al*., 2013; Walley and Moore, 2015; Kell *et al*., 2017 – Chapter 6) and may become progressively affordable. The creation of CWR checklists based on a reduced list of crop genera (for example, those containing human food crops) may be the preferred choice for some countries, and certainly when floristic data are not available in electronic format, this approach has obvious practical advantages. A major limitation of using a reduced list of crop genera to create a partial CWR checklist (e.g., only including genera containing human food crops) is that crops with other uses that may be important—for example, for primarily economic reasons—may be overlooked in conservation planning. While it is fair to say that human food crops, and perhaps also animal feed crops are most critical for human society, crops cultivated for industrial, environmental, medicinal and recreational purposes are also important for people’s lives, both in terms of their economic and use values.

Further, if the basis of a CWR checklist is a list of genera selected on the basis that they contain human food crops, questions then arise regarding how to define that list of crop genera. For example, should all food crops cultivated in the country be included, or all those cultivated in the region, or those cultivated globally? Should only crops of major importance for food and economic security be included, or also those of lesser importance? Because of the inter-dependency of countries and regions on plant genetic resources, the author of this thesis promotes the use of a global list in the analysis to allow the identification of CWR diversity that may be important for food, nutrition and economic security outside the target country or region (as advocated in Chapters 4, 5 and 6). And while the use of CWR is most likely to be for the improvement of crops of highest value for food and economic security in the short term (Kell *et al*., 2017 – Chapter 6), in the longer term, the production of new varieties of crops of lesser socio-economic value (either due to their relatively small contribution to dietary energy and nutrition in the human diet or because they are limited to use at a local level), may become more prevalent—especially because of the need to diversify crops both in terms of intra- and inter-specific diversity (Kovats *et al*., 2014), and, as already noted, because of the increasing availability of gene transfer techniques which are likely to become more cost-effective over time. Therefore, an inclusive approach that includes wild relatives of crops of lesser socio-economic value provides a basis for future conservation planning, action and use of those species.

Furthermore, as noted in Chapter 2 (section 2.2.2), while a 'monographic' approach to planning CWR conservation (i.e., with a focus on selected crop gene pools only) can be undertaken, a floristic approach is more likely to optimize the use of financial and human resources because when planning CWR conservation actions for an entire national or regional flora, diversity analyses can be employed to identify locations containing multiple taxa, as well as optimize the conservation of infra-specific diversity (Kell *et al*., 2012b – Annex 1).

7.2.2 The crop wild relative Red List assessment process

The methodology for undertaking Red List assessments using the IUCN Red List Categories and Criteria (IUCN, 2001) is the result of many years of development by conservation practitioners. The system is widely applied across different taxonomic groups (plants, animals and fungi) to assess the extinction risk of taxa—mainly species, but also sometimes subspecies and varieties, and rarely, subpopulations. Assessments may be undertaken either at global or regional level—the latter applying to any defined geographical region, including a country.

Chapter 3 (Kell *et al*., 2012a) presents the procedure and results of undertaking Red List assessments of 591 wild relative species native to Europe in the gene pools of 25 human and animal food crops/crop groups[28] selected on the basis of their relative economic value and inclusion in Annex I of the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) (FAO, 2001). This work was undertaken to generate knowledge of the threat status of CWR in Europe to inform conservation planning in the region and was not only the first concerted effort to assess the Red List status of CWR, but also the first attempt by the lead author to develop a pragmatic method of taxon prioritization on the basis of the relative socio-economic importance of crops. This prioritization approach was later extended to include consideration of the use potential and threat status of CWR taxa and elaborated in case studies at national level in China (Chapter 4 – Kell *et al*., 2015) and at regional level in Europe (Chapter 5 – Kell *et al*., 2016).

[28] Crop groups are either i) genera containing multiple crops (e.g. onion, leek, garlic, etc. in the genus *Allium*); ii) crop complexes such as the brassica complex, which contains multiple crops within multiple genera; or iii) crops grouped according to their category of use (e.g. legume forages), as listed in Annex I of the ITPGRFA.

Undertaking Red List assessments of a large number of taxa in a range of crop gene pools is highly resource intensive as data of differing types and from different sources need to be amassed for individual taxa. As elaborated in Chapter 3, there are practical and logistical challenges in obtaining these data which have to be overcome but the benefits of accumulating them are substantial. Not only do the results of the Red List assessments provide a picture of the threat status of CWR to aid conservation planning, but the vast amount of data collated and documented has served to exponentially increase the knowledge base on CWR (including their distribution, habitats and conservation status). Analyses of the data have also revealed the factors threatening CWR populations, population trends, and helped to identify research and conservation needs. Critically, this work highlighted the significant gaps in knowledge of the status of CWR populations (distribution, size, trends and threats) and served to emphasize that a major limitation of the Red List assessment process is the lack of consideration of genetic diversity within and between subpopulations.

7.2.3 Prioritizing crop wild relative taxa for conservation action

In Chapters 4, 5 and 6 (Kell *et al*., 2015, 2016, 2017), three main criteria are proposed for identifying CWR taxa that are priorities for conservation action: "i) the socio-economic value of crops; ii) the potential value of the wild relatives of socio-economically valuable crops for variety improvement; and iii) the threat status of the wild relatives of socio-economically valuable crops" (Kell *et al*., 2017, p. 1043). These criteria were developed from work first undertaken by Ford-Lloyd *et al*. (2008) (criteria 1 and 3), Maxted *et al*. (2006, 2012) (criterion 2), and Maxted and Kell (2009) (criteria 2 and 3). Criterion 1, the socio-economic value of crops is of fundamental importance for planning the conservation of CWR diversity. The reason for conserving these genetic resources is for their potential use to develop improved crop varieties—it is therefore logical that taxa related to crops of relatively high socio-economic importance are apportioned higher priority for conservation action in the immediate term. This is not only because they have a greater indirect socio-economic value as gene donors, but also because the use of exotic material from CWR populations is most likely (at least in the short term) to be in the improvement of crops of high socio-economic value, since the costs of introducing traits from CWR are likely to be offset by the value of the new varieties produced (Kell *et al*., 2017).

This latter point raises the question of where wild relatives of crops of lesser socio-economic value fit in to the prioritization process. As noted in section 7.2.1, in the longer term, the production of new varieties of crops of lesser socio-economic value may become more prevalent in the future—therefore, when planning CWR conservation at national or regional scale, consideration needs to be given to which crops to include when applying criterion 1, the socio-economic value of crops. Kell *et al*. (2015, 2016) advocated the identification of a limited number of high priority crops based on their economic and food security value, combined with criterion 2 (the potential value of the wild relatives of those crops for variety improvement) and 3 (the threat status of the wild relatives of those crops) applied in parallel. This approach—which is elaborated in Chapter 6 (Kell *et al*., 2017)—promotes conservation action for taxa in Gene Pools 1b and 2 or Taxon Groups 1, 2 and 3 of the highest priority crops, regardless of their threat status, as well as for threatened (i.e., Critically Endangered, Endangered and Vulnerable) and Near Threatened taxa of those crops, regardless of their position in the crop gene pool. It is pragmatic and justifiable and lends greater weight to the need for resources to be made available for the conservation of these highest priority taxa—however, it side-lines the wild relatives of crops of lesser socio-economic value. An option for taking a more inclusive approach, while still justifiable to policy-makers is currently being explored by the author (Kell *et al*., 2019b) in a revision of the list of priority CWR of Europe presented in Chapter 5 (Kell *et al*., 2016). In the revised analysis, the options of including wild relatives of all crops/crop groups for which production value data for the region are available and the inclusion of fodder and forage species are being explored. Another option to consider would be the inclusion of threatened or Near Threatened wild relative taxa of a wider range of crops in a priority CWR list, thus ensuring that those taxa are afforded conservation effort for their option value, in addition to taxa related to the highest priority crops. However, this is dependent on the availability of a Red List of all known taxa in the flora of the area under concern. At national level, these data may often be available, as they are for example in China (MEP and CAS, 2013). However, at regional level this is less likely to be the case since a consolidated Red List of the flora of all countries in the region would have to be in existence or data in national floristic Red Lists easily accessible for inclusion in the analysis.

Consultations with the plant breeding community have been carried out by some authors when developing a national inventory of priority CWR taxa (e.g., Phillips *et al*., 2014 for Cyprus). This action was supported by Kell *et al*. (2017) (Chapter 6), although with the caveats that it is improbable that all relevant stakeholders can practically be consulted and that their priorities may not take account of the potential socio-economic value of CWR in other countries and regions. Added to this, such a consultation may significantly bias taxon prioritization if applied at species level because selection at that taxonomic level is necessarily based on prior knowledge of the potential value of the taxon and may result in taxa with as yet unknown value for crop improvement being overlooked in the conservation planning process. Furthermore, the traits that plant breeders are interested in now or anticipate needing in the short to medium term may not be the ones needed in the longer term, since no-one can reliably predict the traits that may be required in the future. Nonetheless, as long as stakeholder interests are not given precedence over other prioritization criteria, involving the user community in the conservation planning process may be critical to gain support for and sustain conservation actions.

7.3 Recommendations for future work in the research area

7.3.1 The CWR Catalogue for Europe and the Mediterranean

In Chapter 2 (Kell *et al.*, 2018), the lead author considered and explored two areas for enhancement of the CWR Catalogue for Europe and the Mediterranean: a) the identification of crop–CWR relationships, and b) the addition of use categories for the included taxa. In both cases, to add these elements so that they are integral to the database presents technical challenges and would be in part duplicating effort. The author therefore recommends that options are explored for making the CWR Catalogue available as a searchable online database and providing links from the included taxa to GRIN Taxonomy for Plants, as well as to other relevant online databases such as Mansfeld's World Database of Agricultural and Horticultural

Crops (Hanelt and IPK, 2001; http://mansfeld.ipk-gatersleben.de) and the IUCN Red List of Threatened Species[29]. Discussions among the actors involved in managing and publishing these and other major datasets (e.g., GENESYS for gene bank accession data[30], and GBIF, the Global Biodiversity Information Facility for population occurrence data[31]) could be initiated through appropriate channels such as the Wild Species Conservation in Genetic Reserves Working Group of the European Cooperative Programme for Plant Genetic Resources (ECPGR)[32] and Crop Wild Relative Specialist Group (CWRSG) of the IUCN Species Survival Commission (SSC)[33]. In the shorter term, the author anticipates publication of the CWR Catalogue version 4.0 via the Dataverse Project[34] (see Chapter 2, section 2.4.1) in association with the paper describing how the Catalogue was created, what it contains and how it can be used (Chapter 2 – Kell *et al*., 2018). A database containing lists of crops and crop genera that will be freely available online and can be used to aid the production and prioritization of CWR checklists is also under preparation (Kell *et al*., 2019a).

7.3.2 Crop wild relative Red List assessments

As highlighted in Chapter 3 (Kell *et al*., 2012a) and in the current chapter (section 7.2.2), there are significant gaps in knowledge of the status of CWR populations (distribution, size, trends and threats), which not only means that a substantial proportion of species are assessed as Data

[29] www.iucnredlist.org/

[30] www.genesys-pgr.org/

[31] www.gbif.org/

[32] www.ecpgr.cgiar.org/working-groups/wild-species-conservation/

[33] www.cwrsg.org/

[34] https://dataverse.org/

Deficient, but also that there is a fundamental lack of knowledge needed to inform conservation planning of CWR taxa, both *in situ* and *ex situ*. It is therefore clear that there is much work to be done to fill these knowledge gaps. As recommended by Kell *et al*. (2012a) (Chapter 3), it will be important to direct resources to the assessment of those species assessed as Data Deficient. Encouragingly, under the auspices of the CWRSG, efforts are underway to assess the global Red List status of CWR, although resources for this work are limited and the focus is necessarily on the highest priority crop gene pools for worldwide food and economic security. Another recommendation of Kell *et al*. (2012a) (Chapter 3) was to encourage the publication of Red List assessments of endemic CWR species already included in national Red Lists in the IUCN Red List of Threatened Species. A minimal amount of work would be required to update these assessments and they would serve to increase the number of CWR in the global Red List, raise the profile of CWR as critical resources for food and economic security, and provide an additional vehicle to attract resources for their conservation.

A further suggestion of Kell *et al*. (2012a) was the development of an additional means of Red List assessment that takes into account intra-specific genetic diversity, either as an amendment to the current assessment process or to extend and complement the system. As far as the author of this thesis is aware, this proposal has not yet been taken forward, although there has been some informal discussion among interested parties about how such a process could be developed and implemented. In addition, the IUCN Red List Categories and Criteria do not take into account the potentially negative impacts of climate change on populations of wild species (Maxted *et al*., 2013a). During the process of undertaking Red List assessments for European

CWR (see Kell *et al*., 2012a – Chapter 3), climate change was rarely recorded as a threat because its potential impacts on the majority of these species is unknown. Climate change was only recorded as a potential threat in a limited number of cases where populations of a species are known to occur exclusively in a habitat that is likely to be affected (e.g., a high altitude mountain habitat). The potential impact of threatening factors induced by the effects of climate change on European (and largely also for non-European) CWR is therefore unknown.

We need to know to what extent climate change could affect these socio-economically important species. What are the threatening factors associated with climate change that might have an influence on CWR populations and what species' characteristics might cause CWR populations to be more or less susceptible to these threats? How will knowledge of these potential impacts affect conservation planning, both *in situ* and *ex situ*? With the aim of understanding the extent to which climate change could affect these species, a study has been initiated by the author of this thesis to assess the climate change vulnerability of European CWR which, in addition to increasing the knowledge base for planning CWR conservation, may also inform potential future refinement of the IUCN Red List Categories and Criteria (IUCN, 2001) to increase their value as a conservation planning tool.

7.3.3 Crop wild relative prioritization

Methods of prioritizing CWR for conservation action inevitably vary according to the priorities of the country or region in terms of food and economic security, the crop genetic diversity in the area, the priorities of the agencies involved in their conservation, the preferences of the practitioner or committee undertaking the work, and on data availability. Time will tell whether the review of the criteria and methods used by different authors and proposal for a harmonized, logical, and pragmatic method advocated by Kell *et al*. (2017) (Chapter 6) will be viewed positively by the PGRFA conservation community, so for the time being, the author does not intend any further work to amend or enhance the general prioritization methodology proposed. However, as already noted in section 7.2.3, a method that takes a more inclusive approach to the selection of priority CWR taxa for conservation planning at regional scale in Europe is under preparation in which the lead author anticipates including wild relatives of all crops/crop groups for which production value data for the region are available, as well as fodder and forage species (Kell *et al*., 2019b). The main reasons for this are to: a) increase the likelihood of including all or at least a large percentage of countries in Europe in the share of responsibility for conserving regionally important CWR populations; b) recognize the importance of fodder and forage crops in the region, particularly in countries where they are prominent in the agricultural industry; and c) develop a conservation strategy that is pragmatic and clearly justified in terms of the method of taxon prioritization while expanding its scope to be inclusive of a wider range of taxa, thus increasing options for crop improvement in the immediate and longer term future.

7.4 Concluding remarks

The methods for cataloguing and prioritizing CWR taxa developed and presented in this thesis, as well as the associated results and products, contribute to the process of planning conservation actions for CWR diversity and subsequently to the use of that diversity in the production of improved crop varieties. Without these two steps, conservation activities are necessarily *ad hoc* and lack concrete foundations. CWR checklists are essential bases for conservation planning and taxon prioritization is fundamental for imparting strong justification for the conservation of these vital genetic resources, as well as to ensure that financial resources for conserving CWR diversity are appropriately directed. The next step in the conservation planning process is to undertake diversity and gap analyses for priority taxa to identify target populations and sites for conservation action (e.g., see Maxted and Kell, 2009; Maxted *et al*., 2013b; 2015; Kell *et al*., 2012b, 2016 – Annex 1 and Chapter 5; Magos Brehm *et al*., 2017). Each stage in the process builds on the preceding step—therefore, the results of diversity and gap analyses clearly depend on the availability of a carefully prepared CWR checklist and robust method of taxon prioritization.

The knowledge generated through the production of the CWR Catalogue for Europe and the Mediterranean (Chapter 2 – Kell *et al*., 2018) and the European Red List of CWR (Chapter 3 – Kell *et al*., 2012a) has enabled the identification of priority CWR taxa for conservation planning in the region (Chapter 5 – Kell *et al*., 2016; Kell *et al*., 2019b). Subsequent to the production of an expanded list of target CWR taxa, diversity and gap analyses will be undertaken to identify populations and sites for conservation action. A similar process of producing a CWR checklist and identifying priority taxa was undertaken at national level for China (Chapter 4 – Kell *et al*., 2015), although with the advantage that a comprehensive Red List of the flora of that country (MEP and CAS, 2013) was already close to completion and available for use in the analysis. There are indications that some concerted actions to take forward CWR conservation in China are underway involving the Ministry of Agriculture of China and a recently established National Forestry and Grassland Administration (H. Qin, Institute of Botany, Chinese Academy of Sciences, Beijing, pers. comm., January 2018).

As expounded in Chapter 1, significant advances have been made since the beginning of the 21st century in building a knowledge base on CWR diversity and the critical indirect use value of these wild plant species for food, nutrition and economic security is now more firmly acknowledged throughout the world, including through a number of international policies and legislative instruments. Furthermore, a strategic approach for conserving CWR diversity has been developed that is based on a range of widely tested and commonly agreed scientific concepts and techniques (Maxted *et al*., 2015). While these are positive outcomes providing a springboard for future efforts to conserve and sustainably utilize CWR, on the other side of the coin, results of the numerable concerted efforts to increase knowledge of CWR diversity, conservation and use have drawn attention to the some worrying realities. Relatively little is known about CWR diversity within species (population and genetic diversity), a substantial proportion of CWR species and populations are threatened with extinction, they are under-conserved *ex situ* and almost exclusively not actively conserved *in situ*, and fundamentally, there is a lack of coordination between the government agencies responsible for their *in situ* and *ex situ* conservation. Further, while research on the use of CWR has been quite extensive for some crops (e.g., rice), in general, the material that is already in *ex situ* collections has not been systematically characterized across a broad range of crop gene pools, and for the accessions that do have promising traits, this information is not always available to potential users. In addition, there has been relatively little pre-breeding work carried out to help facilitate the use of CWR (i.e., the transfer of traits into transitional plant breeding materials that can be used by plant breeders to assist in the transfer of exotic germplasm to crops), partly because of a reduction in national funding for public breeding programmes (Bhatti *et al.*, 2015).

Fortunately, the major developments in the realm of CWR conservation planning during the past two decades has increased awareness within the plant genetic resources conservation and user communities, not only of the CWR diversity that exists but of the generally poor state of affairs regarding its conservation and utilization. Much work is now being done to redress this situation—particularly in terms of collecting wild relative material of globally important crops for *ex situ* conservation, characterization and pre-breeding, improving access to information on traits of interest to plant breeders, and in planning *in situ* conservation of priority CWR populations. It is critical now that the momentum that has built up during this recent period of concerted efforts in planning the conservation of CWR diversity, and in calling attention to its value for crop improvement, is maintained to ensure that this vital ecosystem service continues to be promoted and the option value of CWR diversity fully realized to advocate its long-term maintenance, both *ex situ* and *in situ*.

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ANNEX 1

IN SITU CONSERVATION OF CROP WILD RELATIVES: A STRATEGY FOR IDENTIFYING PRIORITY GENETIC RESERVE SITES

Shelagh Kell, Nigel Maxted, Lothar Frese and José Iriondo

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Declaration of co-author contributions

Shelagh Kell developed the methodology, largely based on work undertaken by Maxted and Kell (2009), and wrote the chapter narrative. Lothar Frese provided information for the beet case study and the content for the tables. Nigel Maxted, Lothar Frese and José Iriondo provided input to the draft chapter and had been involved in discussions relating to the content of the chapter during the EU AGRI GEN RES project, An Integrated European *In Situ* Management Work Plan:

Implementing Genetic Reserves and On Farm Concepts (AEGRO – http://aegro.julius-kuehn.de/aegro/).

The methodology presented in this book chapter is based on the methodology presented in the CWR *In Situ* Strategy Helpdesk (http://aegro.julius-kuehn.de/aegro/index.php?id=188) which was written and created by Shelagh Kell (see credits at http://aegro.julius-kuehn.de/aegro/index.php?id=95). Some of the narrative in this book chapter is the same or similar to narrative in those web pages.

Reference

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14 January 2018

Statements of co-authors

I, Nigel Maxted, of the University of Birmingham, UK, confirm that the above declaration of co-author contributions is true and accurate.

I, Lothar Frese, of the Julius Kühn-Institut, Germany, confirm that the above declaration of co-author contributions is true and accurate.

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2 *In Situ* Conservation of Crop Wild Relatives: A Strategy for Identifying Priority Genetic Reserve Sites

S.P. Kell, N. Maxted, L. Frese and J.M. Iriondo

2.1 Introduction

Crop wild relatives (CWR) are species closely related to crops and are defined by their potential ability to contribute beneficial traits for crop improvement (Maxted *et al.*, 2006). They have been used increasingly in plant breeding since the early 20th century and have provided vital genetic diversity for crop improvement – for example, to confer resistance to pests and diseases, improve tolerance to environmental conditions such as extreme temperatures, drought and flooding and to improve nutrition, flavour, colour, texture and handling qualities (Maxted and Kell, 2009). In monetary terms, CWR have contributed significantly to the agricultural and horticultural industries, and to the world economy (Maxted *et al.*, 2008a; Maxted and Kell, 2009).

Today, agricultural production is challenged by climate change. The International Panel on Climate Change (IPCC, 2007) estimates that by 2100, maize and wheat yields will be reduced by 40% at low latitudes, while in China, rice yields will decrease by up to 30% unless climate change mitigation is undertaken. Breeders will therefore have to provide varieties able to cope with the impacts of changing growing conditions. Due to the breadth of genetic diversity inherent in CWR populations, which are adapted to a wide range of environmental conditions, they are likely to be needed more than ever before to maintain the adaptability of crops. Thus, CWR are a critical component of plant genetic resources for food and agriculture (PGRFA) and are vital for future food security; however, despite their recognized value, they have historically received relatively little systematic conservation attention.

There are two primary techniques for CWR conservation: *in situ*, primarily in natural habitats managed as genetic reserves (GRs) (Box 2.1) and *ex situ* as seed in gene banks. Historically, CWR conservation has focused almost entirely on *ex situ* collection and storage, but it can be argued that *in situ* conservation is more appropriate because the genetic diversity inherent in and between wild CWR populations is constantly changing in response to their environment; therefore, CWR populations are a component of natural ecosystems that cannot effectively just be maintained *ex situ* (Maxted *et al.*, 2008a).

A number of recent initiatives have raised the profile of CWR and put them on the international conservation agenda. However, conservationists and policy makers are faced with the difficult challenge of how to conserve the large number of CWR species and the genetic diversity that they

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Box 2.1 The Genetic Reserve Concept

A genetic reserve is defined as 'the location, management and monitoring of genetic diversity in natural populations within defined areas designated for long-term conservation' (Maxted *et al.*, 1997). The concept combines *in situ* conservation with active management and a long-term approach. The rationale for this type of conservation is that it is: (i) applicable to all plant species; (ii) allows for continued evolution; and (iii) allows for multiple-taxon conservation. Moreover, it conserves the genetic diversity of the target taxon in a dynamic way, as well as its habitat and all existing biotic and abiotic interactions (including humans).

Several approaches to GR conservation can be identified, each with different aims and strategies, depending on the approach (see Maxted and Kell, 2009). For example, the aims for CWR GRs in Europe are to conserve genetic diversity in the widest range of priority CWR taxa at the European scale; therefore, the aim is to design a network of reserves that adequately and efficiently maintains the genetic diversity of the target taxa. When we talk about 'adequately' maintaining the genetic diversity of target taxa, we mean conserving a good representation of the genetic diversity of adaptive and agricultural value present in such taxa. Similarly, by 'efficiently' we mean to obtain this goal using the minimum number of GRs.

Coordination with *ex situ* holdings and crop databases is an important part of the genetic reserve concept. *Ex situ* seed banks can be a relevant component in the functioning of GRs as they provide a back-up of genetic diversity in case any catastrophe should occur. Furthermore, they facilitate information exchange, access for breeding and other research, and promote use.

contain. If a broad definition of a CWR is used (i.e. all the species in the same genus as a cultivated plant), there are more than 16,000 crop and CWR species in the territories of the EU Member States – 13,875 of these are native and at least 2665 are endemic (Kell *et al.*, 2008). CWR are under threat from habitat loss, agricultural intensification, over-collection, climate change and lack of conservation attention, yet only 9% of PGR accessions in European gene bank collections are CWR (Dias *et al.*, Chapter 33, this volume), while most wild populations *in situ* are not actively monitored and managed in or outside protected areas (PAs) (Maxted *et al.*, 2008b). There is therefore a real challenge to the nature conservation and PGRFA sectors to conserve these valuable resources.

The establishment of GRs for CWR is a priority in order to maintain a broad range of genetic diversity within and between populations; however, with a large number of species to conserve, a systematic approach to the identification of GR sites is needed to maximize resource use. This chapter provides a generic methodology that can be used to prioritize taxa on the basis of their potential use for crop improvement and relative threat status, gather the necessary data to undertake diversity and gap analysis for target taxa, and select the most appropriate CWR GR sites. It is built on those proposed by Maxted *et al.* (2008c), Maxted and Kell (2009) and Maxted *et al.* (in prep.), which address floristic and monographic approaches to CWR conservation (Box 2.2). Although it may be necessary to adjust parts of the methodology according to the specific biological, ecological and geographical attributes of individual crop complexes, it provides a generic framework for the conservation of any crop gene pool.

2.2 Methodology for Identifying CWR Genetic Reserve Sites for a Target Crop Gene Pool

In this section, a summary of the methodology for identifying CWR GR sites for a target crop gene pool is provided and illustrated with a case study for the gene pool of cultivated beets. For more detailed step by step guidance on implementing the methodology, including a list of data sources, the reader is referred to the 'CWR *In Situ* Strategy Helpdesk' (http://aegro.Jki.bund.de/aegro/index.PhP?id=188), which is provided as a

Box 2.2 Floristic and Monographic Approaches to CWR Conservation (Maxted *et al.*, 2011)

Floristic and monographic approaches relate to the breadth of coverage of the CWR conservation strategy. A floristic approach involves the development of a CWR conservation strategy for CWR diversity that occurs in a defined geographical area, which may be a sub-national area such as an administrative unit or protected area, a whole country, a supra-national region, or even the whole world. A monographic approach on the other hand is restricted to certain crop gene pools, but like the floristic approach may be carried out at any geographic scale.

The floristic approach is comprehensive because it attempts to encompass all CWR diversity that occurs within a geographical unit; however, while being comprehensive for the geographical unit, the full geographic range of an individual taxon may or may not be included, depending on whether it is endemic to that geographical unit. The monographic approach focuses on CWR diversity within target crop gene pools, which are usually identified on the basis of their perceived value for food security and/or economic stability. Both approaches will ultimately conclude with the systematic conservation of priority CWR diversity via a network of conservation sites and genetic reserves, with backup in *ex situ* collections.

Whether a floristic or monographic approach is taken is likely to depend on: (i) the quantity and quality of existing data; and (ii) the resources available to prepare the conservation strategy. The scope of the parent organization undertaking the conservation may also impact the approach; for example, an international cereal research institute is likely to focus monographically on cereal crops, while a national biodiversity institute is likely to adopt a more floristic approach. It is worth noting that if the goal is to maximize CWR diversity, it is likely that both approaches need to be combined.

guide and information facility for national programmes, research institutes, NGOs, PA managers, or individuals involved in the development of a CWR *in situ* conservation strategy.

There are four basic steps in the *in situ* methodology: (i) taxon delineation; (ii) selection of target taxa; (iii) diversity analysis; and (iv) selection of target sites. The end point of the methodology is the identification of 'ideal' CWR GR sites. The political and legal steps that need to be taken beyond this point to establish the GRs are not part of the methodology. The next step beyond the methodology for identification of GRs is to make recommendations for site and population management (see Maxted *et al*., 2008d).

2.2.1 Step 1: taxon delineation

The starting point for a crop gene pool CWR conservation strategy is a list of target taxa; therefore, for the target crop gene pool it is necessary to:

1. Generate a list of taxa that occur in the crop gene pool. Although not all the taxa in the gene pool will necessarily be immediately included in the CWR conservation strategy, the complete list of taxa provides a reference point for future potential conservation actions of lower priority taxa.

2. Generate a list of taxa that occur within the defined geographic range of the conservation strategy (i.e. national, regional or global). These may be both native and introduced, but the conservation strategy is most likely to focus on native species.

To achieve these two steps, online information sources and/or literature (monographs, crop-specific studies etc.) need to be consulted (see Maxted and Guarino, 2003).

At this stage, it is necessary to adopt an accepted taxonomy to form the basis of the taxon list and the subsequent conservation strategy. The list of taxa should show the accepted taxon name and authority and list primary synonyms with authorities. This is important because different information systems use different accepted taxonomies; therefore, when searching for information on a specific taxon it could be possible to miss important information if synonymy is not taken into account.

Beet case study step 1

The beet gene pool consists of two genera – *Beta* and *Patellifolia* (Table 2.1). The genus *Beta* is divided into section *Beta* with three species and two subspecies, section *Corollinae*, which is composed of three base species and two hybrid species, as well as *B. nana* (the only species of the former section *Nanae*). The genus *Patellifolia* encompasses three species. Nine wild relatives of cultivated beets are native to Europe.

2.2.2 Step 2: selection of target taxa

In general, it is not practical to attempt to actively conserve all the taxa within the crop gene pool due to resource limitations; therefore, we need to prioritize and select taxa from the list that will be proposed for active conservation. Factors that can be used to ascribe 'value' and establish conservation priorities include (Maxted *et al.*, 1997):

- Current conservation status;
- Socio-economic use;
- Threat of genetic erosion;
- Genetic distinctiveness;
- Ecogeographic distribution;
- Biological importance;
- Cultural importance;
- Cost, feasibility and sustainability;
- Legislation;
- Ethical and aesthetic considerations;
- Priorities of the conservation agency.

For CWR, an initial, simple prioritization on the basis of socio-economic use of the associated crop (a step which will already have been taken in selecting the target crop gene pool) and relative threat has been proposed (e.g. Ford-Lloyd *et al.*, 2008; Magos Brehm *et al.*, 2008). In addition, Maxted and Kell (2009) proposed that within each crop gene pool, the closest wild relatives should be afforded higher conservation priority over the more distantly related species because these are the taxa that can more

Table 2.1. *Beta* working taxonomy and Gene Pool concept.[a]

Gene pool	Taxa
Primary	Section *Beta* Transhel
	B. vulgaris L. subsp. *vulgaris* (cultivated beets)
	Leaf Beet Group
	Garden Beet Group
	Fodder Beet Group
	Sugar Beet Group
	B. vulgaris L. subsp. *maritima* (L.) Arcang.*
	B. vulgaris L. subsp. *adanensis* (Pamuk.) Ford-Lloyd & Will.*
	B. macrocarpa Guss.*
	B. patula Ait.*
Secondary	Section *Corollinae* Ulbrich
	Base species:
	B. corolliflora Zosimovich
	B. macrorhiza Steven
	B. lomatogona Fisch & Meyer
	Hybrid species:
	B. intermedia Bunge
	B. trigyna Wald. & Kid.*
	B. nana Boiss. & Heldr.*
Tertiary	Genus *Patellifolia* Williams, Scott & Ford-Lloyd
	P. procumbens (Smith) A.J. Scott, Ford-Lloyd & J.T. Williams*
	P. webbiana (Moq.) A.J. Scott, Ford-Lloyd & J.T. Williams*
	P. patellaris (Moq.) A.J. Scott, Ford-Lloyd & J.T. Williams*

[a]Synonyms are not shown in this table but are recorded in an associated database.
*Wild relative native to Europe

easily be used in crop improvement using conventional breeding methods. However, the literature on the taxa within the target crop gene pool should be thoroughly searched to check for cases where a more distantly related taxon has been highlighted as a gene donor (or potential gene donor), and these taxa should also be afforded conservation priority. Of these prioritized taxa, those in most urgent need of conservation action (i.e. those with a very limited geographic range, often rare or endemic taxa, and/or known to be under threat) are given precedence.

This methodology therefore primarily targets the taxa that are most closely related to the crop species (or that have shown promise in crop improvement programmes) and that are threatened or have restricted distribution ranges. However, ideally, national and regional *in situ* networks of CWR GRs should in the long term be expanded to ensure that all taxa of potential importance for crop improvement are actively conserved. In particular, selected populations of the closest wild relatives that are widespread and common should be actively conserved throughout their range, ensuring that populations representing the extremes of the range (both geographically and topographically) are conserved. Individual populations of these taxa may harbour important genes adapted to particular environmental conditions – genes that may confer important traits to improve crops in the future. Populations of these taxa that already occur within PAs should also be monitored. In many cases, if a floristic approach is taken, it is possible to establish a reserve that conserves multiple CWR taxa, which, when possible, has obvious advantages.

There are two stages to the selection of target taxa: (i) creation of a level 1 prioritized list based on actual or potential use as gene donors; and (ii) creation of a level 2 prioritized list based on threat and/or distribution. In this methodology, the two steps are presented sequentially (i.e. the level 2 prioritized list is based on the level 1 prioritized list). The advantage of this approach is that in cases where there is limited information on the distribution of the taxa and/or for gene pools containing a very large number of taxa, the level 1 prioritization narrows the list of taxa down to those that are likely to be most important as gene donors for crop improvement and further information is only sought for that list of taxa.

The disadvantage of this approach is that some of the more distantly related taxa in the gene pool that are threatened or have restricted distributions may be missed in the conservation planning process. Therefore, in cases where a gene pool contains a relatively small number of taxa or where distribution data are readily available for all the taxa (e.g. in the case of the beet gene pool), it is desirable to undertake the prioritization in the reverse order by collating threat and distribution data on all taxa in the gene pool first, then applying the second level of prioritization based on potential use as gene donors. Using this approach, more distantly related taxa that are threatened or have restricted distributions can be highlighted as a conservation priority on that one criterion, and even though they may still not be given the highest level of priority for immediate conservation action, they may be promoted as candidates for conservation at a later date. Furthermore, if it is not immediately possible to put in place *in situ* conservation measures for these taxa, they can be earmarked for collection and storage in *ex situ* collections.

To organize the list of taxa within the crop gene pool according to their degree of relationship to the crop, a literature search should be carried out on the crop complex. Taxa should be organized into a table showing primary, secondary or tertiary wild relatives using one of three methods:

1. Where genetic information is available and taxa have been classified using the Gene Pool (GP) concept (Harlan and de Wet, 1971), organize the taxa into the table listing those in GP1B as primary wild relatives, those in GP2 as secondary wild relatives and those in GP3 as tertiary wild relatives.

2. Where genetic information is not available, if possible, substitute the Gene Pool concept with the Taxon Group (TG) concept

(Maxted *et al.*, 2006), which provides a proxy for taxon genetic relatedness. Organize the taxa into the table listing those in TG1b as primary wild relatives, those in TG2 as secondary wild relatives, and those in TG3 and TG4 as tertiary wild relatives.
3. For crop genera that have not been classified using the GP concept and not subclassified into sections and subgenera, the available information on genetic and/or taxonomic distance must be analysed to make reasoned assumptions about the most closely related taxa.

Whichever system is used, it is important to ensure that references are provided to substantiate the assumptions made about taxon relatedness.

In general, the primary and secondary wild relatives are selected as a priority for conservation action, but tertiary wild relatives that have been highlighted as gene donors or potential gene donors should also be added to the priority list. As carried out under Step 1, taxa in the priority list that occur within the geographical area of the conservation strategy are then tagged for further action.

To select taxa on the basis of relative threat and/or distribution (either the entire gene pool or the priority taxon list based on use potential): (i) consult the IUCN Red List of Threatened Species and national or regional Red Lists or carry out a literature search which may reveal important information about the threat status of a taxon; and (ii) compare the geographical range of the taxa. At this stage, a degree of objectivity is required, since there is no clear dividing line between a taxon with a limited range and one with a distribution that is deemed to enable 'classification' of the taxon as one not in immediate need of conservation action, unless very detailed information is already available about genetic erosion of the taxa. However, where the range of a taxon is known, the methodology proposed by Ford-Lloyd *et al.* (2008, 2009) can be used as a guide when establishing taxon conservation priorities at regional level (e.g. across Europe). Generally speaking, taxa that are known to be endemic to a country or subnational unit or those that occur in only a few countries or subnational units are more likely to be under threat at regional level. Similarly, at national or subnational level, available information must be gathered on the range of the taxa in order to establish which are most likely to be threatened by their limited distribution range.

Step 2 results in a reduced list of taxa that have been selected on the basis of their value as gene donors and relative threat. This list of target taxa now forms the basis for immediate conservation planning for the crop gene pool.

Beet case study step 2

The taxa in the gene pool were organized according to their degree of relationship to cultivated beets (Table 2.1). All wild species in the beet gene pool are either known as potential donors of useful genes or have already been used in crop enhancement programmes; therefore, all taxa are considered as a priority for conservation action on the basis of their potential use value. Considering relative threat, a recent initiative to carry out regional Red List assessments of a selection of European CWR (see Kell *et al.*, Chapter 28, this volume) highlighted five wild relatives of beet as a priority on the basis of their threat status: *B. patula* and *Patellifolia webbiana* (Critically Endangered), *B. macrocarpa* (Endangered), *B. vulgaris* subsp. *adanensis* and *B. nana* (Vulnerable). The remaining four taxa native to Europe were assessed as Data Deficient (*B. trigyna*) and Least Concern (*B. vulgaris* subsp. *maritima*, *P. patellaris* and *P. procumbens*).

It is important to note that the selection of target taxa on the basis of relative threat (whether based on Red List assessments or relative distribution) is likely to vary depending on the geographical scope of the conservation strategy. For example, in the case of beet, at European level, *P. patellaris* and *P. procumbens* are not immediate priorities for conservation action due to their relatively widespread distribution. However, if the scope of the conservation strategy is national, these taxa may be targeted as a priority for conservation action; for example, in Portugal, they are both a priority due to the fact that only a few subpopulations occur.

2.2.3 Step 3: diversity analysis

Once the priority list of CWR species has been identified (Step 2), the next step is to collate the available ecogeographic information to assist in further formulation of the CWR conservation strategy. This involves the collation and analysis of geographic, ecological, environmental and genetic data. These data are predictive and aid the location of the CWR taxonomic (inter-taxa) and genetic (intra-taxon) diversity that can then be targeted for conservation. As the goal is to maximize conserved genetic diversity, information on the partitioning of genetic diversity across the ecogeographic distributions of the target taxa is useful in identifying sites or combinations of sites of maximum diversity. However, even with rapidly decreasing costs of analysing genetic diversity, this information may be extremely limited; in which case, analysis of ecological and environmental data associated with the sites at which the populations occur can be used as a proxy for genetic diversity. The culmination of the diversity analysis should be a set of areas with high concentrations of the priority CWR species and populations of CWR taxa containing or thought to contain complementary and/or unique genetic diversity.

Geographic data are of two types – coordinate and descriptive. Ideally, coordinate data should be used for accuracy (however, even coordinate data can sometimes be misleading, depending on the accuracy and quality of the original data). Descriptive data can be converted to coordinate data by consulting gazetteers. At this stage in the analysis, issues of data quality have to be taken into account and steps may need to be taken to improve the accuracy of the distribution data to remove any erroneous entries. For example, it has been suggested that only population occurrences with geographic coordinates that have two decimal digits or more are used in the analysis. Another limitation is that the availability of occurrence data may be very heterogeneous across the range of the target taxon – this needs to be taken into account when making decisions on the selection of target sites (Step 4). Where distribution data are too sketchy or otherwise incomplete or inaccurate, it may be necessary to recommend that a detailed ecogeographic survey is undertaken before further analysis.

Genetic diversity analysis is only possible where the necessary information already exists or where resources permit the generation of novel genetic diversity information. There are two types of genetic diversity information of interest for the establishment of GRs and for backup in *ex situ* collections: intra-population and inter-population diversity. The precise method of generating genetic diversity information is taxon-specific. Decisions regarding the type of genetic analysis to undertake can be based on existing studies of related taxa or taxa sharing similar biological attributes. Literature searches can be undertaken to obtain this information, as well as consulting specialist databases and taxon experts.

Ecological and environmental data associated with the target taxa can be of two types: actual (i.e. data directly linked to a taxon) or secondary (i.e. data indirectly linked to a taxon via the attributes of the site in which it is found). Actual ecological and environmental data can be sourced by obtaining characterization and evaluation data associated with *ex situ* accessions, and/or by consulting the available literature on the target taxon – for example, there may be published or grey literature as a result of ecological studies of the taxon or of associated taxa that occur in the same habitats – or by collecting fresh data in the field. Secondary data are obtained by gathering data associated with known locations of a taxon (e.g. climate, soil type, geological substrate, habitat type, altitudinal range and land use). Some of these data are readily available in the form of Geographical Information System (GIS) files, which are overlaid with the distribution data, and from which inferences can be made about the ecological preferences of a taxon.

The data collated are analysed to build detailed taxon ecogeographic profiles. A GIS program such as ArcGIS can be used to create distribution maps overlaid with ecological, environmental and genetic data, and locate complementary GR locations (i.e. those that represent the widest range of ecogeographic diversity of the target taxa as possible). The analysis may be simple to complex, depending on availability of data, expertise, time and resources. The data should also be imported into an appropriate information management system from which standard taxon data sheets can be extracted to form the basis of GR proposals and management plans.

Complementarity analysis may also be undertaken. This aims to maximize taxonomic diversity conservation in the minimum number of sites and may be useful when dealing with gene pools containing a large number of taxa or for multiple gene pools. The GIS program DIVA GIS (see Hijmans *et al.*, 2001) is useful for undertaking complementarity analysis and is available for download free of charge.

Beet case study step 3

Diversity analysis of the beet gene pool was carried out in two stages. First, a review and compilation of the available geographic, ecological, environmental and genetic information for each of the target taxa was carried out. At this stage, the emphasis was on the use of genetic data to establish the ecogeographic pattern of genetic diversity. Second, a detailed ecogeographic diversity analysis of the target taxa using GIS was undertaken (see Parra-Quijano *et al.*, Chapter 3, this volume). This part of the analysis involved the compilation of information on factors related to abiotic adaptation upon a GIS background containing environmental variables (climatic, edaphic and geophysical). Using this method, each potential site for the establishment of a GR was environmentally characterized to aid the final selection of target sites.

2.2.4 Step 4: selection of target sites

In some cases, the range of the target taxon will define the precise site or sites where active *in situ* conservation is needed. Obviously, for a taxon that is known only to occur at one location and is considered a high priority as a potential gene donor, then that single location must be targeted for reserve establishment. Where the geographic range of the target taxon is broader, sites should be selected that represent the widest range of ecogeographic characteristics as possible.

Once the target taxon distribution has been identified and mapped, and diversity analysis undertaken (Step 3), PA overlays are used to ascertain whether the target taxon populations occur within the boundaries of existing PAs. CWR, like any other group of wild plant species, are located both within and outside existing PAs; however, the most efficient approach in the first instance (to avoid the purchase and establishment of new sites) is to establish CWR GRs within existing PAs (Maxted *et al.*, 2007). Therefore, the most appropriate PAs (e.g. national parks and heritage sites) within which to locate GRs should be identified.

GIS analysis using PA shapefiles provides an indication of which PAs contain populations of the target taxa. In addition, this method can be used to predict which PAs contain high concentrations of CWR diversity. To be certain that the populations do exist within the PA(s), it is necessary to confirm their presence before GR establishment is recommended. This information is not always easy to obtain; however, if the taxon expert is not certain of its presence at the site, it may be possible to contact the agency responsible for the management of the PA to see if they have an inventory of taxa available or whether it is possible for site staff to confirm the presence of the taxon. If possible, ground truthing by visiting the site(s) personally should be undertaken. This is of course subject to available time and resources.

Where target taxon populations are found to already occur within existing PAs, these populations should be prioritized for inclusion in the CWR GR network on the basis that they have already been afforded some degree of protection, even if only by default. However, it is important to stress that even though a target taxon population may occur within the boundaries of a PA, this does not automatically mean that the population is actively conserved. On the contrary, few PAs are established to conserve specific target taxa, and those that have tend to focus on animal conservation. To conserve the range of genetic diversity inherent in CWR populations, active site management and monitoring is needed (see Iriondo *et al.*, Chapter 10, this volume) – some PAs do not even have management plans, and those that do are often limited by financial resources and lack of capacity to put the plan into practice.

In cases where a few to several PAs are found to contain populations of a target taxon, results of the diversity analysis can be used to select sites that best represent the ecogeographic diversity within the target taxon. A further consideration for the selection of PAs is the option for multiple taxa GRs. Analysis of all target taxa within the crop gene pool (and preferably across several crop gene pools) may reveal that some PAs contain populations of more than one taxon. In terms of expediency of resource use, multi-taxa reserves have obvious advantages over those that only contain a population of one taxon.

Where target taxon populations do not already occur within existing PAs, these populations should also be prioritized for inclusion in the CWR GR network on the basis that they have not already been afforded any degree of protection; especially for rare or threatened species. Obviously, justifying the need for and actually establishing new PAs will involve a significant initial injection of time and resources. Nomination of GRs at the target locations may of course be hindered by a range of socio-political factors, such as legal issues, land use conflicts, issues of land ownership, or lack of local support. Therefore, if possible a range of alternative sites should be recommended and ranked according to their suitability based on ecogeographic considerations.

The main criterion for allocating priorities to sites is the conservation of the maximum genetic diversity possible. When assigning priorities for a particular target taxon, the ecogeographic analysis will form the basis of the priority ranking of sites. When the aim is to conserve multiple taxa within the same sites, a balance has to be met between prioritizing those sites that contain the greatest taxonomic diversity and those that contain less taxonomic diversity, but more genetic diversity specific to particular target taxa. Other factors to take into account when assigning priority ranking to selected sites include: land use, potential development pressures (e.g. sites closer to towns and cities may be less secure), presence of invasive species (particularly on islands), level and quality of site management, legal status, potential conflict with existing site management aims and social unrest. A thorough assessment of all factors, both scientific and socio-political, must be made and considered when selecting the ideal sites.

The potential effects of climate change on populations of the target taxa also need to be taken into account. Considerations include the particular vulnerability of populations in coastal and high altitude areas, whether there is sufficient intra-population genetic diversity and reproductive success in populations to allow adaptation to new conditions, and whether small, fragmented populations with little migration will be able to colonize new sites (Veteläinen *et al.*, 2007). In the absence of detailed studies on individual target taxa, it will not be possible to predict exactly where sites need to be established because: (i) we will not know whether populations of a taxon will have the ability to adapt to new conditions at current sites; (ii) we will not know whether populations will have the ability to migrate to new sites; and (iii) if migration occurs, how quickly it will take place and in what direction. However, greater emphasis on habitat protection to prevent and reduce habitat fragmentation and the establishment of corridors between habitat patches to facilitate range shifts of mobile species is likely to be important for many CWR taxa (Jarvis *et al.*, 2008).

Beet case study step 4

The selection of target GR sites for the beet gene pool involved collaboration between a taxon expert with good knowledge of the European populations and a GIS expert who carried out the detailed ecogeographic diversity analysis. Initially, candidate sites for the target taxa were identified by the taxon expert using genetic distance and genetic diversity data, as well as geographic data. Sites were recommended for immediate action if: (i) the occurrence was known to be distributed in a Natura 2000 protected site; and/or (ii) the occurrence was known to represent a unique or specific fraction of the taxon's genetic diversity. As one of main objectives of the *in situ* management strategy is the maintenance of the highest possible amount of genetic diversity of a gene pool in nature, which is prerequisite for the evolutionary processes generating novel genetic variation, ten candidate GR sites for *B. vulgaris* subsp. *maritima* were also proposed. Although the taxon was not included in the prioritized list, these sites are known to harbour genetic variation for traits useful for plant breeding. As this taxon is widely distributed there is no immediate need for active management; however, as little is known about the geographic distribution pattern of traits useful for plant breeding, the establishment of GRs should be seen as a precautionary measure to secure these materials.

In parallel, a systematic protocol (using the ecogeographic information obtained in Step 3 and species occurrence data) was developed by the GIS expert to assist the taxon expert in the selection and ranking of GR sites for the creation of a network at the European level. This protocol is described in detail by Parra-Quijano *et al.* (Chapter 3, this volume). The approach is based on the generation of an Ecogeographical Land Characterization (ELC) map that identifies different ecogeographical units that are likely to promote local adaptation in the target species populations. It maximizes the ecogeographical representation of the selected sites that fall within PAs and positively informs other criteria such as the occurrence of other taxa of the same genus at the site, generating a selected number of potential sites. This information assisted the taxon expert to produce a list of 28 candidate sites distributed in seven European countries.

Geographic information of selected sites provided by the taxon expert was verified by the GIS expert by importing coordinates of the target taxon populations into a GIS. These data were overlaid with the geographic coordinates of the PAs proposed for the establishment of GRs by the taxon expert. Thus, the preliminary list of PAs containing proposed GRs were obtained and a map with these areas was developed. Subsequently, the information provided by the taxon expert concerning the list of proposed PAs was checked. When inconsistencies were found between the location of the populations of the target taxa and the location of the proposed sites, alternative PAs were suggested to the expert for consideration. When no PAs could be found where suitable populations of a particular target taxon occurred, the taxon expert provided the geographic coordinates of the target population of the target taxon where a GR could be established. Thus, a final list of locations (mainly within PAs) was identified where GRs could potentially be established (Table 2.2) and a final map was obtained.

After this stage, further information relating to the sites and populations was gathered to aid the documentation and verification of the selected sites. This involved the collation of habitat types, land use and conservation status of the sites, as well as information on the status of the populations of the target taxa at the sites.

2.3 Conclusion

Crop wild relatives contain a wide pool of genetic diversity that is important to maintain for its use in plant breeding for crop improvement. The highest priority CWR for food security are not adequately conserved,

Table 2.2. Target genetic reserve sites for the beet gene pool.

Target taxon(a)	Country	Site name	Site code	Designation
Beta macrocarpa	Portugal	Ria Formosa – Castro Marim	PTCON0013	Natura 2000
	Spain	Amagro	ES7010011	Natura 2000
	Spain	Archipielago Chinijo	ES7010045	Natura 2000
	Spain	Cabo de Gata – Níjar	ES0000046	Natura 2000
	Spain	Costa del Norte de Fuerteventura	ES0000348	Natura 2000
	Spain	Interian	ES7020081	Natura 2000
	Spain	Lomo del Carretón	ES7020037	Natura 2000
	Spain	Salinas de Santa Pola	ES0000120	Natura 2000
B. macrocarpa, *Patellifolia procumbens*	Spain	Anaga	ES0000109	Natura 2000
B. nana	Greece	Notoanatolikos Parnassos – Ethnikos Drymos Parnassou - Dasos Tithoreas	GR2450005	Natura 2000
	Greece	Oros Gkiona	GR2450002	Natura 2000
	Greece	Oros Olympos	GR1250001	Natura 2000
B. patula, *P. procumbens*	Portugal	Parque Natural da Madeira – Ponta de São Lourenço	PTMAD0003	Natura 2000
B. vulgaris subsp. *adanensis*	Greece	Arkoi, Lepsoi, Agathonisi Kai Vrachonisides	GR4210010	Natura 2000
	Greece	Rodos: Profitis Ilias – Epta Piges – Petaloudes	GR4210006	Natura 2000
B. vulgaris subsp. *maritima*	Denmark	Gisseløre, Houget	DNK349790	CDDA
	Germany	Helgoland mit Helgoländer Felssockel	DE1813391	Natura 2000
	Germany	Küstenstreifen west – Und Nordfehmarn	DE1532391	Natura 2000
	Italy	Delta del Po: Tratto Terminale e Delta Veneto	IT3270017	Natura 2000
	Portugal	Ria de Aveiro	PTZPE0004	Natura 2000
	France	Estuaires et Littoral Picards (Baies de Somme et d'Authie)	FR2200346	Natura 2000
P. procumbens	Portugal	Laurisilva da Madeira	PTMAD0001	Natura 2000
	Spain	Cuenca de Benchijigua – Guarimiar	ES7020107	Natura 2000
	Spain	El Hierro	ES0000103	Natura 2000
	Spain	Laderas de Enchereda	ES7020101	Natura 2000
P. webbiana	Spain	Area maritima de la Isleta	ES7010016	Natura 2000

either *in situ* or *ex situ*, and we cannot rely only on *ex situ* conservation of these resources as it does not maintain the evolutionary process of adaptation found in wild populations – this can only be achieved by managing *in situ* populations in CWR genetic reserves. The value of CWR for food security and the need for their conservation has recently been placed firmly on the international conservation agenda, but due to the large number of taxa that exist, coupled with limited resources, a means of setting priorities for their conservation is needed. Further, as CWR have largely been neglected by the conservation community, we face the challenge of identifying where and how to conserve them *in situ*.

In this chapter, we have proposed a methodology for the identification of GR sites for a target crop gene pool, which addresses the need to conserve the maximum range of genetic diversity in the highest priority taxa in terms of their known or potential value for crop improvement and relative threat. This approach has already been applied at a global scale for a number of globally important crop gene pools (see Maxted and Kell, 2009) and for four crop gene pools important for food security and economic stability in Europe – oats (*Avena* spp.), beet (*Beta* spp.), brassicas (*Brassica* spp.) and cherry (*Prunus* spp.). By applying the methodology across a range of different crop types, including cereals, leafy vegetables, root crops and fruit trees, it has been possible to: (i) reveal different perspectives on its application by several experts; (ii) investigate ways in which the application of the individual steps may differ between different crop groups; (iii) scrutinize the methodology to confirm its applicability to a range of crop groups; and (iv) refine the methodology to ensure that it is widely applicable to any crop gene pool and easily understood by all those involved in CWR *in situ* conservation strategy planning.

We have found that the model can be widely used; however, it is clear that its application will necessarily be slightly adapted according to the different crop gene pools to which it is applied. For example, the means of selecting target taxa varies from one gene pool to another, depending on:

- The number of species in the gene pool (e.g. *Brassica* is a large genus compared to *Avena*, *Beta* and *Patellifolia*).
- The number of crops in the gene pool (e.g. *Brassica* contains several crops).
- Knowledge of the genetic relationship between taxa (e.g. there is better knowledge for *Avena*, *Beta* and *Patellifolia* than for *Brassica*).
- Knowledge of the breeding potential of species (e.g. there is better knowledge for *Avena*, *Beta* and *Patellifolia* than for *Brassica*).

Further, the means of selecting target sites varies from one gene pool to another, depending on: (i) existing knowledge of intra- and inter-specific genetic diversity of target taxa; and (ii) existing knowledge of localities of target species (e.g. population size, threats and suitability of the site to establish a GR). In addition, the application of the methodology highlighted the difficulty of dealing with taxonomic data (i.e. different nomenclature in different information systems) and occurrence data (e.g. lack of coordinates, problems of data quality, and evenness of data quality across Europe). However, these are challenges that we face in conservation planning in general and are not specific to this model.

To conclude, a logical and systematic framework for CWR conservation is needed that is applicable to any country or region and to any crop gene pool. This may involve both the floristic and monographic approaches, but in order to conserve the maximum range of genetic diversity in the highest priority crop gene pools for global, regional and local food security, a crop gene pool approach is needed that can be applied in tandem with the floristic approach at national level. The methodology presented in this chapter can now be applied to develop conservation strategies for more priority crop gene pools with the aim of eventually ensuring that the genetic diversity that we may rely on in years to come is secured in a network of national, regional and global CWR genetic reserves.

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ANNEX 2

CROPS AND WILD RELATIVES OF THE EURO-MEDITERRANEAN REGION: MAKING AND USING A CONSERVATION CATALOGUE

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The declaration of author contributions accompanying Chapter 2 of this thesis is also relevant to this annex.

5 Crops and Wild Relatives of the Euro-Mediterranean Region: Making and Using a Conservation Catalogue

S.P. KELL, H. KNÜPFFER, S.L. JURY, B.V. FORD-LLOYD AND N. MAXTED

5.1 Why Catalogue the Crop Resources of Europe and the Mediterranean?

The combined European and Mediterranean region (the Euro-Mediterranean region) is an important centre for the diversity of crops and their wild relatives – a major socio-economic resource and the cornerstone of agrobiodiversity for the region. Major food crops, such as wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.), cabbage (*Brassica oleracea* L.) and olive (*Olea europaea* L.), originated in the Euro-Mediterranean and the wild relatives of these crops, along with several other major crops that have wild relatives in the region, are an important genetic resource for crop improvement and food security. Many minor crops have also been domesticated and developed in the region, such as chickpea (*Cicer arietinum* L.), lentil (*Lens culinaris* Medik.), sugarbeet (*Beta vulgaris* L.), almond (*Prunus dulcis* (Mill.) D.A. Webb) and apple (*Malus domestica* Borkh.). Other crops of socio-economic importance with wild relatives in the region are forestry species such as *Abies alba* Mill., *Populus nigra* L. and *Quercus ilex* L., ornamentals such as species of *Dianthus* L., *Euphorbia* L., *Geranium* L. and *Primula* L. and medicinal and aromatic plants such as species of *Anemone* L., *Campanula* L., *Helianthemum* Mill., *Orchis* L. and *Verbascum* L. Although it is acknowledged that populations of crop wild relatives (CWR) are under threat in the Euro-Mediterranean region, their conservation has historically received relatively little systematic attention. Creating a CWR inventory is the first step in the conservation and effective use of these vital resources – to tackle CWR conservation, we need to know how many taxa there are, what they are and where they are.

Taxon inventories provide the baseline data critical for biodiversity assessment and monitoring, as required by the Convention on Biological Diversity (CBD) (CBD, 1992), the Global Strategy for Plant Conservation (GSPC) (CBD, 2002), the European Plant Conservation Strategy (EPCS) (Council of Europe

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and Planta Europa, 2002) and the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) (FAO, 2001). They provide the essential foundations for the formulation of strategies for *in situ* and *ex situ* conservation and on the species' current and potential uses as novel crops or gene donors. Some species may already be included in areas managed for conservation purposes, but their status as CWR may be unknown and they may not be actively monitored and managed. We already know that relative to the number of crops conserved *ex situ* in European gene banks, the number of CWR conserved are few (see Maxted *et al.*, Chapter 1, this volume). Inventories are needed to establish which species are already conserved, where the gaps are in their conservation and to provide the data needed for integrating CWR into existing conservation initiatives.

At regional level, a CWR inventory provides policy makers, conservation practitioners, plant breeders and other user groups with an international view of CWR species' distributions and a means of prioritizing conservation activities (see Ford-Lloyd *et al.*, Chapter 6, this volume). A regional inventory provides the basis for monitoring biodiversity change internationally, by linking CWR information with information on habitats, policy and legislation and climate change. It also serves to highlight the breadth of CWR diversity available in the region, which may include important resources for CWR conservation and use in other parts of the world. Furthermore, a regional inventory provides the backbone for the creation of national CWR inventories (e.g. see Scholten *et al.*, Chapter 7, this volume; Maxted *et al.*, in press).

The creation of CWR inventories within Europe has been tackled in some cases at country level – for example, Schlosser *et al.* (1991) for the former German Democratic Republic, and Mitteau and Soupizet (2000) for France – and at regional level, for Europe – especially those proposed by Zeven and Zhukovsky (1975), Heywood and Zohary (1995) and Hammer and Spahillari (1999). However, a comprehensive and systematic approach has not yet been proposed and applied, and previously there has not been a coordinated effort focusing on the production of a comprehensive online Euro-Mediterranean Catalogue.

This chapter summarizes a methodology for establishing a regional catalogue of crops and their wild relatives for the Euro-Mediterranean region (see Kell *et al.*, 2007, unpublished data, for a full explanation of the methodology). The Catalogue (Kell *et al.*, 2005a) is made available through the web-enabled Crop Wild Relative Information System (CWRIS) (PGR Forum, 2005), which provides access to CWR information to a broad user community, including plant breeders, protected area managers, policy makers, conservationists, taxonomists and the wider public (see Kell *et al.*, Chapter 33, this volume) – information that is vital for the sustainable utilization and conservation of CWR. The Catalogue has been created using a systematic approach that can accommodate changes in nomenclature and status, and can be applied at both regional and national levels in any part of the world.

In addition to providing an online information resource, the actual Catalogue data can be analysed to provide statistics on the crop and CWR taxa of the region. This chapter provides information on the number of crop and CWR taxa in the region and how many are native and endemic; the number of crop and CWR species present in individual nations and intranational regions; the number of species within and shared by the different crop groups; the number of worldwide crop genera that are found in the region; the major and minor food crops of the world that are native to the Euro-Mediterranean region and those that have wild relatives in the region. The Catalogue data can also be compared with taxon lists from existing conservation initiatives to establish which species are currently conserved and/or have undergone conservation assessment as a step towards the recognition and inclusion of CWR in current conservation programmes – some examples of this are given here.

5.2 Creating the Catalogue

5.2.1 Scope and basic methodology

The scope of the Catalogue is all species of direct socio-economic importance and their wild relatives – including food, fodder and forage crops, medicinal plants, condiments, ornamental and forestry species, as well as plants used for industrial purposes, such as oils and fibres. Applying the broad definition proposed by Maxted *et al*. (2006), a CWR includes any taxon belonging to the same genus as a crop species – it is upon this premise that the methodology for the creation of the CWR Catalogue is based.

In its simplest terms, the process of creating the Catalogue involves creating a list of genera containing crops, matching these with the genera contained in the flora of the country or region and selecting the taxa within the matching genera from the flora to create the Catalogue (see Kell *et al*., 2007, unpublished data, for a detailed explanation of the methodology). For example, taking the crop species, *B. oleracea* L. (cabbage) as an example, because taxa within the genus *Brassica* L. occur in the Euro-Mediterranean region, we include all the accepted *Brassica* taxa that occur in the region in the CWR Catalogue – in this case, 34 species and 54 subspecies. All taxa, whether cultivated, wild, native or introduced, are included. For example, the introduced, cultivated taxon, *B. napus* L. subsp. *napus*, is included in the Catalogue, along with native or introduced wild-occurring taxa – for example, *B. tournefortii* Gouan (native) and *B. elongata* Ehrh. subsp. *elongata* (mainly introduced but possibly native in some countries) – and native, cultivated taxa – for example, *B. macrocarpa* Guss.

The reason for including both cultivated and wild taxa in the Catalogue is that we are providing an information resource as a tool for the conservation of plant genetic resources (PGR) of socio-economic importance (i.e. both the crops and their wild relatives). It is not only the wild relatives that may harbour useful genes for crop improvement, but also the crops themselves, particularly in the case of locally adapted forms or landraces. There is also a strong argument for including native and introduced taxa in the Catalogue – populations of crops or wild relatives that are not native may still be an important genetic resource and worthy of conservation efforts, particularly in cases where native populations of taxa have suffered from genetic erosion. While countries may choose to conserve their native flora above the introduced flora, at regional level, in terms of conservation of crop genetic resources, the need to actively conserve introduced populations in some areas may be justified. Ultimately, the CWR Catalogue is a comprehensive information resource, which policy makers, conservation practitioners and crop germplasm user groups can use as an aid to conservation planning and sustainable use. Therefore, the more comprehensive the Catalogue is, the greater its uses will be.

5.2.2 Data sources

The Catalogue is primarily derived from two major databases: Euro+Med PlantBase (Euro+Med PlantBase, 2005), which provides the taxonomic core, and Mansfeld's World Database of Agricultural and Horticultural Crops (Hanelt and IPK Gatersleben, 2001; IPK Gatersleben, 2003), which provides lists of genera containing agricultural and horticultural crops and the crop species themselves.

Euro+Med PlantBase is an online database and information system for the vascular plants of the Euro-Mediterranean region. The database comprises names and associated data from *Flora Europaea*, the MedChecklist database, the Flora of Macaronesia data set and published Floras from the Euro-Mediterranean region. Euro+Med PlantBase includes native species, naturalized aliens, frequently occurring casuals, frequent and well-characterized hybrids, crop weeds and plants that are conspicuously cultivated outdoors. The geographical area covered includes all of Europe,[1] the Caucasus, Asiatic Turkey and the East Aegean Islands, Syria, Lebanon, Israel, Jordan, Cyprus, Egypt, Libya, Tunisia, Algeria, Morocco and Macaronesia.

Mansfeld's World Database of Agricultural and Horticultural Crops (Hanelt and IPK Gatersleben, 2001; IPK Gatersleben, 2003) contains more than 6100 cultivated species of agricultural and horticultural plants worldwide, including medicinal and aromatic plants, but with the exception of ornamental and forestry plants. The database also includes cultivated algae and fungi, pteridophyta and gymnosperms.

Genus lists for forestry and ornamental species and additional medicinal and aromatic plant taxa were drawn from other sources. For forestry taxa, a list of genera was extracted from the 'enumeration of cultivated forest plant species' (Schultze-Motel, 1966). For ornamentals, a list of taxa was provided by the Community Plant Variety Office (CPVO, 2001), which is the organization responsible for implementing the 'system for the protection of plant variety rights' established by European Community legislation, allowing intellectual property rights to be granted for plant varieties within the European Union

[1] The eastern o ndar o E ro e in R ssia and Ka a hstan ollo s the de inition o *Flora Europaea* (T tin *et al*., 1968 1980, 199): ro the Ar ti O ean alon the Kara Ri er to 68 N, alon the rest o the Ural Mo ntains (ollo in ad inistrati e o ndaries) to 58 0 N, then an ar itrar strai ht line to a oint 50 east o S erdlo s , and another ar itrar strai ht line to the head aters o the Ural Ri er (so th o lato st) and inall alon the Ural Ri er to the Cas ian Sea.

(EU). This list contains taxa for which the title had been granted and all active applications as of July 2003 (T. Kwakkenbos, France, 2003, personal communication). For medicinal and aromatic plants, a genus list was extracted from the database, Medicinal and Aromatic Plant Resources of the World (MAPROW) (U. Schippmann, Bonn, 2004, personal communication), which includes wild-harvested as well as cultivated medicinal and aromatic plant species (the cultivated ones are also included in Mansfeld's Database), thus broadening the scope of the CWR Catalogue.

Accepted and synonymous genus names were selected from Mansfeld's Database in order to capture as wide a range of agricultural and horticultural crop and CWR taxa in the Catalogue as possible; thus, when a genus name is considered a synonym in Mansfeld's Database but is accepted by Euro+Med PlantBase, it is included in the CWR Catalogue in addition to accepted genus names that match. Only accepted genus names were selected from Schultze-Motel (1966); since the data was not previously digitized, extraction of synonyms in addition to accepted names was not possible with the available resources. However, it is unlikely that this would have a significant effect on the number of species included in the Catalogue overall, since analysis shows that 95% of forestry species are common to the species in the list of agricultural and horticultural crops. The CPVO and MAPROW do not adopt specific accepted taxonomies; therefore, no distinction was made in these data sets between accepted and synonymous genus names – the genus names were thus used as provided by these data sources. However, again, the list of agricultural and horticultural crop and CWR species shares 90% of its taxa with the ornamental list and 92% with the medicinal and aromatic plants list, thus, taking into account the synonymy in Mansfeld's Database captures the majority of species in all groups. For a detailed discussion on dealing with synonymy in the creation of the CWR Catalogue, readers are referred to Kell *et al*. (2007, unpublished data).

The crop genus list contains 7363 genera in total. Table 5.1 summarizes the number of genera attributable to each data source. Note that some genera are common to two or more sources; for example, Mansfeld's Database contains 68% of the CWR genera sourced from the other crop data sources (forestry, ornamental, medicinal and aromatic genera combined). When the crop genera are matched with Euro+Med PlantBase to select those taxa that occur in Europe and the Mediterranean, Mansfeld's Database is found to contain 82% of the CWR genera sourced from the other crop data sources.

5.2.3 Euro+Med PlantBase data filtering

Euro+Med PlantBase (version September 2005) provides the taxonomic backbone to the CWR Catalogue. The database contains more than 45,000 accepted species and infraspecific taxa (of which more than 33,000 are species and nearly 12,000 are infraspecific taxa) and more than 39,000 specific and infraspecific synonyms (Table 5.1). Only accepted names in Euro+Med PlantBase were used to create the CWR Catalogue. However, the online Catalogue can be searched on any taxon name to find its associated data.

Table 5.1. S ar statisti s: C R Catalo e data so r es.

Data so r e	No. o re ords	Data so r e/notes
Euro+Med PlantBase		a
E ro Med PlantBase: a e ted s e ies	,471	
E ro Med PlantBase: a e ted in ras e i i taxa	11,989	
E ro Med PlantBase: s non s (s e ies and in ras e i i taxa)	9,924	
Crop genera		
A ri lt ral and horti lt ral ro enera	1,98	
Forestr enera	8	
Orna ental enera	66	d
Medi inal and aro ati enera	1,057	e
Total crop genera	2,5 9	
Crop species		
E ro Med PlantBase s e ies oded lti ated	1,299	
A ri lt ral and horti lt ral ro s e ies	6,076	
Forestr ro s e ies	1,0 8	h
Orna ental ro s e ies	00	

[a]E ro Med PlantBase (.e ro ed.or .) ersion Se te er 2005.
Mans eld s orld Data ase o A ri lt ral and Horti lt ral Cro s (Hanelt and IPK, 2001 htt :// ans eld.i - atersle en.de) a e ted en s na es. This list in l des, a on st others, enera ontainin lti ated edi inal and aro ati lants. Note that a e ted and s non o s en s na es ro Mans eld s Data ase (6914 taxa) ere at hed ith a e ted na es in E ro Med PlantBase to reate the Catalo e (see Kell *et al*., 2007, n lished data).
En eration o lti ated orest lant s e ies (S h lt e-Motel, 1966) a e ted na es onl .
[d]Co nit Plant Variet O i e (. o.e .int) (T. K a en os, Fran e, 200 , ersonal o ni ation) no a e ted taxono .
[e]Medi inal and Aro ati Plant Reso r es o the orld (MAPRO) (S hi ann, Bonn, 2004, ersonal o ni ation) no distin tion et een a e ted na es and s non s. These enera o er all s e ies no n to e tili ed or edi inal r oses, hether ild-har ested or lti ated.
The o r ro s listed or the ro en s list, ontainin 25 9 enera (7 6 , in l din the s non o s en s na es ro Mans eld s Data ase (see note 2). Note that so e enera are o on to t o or ore so r es.
Mans eld s orld Data ase o A ri lt ral and Horti lt ral Cro s (Hanelt and IPK, 2001 htt :// ans eld.i - atersle en.de) a e ted s e ies onl . Note that a e ted and s non o s s e ies na es ro Mans eld s Data ase (24,578 taxa) ere at hed ith the Catalo e to ta the lti ated s e ies (see Kell *et al*., 2007, n lished data).
[h]Fi re ro the re a e o S h lt e-Motel s (1966) reli inar orld ide a o nt o lti ated orestr s e ies.

Therefore, if a user searches for a synonym of an accepted taxon name in the Catalogue, CWRIS takes the user to the accepted name and the data associated with it.

Euro+Med PlantBase uses the ‘Plant Occurrence and Status Scheme’ (WCMC, 1995) – a Standard of the International Working Group on Taxonomic Databases (TDWG) – to record the status of taxa within each geographical unit (Table 5.2). Some taxa are recorded as ‘extinct’, ‘recorded as present in error’ or ‘absent’ – taxon records with these codes were therefore excluded from the Catalogue. Where there is any doubt about the presence

Table 5.2. Codes sed in the ields nati e , introd ed , lti ated and stat s n no n in E ro Med PlantBase. (Ada ted ro E ro Med PlantBase Se retariat, 2002.) Ori inal data standard: CMC (1995).

Code	Val e	Ex lanation
Native status		
N	Nati e	The taxon is nati e (a to hthono s) ithin the area on erned (as ontrasted ith introd ed and lti ated de ined elo).
S	Ass ed to e nati e	Ass ed to e nati e to the area on erned.
D	Do t ll nati e	There is do t as to hether the stat s o the lant in the area on erned is nati e or not.
E	For erl nati e (extin t)	The lant is nati e, do t ll nati e or ass ed to e nati e in the area on erned and has e o e extin t as s h.
A	Not nati e	The lant is de initel not nati e.
F	Re orded as nati e in error	The lant has een re orded as nati e in the area on erned, t all s h re ords ha e een dis ro ed or dis o nted.
Introduced status		
I	Introd ed	The lant has een re orded ro in in an area that is o tside o its ass ed tr e and nor al distri tion. This i lies e iden e that the lant did not or erl o r in the area and also that the lant is either esta lished and s ess ll re rod in (either sex all or asex all) or a re entl o rrin as al. The lant st not e in lti ation: it does not ean (or in l de) introd ed to lti ation . The eans o introd tion, hether an or an nat ral eans, is irrele ant and a e n no n.
S	Ass ed to e introd ed	Ass ed to e introd ed to the area on erned.
D	Do t ll introd ed	There is do t as to hether the stat s o the lant in the area on erned is introd ed, as de ined a o e, or not. All re ords a o t the introd ed stat s o the lant in the area are in do t.
E	For erl introd ed (extin t)	The lant is introd ed, do t ll introd ed or ass ed to e introd ed in the area on erned and has e o e extin t as s h. The riterion o extin tion is that the lant as not o nd (as an introd tion) a ter re eated sear hes o no n and li el areas (i.e. sites ithin the area o ered the re ord), e en tho h the lant a e extant else here.
A	Not introd ed	The lant is de initel not introd ed (as de ined a o e) in the area on erned.
F	Re orded as introd ed in error	The lant has een re orded as introd ed in the area on erned, t all o those re ords ha e een dis ro ed or dis o nted. A no n alla io s introd ed re ord st ha e een ade, and it st e no n that the lant does not o r as an introd tion in the area.

Continued

Table 5.2. *Continued*

Code	Val e	Ex lanation
Cultivated status		
C	C lti ated	The lant is esta lished in o tdoor lti ation in the area on erned. Onl lants that are ons i o sl lti ated o tdoors sho ld e in l ded (in l des ro s lanted on a ield-s ale and street and roadside trees).
S	Ass ed to e lti ated	Ass ed to e lti ated in the area on erned.
D	Do t ll lti ated	There is do t as to hether the stat s o the lant is lti ated or not in the area on erned. All re ords a o t the lti ated stat s o the lant in the area are in do t.
E	For erl lti ated (extin t)	The lant as at one ti e lti ated, do t ll lti ated or ass ed to e lti ated in the area on erned and has e o e extin t in lti ation in this area, e en tho h it a e extant else here.
A	Not lti ated	The lant is de initel not lti ated (as de ined a o e) in the area on erned.
F	Re orded as lti ated in error	The lant has een re orded as lti ated in the area on erned, t all o those re ords ha e een dis ro ed or dis o nted. A no n alla io s re ord o lti ation st ha e een ade, and it st e no n that the lant is not lti ated in the area.
Status unknown		
P	Present	The lant is resent in the area and eets the riteria or in l sion in E ro Med PlantBase i.e. it is a nati e s e ies, nat rali ed alien, re entl o rrin as al, re ent and ell- hara teri ed h rid, ro eed or a lant that is ons i o sl lti ated o tdoors (either a ro lanted on a ield-s ale or street tree, t not a o onl ro n ar or arden lant). Ad enti es, as als, et . are not in l ded altho h noxio s eeds (other than those that ha e e o e nat rali ed hi h ill e in l ded or that reason) a e re orded.
S	Ass ed resent	It is hi hl ro a le that the lant does o r in the area.
D	Do t a o t resen e	There is do t a o t hether the lant resentl o rs in the area. This i ht e e a se all re ords are er old, lo alit details are n ertain, et .
E	Extin t	The lant as on e in the area (P or S) or a on e ha e een in the area (D), t is no extin t in the area.
F	Re orded as resent in error	The lant has een re orded as resent in the area on erned, t the re ord has een dis o nted or dis ro ed.
A	A sent	There are no re ords to s est that a lant has e er o rred in the area on erned.

of a taxon, the record is maintained in the Catalogue until such time as the Euro+Med PlantBase records for that taxon are updated and the status is confirmed (note that the Catalogue is updated automatically by linking directly to the Euro+Med PlantBase data set). Inclusion of these records in the Catalogue makes very little difference to the overall number of species. After filtering, the number of accepted species names in Euro+Med PlantBase is reduced from 33,471 to 30,983; these species are contained within 218 families and 2437 genera (Table 5.3). These taxa form the base taxonomy for the CWR Catalogue.

Table 5.3. Creation o the C R Catalo e: s ar statisti s. The total n er o a ilies, enera and s e ies are sho n or the iltered ersion o E ro Med PlantBase (E M), Mans eld s orld Data ase o A ri lt ral and Horti lt ral Cro s and or ea h ro ro a ter at hin the ro en s list ith E ro Med PlantBase. The total n er o ro taxa in the E ro-Mediterranean re ion and the n er o ro and C R nati e and ende i to E ro e and the E ro-Mediterranean re ion are i en.

	No. o taxa		
Plant taxa resent in the E ro-Mediterranean re ion	Fa ilies	enera	S e ies
Total no. o lant taxa (E M)	218	2,4 7	0,98
A ri lt ral and horti lt ral taxa	166	1,109	2 ,51
Forestr taxa	57	14	2,84
Orna ental taxa	90	2 0	7,499
Medi inal aro ati taxa	146	618	19,784
CWR Catalogue for Europe and the Mediterranean (total no. o ro and C R taxa)	18	1,2 9	25,687
Crop taxa[a]			
A ri lt ral and horti lt ral ro s	147	754	1,994
Forestr ro s	41	102	282
Orna ental ro s	62	104	1 1
Other ro s	66	166	486
Total crop taxa	155	817	2,204
Native and endemic species			
Cro and C R s e ies nati e to E ro e and the Mediterranean			2 ,216
Cro and C R s e ies ende i to E ro e and the Mediterranean			14,994
Cro and C R s e ies nati e to E ro e			15,656
Cro and C R s e ies ende i to E ro e			8,624

[a]Taxa no n to e lti ated orld ide and not ne essaril lti ated in the E ro-Mediterranean re ion. It is not ossi le to reate a list o edi inal and aro ati ro s sin this data e a se MAPRO in l des ild-har ested taxa and Mans eld s Data ase does not ontain a sin le data ield that ate ori es ro s e ies a ordin to their se.
Other ro s are s e ies re orded E ro Med PlantBase as lti ated in the re ion that are not alread in l ded in the lists o a ri lt ral and horti lt ral, orestr and orna ental ro s.
Not a li a le.

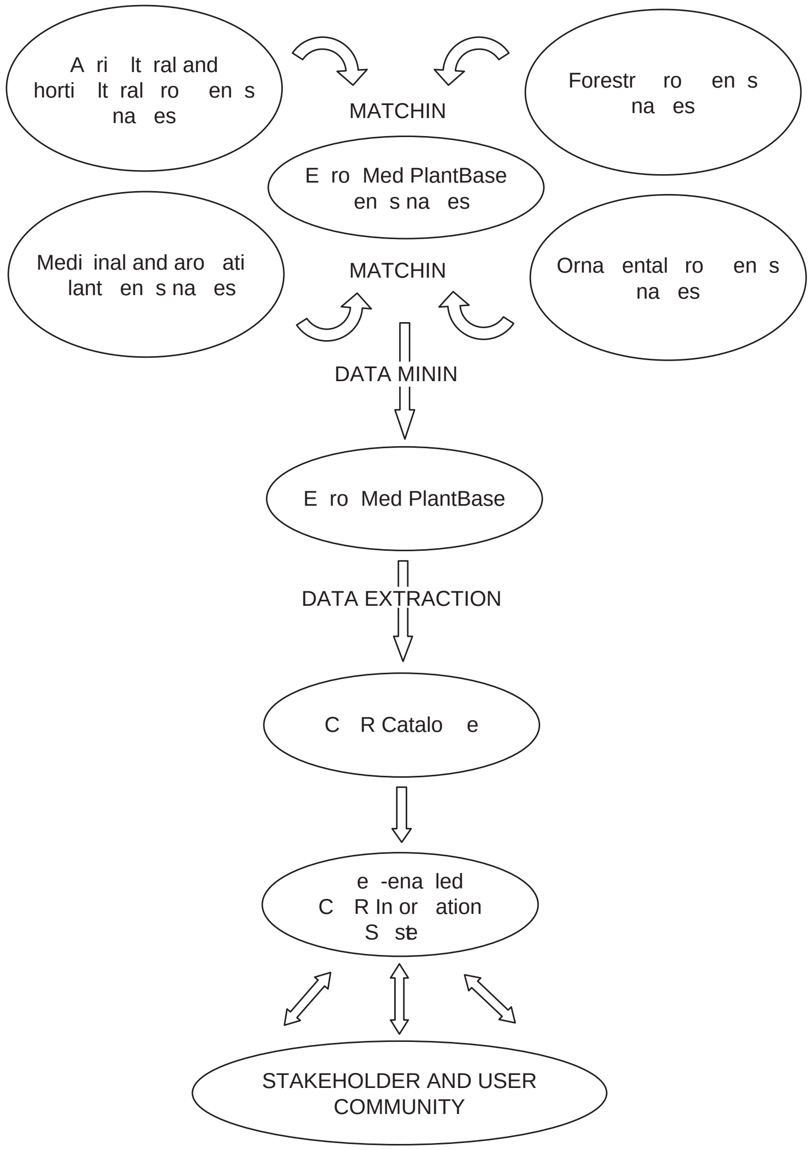

Fig. 5.1. Flo hart sho in the asi ethodolo or the reation and tili ation o the C R Catalo e or E ro e and the Mediterranean.

5.2.4 Mining and extraction of crop and CWR taxa from Euro+Med PlantBase

The genera in the filtered version of Euro+Med PlantBase corresponding with the crop genus list described earlier were selected. Following the genus name matching, the accepted taxa within the harmonized genera were selected, forming the CWR Catalogue. Figure 5.1 is a simplified flow chart illustrating the basic methodology, which could be utilized in any region or country. The chart shows the four crop name sources forming the crop genus list, which is matched with the genera contained in the flora of the country or region – in this case, the flora of Europe and the Mediterranean. The flora is then mined for the accepted taxa contained in the matching genera and these are extracted to form the CWR Catalogue.

5.2.5 Coding crop species in the Catalogue

We generally refer to the Catalogue as the 'CWR Catalogue'; however, the Catalogue also contains the crop taxa themselves. To distinguish the crop taxa in the Catalogue, all taxa coded 'C' (cultivated) in Euro+Med PlantBase were selected and tagged. These include plants that are conspicuously cultivated outdoors, such as crops planted on a field-scale and street and roadside trees (Euro+Med PlantBase Secretariat, 2002). In addition, species names from Mansfeld's World Database of Agricultural and Horticultural Crops (Hanelt and IPK Gatersleben, 2001; IPK Gatersleben, 2003), the 'enumeration of cultivated forest plant species' (Schultze-Motel, 1966) and the CPVO ornamental list (T. Kwakkenbos, France, 2003, personal communication) matching species listed in the Catalogue were tagged as crops. To capture as wide a range of crop species as possible, matching between synonymous species in Mansfeld's Database and species in the Catalogue was carried out.

Mansfeld's Database is inclusive of a very wide range of cultivated species, so the agricultural and horticultural species tagged as crops in the Catalogue are wide-ranging. For example, in addition to food, fodder, forage, medicinal, aromatic and industrial crops, plants cultivated for soil improvement, sand dune fixation, hedging, grafting stock, shade and support are included; thus, a broad definition of a 'crop' is adopted. On the other hand, the list of species used to tag the cultivated ornamental species in the Catalogue cannot be considered representative of the extensive number of species utilized in the ornamental plant industry. The reasons for this are that the ornamental genera from the CPVO varieties list were deliberately chosen to keep the ornamental component of the Catalogue to a reasonable minimum, since the use of plant species in the ornamental industry is extremely wide-ranging, and the CPVO does not use a standard nomenclatural system, therefore, many cultivars are listed without inclusion of the specific epithet. A better coverage of cultivated ornamental species could be provided by matching the species in the Catalogue with a more comprehensive database such as the RHS Horticultural Database (Royal Horticultural Society, 2006), which was not completed and thus not available during the time that the CWR Catalogue was created.

It is important to point out that not all the species tagged as crops are necessarily cultivated in the Euro-Mediterranean region – some crop species may occur in the region, but only in their wild form. For example, 1313 species of agricultural and horticultural crops that occur in the region are not actually recorded by Euro+Med as being cultivated. However, knowledge that a cultivated taxon occurs as a wild relative in a country where it is not cultivated may be important for crop security, because the wild material may be utilized in breeding for crop improvement. Table 5.1 summarizes the number of crop species from each data source used to code species in the Catalogue as cultivated.

5.3 What Does the Catalogue Tell Us about Crops and CWR in the Region?

5.3.1 Analysing the Catalogue data

The Catalogue data can be analysed in numerous ways to provide both broad brush-stroke statistics about the crop and CWR species present in the region and more detailed analysis about the species present at national level and about individual crops or crop groups. Results of the following data analyses are presented here:

- The number of crop and CWR species within the Euro-Mediterranean region and within Europe alone, including the number of species native and endemic to the regions;
- The number of crops and their wild relatives within the different crop groups;
- The number of species shared by the different crop groups;
- The number of worldwide crop genera that are found in the region;
- National species richness;
- Which major and minor food crops of the world are native and endemic to the Euro-Mediterranean region and which have wild relatives in the region.

However, the role of the Catalogue goes far beyond provision of interesting statistics on the crop and CWR species of the region – one of its most important functions is to provide a basis for creating comprehensive national inventories (e.g. see Scholten *et al.*, Chapter 7, this volume; Maxted *et al.*, in press) and to aid CWR conservation gap analysis. For example, a regional or national inventory can be compared with protected area inventories (where the data is available), to establish which CWR species are already included within existing protected areas. Detailed gap analysis is beyond the scope of this chapter; however, we have undertaken some preliminary analysis to investigate which CWR taxa are included in: (i) the IUCN Red List of Threatened Species; (ii) the EC Habitats Directive; (iii) Important Plant Areas (IPAs); and (iv) the Plant Search Database of world botanic garden collections, to begin to build up a picture of to what extent CWR have been assessed and included in existing conservation initiatives.

5.3.2 Numbers of crop species and their wild relatives in Europe and the Mediterranean

The CWR Catalogue contains 25,687 of the 30,983 plant species recorded by Euro+Med PlantBase as present in the region. This indicates that approximately 83% of the Euro-Mediterranean flora consists of crops and their wild relatives; in other words, more than three-quarters of plant species in the region have a current or potential direct use to humankind. Ninety percent (23,216 species) are native to the Euro-Mediterranean region and 58% (14,994) are endemic (Table 5.3). However, taking into account synonymy and issues of taxonomic uncertainty, this is probably a slightly artificially large number of species (Kell *et al.*, 2007, unpublished data). Therefore, for the purposes of argument, we may conclude that around 80% of the flora of the region is of current or potential direct use.

Forty-nine percent of genera containing agricultural, horticultural, forestry and ornamental crops and medicinal and aromatic plants worldwide are found in the Euro-Mediterranean region and at least 2204 species in the CWR Catalogue (9%) are known to be cultivated worldwide (Table 5.3). As noted earlier, not all these species are necessarily cultivated within the Euro-Mediterranean region. At least 8% of the species listed in the CWR Catalogue are agricultural and horticultural crops in the Mansfeld sense (see Hanelt and IPK Gatersleben, 2001; IPK Gatersleben, 2003), while at least 1% are forestry crops as recorded by Schultze-Motel (1966). At least 8% of agricultural and horticultural and 10% of forestry crop and CWR species are cultivated worldwide. Although a taxon can be both cultivated and a wild relative (i.e. in some places it might be cultivated, while in others it may occur in its wild form), we can say that approximately 90% of the species in the agricultural, horticultural and forestry groups are wild relatives. In the CPVO (ornamental) list, 131 species match the names in the CWR Catalogue; however, this is not representative of the number of cultivated ornamental species. As explained earlier, if another source of data were consulted, such as the RHS Horticultural Database (Royal Horticultural Society, 2006), the figures for ornamental crop species would undoubtedly increase significantly.

Table 5.4 shows the total number of crop and CWR species in each of the four socio-economic groups: agricultural and horticultural crops, forestry species, ornamentals and medicinal and aromatic plants (note that the medicinal and aromatic species list includes wild-harvested plants and their wild relatives, as well as cultivated species). The percentage of the total number of Euro-Mediterranean crop and CWR species (25,687) attributable to each group is given. Table 5.5 is a matrix showing the percentage of species common to all four groups. Note that very high percentages of crop and CWR species extracted from the genus list derived from Mansfeld's World Database of Agricultural and

Table 5.4. Total n er o ro and C R s e ies in the E ro-Mediterranean re ion and the n ers and er enta es o s e ies in ea h ro .

	Cro s	C R	Total ro and C R s e ies	Total s e ies er ro as er enta e o Catalo e
A ri lt ral and horti lt ral s e ies[a]	1,994	21,519	2 ,51	92
Forestr s e ies	282	2,561	2,84	11
Orna ental s e ies	1 1	7, 68	7,499	29
Medi inal and aro ati s e ies			19,784	77
Total Euro-Mediterranean species	2,204	2 ,48	25,687	

[a]The a ri lt ral and horti lt ral s e ies list in l des lti ated edi inal and aro ati lants.
The edi inal and aro ati s e ies list in l des ild-har ested lants and their relati es, as ell as lti ated s e ies.
In l des 486 other ro s e ies re orded as lti ated in E ro Med PlantBase (see Ta le 5.).
Not a li a le or data not a aila le.

Table 5.5. Matrix sho in the er enta e o ro and C R s e ies shared ea h o the o r ro s. The otto le t side o the atrix sho s the er enta e o s e ies shared ea h ro in the le t-hand ol n as a er enta e o the s e ies in ea h ro i en a ross the to ro . The to ri ht side o the atrix ex resses the er enta es in re erse. For exa le, 11 o s e ies in the a ri lt ral and horti lt ral list are also o nd in the orestr list and on ersel , 95 o orestr s e ies are o nd in the a ri lt ral and horti lt ral list. Note that the edi inal and aro ati s e ies list in l des ild-har ested lants and their ild relati es, as ell as lti ated s e ies.

	A ri lt ral and horti lt ral ( )	Forestr ( )	Orna ental ( )	Medi inal and aro ati ( )
A ri lt ral and horti lt ral ( )		95	90	92
Forestr ( )	11		17	14
Orna ental ( )	29	45		
Medi inal and aro ati ( )	77	95	88	

Not a li a le.

Horticultural Crops are common to the other three socio-economic groups – i.e. 95% of the species in the forestry list, 90% in the ornamental list and 92% in the medicinal and aromatic plant list. This can be explained by the fact that many crop species have several uses, as do ornamental plants (e.g., medicinal and vegetable), and that cultivated medicinal and aromatic plants are also included in the Mansfeld's Database. Moreover, there are many species within the same genera as the agricultural and horticultural crop genera that have been classified within one of the other three socio-economic groups; thus, these groups will share many of the same CWR. The high percentages of medicinal and aromatic plant species common to the other three groups are also notable (i.e. 77% of agricultural and horticultural crops – though as observed earlier, Mansfeld's Database also includes cultivated medicinal and aromatic plants – 95% of forestry species and 88% of ornamental species). This illustrates the extremely broad use of plants for medicinal and aromatic purposes, many of which are species harvested from the wild. Perhaps not surprisingly, the forestry group has the lowest percentages of species common to the other three groups, with 11% of species common to the agricultural and horticultural crops, 17% to the ornamental species and 14% to the medicinal and aromatic plants.

Looking at Europe alone (as defined by Hollis and Brummitt, 2001), there are 17,495 crop and CWR species; therefore, 68% of crop and CWR species found across the Euro-Mediterranean region are found in Europe alone. Of these, 15,656 species (89%) are native to Europe and 8624 (49%) are endemic. As many as 1078 (42%) worldwide crop genera are found in Europe.

5.3.3 National species richness

Data in Euro+Med PlantBase are recorded within 130 geographical units, representing 58 nations. The number of crop and CWR species of each nation is shown in Table 5.6. Four nations contain more than 20% of the species in the region: Turkey, Spain, Italy and France. The nation with the highest CWR species richness is Turkey,

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Table 5.6. List o E ro-Mediterranean nations, sho in the total n er o ro and C R s e ies er nation in des endin order. The ri ht ol n sho s the n er o s e ies as a er enta e o the total n er o ro and C R s e ies in the re ion.

Nation	No. o ro and C R s e ies	Per enta e o E ro-Mediterranean ro and C R s e ies
T r e	72 5	28
S ain	6669	26
Ital	5712	22
Fran e	5528	22
ree e	4818	19
U raine	4265	17
R ssia	4259	17
er an	4211	16
Slo a ia	87	15
B l aria	619	14
A stria	56	14
C e h Re li	526	14
Ro ania	484	14
Croatia	4 6	1
S it erland	41	1
Moro o	409	1
Port al	296	1
Al ania	0 0	12
Al eria	2911	11
Poland	2751	11
H n ar	26 9	10
Le anon	2577	10
Slo enia	25	10
S ia	2421	9
S eden	2 62	9
Ser ia	2 59	9
Nor a	2276	9
Ar enia	22 5	9
United Kin do	2169	8
Israel	2084	8
Den ar	2056	8
T nisia	1882	7
eor ia	1882	7
Moldo a	1795	7
Finland	1771	7
E t	1745	7
Bel i	17 0	7
The Netherlands	172	7
Li a	1547	6
Estonia	1501	6
Lith ania	1477	6
C r s	1448	6
Lat ia	1 2	5
Ireland	1299	5
A er ai an	882	

Continued

Table 5.6. *Continued*

Nation	No. o ro and C R s e ies	Per enta e o E ro-Mediterranean ro and C R s e ies
Belar s	754	
Malta	7 8	
Ka a hstan	592	2
I eland	540	2
Andorra	504	2
Jordan	474	2
Bosnia-Her e o ina	241	1
Montene ro	185	1
Ser ia and Montene ro	148	1
L xe o r	118	1
Lie htenstein	4	1
San Marino	8	1

with 7235 species – 28% of the crop and CWR species of the Euro-Mediterranean region. As might be expected, the proportion of the flora of these four countries that comprises crops and their wild relatives is fairly consistent with the overall proportion of the flora of the region: Turkey – 83%, Spain – 81%, Italy – 84% and France – 86%. Nineteen nations contain between 10% and 20% of the crop and CWR flora of the region, 31 between 1% and 10% and three less than 1%.

We can also look at which crop groups are most prevalent in individual countries and the number of crop species present. For example, of the 2276 crop and CWR species recorded in Norway, 2084 species (92%) are included in the agricultural and horticultural crop group, 345 (15%) in the forestry group, 782 (34%) in the ornamental group and 1855 (82%) in the medicinal and aromatic plant group. Also, 633 of these species (28%) are known to be cultivated worldwide and these comprise: agricultural and horticultural crops – 550 species (87%); forestry crops – 113 species (18%); ornamental crops – 46 species (7%). Euro+Med PlantBase indicates that at least 95 of these species (15%) are cultivated in Norway – of these species, 56 (59%) are agricultural and horticultural crops, 45 (47%) are forestry crops and 10 (11%) are ornamental crops. By comparison, taking a southern European example, of the 6669 crop and CWR species found in the Spanish territories, 5947 species (89%) are included in the agricultural and horticultural crop group, 659 (10%) in the forestry group, 2073 (31%) in the ornamental group and 4829 (72%) in the medicinal and aromatic plant group. Of these, 1279 (19%) are known to be cultivated worldwide (agricultural and horticultural crops – 1172 species (92%); forestry crops – 173 species (14%); ornamental crops – 92 species (7%)) and of the 215 species recorded by Euro+Med PlantBase as cultivated in Spain, 194 (90%) are agricultural and horticultural crops, 54 (25%) are forestry crops and 20 (9%) are ornamental crops. Notable are the significantly different percentages of agricultural and horticultural crops and forestry species cultivated in Norway and Spain.

Because Euro+Med PlantBase is organized into geographical units, it is also possible to look at the proportion of crop and CWR species within different intranational regions, where they exist. This is particularly interesting for those nations that include islands – especially, the oceanic islands such as the Canary Islands (Spain) and the Azores (Portugal) – and also other islands such as Sicily and Malta (Italy) and Corsica (France). Islands exhibit high levels of endemism due to their isolation from continental areas, so they are natural reservoirs of unique genetic diversity. However, it is widely recognized that island populations are also extremely vulnerable to genetic erosion because of the disruption caused by human colonization and associated biological invasions; for example, see Loope and Mueller-Dombois (1989), Schofield (1989), Bramwell (1990), Vitousek (1992) and Simberloff (1995). Taking Spain as an example, around 10% of the crop and CWR taxa of the Spanish territories occur in the Canary Islands – taxa that are not found in mainland Spain – and, of these, an estimated 249 species and 162 subspecies are endemic.[2] The islands of Sicily and Malta also contain a large proportion of the crop and CWR species of Italy – 2404 out of a total of 5712 species. Of the species found in Sicily and Malta, 277 are not found in mainland Italy and of these, 24 are recorded as endemic.[3] Of these endemic species, 23 fall into the agricultural and horticultural group, 3 in the forestry group, 13 in the ornamental group and 21 in the medicinal and aromatic group. As these taxa are endemic to small islands, their conservation may be considered of high priority due to their potential use for crop improvement in the future, combined with their innate vulnerability as island populations.

It is therefore possible to extract a list of crop and CWR taxa for each nation in the Euro-Mediterranean region and to provide a breakdown of the taxa for each geographical unit per nation, for those nations where this occurs. National crop and CWR lists have already been sent to each National PGR Coordinator in the region. Individual nations can then use these lists as a basis for conservation planning, once the list has been checked and verified to account for any potential errors. In turn, nations can feed back any errors they have found and their proposed corrections to the Euro+Med PlantBase Secretariat. Any changes that are made to Euro+Med PlantBase will automatically be made in the CWR Catalogue, which will remain available through the Internet. The Catalogue can be utilized not only to aid national conservation planning, but also to estimate the distribution of crops and their wild relatives within the region – for example, to aid regional conservation planning within the EU. Furthermore, the data can be used to target those taxa that have limited distributions (i.e. they occur in one to a few nations or intranational regions) (see Ford-Lloyd *et al*., Chapter 6, this volume). For example, of the 25,687 crop and CWR species in the Euro-Mediterranean region, at least 2873 (11%) are endemic to one nation.[4] One of

[2] Esti ates are ased on taxa onl re orded as o rrin in the Canar Islands and ende i to the eo ra hi al nit Ma aronesia .

[3] Anal sis o the Catalo e data indi ates that there are ro a l si ni i antl ore ende i C R s e ies in Si il (ossi l as an as 86). Ho e er, the data are not o lete there ore, sin the rrent data set, e annot e ertain o the exa t n er.

[4] This is a onser ati e esti ate e a se there are ore s e ies re orded in E ro Med PlantBase in onl one o ntr (6867) than are re orded as ende i to the E ro-Mediterranean re ion, t the data ha e not et een eri ied and e annot e ertain that these taxa do not o r in other o ntries.

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the major reasons for providing an information resource on where crop and CWR taxa can be found and for conserving these taxa is for their utilization as gene donors for crop improvement. The CWR Catalogue provides the information needed for plant breeders to source new material and for conservationists to collect material from as wide a range of a taxon's distribution as possible.

5.3.4 Major and minor food crops

So far, we have looked at the number of species within four socio-economically important plant groups: agricultural and horticultural crops, forestry crops, ornamentals and medicinal and aromatic plants. This is useful information, but many people might ask, how many species are found in the region in the major crop groups or within the world's food crops? This is a very good question and one which we have at least partially addressed by looking at the major and minor food crops of the world. Using the food crops of major significance (major food crops) and secondary or local importance (minor food crops) listed by Groombridge and Jenkins (2002), an analysis was undertaken to ascertain how many taxa (cultivated and wild, native and introduced) are found in the Euro-Mediterranean region within the major and minor food crop groups.

Of the 28 major food crop genera of the world, 22 occur in the Euro-Mediterranean region – 15 (54%) of these encompassing wild relatives (Table 5.7). There are 219 species and 100 subspecific taxa (subspecies and varieties) within these major food crop genera which can be found growing in the region. Of these, 106 species are known to be cultivated worldwide and at least 44 species and 24 subspecies are recorded by Euro+Med PlantBase as being cultivated in the region. National-level analysis is required to ascertain the exact number of cultivated and wild-occurring taxa within this list; however, even those taxa that are cultivated, whether also found in their wild form or not, may be a useful, if not vital source of germplasm for crop improvement, especially locally adapted forms or landraces. Four (11%) of the 38 major food crops of the world are native to the Euro-Mediterranean region: cereals – *H. vulgare* L. (barley) and *T. aestivum* L. (wheat); leaf vegetables – *B. oleracea* L. (cabbage); and oil crops – *O. europaea* L. (olive).[5] Three of these crops are native to Europe (as defined by Hollis and Brummitt, 2001): wheat, cabbage and olive.

Within the 28 major food crop genera of the world, 57 species are endemic to the Euro-Mediterranean region. Of these, at least 11 species are endemic to only one nation[6] and many of these are limited to islands

[5] *Vigna unguiculata* (L.) al . is also re orded E ro Med PlantBase as nati e to E t, t its nati e distri tion is ro a l li ited to s -Saharan A ri a there ore, it is ro a l nat rali ed in E t.

[6] Esti ate ased on E ro Med PlantBase (ersion Se te er 2005) data onl . There are li el to e rther s e ies ithin the a or and inor ood ro enera re orded in E ro Med PlantBase in onl one o ntr , t the data ha e not et een eri ied and e annot e ertain that these taxa do not o r in other o ntries.

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Table 5.7. Ma or ood ro s o the orld ith ild relati es in the E ro-Mediterranean re ion (in l din oth nati e and introd ed taxa), the n er o s e ies and s s e i i taxa ithin ea h en s (in l din ro s) and the a or ood ro s e ies nati e to the re ion.

	Cro [a]	en s	No. o s e ies	No. o s - s e i i taxa	Nati e ro s e ies
	Barle	*Hordeum* L.	1	8	*H. vulgare* L.
	Beans	*Vigna* Sa i	4	1	
	Ca a e	*Brassica* L.	4	54	*B. oleracea* L.
	Millet	*Echinochloa* P. Bea .	11	2	
	Millet	*Eleusine* aertn.	5	2	
	Millet	*Panicum* L.	21		
	Millet	*Pennisetum* Ri h.	11	5	
	Millet	*Setaria* P. Bea .	16	7	
	Oli e	*Olea* L.	4	5	*O. europaea* L.
	Potato	*Solanum* L.	60	6	
	R e	*Secale* L.	6		
	Sor h	*Sorghum* Moen h	8	0	
	S n lo er seed	*Helianthus* L.	12	0	
	heat	*Triticum* L.	1	4	*T. aestivum* L.
	Ya	*Dioscorea* L.	1	0	
Total	11	15	219	100	4

[a]Ma or ood ro s ased on ood ro s o a or si ni i an e listed roo rid e and Jen ins (2002).
S s e ies and arieties.
Vigna unguiculata (L.) al . is re orded E ro Med PlantBase as nati e to E t its nati e distri tion is ro a l li ited to s -Saharan A ri a there ore, it is ro a l nat rali ed in E t.
Not a li a le.

(Table 5.8). For example, *Brassica balearica* Pers. is endemic to the Balearic Islands (Spain), *B. rupestris* Raf., *B. macrocarpa* Guss. and *B. villosa* Biv. are endemic to the islands of Sicily and Malta (Italy), *B. hilarionis* Post is endemic to Cyprus and *Solanum patens* Lowe and *S. trisectum* Dunal are endemic to Macaronesia (possibly endemic to the island of Madeira). In addition, 46 subspecies within the 28 major food crop genera of the world are endemic to the Euro-Mediterranean region and at least 22 of these are endemic to only one nation (Table 5.8). Again, some of these taxa are limited to islands; for example, *B. oleracea* subsp. *bourgeaui* (Webb) Gladis & K. Hammer and *O. europaea* subsp. *guanchica* P. Vargas, J. Hess, Muñoz Garm. & Kadereit are only found in the Canary Islands (Spain).

Of the 51 minor food crop genera of the world (listed by Groombridge and Jenkins, 2002), 39 (76%) occur in the Euro-Mediterranean region – 35 (69%) of these encompassing wild relatives (Table 5.9). Within these minor food crop genera, 938 species and 372 subspecific taxa (subspecies and varieties) can be found growing in the region. Of these, 382 species and 46 subspecies are endemic and at least 99 species and 41 subspecies are endemic to only one nation (Table 5.8). Of the 69 minor food crops of the world, 23 (33%) are native to the Euro-Mediterranean region and 22 are native to Europe.

Table 5.8. Taxa ithin the 28 a or and 51 inor ood ro enera o the orld ende i to one nation in the E ro-Mediterranean re ion.[a]

Cro	Taxon	Ende i to
Wild relatives of major food crops		
Ca a e	*Brassica balearica* Pers.	Baleares (S ain)
	B. cadmea O.E. S h l	ree e
	B. cretica s s . *laconica* M.A. st. Sno er	ree e
	B. desertii Danin Hed e	Sinai (E t)
	B. desnottesii E . Maire	Moro o
	B. elongata s s . *imdrhasiana* el	Moro o
	B. elongata s s . *subscaposa* (Maire eiller) Maire	Moro o
	B. fruticulosa s s . *numidica* (Coss.) Maire	Al eria
	B. fruticulosa s s . *pomeliana* Maire	Al eria
	B. fruticulosa s s . *radicata* (Des .) Batt.	Al eria
	B. hilarionis Post	C r s
	B. macrocarpa ss.	Si il ith Malta (Ital)
	B. nivalis s s . *jordanoffii* (O.E. S h l) A ero d Leadla	B l aria
	B. nivalis Boiss. Heldr. s s . *nivalis*	ree e
	B. oleracea s s . *bourgeaui* (e) ladis K. Ha er	Canar Islands
	B. repanda s s . *almeriensis* e -Ca o	S ain
	B. repanda s s . *blancoana* (Boiss.) He ood	S ain
	B. repanda s s . *cadevallii* (Font er) He ood	S ain
	B. repanda s s . *cantabrica* (Font er) He ood	S ain
	B. repanda s s . *dertosensis* Molero Ro ira	S ain
	B. repanda s s . *diplotaxiformis* (Maire) e -Ca o	Moro o
	B. repanda s s . *galissieri* (ira dias) He ood	Fran e
	B. repanda s s . *glabrescens* (Poldini) e -Ca o	Ital
	B. repanda s s . *gypsicola* e -Ca o	S ain
	B. repanda s s . *humilis* (DC.) O. Bol s Vi o	Fran e
	B. repanda s s . *silenifolia* (E .) re ter B rdet	Moro o
	B. rupestris Ra .	Si il ith Malta (Ital)
	B. spinescens Po el	Al eria
	B. villosa Bi .	Si il ith Malta (Ital)

Oli e	*Olea europaea* s s . *cerasiformis* . K n el S ndin	Madeira, Porto Santo, Desertas (Port al)
	O. europaea s s . *guanchica* P. Var as, J. Hess, M o ar . Kadereit	Canar Islands (F erte ent ra ith Lo os, Teneri e, Lan arote ith ra iosa, La Pal a, Hierro, o era, ran Canaria) (S ain)
Potato	*Solanum patens* Lo e	Ma aronesia (ossi l ende i to Madeira (Port al))
	S. trisectum D nal	Ma aronesia (ossi l ende i to Madeira (Port al))
Wild relatives of minor food crops		
Onion, arli	*Allium autumnale* P. H. Da is	C r s
	A. bourgeaui s s . *creticum* Both er	Crete (ith Kar athos, Kasos and a dhos) (ree e)
	A. callimischon Lin s s . *callimischon*	ree e
	A. chrysantherum Boiss. Re t.	T r e
	A. chrysonemum Stearn	S ain
	A. circinnatum Sie er	Crete (ith Kar athos, Kasos and a dhos) (ree e)
	A. corsicum Ja ein, J.-M. Tison, Des h tres H. Co der	Corsi a (Ital)
	A. cupani s s . *cyprium* Mei le	C r s
	A. czelghauricum Bord .	T r e
	A. deciduum hata Koll ann s s . *deciduum*	T r e
	A. deciduum s s . *retrorsum* hata Koll ann	T r e
	A. djimilense Re el	T r e
	A. eldivanense hata	T r e
	A. favosum ahar.	ree e
	A. fuscum aldst. Kit. s s . *fussii*	Ro ania
	A. guttatum s s . *dilatatum* (ahar.) B. Mathe	Crete (ith Kar athos, Kasos and a dhos) (ree e)
	A. gorumsense Boiss.	T r e
	A. grosii Font er	I i a ith For entera (S ain)
	A. heldreichii Boiss.	ree e
	A. hierochuntinum Boiss.	Israel
	A. hierosolynmorum Re el	Israel
	A. humbertii Maire	Al eria
	A. hymettium Boiss. Heldr.	ree e
	A. ilgazense hata	T r e
	A. incensiodorum Radi	Croatia

Continued

Table 5.8. *Continued*

Cro	Taxon	Ende i to
	A. insubricum Boiss. Re t.	Ital
	A. integerrimum ahar.	ree e
	A. junceum s s . *tridentatum* Koll ann, hata M. Ko n	T r e
	A. karamanoglui Ko n Koll ann	T r e
	A. kastambulense Koll ann	T r e
	A. kurtzianum Koll ann	T r e
	A. lenkoranicum Mis .	A er ai an
	A. leonidi rossh.	A er ai an
	A. luteolum Hal s	ree e
	A. macedonicum ahar.	ree e
	A. mareoticum Born . a a	E t
	A. mariae Bord .	A er ai an
	A. materculae Bord .	A er ai an
	A. negrianum Maire eiller	Li a
	A. nemrutdaghense Kit Tan Sor er	T r e
	A. olympicum Boiss.	T r e
	A. palentinum Losa P.Monts.	S ain
	A. paniculatum s s . *antiatlanticum* (E . Maire) Maire eiller	Moro o
	A. paniculatum s s . *breviscapum* Litard. Maire	Moro o
	A. paniculatum s s . *exaltatum* Mei le	C r s
	A. parnassicum (Boiss.) Hal s	ree e
	A. phthioticum Boiss.	ree e
	A. pruinatum S ren .	Port al
	A. pruinatum ar. *bulbiferum* Co t.	Port al
	A. regnieri Maire	Moro o
	A. robertianum Koll ann	T r e
	A. rouyi a t.	S ain
	A. ruhmerianum As h.	Li a
	A. seirotrichum D ellier	Al eria
	A. sintenisii Fre n	T r e

	A. talyschense Mis .	A er ai an
	A. tardans re ter ahar.	Crete (ith Kar athos, Kasos and a dhos) (ree e)
	A. trichocnemis J. a	Al eria
	A. valdecallosum Maire eiller	Moro o
	A. vuralii Kit Tan	T r e
	A. willeanum Hol oe	C r s
S ar eet	*Beta nana* Boiss. Heldr.	ree e
	B. patula Aiton	Madeira, Desertas (Port al)
M stard seed, ra e seed	See a or ro s, a a e (*Brassica* s .)	
Chi ea	*Cicer graecum* Boiss.	ree e
Ha el, il ert	*Corylus cervorum* Petro	A er ai an
Arti ho e	*Cynara alba* DC.	S ain
	C. baetica (S ren .) Pa	S ain
	C. cyrenaica Maire eiller	Li a
	C. hystrix Ball	Moro o
Carrot	*Daucus carota* s s . *gadecaei* (Ro E. . Ca s) He ood	Fran e
	D. tenuisectus Coss.	Moro o
Fi	*Ficus hyrcana* rossh.	A er ai an
Mate	*Ilex perado* Aiton s s . *perado*	Madeira (Port al)
Lett e	*Lactuca impure* Maire	Moro o
	L. livida Boiss. Re t.	S ain
	L. longidentata DC.	Sardinia (Ital)
	L. reviersii Litard. Maire	Moro o
	L. seticuspis Boiss.	S ria
	L. triquetra (La ill.) Benth. Hoo . .	Le anon
	L. viminea s s . *alpestris* (and.) Fer o	Crete (ith Kar athos, Kasos and a dhos) (ree e)
	L. virosa s s . *cornigera* (Pa Font er) E . Maire	Moro o
	L. watsoniana Trel.	A ores (Faial, Pi o, S o Jor e, S o Mi el, Ter eira) (Port al)
Al ond, a ri ot, l , herr	*Prunus lusitanica* s s . *azorica* (Mo ill.) Fran o	A ores (Ter eira, S o Mi el, S o Jor e, Pi o) (Port al)
	P. ramburii Boiss.	S ain
	P. spinosa s s . *insititioides* (Fi alho Co t.) Fran o	Port al

Continued

Table 5.8. *Continued*

Cro	Taxon	Ende i to
Pear	*Pyrus communis* s s . *mamorensis* (Tra .) Maire	Moro o
	P. complexa R t o	Ar enia
	P. elata R t o	Slo enia
	P. hakkiarica Bro i	T r e
	P. magyarica Ter	H n ar
	P. mamorensis Tra .	Moro o
	P. medvedevii R t o	Ar enia
	P. nutans R t o	Ar enia
	P. raddeana orono	Ar enia
	P. rossica A.D. Danilo	R ssia
	P. sosnovskyi Fed.	Ar enia
	P. tamamschianae Fed.	Ar enia
	P. voronovii R t o	Ar enia
	P. zangezura Malee	Ar enia
Bla rrant,	*Ribes multiflorum* s s . *sandalioticum* Arri oni	Sardinia (Ital)
red rrant	*Ribes sardoum* Martelli	Sardinia (Ital
A er ine	See a or ro s, otato (*Solanum* s .)	
Broad ean	*Vicia bifoliolata* Rodr.	Baleares (S ain)
	V. capreolata Lo e	Madeira, Desertas (Port al)
	V. costae A. Hansen	Madeira, Porto Santo (Port al)
	V. ferreirensis o der	Madeira, Porto Santo (Port al)
	V. glauca s s . *giennensis* (C atre .) Blan a F. Valle	S ain
	V. pectinata Lo e	Madeira (Port al)
	V. sativa s s . *devia* J. . Costa	Madeira, Porto Santo (Port al)
	V. sinaica Bo los	Sinai (E t)

[a]Esti ate ased on E ro Med PlantBase (ersion Se te er 2005) data onl . There are li el to e ore sin le o ntr ende i taxa ithin the a or and inor ood ro enera, t these are not eri ied as sin le o ntr ende i taxa in this data set.

Table 5.9. Minor ood ro s o the orld ith ild relati es in the E ro-Mediterranean re ion (in l din oth nati e and introd ed taxa), the n er o s e ies and s s e i i taxa ithin ea h en s (in l din ro s), and the inor ood ro s e ies nati e to the re ion.

Cro [a]	en s	No. o s e ies	No. o s - s e i i taxa	Nati e ro s e ies
Al ond	*Prunus*	41	24	*P. dulcis* (Mill.) D.A. e
A le	*Malus*	12	4	*M. domestica* Bor h.
A ri ot	*Prunus*	41	24	*P. armeniaca* L.
Arti ho e	*Cynara*	10		*C. scolymus* L.
A er ine	*Solanum*	60	6	
A o ado	*Persea*	1	0	
Bla rrant	*Ribes*	18	5	*R. nigrum* L.
Broad ean	*Vicia*	141	7	
Carrot	*Daucus*	26	18	*D. carota* L.
Cherr	*Prunus*	41	24	*P. avium* L.
Chi ea	*Cicer*	17	0	*C. arietinum* L.
C er	*Cucumis*	7	2	
Date	*Phoenix*		0	*P. dactylifera* L.[d]
Fi	*Ficus*	10	4	*F. carica* L.
Fil ert	*Corylus*	11	0	*C. maxima* Mill.
Fonio	*Digitaria*	11	2	
arli	*Allium*	276	76	
ra e	*Vitis*	10	2	*V. vinifera* L.
Ha el	*Corylus*	11	0	*C. avellana* L.
Lentil	*Lens*	8	0	*L. culinaris* Medi .
Lett e	*Lactuca*	1	11	
L in	*Lupinus*	15	8	
Mate	*Ilex*	4	8	
Melon	*Cucumis*	7	2	*C. melo* L.
Melon seed/ ater elon	*Citrullus*	2	0	*C. lanatus* (L.) S hrad.
M stard seed	*Brassica*	4	54	
Oats	*Avena*	29	17	
Onion	*Allium*	276	76	
Pea	*Pisum*	2	5	*P. sativum* L.
Pear	*Pyrus*	49	16	*P. communis* L.
Pista hio	*Pistacia*	7	5	
Pl	*Prunus*	41	24	*P. domestica* L.
inoa	*Chenopodium*	51	16	
Ra eseed	*Brassica*	4	54	*B. napus* L.
Red rrant	*Ribes*	18	5	*R. rubrum* L.
Sesa e seed	*Sesamum*	2	0	
S ina h	*Spinacia*	2	0	
Stra err	*Fragaria*	12		
S ar eet	*Beta*	14	6	*B. vulgaris* L.
S eet otato	*Ipomoea*	1	1	

Continued

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Table 5.9. *Continued*

	Cro [a]	en s	No. o s e ies	No. o s - s e i i taxa	Nati e ro s e ies
	Taro	*Colocasia*	1	0	
	To ato	*Lycopersicon*	2	2	
	aln t	*Juglans*	6	0	*J. regia* L.
Total	4	5	9 8[e]	72[e]	2

[a]Minor ood ro s ased on ood ro s o se ondar or lo al i ortan e listed roo rid e and Jen ins (2002).
S s e ies and arieties.
Persea indica (L.) S ren . o rs in the A ores onl .
[d]All ro s e ies nati e to the E ro-Mediterranean re ion are nati e to E ro e, ex e t *Phoenix dactylifera*.
[e]The total n er o s e ies and s s e i i taxa ithin enera ontainin inor ood ro s o the orld (i.e. not the ol n totals).
Not a li a le.

The major and minor food crop groups that can be found in the Euro-Mediterranean region, along with other crops of high socio-economic value that are not included in this analysis, for example, forage and fodder crops, are an important genetic resource which may contribute to crop improvement in the future. Taxa that have limited distributions, particularly those that are endemic to one country should be a high priority for conservation and steps need to be taken to assess their conservation status, both *in situ* and *ex situ* (see Ford-Lloyd *et al*., Chapter 6, this volume, for further discussion about prioritization).

5.3.5 How many CWR are included in the IUCN Red List of Threatened Species?

The answer to this question is simple – currently, very few. The CWR Catalogue data were cross-checked with the 2004 IUCN Red List of Threatened Species to reveal only 161 species and 23 subspecific CWR taxa that occur in the Euro-Mediterranean region are included in the global Red List[7] (Table 5.10). The majority of these taxa are trees and the explanation for this is that much work has been undertaken in the past decade to assess the conservation status of the world's trees; for example, see Oldfield *et al*. (1998) and Farjon (2001). Of the CWR taxa included, 130 are native to the region and 76 are endemic. At least 13 of these are endemic to only one country and of these, one is extinct in the wild (*Betula szaferi* Jentys-Szaferowa & Staszk.) and two are critically endangered (*Abies nebrodensis* (Lojac.) Mattei, endemic to Sicily (Italy), and *Salix tarraconensis* Pau, endemic to Spain). Of the CWR species included in the Red List, 120 fall into the agricultural and horticultural crop group,[8] 152 in the forestry group, 124 in the ornamental group and 148 in the medicinal

[7] Mat hin arried o t ith a e ted na es in the Catalo e onl .
[8] Altho h ost o the C R s e ies in the Red List are trees, the are in l ded in the a ri lt ral and horti lt ral ro ro e a se Mans eld s Data ase in l des a er ide ran e o lti ated lants.

Table 5.10. The n er o C R taxa (s e ies, s s e ies and arieties) that o r in the E ro-Mediterranean re ion that are in l ded in the 2004 IUCN Red List o Threatened S e ies.[a]

Red List ate or	No. o taxa	No. o nati e taxa	No. o ende i taxa	Taxa ende i to one nation[d]
Extin t in the ild	1	1	1	1
Criti all endan ered	14	10	6	2
Endan ered	9	9		0
V lnera le		28	14	6
Least on ern	2	2	2	0
Lo er ris /near threatened	1	27	17	0
Lo er ris / onser ation de endent	11	8	5	2
Lo er ris /least on ern	77	40	25	0
Data de i ient	6	5		2
Total	184	1 0	76	1

[a]Anal sis ased on taxa at hin a e ted na es in the C R Catalo e onl .
The taxa listed ha e een assessed sin the 1994 Cate ories and Criteria (IUCN, 1994).
Taxa nati e and ende i to the E ro-Mediterranean re ion.
[d]Taxa eri ied as ende i a ordin to E ro Med PlantBase (ersion Se te er 2005).

and aromatic group, so at least we know that the small number of CWR included have a wide range of uses. Only one taxon, *O. europaea* subsp. *cerasiformis* is a wild relative of a major food crop (olive) – 16 taxa are wild relatives of the minor food crops: almond, apricot, avocado, cherry, date, mate, pear and plum.

While it is interesting to look at which CWR taxa are included in the global Red List, we cannot draw any firm conclusions from this analysis, except to state obviously that there are currently very few taxa included. We must not assume that only few CWR are under threat, because although it is the Red List of Threatened Species, not all species listed are under threat – they have simply been assessed using the IUCN criteria. A Red List assessment may show that a taxon is not threatened, but the taxon will still appear in the Red List. It is only those taxa assigned the categories 'critically endangered', 'endangered' and 'vulnerable' that are considered threatened – the other categories present the conservation status of the taxon and provide a reference point for future monitoring. In fact, of this small number of assessed CWR taxa, 30% have been categorized as threatened and 42% as lower risk or least concern (Table 5.10). We cannot take this small sample of global Red List assessments as representative of CWR in general, but it would be interesting to review the percentage of threatened CWR over time, as more taxa are assessed and added to the List.

One reason for the lack of CWR taxa included is likely to be that the vast majority of plant taxa listed in the 1997 IUCN Red List of Threatened Plants (Walter and Gillett, 1998) have not yet been evaluated against the revised Red List Criteria and are therefore not included in the 2004 Red List. Analysis of the 1997 Red List would probably provide a more realistic picture of progress with Red Listing of CWR, but to ascertain how many CWR are included in the 1997 Red List, we would need access to the electronic data set, which was not available for this analysis (except through an online search facility – see WCMC and RBG Edinburgh, no date). However, analysis of IPA data indicates that at least 488 European CWR species were categorized as globally threatened in the 1997 Red List.

Another reason for the lack of CWR species in the Red List may be that, historically, there has not been a group of specialists taking CWR Red Listing in hand. The establishment of the CWR Specialist Group (CWRSG) of the IUCN Species Survival Commission should rectify this (see Dulloo and Maxted, Chapter 48, this volume). Ultimately, while it is useful to have global Red List assessments available for CWR taxa (or any plant taxa), it may be more useful to investigate which taxa have been assessed at national level. Again, national Red Listing, or investigating which CWR taxa are already included on national Red Lists, could be an important role for the CWRSG.

5.3.6 Does the EU Habitats Directive aid CWR conservation?

In 1992, the European Community adopted Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora (the EU Habitats Directive). The provisions of the Directive require EU member states to introduce a range of measures, including the protection of species listed in the Annexes, to undertake surveillance of habitats and species and produce a report every 6 years on the implementation of the Directive. Annexes I and II list natural habitat types and plant (and animal) species of community interest, 'whose conservation requires the designation of special areas of conservation', Annex IV lists plant (and animal) species of community interest 'in need of strict protection' (most species listed in Annex II are also listed in Annex IV) and Annex V lists plant (and animal) species of community interest 'whose taking in the wild and exploitation may be subject to management measures' (European Communities, 1995–2007). Species of community interest are those that are: (i) endangered, except those species whose natural range is marginal in that territory and which are not endangered or vulnerable in the western Palaearctic region; or (ii) vulnerable (i.e. believed likely to move into the endangered category in the near future if the causal factors continue operating); or (iii) rare (i.e. with small populations that are not at present endangered or vulnerable, but are at risk); the species are located within restricted geographical areas or are thinly scattered over a more extensive range; or (iv) endemic and requiring particular attention by reason of the specific nature of their habitat and/or the potential impact of their exploitation on their habitat and/or the potential impact of their exploitation on their conservation status (European Communities, 1995–2007).

Each member state is required to prepare and propose a national list of sites for evaluation in order to form a European network of sites of community importance (SCIs). Once adopted, these are designated by member states as special areas of conservation (SACs) and, along with special protection areas (SPAs) classified under the EC Birds Directive, form a network of protected areas known as Natura 2000.

Species listed in Annexes II, IV and V (as of March 2007, including data from all 27 member states) were cross-checked against the Catalogue to see how many CWR are included (Table 5.11).[9] There are 641 plant species listed

[9] Mat hin arried o t ith a e ted na es in the Catalo e onl .

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Table 5.11. C R o the E ro ean Union e er states in I ded in Annexes II, IV and V o the EU Ha itats Dire ti e.

S e ies list	No. o s e ies in the o r ro ro s: A ri lt ral and horti lt ral	Forestr	Orna ental	Medi inal and aro ati	Total no. o s e ies	Per enta e o EU C R s e ies	Per enta e o as lar lant s e ies in Annexes II, IV and V o the Ha itats Dire ti e
EU C R s e ies[a]	14,515	2,126	4,785	12,448	16,052		
Vas lar lant s e ies listed in Annexes II, IV and V o the EU Ha itats Dire ti e					641		
EU C R in HD Annex II	1	18	120	275	80	2	59
EU C R in HD Annex IV	70	21	1 7	12	422		66
EU C R in HD Annex V[d]	15	2	4	18	18	1	
EU C R HD riorit s e ies[e]	117	9	42	105	141	1	22
Total no. o EU C R in I ded in Annexes II, IV and V o the EU Ha itats Dire ti e	85	2	141	0	440		69

[a]In I des all ro and C R s e ies that o r ithin the territories o the 27 EU e er states.
Annex II in I des lant (and ani al) s e ies o o nit interest hose onser ation re ires the desi nation o s e ial areas o onser ation. Most s e ies listed in this Annex are also listed in Annex IV.
Annex IV lists lant (and ani al) s e ies o o nit interest in need o stri t rote tion.
[d]Annex V lists lant (and ani al) s e ies o o nit interest hose ta in in the ild and ex loitation a e s e t to ana e ent eas res.
[e]Priorit s e ies are endan ered s e ies or hi h the Co nit has arti lar res onsi ilit in ie o the ro ortion o their nat ral ran e hi h alls ithin the territor .
Not a li a le.

in Annexes II, IV and V – 440 (69%) of these are included in the CWR Catalogue. Of these, 385 species (60%) fall into the agricultural and horticultural crop group, 23 species (4%) in the forestry group, 141 species (22%) in the ornamental group and 330 species (51%) in the medicinal and aromatic plant group. A high percentage of priority species (endangered species for which the Community has particular responsibility in view of the proportion of their natural range which falls within the territory) are in the agricultural and horticultural, and medicinal and aromatic plant groups (83% and 74%, respectively). It is notable that only four species included in the Habitats Directive Annexes II, IV and V are wild relatives of major food crops: three *Brassica* species and one *Solanum* sp. This is out of a total of 153 wild relative species of major food crops that occur in the EU territories. A further 13 species are included in the minor food crop group, out of a total of 542.

It is not surprising that quite a high percentage of species listed in Annexes II, IV and V of the Habitats Directive are CWR because more than three-quarters of the flora of the region is of current or potential socio-economic use. What is striking is the relatively small percentage of CWR species listed overall as a proportion of the CWR flora of the region (3%); however, this equates almost exactly to the proportion of vascular plant species that occur in the EU territories included in the Habitats Directive Annexes (641 species out of an estimated total of 19,020). Perhaps this raises a question about the overall effectiveness of the Habitats Directive for plant conservation, let alone the conservation of CWR. Certainly, a small number of CWR in the major and minor food crop groups that are listed in the Habitats Directive Annexes is a strong indication that *in situ* CWR conservation of the most important groups is not being adequately addressed within the EU territories.

It is important to stress that the above analysis only takes into account the species listed in the Habitats Directive Annexes II, IV and V – there are, of course, many more species included within the habitats that are designated for conservation within the Natura 2000 network. As for any *in situ* conservation area, site inventories are required to find out which species are included. At EU level, these data are not available; however, it is possible to look at which CWR species are mentioned as characteristic of the habitats listed in the European Nature Information System (EUNIS) Database (EEA, 2007), some of which are included in the Habitats Directive Annex I (natural habitat types of community interest whose conservation requires the designation of SACs). Here, 1665 CWR species that occur in the EU territories are included (10% of the CWR flora of the EU) – 54 of these species are included in Annex II, 55 in Annex IV and five in Annex V. Of these, 91% are in the agricultural and horticultural crop group, 17% in the forestry group, 36% in the ornamental group and 78% in the medicinal and aromatic plant group. Nine wild relatives in the major food crop genera and 57 in the minor food crop genera, are included. Although not all these habitats are necessarily included in the Natura 2000 network, it is useful to discover that around 10% of the CWR flora of the EU is mentioned as characteristic of the habitats, because many of these habitats are included in the network – however, we cannot assume that these species are actively conserved.

5.3.7 Are CWR important in Important Plant Areas?

IPAs are natural or semi-natural sites exhibiting exceptional botanical richness and/or supporting an outstanding assemblage of rare, threatened and/or endemic plant species and/or vegetation of high botanical value (PlantLife International, no date). IPAs are not legal site designations, but a framework for identifying and highlighting the best sites for plants, and by implication, their conservation. Site selection is based on three criteria: threatened species, botanical richness and threatened habitats – a site qualifies as an IPA if it fulfils one or more criteria.

The CWR Catalogue data for Europe (as defined by Hollis and Brummitt, 2001) were compared with the list of species included in IPAs (designated under Criterion A) as of May 2005 (Table 5.12).[10] Criterion A sites hold significant populations of one or more species that are of global or European conservation concern. Criterion A is further divided into four categories: A(i) – the site contains globally threatened species; A(ii) – the site contains regionally threatened species; A(iii) – the site contains national endemic species with demonstrable threat not covered by A(i) or A(ii); A(iv) – the site contains near endemic or limited range species with demonstrable threat not covered by A(i) or A(ii) (Anderson, 2002). Species included under Criteria A(iii) and A(iv) are nationally threatened species from Belarus, Czech Republic, Slovakia, Estonia, Slovenia, Poland and Romania only, which were the first seven countries in Europe to identify IPAs (see Anderson *et al.*, 2005).

Nine hundred and twelve CWR species of Europe are included in the IPAs – 51% of the vascular plant species included in the IPAs and 5% of the CWR flora of Europe. Of these, 488 (54%) are globally threatened species[11] and 426 (47%) are regionally threatened. The endemic species included under Criteria A(iii) and A(iv) (Belarus, Czech Republic, Slovakia, Estonia, Slovenia, Poland and Romania only) represent around 10% of the CWR species included in the IPAs. Three percent of the agricultural and horticultural crops and CWR of Europe are included under the globally threatened Criterion A (i). Likewise, 2% of species in the forestry group, 4% in the ornamental group and 2% in the medicinal and aromatic group are included under this criterion. Looking at the overall number of European CWR species included in the IPAs, 5% of species in the agricultural and horticultural crop group are included, 3% in the forestry group, 7% in the ornamental group and 5% in the medicinal and aromatic plant group.

As for the CWR species included in the EU Habitats Directive, a relatively small percentage of the CWR species of Europe are included in IPAs (5%); however, this is in the context of the proportion of vascular plant species of Europe included in IPAs – 912 species out of an estimated total of 20,590 – around 4%. Again, the number of CWR in the major and minor food crop groups included in the IPAs may be an indication of how much attention is being paid to CWR in the context of this conservation initiative. With only three out of the 152 species in the major food crop genera that occur in Europe included and none of the 559 species in the minor food crop genera, we might conclude that more needs to be done to ensure that CWR are represented in IPAs.

[10] Mat hin arried o t ith a e ted na es in the Catalo e onl .
[11] Based on the 1997 IUCN Red List o Threatened Plants (alter and illett, 1998).

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Table 5.12. C R o E ro e in l ded in I ortant Plant Areas (IPAs).

S e ies list	No. o s e ies in the o r ro ro s: A ri lt ral and horti lt ral	Forestr	Orna ental	Medi inal and aro ati	Total no. o s e ies	Per enta e o total E ro ean C R	Per enta e o total as lar lant s e ies in IPAs	Per enta e o total C R s e ies in IPAs
E ro ean C R s e ies[a]	15,828	2,267	5,12	1 ,727	17,495			
Vas lar lant s e ies in l ded in IPAs					1,80			
Criterion A(i) E ro ean C R s e ies (lo all threatened)	400	52	214	8	488		27	54
Criterion A(ii) E ro ean C R s e ies (re ionall threatened)	79	16	1 8	28	426	2	24	47
Criterion A(iii) E ro ean C R s e ies (national ende i s e ies not o ered A(i) or A(ii))	86	16	41	69	95	1	5	10
Criterion A(i) E ro ean C R s e ies (near ende i or restri ted ran e s e ies not o ered A(i) or A(ii))	8	2	22	7	86	1	5	9
Total E ro ean C R s e ies in IPAs	791	75	49	668	912	5	51	

[a]In l des all ro and C R s e ies that o r in E ro e (E ro e as de ined Hollis and Br itt (2001)).
S e ies in l ded nder Criteria A(iii) and A(i) are nationall threatened s e ies ro Belar s, C e h Re li , Slo a ia, Estonia, Slo enia, Poland and Ro ania onl .
In l ded nder Criterion A onl (A(iii) and A(i) s e ies ro Belar s, C e h Re li , Slo a ia, Estonia, Slo enia, Poland and Ro ania onl).
Not a li a le.

5.3.8 Are botanic gardens' living collections helping to conserve crop resources?

Using data extracted from the Plant Search database managed by Botanic Gardens Conservation International (BGCI, 2007), which is a database compiled from lists of living collections submitted to BGCI by the world's botanic gardens, an analysis of the number of crop and CWR taxa in cultivation in botanic gardens around the world was undertaken (Table 5.13).

Table 5.13. Cro and C R s e ies in otani ardens li in olle tions.[a]

	No. o s e ies in the o r ro ro s				
S e ies in Plant Sear h (B CI, 2007)	A ri lt ral and horti lt ral	Forestr	Orna ental	Medi inal and aro ati	Total no. o s e ies
Total no. o s e ies					89,80
Cro and C R s e ies	54,828	12,199	22,522	8, 75	62,746
S e ies lti ated orld ide	6, 88				
Total s e ies in the a or ood ro enera					791
Cro s e ies in the a or ood ro enera					2
Total s e ies in the inor ood ro enera[d]					2,668
Cro s e ies in the inor ood ro enera					6
Cro and C R s e ies in E ro e and the Mediterranean[e]	9,107	1, 12	,6 1	7,55	9,948
E ro-Mediterranean s e ies in the a or ood ro enera					152
E ro-Mediterranean s e ies in the inor ood ro enera					521

[a]Based on anal sis o data ontained in Plant Sear h (B CI, 2007).
S e ies in Plant Sear h at hin s e ies in Mans eld s Data ase (a e ted na es and s non s).
Mans eld s Data ase in l des lti ated edi inal and aro ati lants.
Based on ood ro s o a or si ni i an e, listed roo rid e and Jen ins (2002).
[d]Based on ood ro s o se ondar or lo al i ortan e, listed roo rid e and Jen ins (2002).
[e]Mat hin a e ted s e ies in the C R Catalo e or E ro e and the Mediterranean. Total no. o s e ies in the Catalo e 25,687.
Not a li a le, or data not a aila le.

Initial results indicate that botanic gardens may be the storehouses of important crop resources and other species of socio-economic importance. Of the 25,687 accepted species in the Euro-Mediterranean Catalogue, 9948 (39%) are recorded in Plant Search as being cultivated in botanic gardens around the world. Of these, 92% are included in the agricultural and horticultural crop group, 13% in the forestry group, 36% in the ornamental group and 76% in the medicinal and aromatic group.

The above analysis only takes into account the socio-economically important species in the Euro-Mediterranean region. Taking a global view, of the 89,803 species included in Plant Search, 62,746 (70%) are species within the combined list of genera containing crops and wild-harvested medicinal and aromatic plants of the world (including synonymous genera in Mansfeld's Database) – at least 10% of these species are known to be agricultural and horticultural species cultivated worldwide. Breaking this list of 62,746 species down into the four crop groups, 87% are in the agricultural and horticultural group, 19% in the forestry group, 36% in the ornamental group and 61% in the medicinal and aromatic group – fairly consistent with the ratios of Euro-Mediterranean crop and CWR species in the database.

Although the total number of species housed in the botanic gardens' living collections that are included in the Plant Search database is not wholly representative of the world flora, if we assume that they are a representative sample, the figure of 70% is not far off what might be expected, since the results of the Euro-Mediterranean analysis indicate that at least three-quarters of the flora of the region are of current or potential socio-economic use. Of course, we cannot confirm this conclusion without further detailed analysis. Other possible explanations for the large proportion of species of socio-economic importance in cultivation in botanic gardens' living collections are that: (i) historically, some botanic gardens were physic gardens and therefore almost exclusively housed medicinal plants; (ii) some gardens were used as repositories and/or quarantine centres for the early movement of crops around the world; and (iii) many gardens have educational displays of crop plants to show visitors what they look like and how they grow; for example, coffee, tea, banana and coconut.

If we look at the major and minor food crop groups (as defined earlier in the chapter) we find that 791 species in the 28 major food crop genera of the world and 2668 in the 51 minor food crop genera can be found in cultivation in the botanic gardens whose collections are recorded in Plant Search – not a vast number, but significant none the less. It is notable that 41% of the species in the major food crop genera and 24% in the minor food crop genera are cultivated species listed in Mansfeld's Database. Perhaps the high proportion of cultivated species in the major food crop groups may be attributable to the fact that botanic gardens often maintain educational displays of important food crops and other cultivated plants.

So, what does this tell us about the potential role of botanic gardens' living collections in crop genetic resources conservation? Taxonomically (i.e. looking at the number of species included), this preliminary analysis indicates that botanic gardens may harbour important resources that could have a role to play in providing germplasm for crop improvement.

However, the analysis does not inform us of the quantity or quality of the plant material in cultivation.[12] Botanic gardens' living collections are sometimes accused of effectively being plant 'museums' because they frequently maintain only one or a few accessions of a taxon in cultivation. None the less, although they may not always conserve genetically representative samples of a taxon or population, the germplasm that is maintained may still be of some value, especially in cases where a taxon is severely threatened in the wild. Another common criticism of botanic gardens' living collections is that once plants have been kept in cultivation for several years, they may no longer resemble the genetic make-up of the wild form that was originally collected. This may be so, but only genetic analysis could reveal the true picture (i.e. if there is still wild material available to compare the cultivated material with). Furthermore, many botanic gardens are focusing their efforts on the conservation of threatened populations and these days are more aware of the need to collect and maintain representative samples.

Even if the germplasm itself is of limited use to plant breeders, perhaps the associated information contained in botanic gardens' collections databases, such as details on locations and habitats, may be a useful resource to the conservation and user community in itself. This, of course, is dependent on the quality and efficiency of botanic gardens' information management systems. Finally, we should acknowledge the important role that botanic gardens' living collections play in educating the public. Many botanic gardens already provide educational information about the importance of directly utilized plants to society – perhaps this role could be extended to include educational information about the wild relatives of crop plants, their role in future food security and what needs to be done to conserve them.

5.4 Conclusions

The Catalogue of CWR for Europe and the Mediterranean (Kell *et al*., 2005a) is the first comprehensive CWR Catalogue at a continental scale and, through extraction, for the countries included. It provides an informative regional overview of crop and CWR diversity and acts to raise awareness about the importance of crop genetic resources in the region, both within the professional PGR community and other interest groups. Furthermore, it provides the baseline data needed to monitor biodiversity change and to improve access to germplasm for the CWR user community. The Catalogue can be used as the basis for creating national crop and CWR inventories, as a vehicle for conservation gap analysis and for integrating CWR conservation into existing conservation initiatives. It is a core data set providing an opportunity for linking to and building on existing taxon data, such as information on uses, population biology, threats and *in situ* and *ex situ* conservation activities. The Catalogue is available online through CWRIS (PGR Forum, 2005), where users can search by

[12] This in or ation o ld e o tained onta tin indi id al otani ardens.

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taxon names and geographical units to obtain this information. To read more about CWRIS and for examples of use cases, see Kell *et al*. (Chapter 33, this volume).

The methodology used for creating the Euro-Mediterranean Catalogue can be applied in any part of the world, either at regional or national level. Although digitized floras are not immediately available in all parts of the world, increasingly, countries are working to create biodiversity databases, particularly in response to the requirements of the provisions of the CBD. Even without a digitized flora, it is possible to undertake the analysis, although this would obviously take more time.

An important and fundamental application of the CWR Catalogue is to aid gap analysis for CWR conservation – for example, by analysing which taxa are already included within existing protected areas and *ex situ* collections and to ascertain how many taxa are included in other conservation databases, such as the IUCN Red List of Threatened Species (IUCN, 2006). Some examples of how the data can be used in this way have been provided in this chapter. Although these are preliminary and largely broad brush-stroke investigations, results do indicate that we may not be paying sufficient attention to CWR in current conservation endeavours. We strongly urge policy makers and conservationists to give greater credence to the inclusion of crops and wild relatives within existing or new conservation initiatives (including legislation), both at regional and national level. For example, by creating a priority list of CWR for the Euro-Mediterranean region (see Ford-Lloyd *et al*., Chapter 6, this volume), combined with the formulation of national priority lists, the conservation status of these taxa could initially be assessed and a more detailed gap analysis undertaken. Building on the data that are now available, networks of national genetic reserves can be established, following the guidelines provided by the draft Global Strategy for CWR Conservation and Use (see Heywood *et al*., Chapter 49, this volume).

A more systematic approach to complementary CWR conservation is certainly needed. Looking, for example, at the number of species included in botanic gardens' living collections, we find that there are a significant number of CWR in cultivation around the world. However, it is likely that these were collected for diverse reasons, rather than specifically because of their value as gene donors for crop improvement. National PGR Coordinators and regional and international conservation organizations could do more to put in place a coordinated approach to CWR conservation. A combined approach targeting existing protected areas and establishing new *in situ* conservation sites where necessary, and encouraging managers of *ex situ* collections (gene banks and botanic gardens' living collections) to take a more systematic approach to CWR conservation is needed.

There is undoubtedly an urgent need to undertake Red List assessments for Euro-Mediterranean CWR and most likely for CWR worldwide. Red Listing could initially be undertaken in three phases: (i) the CWR taxa listed in the 1997 IUCN Red List of Threatened Plants could be reassessed using the 2001 Criteria (IUCN, 2001) and assessments submitted for inclusion in the IUCN Red List of Threatened Species; (ii) single country endemic taxa could be

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assessed and submitted for inclusion in the IUCN Red List; and (iii) national PGR Coordinators could establish which CWR are included in national Red Lists and make these data available for regional and global assessments.

Further investigation can be carried out to provide an indication of to what extent CWR are already conserved, both within the Euro-Mediterranean region and elsewhere in the world. Many taxon data sets are available electronically – it is simply a matter of working together and making the data accessible. For example, global protected area data are available and, using the CWR Catalogue for Europe and the Mediterranean (or other regional CWR inventories as they become available), analysis can be undertaken to assess how many species are afforded some level of protection *in situ*. At national level, the data can also be compared with protected area inventories and *ex situ* collections, which would provide a more detailed picture of CWR conservation within any given region. It would also be interesting to compare CWR inventories with the data contained in EURISCO (European Internet Search Catalogue of *Ex Situ* PGR Accessions) (ECPGR, no date), though this is not straightforward because the data within EURISCO do not currently follow a standard taxonomy.

Sharing and cross-checking conservation data sets is one way of assisting CWR conservation gap analysis. Another way is to bring CWR information together through the Internet, which provides a unique opportunity to link any number of information sources together. CWRIS (PGR Forum, 2005) (see Kell *et al*., Chapter 33, this volume), which was created under the auspices of the EC-funded project, PGR Forum (see Maxted *et al*., Chapter 1, this volume; PGR Forum, 2003–2005), goes some way towards achieving this goal. The Catalogue data housed in CWRIS is linked to a number of selected online information resources, such as the Germplasm Resources Information Network (GRIN) (USDA, ARS, National Genetic Resources Programme, 2006), IUCN Red List of Threatened Species (IUCN, 2006), Survey of Economic Plants for Arid and Semi-Arid Lands (SEPASAL) (Royal Botanic Gardens, Kew, 1999), International Legume Database and Information Service (ILDIS, 2007) and FAO Worldwide Information System on Forest Genetic Resources (REFORGEN) (FAO, no date). With the appropriate financial resources, the opportunity exists to develop CWRIS further as a sophisticated online tool to provide access to CWR information at both taxon and geographic level to cater for a wide range of user groups (Kell *et al*., Chapter 33, this volume).

The results presented in this chapter are based on data extracted from Euro+Med PlantBase (version September 2005). Euro+Med PlantBase is undergoing a process of critical review and updating by taxon experts on a family by family basis. Although it is not anticipated that the overall number of species included in the Catalogue will change significantly once the updates to Euro+Med PlantBase have been incorporated, there are likely to be some changes, particularly with regard to the number of single country endemic species. Currently, the coding system used in the database to record endemic species makes it difficult to gain a reliable estimate. However, crop and CWR lists extracted from the Catalogue have already been sent to National PGR Coordinators throughout the region. These lists can be used as a basis for the development of national CWR Catalogues and this may provide an opportunity to ascertain more accurately how many single country endemic species exist. Data from National PGR Coordinators could be fed back to the Euro+Med PlantBase Secretariat to be considered for inclusion in the database, and in turn, the data in the CWR Catalogue for Europe and the Mediterranean will be automatically updated.

The Catalogue shows that a large proportion of the Euro-Mediterranean flora is of current or potential socio-economic use, both within the region and elsewhere in the world. These resources need to be conserved to benefit the environment and humankind in the future. Knowing what occurs in nature in the region is a first step in CWR conservation. The next steps are to use the Catalogue data to establish conservation priorities, both regionally and nationally, then to ascertain which species are conserved and to what extent they are protected. This should be part of a coordinated systematic approach to the complementary conservation of CWR. This is likely to involve the establishment of new *in situ* sites or at least the adaptation of existing site management plans to accommodate monitoring and management of CWR populations, and systematic collection and *ex situ* conservation of genetically representative CWR population samples.

Results of this analysis confirm the direct and indirect use values of a high proportion of the vascular flora of the Euro-Mediterranean region. We may confidently assume that a similar proportion of the world's flora has the same current or potential use. The method used to create the Euro-Mediterranean Catalogue can be repeated in other regions of the world and/or nationally as a first step in putting in place a systematic complementary global approach to CWR conservation to ensure that these vital resources are maintained for the benefit of society worldwide. The Global Strategy for CWR Conservation and Use, which was a significant outcome of the First International Conference on CWR Conservation and Use (see Kell *et al.*, 2005b; Heywood *et al.*, Chapter 49, this volume) is already being taken forward as an adjunct to the ITPGRFA. This will provide the much-needed guidance and framework for a coordinated approach to the conservation and sustainable utilization of CWR.

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