UNIVERSITY OF BIRMINGHAM

A PRELIMINARY GLOBAL RED LIST ASSESSMENT OF SELECTED CROP WILD RELATIVES: CONSERVATION STATUS, ANALYSIS AND IMPLICATIONS

By

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A thesis submitted to the
University of Birmingham
for the degree of

MSCI BY RESEARCH

School of Biosciences
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September 2015

Abstract

Crop wild relatives (CWR) are valuable socio-economic resources that provide a genetic reservoir of potential adaptability for our food crops. Despite their importance, these vital resources are in dire need of sustainable and strategic conservation. The IUCN Red List Categories and Criteria are the world's most widely accepted methodology for assessing species' risk of extinction, and was applied to a selection of priority CWR extracted from the Harlan and de Wet CWR Inventory (Vincent *et al.*, 2013). Preliminary results show that, seventeen CWR species (6.3%) were found to be threatened with extinction, with 0.7% (two species) being Critically Endangered (CR), 3.4% (nine species) being Endangered (EN), and 2.2% (six species) being Vulnerable (VU). In addition to this, 60.7% of CWR species studied were found to be LC, and a further 29.6% were deemed DD. Threatened species were considered highest priority for conservation efforts, while monitoring and management of those species for which population is in decline is also important regardless of threat category. While the current project presents valuable insight, expansion of this to a larger, more representative sample of priority CWR species is advised. Further analysis highlighted the lack of data available for CWR in general and more specifically concerning population information such as size, status and trends; further research to increase the knowledge base for CWR is vital in securing the complementary and strategic conservation of these resources and future food security.

Acknowledgements

I would like to thank my supervisor Nigel Maxted for his patience and help throughout the duration of this project, as well as Shelagh Kell for her advice and support.

I would also like to thank Holly Vincent and Jade Phillips for their invaluable friendship and guidance. And last but certainly not least I would like to thank Dr. Hannah Fielder, without whom this project would not have reached completion.

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1 Introduction

1.1 Biodiversity: definition, threats and status

Biodiversity is a complex and dynamic entity which has spawned wide debate and various definitions over time. It can be simply explained as:

> ***"The number, variety, and variability of living things"***
>
> Groombridge (1992)

This kind of oversimplification can make the concept of biodiversity somewhat elusive and is sometimes seen as lacking the power to adequately confer the sheer complexities of the notion. Additionally for the scientific community the vague quality of simpler definitions makes quantification of biodiversity all the more difficult.

The concept put forward by the Convention on Biological Diversity (CBD) is one of the most widely used definitions of biodiversity:

> ***"the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems."***
>
> *Article 2,* CBD (1992)

This definition is popular as it encompasses the hierarchical view of biodiversity where variation may occur at any or all of three levels: genetic, species and ecosystem. This can be further organised into compositional, structural and functional components as demonstrated in Figure 1.1.

All elements of biodiversity have a profound impact on human wellbeing and the definition described above can be built upon by identifying the actual or potential value of biodiversity to humankind.

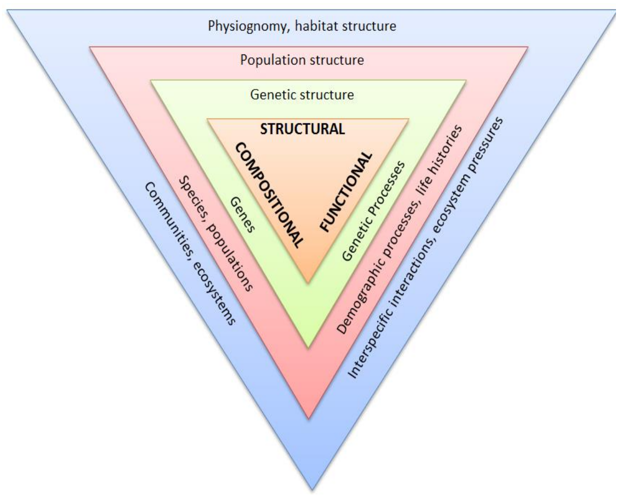


Figure 1.1 Defining the concept of biodiversity from a hierarchical viewpoint by depicting compositional, structural and functional variation at three levels of diversity (Source: adapted from Noss, 1990).

This can be achieved through the concept of ecosystem services which has been developed to provide a means of quantification of biodiversity and ecosystems in relation to the benefits that they create (or have the potential to create) for society. Ecosystem services can be defined in numerous ways, but broadly speaking are ***"the benefits that people obtain from ecosystems"*****.** This definition is taken from the Millennium Ecosystem Assessment (MA, 2005; sometimes abbreviated to MEA instead of MA) which was undertaken from 2001 to 2005 in order to:

> ***"…to assess the consequences of ecosystem change for human well-being and the scientific basis for action needed to enhance the conservation and sustainable use of those systems and their contribution to human well-being"***
>
> MA (2005)

Within the framework of the MA, ecosystem services can be categorised into: supporting services, provisioning services, regulating services, and cultural services, examples of which are shown in Figure 1.2 alongside their links with human well-being as found by the MA (MA,

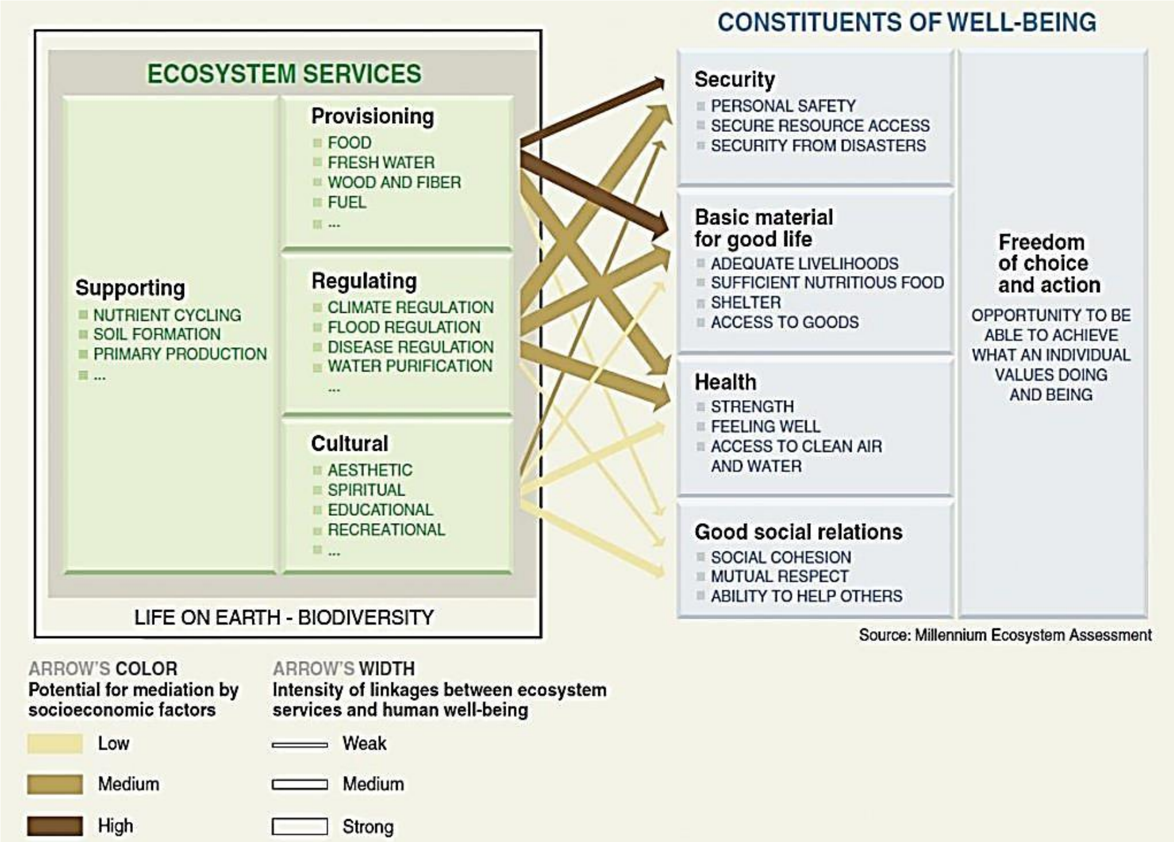


Figure 1.2 Benefits of ecosystem services to human well-being and the magnitude and irreplaceability of these benefits. Arrow colour shows the extent to which it may be possible to compensate for degraded ecosystem services through socio-economic factors while the width of arrow shows the strength of the link. (Source: MA, 2005).

2005). Appropriation of value of ecosystem services will vary on a regional scale and also it is necessary to mention that human well-being may be affected by additional, external factors (social, technological, economic, other environmental factors). In addition to this, the relationship between humankind and ecosystems is dynamic and so ecosystems are in turn affected by human well-being.

After having discussed biodiversity and the ecosystem services it provides, it is necessary to say that, despite being the least well studied level of biodiversity (out of genetics, species and ecosystems) (Hargreaves, 2011), genetic diversity is widely recognised as the one of the most important targets of conservation biology. This is mainly because diversity at this level is vital for adaptation to environmental change which facilitates the process of evolution. This relationship is illustrated by Reed and Frankham (2003) who demonstrated that heterozygosity is positively correlated with population fitness. Inbreeding, genetic drift, mutation, and migration are all mechanisms of evolutionary change that act upon genetic material. While mutation and migration provide a source of genetic diversity and hence the capacity to adapt to changing environments, inbreeding and genetic drift are both associated with the loss of genetic diversity and a reduction in reproductive fitness and adaptive potential which may lead to an increased risk of extinction.

Unfortunately biodiversity is threatened at all of the levels mentioned above and most threats have anthropogenic origins, as demonstrated in Figure 1.3 and discussed later in this section. There are five direct threats to biodiversity that are widely recognised in the literature, including the programme of work of the CBD (habitat change, invasive alien species, overexploitation, pollution and climate change). Unfortunately as demonstrated in Figure 1.3 most threats and their resultant stresses have a synergistic nature whereby the combined impact of one or more threats is more severe than their independent effects, and intensify as they progress. This often results in extinction and irreversible loss of biodiversity and is further discussed in relation to wild plants in section 1.3. It is thought that, current extinction rate is 100 to 1000 times higher than background extinction rate (Pimm *et al.,* 1995) and current demand upon the earth's natural resources is simply unsustainable. This is mainly due to the exponential increase in human population size and consumption pressure,

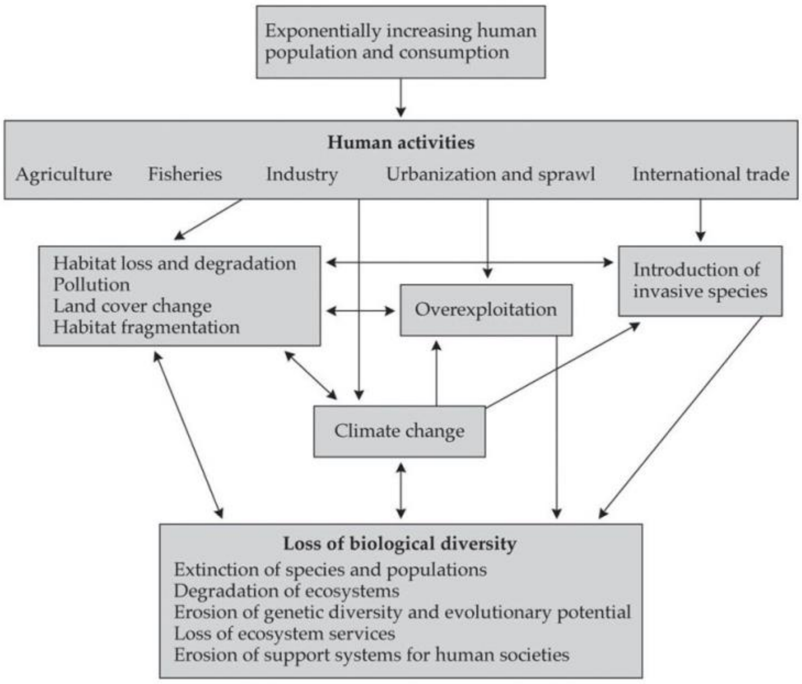


Figure 1.3 Major direct and indirect forces that threaten biodiversity. The most prominent direct threats are: habitat change, invasive alien species, overexploitation, pollution and climate change (Source: Groom *et al.,* 2006)

with the UN estimating that the global population will reach 9.7 billion people by the year 2050 (United Nations, Department of Economic and Social Affairs, Population Division, 2015). Given that humankind depends so profoundly on natural resources and biodiversity as shown in Figure 1.2, is it to our own detriment that we as a species comprise the biggest threat to biodiversity.

The main findings of the MA portray grave losses to biodiversity at all levels, and projects continuation or acceleration of this deterioration. Nearly all of the earth's ecosystems are recorded to have suffered dramatic transformations from human activity, with over half of the biomes assessed by the MA having undergone a 20-50% conversion to human use. Furthermore, the high current and projected species extinction rate is accompanied by an estimate that 10% to 50% of well-studied higher taxonomic groups are currently threatened with extinction when assessed using the IUCN (World Conservation Union, previously the International Union for the Conservation of Nature and Natural Resources) Red List Categories and Criteria version 3.1 (IUCN, 2001). Genetic diversity is also documented to have suffered global decline, especially in domesticated species (MA, 2005). Loss of genetic diversity is presumed to be occurring at a higher rate than loss of species because in addition to genetic erosion resulting directly from species loss, extant species are also subject to loss of genetic diversity through the processes highlighted earlier in this section (Maxted *et al.*, 1997b; Maxted and Kell, 2009). Efforts to halt or decelerate rate of decline at all levels of biodiversity need to be significant and this is especially true for genetic resources considering the threats that biodiversity is currently facing and the critical role of genetic diversity in potential adaptability to these rapidly changing environments.

The MA was partly established to facilitate and inform actions towards fulfilment of the CBD. The CBD is a global agreement that was established in 1992 by its Conference of the Parties (COP) to promote the preservation of biodiversity and its sustainable use. Unfortunately, the 2010 Biodiversity Target was not met in most areas with "*no indication of a significant reduction in the rate of decline in biodiversity, nor of a significant reduction of pressures upon it*" (CBD, 2013). The tenth meeting of the COP for the CBD adopted a revised and updated Strategic Plan for Biodiversity 2011-2020, which aims to:

> ***"…take effective and urgent action to halt the loss of biodiversity in order to ensure that by 2020 ecosystems are resilient and continue to provide essential services, thereby securing the planet's variety of life, and contributing to human well-being, and poverty eradication."***
>
> CBD, (2010a)

This is to be achieved through the Aichi Biodiversity Targets, three of which are aimed specifically at safeguarding biodiversity at the levels of ecosystems, species and genetic diversity (Strategic Goal C, Targets 11, 12, and 13 respectively) (CBD, 2010).

The Global Biodiversity Outlook 4 (GBO-4) (Secretariat of the Convention on Biological Diversity, 2014) reports progress towards meeting the aims set out by the CBD through assessment of current trends, status and projections. As can be seen in Figure 1.4, only one of the six elements that constitute target 11 (aimed at safeguarding ecosystems) predicts achievement for the 2020 deadline and this is dependent on implementation of committed protected area establishment. All other elements show a positive trend and state that meeting the 2020 target is possible but insufficient progress is currently being made.

Target 12 (towards safeguarding species) consists of two elements, both of which are not predicted to succeed by 2020, with further extinctions of threatened species expected and no sign overall of reduced risk of extinction for species in most decline. Target 13 (aimed at safeguarding genetic diversity) shows positive yet insufficient progress for three of the five constituent elements, while one element has insufficient data for evaluation, and a lack of *in situ* conservation for wild relatives of cultivated species means that the last element has not made any significant progress (Secretariat of the Convention on Biological Diversity, 2014; see following section for definition and description of crop wild relatives (CWR)). The main conclusions that can be draw from this are that insufficient progress is currently being made towards the safeguarding of global biodiversity by 2020 and the Aichi Biodiversity Targets will not be met unless efforts are increased. All of this information is summarised in Figure 1.4, where the key depicts meaning of each infographic within the 5 point progress scale and star system represents level of confidence based on available evidence where three stars represents high level of confidence and 0 or 1 star represents low level of confidence.

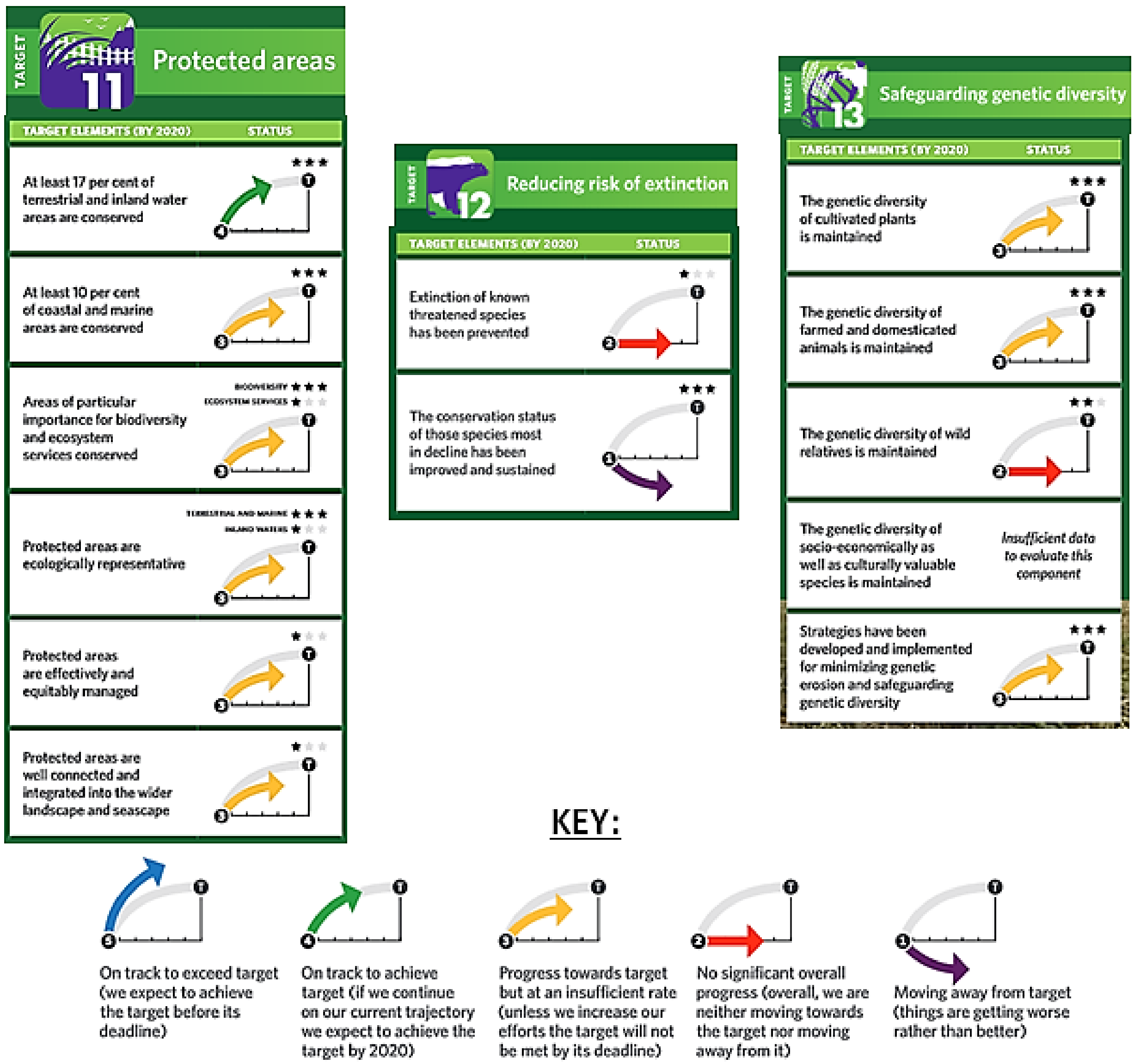


Figure 1.4 Progress towards meeting individual components of Aichi Targets 11, 12, and 13 of the Strategic Plan for Biodiversity 2011-2020. Source: Global Biodiversity Outlook 4 (GBO-4) (Secretariat of the Convention on Biological Diversity, 2014).

1.2 Agrobiodiversity and Plant Genetic Resources

Agrobiodiversity is an important subset of biodiversity, and can be defined as:

> ***"The variety and variability of animals, plants and micro-organisms that are used directly or indirectly for food and agriculture… It comprises the diversity of genetic resources (varieties, breeds) and species used for food, fodder, fibre, fuel and pharmaceuticals. It also includes the diversity of non-harvested species that support production (soil micro-organisms, predators, pollinators), and those in the wider environment that support agro ecosystems (agricultural, pastoral, forest and aquatic) as well as the diversity of the agro-ecosystems"***
>
> (FAO, 1999a)

Today's extant agrobiodiversity has been historically shaped by interactions between the environment, genetic resources and agricultural management systems of culturally diverse people (FAO, 2005). Just as variety in biodiversity is present at different hierarchical levels, the combination of natural and human based selection processes that make up agrobiodiversity also causes variation to arise at three principle levels. These are identified by Veteläinen *et al.* (2009) as: agro-ecosystem level, interspecific level, and intraspecific level. The former most level is derived from the unique melange of biotic and abiotic factors that influence agro-ecosystems, whereas the latter two can more specifically relate to genetic resources, here defined as "any material of plant, animal, microbial or other origin containing functional units of heredity, of actual or potential value" (CBD, 1992), inclusive of plant genetic resources for food and agriculture (PGRFA).

An outline of the main components of Plant Genetic Resources (PGR) is given in Figure 1.5 and general information concerning PGRFA can be found in the literature, for example Hawkes *et al.* (2000) and Jackson and Ford-Lloyd (1990) are both good sources of information. However, the remainder of this project is mainly concerned with crop wild relatives (CWR) and so will focus on this subset of PGRFA.

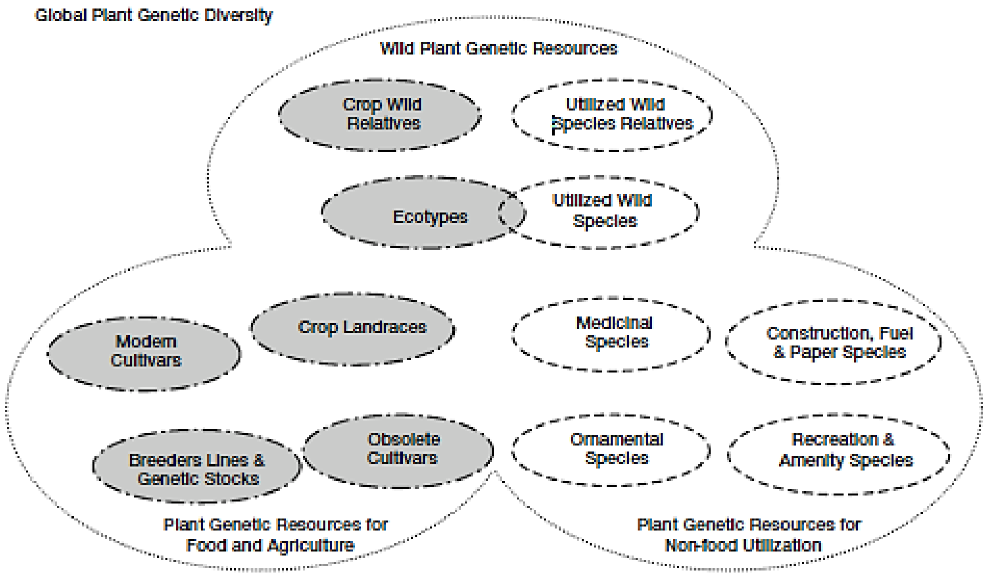


Figure 1.5 Components of global plant genetic diversity. Plant Genetic Resources for Food and Agriculture (PGRFA) are shown in shaded circles, inclusive of harvested and non-harvested species as well as subordinate taxa. (Source: Veteläinen *et al.* (2009); modified from Maxted *et al.* (2008a)

1.3 Crop Wild Relatives:

1.3.1 Defining a Crop Wild Relative

Crop wild relatives (CWR) are a principle component of PGRFA, and are defined as:

> ***"…species closely related to crops that include crop progenitors, and that may contribute beneficial traits to crops such as pest or disease resistance, and yield improvement or stability"***
>
> Maxted *et al.* (2008b)

They are therefore a vital 'provisioning' ecosystem service (see previous section) that is heavily implicated in present and future food security.

Previously, the term CWR was lacking in definition and individual projects depended on expert knowledge to subjectively select taxa as CWR. Vavilov (1920, 1922) was one of the first people to recognise the value of conserving the genetic diversity of wild species capable of natural or artificial introgression with a crop, as well as that of the crop itself (Maxted *et al.,* 2006a). His concepts were formalised by the creation of the Gene Pool Concept (GPC) by Harlan and de Wet (1971) (shown in Figure 1.6).

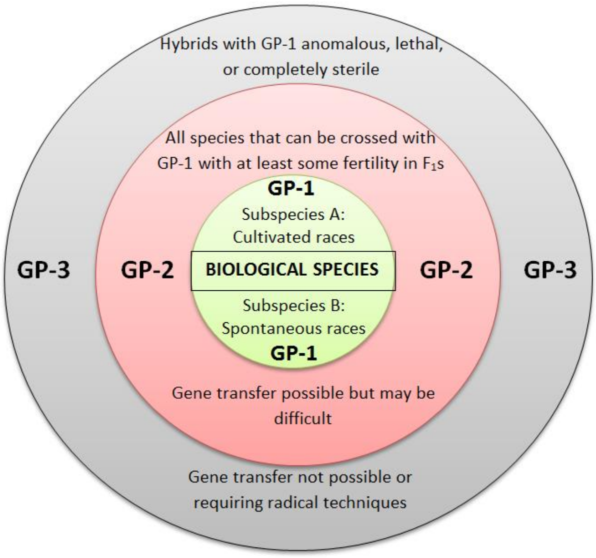


Figure 1.6 The gene pool concept proposed by Harlan and de Wet (1971) that classifies species based on ease of genetic introgression between the crop and related taxa.

This concept recognises three consecutive 'pools' of genetic diversity, each of which constitutes taxa with a certain degree of crossability with the crop. The Primary Gene Pool (GP-1) includes the cultivated forms (GP-1A) and the wild or weedy forms (GP-1B) of the crop. The Secondary Gene Pool (GP-2) constitutes less closely related species (coenospecies) from which gene transfer to the crop is difficult yet possible using conventional breeding techniques. The Tertiary Gene Pool (GP-3) constitutes species from which gene transfer is impossible or requires highly sophisticated techniques (such as embryo rescue, somatic fusion or genetic engineering) (Maxted *et al.,* 2006a).

Although widely used for establishing conservation targets, this concept has limitations, for example while this concept is restricted to setting priorities within a single crop gene pool, application across numerous crop gene pools is often necessary for setting realistic conservation targets in geographic areas or across taxonomic groups. Also, application of this concept requires knowledge of relative crossability and patterns of genetic diversity which, in many cases, is only available for major crop complexes. While only approximately 300 plant species are consistently used by humankind, there are an estimated 7, 000 crop species worldwide (Krishna, 2014) and 270,000 species of higher plants (Groombridge and Jenkins, 2002) all of which must have some degree of relatedness to crops. This means that obtaining the necessary information for application of the GPC to all CWR is unlikely to be feasible in the near future.

Where genetic differentiation is uncertain or unknown, Maxted *et al.* (2006a) suggest using existing taxonomic hierarchy to approximate degree of genetic relatedness. This is referred to as the Taxon Group Concept (TGC) and is shown in Figure 1.7.

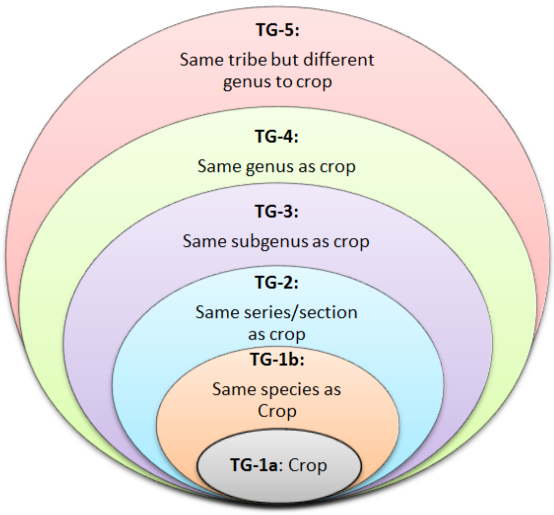


Figure 1.7 Taxon Group Concept (TGC) used to approximate genetic relatedness when genetic crossability information is lacking. Source: adapted from Maxted *et al.* (2006a).

Using the GPC and TGC, the definition of a CWR can be modified to this effect:

> ***"A CWR is a wild plant taxon that has an indirect use derived from its relatively close genetic relationship to a crop; this relationship is defined in terms of the CWR belonging to Gene Pools 1 or 2, or taxon groups 1 to 4 of the crop."***

(Maxted *et al.* 2006a)

However Maxted *et al.* (2006a) go on to identify that being a CWR is a relative concept and further prioritisation is required when establishing conservation priorities to prevent an inordinately large proportion of known taxa being designated CWR from broad use of the TGC. This is illustrated by Kell *et al.* (2005) who found that roughly 80% of European and Mediterranean flora was classified as a CWR using a broad definition (any plant within the same genus or closely related genera as the crop-TG4) (Bilz *et al.,* 2011). Thus, where no other external factors are considered, CWRs in GP-1b, TG-1b, or TG-2 are considered higher priority for conservation while GP-2, TG-3, or TG-4 CWRs are of lower priority.

CWR and other components of PGRFA are important social, ecological and economic assets widely used by humankind both for the provision of food, fibre and fuel and for certain agro-ecosystem services such as "*securing crop protection and soil fertility"* (Altieri, 1999) (see Figure 1.2 for some examples of ecosystem services). In addition to this, the genetic diversity of PGRFA such as CWR is equally significant as a reservoir of genes and alleles conferring potential adaptability to changing environmental conditions or socio-economic pressures for the crop cultivars on which we so heavily depend. This is because wild relatives of cultivated species have not been subject to the genetic bottleneck of domestication or modern breeding practices (see Figure 1.8) and so have a wider gene pool this is potentially inclusive of alleles lost from our current crops (Tanksley and McCouch, 1997). Consequently, the safeguarding of PGRFA diversity is critical as it is a vital component of crop breeding programs that are irrevocably implicated in present and future food security.

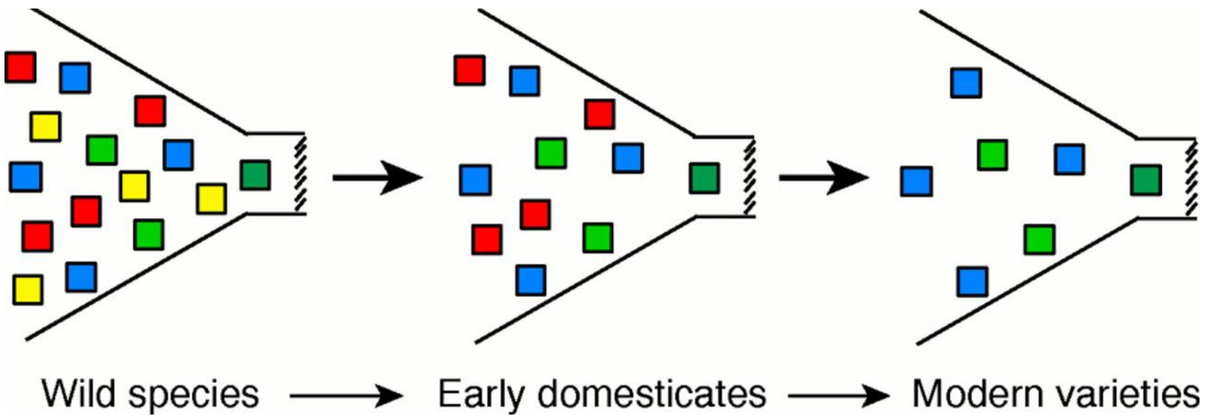


Figure 1.8 The coloured boxes represent allelic diversity of cultivated species. The cultivars that we see today are thought to have experienced two major genetic "bottle necks": domestication and modern plant-breeding practices resulting in decreased allelic diversity. Source: Tanksley and McCouch (1997)

1.3.2 Threats to Wild Plants and PGRFA

CWR and other forms of agrobiodiversity can be found in a wide range of wild and cultivated habitat types. Their existence, diversity, productivity, and sustainability are all intricately linked with the diversity of the natural ecosystems of which they are an intrinsic component (Altieri, 1999). Consequently, the major threats to biodiversity identified in Figure 1.3 also comprise the principle pressures and threats to wild agrobiodiversity and PGRFA. These include: habitat change, invasive species, overexploitation, pollution, and climate change, all of which will now be further discussed in relation to wild plants, while specific effects on CWR will be built upon within later sections of the project.

The sweeping effect of habitat loss and degradation is thought to be the primary cause of species loss, with human instigated destruction and degradation being the major cause of risk for 83% of endangered plant species (BGCI, no date). Furthermore, Sanderson *et al.* (2002a) state that around 83% of the earth's land surface has been drastically changed by anthropogenic activity such as: water and urban development, building of infrastructure, fire suppression or raising, intensive agriculture (see Figure 1.3) and tree logging; all of which can be devastating at both the taxon level and the community or ecosystem levels. The consequent habitat fragmentation that accompanies this threat has additional negative effects due to increased spatial isolation of plant populations and disassembly of ecological networks that facilitate pollen and seed dispersal, and increased edge effect whereby the edges of habitats are strongly influenced by their surrounding habitat. Examples of this can be seen in tropical forests where patch edges have warmer, drier and lighter microclimates that expedite adult tree mortality (BGCI, no date). This causes an overall decrease in patch biomass and size, as well as eliminating natural land surrounding intensive agricultural land; where the fertilisers, herbicides and pesticides contained in runoff from farmed land not only directly reduce viability in some plant taxa, but also cause soil to become nutrient rich and hence less biodiverse (BGCI, no date). The establishment of thin strips ('corridors') or patches ('stepping stones') of habitat to connect fragmented areas and facilitate pollination and seed dispersal is a popular conservation action which has been successfully implemented in an experimental landscape by Tewksbury *et al*. (2002).

"*We live in a world of introduced species"* (Wonham, 2006). With globalisation and increased human travel and dispersal, accidental and intentional introduction of invasive species has occurred at a staggering rate that far surpasses species range expansion that would otherwise occur (BGCI, no date; Wonham, 2006). Invasive species can often increase their range and population density at alarming rates, while having numerous negative impacts on native flora and fauna through direct species interactions (predation, herbivory, competition, parasitism or disease) or indirect interactions (such as habitat modification, competition for resources, and trophic cascade) (Wootton, 1994). Species that are already rare, specialist or narrowly distributed are more likely to suffer range and population decline due to invasive species. This is thought to be especially true for island communities, as species 'novelty' (exploitation of a resource in a new way) may positively influence success (and impact) of invasive species. This is thought to be applicable to predatory and competitive invasive species and has been illustrated by Lonsdale (1999) who found that the prevalence of invasive plant species was 2.6 times higher on islands than on mainland sites within the area of study (Wonham, 2006).

While wild plants provide humankind with many valuable resources and services (see Figure 1.2), utilisation must be sustainable and allow for the replenishment of these sources to facilitate long-term use. Small human population size and primitive technology has historically meant that the impact of human resources use was sustainable; but technological advances and an exponentially growing human population have caused high levels of land conversion to agriculture, habitat degradation, overharvesting, and other forms of overexploitation- resulting in the destruction and deterioration of many CWR and wild plant resources in general. While the consequences of this are widely comprehended, preventative measures are not always readily implemented as the value of these resources can be a subjective concept that may be outweighed by financial or other local, short term incentives (see section 1.1 concerning the value of biodiversity). In addition to this, residents of poorer countries may live more directly off the land and hence have a higher dependence on extraction of natural resources (with limited dependence and availability of imported food) and so simply stopping unsustainable practice may not be a viable without alternative sources of finance such as government subsidies or income from tourism- both of which are not easily obtained in poorer countries (BGCI, no date). This is reflected in key legislation, such as the International Treaty on Plant Genetic Resources for Food and Agriculture (otherwise known as the Seed Treaty, International Treaty, or ITPGRFA) (FAO, 2009) and the Global Strategy for Plant Conservation (GSPC) (CBD, 2012), which both highlight the need for sustainable use while considering human need.

Pollution and disease make up another prominent threat to wild plants which, as these are rarely visible to the naked eye, can be difficult to detect until detrimental effects have already occurred. Over application of pesticides and insecticides is a common example of this and can have adverse effects both on wild plants and ecosystems, and water supplies (through contamination). This and light pollution are also thought to have negative effects on pollinator populations which can have devastating effects on cultivated and non-cultivated plants (BGCI, no date). Soil contamination by heavy metals can also have detrimental effects on wild plant production.

Climate change is another threat to wild plants; in basic terms these species are dependent on certain environmental conditions for growth (e.g. temperature, sunlight, carbon dioxide, water, nutrients etc.) that are expected to alter drastically and somewhat unpredictably in the face of climate change. Therefore there is a vital need for these species to adapt or migrate to avoid extinction (BGCI, no date). However, as predicted interactions between biodiversity and climatic change are difficult and complex, the consequences for wild plants are somewhat multifaceted (Figure 1.9).

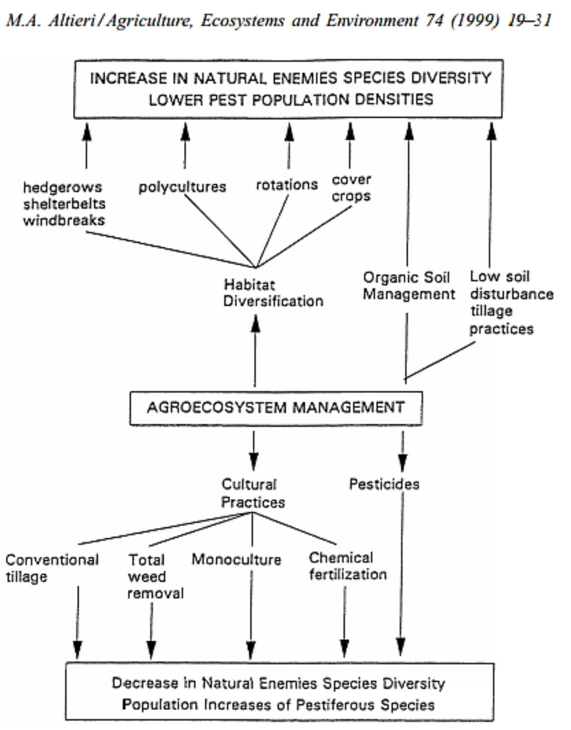


Figure 1.9 Effects of different agricultural management techniques on pest species populations. (Source: Altieri, 1999)

As there is a significant human interface connected with PGRFA, agrobiodiversity as a whole is at the mercy of other anthropological factors in addition to the threats to wild plants as discussed above; the most notable of these threats being changes in farming practices.

Traditional farming uses sustainable, diversified methods that mimic natural ecological processes and promote biodiversity (such as intercropping, agroforestry, and shifting cultivation- see Figure 1.9), while trading locally and maintaining the vital intraspecific and interspecific diversity of agrobiodiversity and PGRFA in long domesticated species.

However, with an exponentially increasing population to feed and the technological progression of the twentieth century industrial revolution, the expectation and demand of a competitive global market saw these traditional management systems being replaced with monoculture and other intensified, automated processes (as seen in Figure 1.9) as well as many traditional crop varieties and landraces being replaced by genetically uniform, high-yielding cultivars (Tanksley and McCouch, 1997).

Although this intensification saw large increases in productivity for most major crops, the reformation of agricultural processes has had devastating effects on agrobiodiversity through genetic erosion of PGRFA, loss of traditional farming practices and knowledge, and of "*crop related culture"* (Veteläinen *et al.,* 2009). During this time it is estimated that around 75% of crop genetic diversity was lost (FAO, 1999b; FAO, 2005), with the resultant genetically uniform crops being more vulnerable to pests, disease and environmental change through a lack of natural adaptability.

1.3.3 Importance and Conservation of PGRFA

It is in light of this that we recognise the vital role of PGRFA as a potential source of genetic diversity that could help to procure future food security through crop improvement. Indeed there are already successful examples of their use in plant breeding, for example rust resistance and yield improvement have both been successfully transferred to Oat (*Avena sativa*) from its wild relative *A. sterilis* (Frey, 1976; Takeda and Frey, 1976; Prescott-Allen and Prescott-Allen, 1986; Maxted and Kell, 2009) while powdery mildew resistance was transferred from *A. macrostachya* (Herrmann, 2006; Maxted and Kell, 2009. See table 1 of this publication for further examples of CWR traits successfully transferred to crops). Plant breeding such as this is identified by Hopkins and Maxted (2011) as the only technology proven to be capable of producing new varieties that make less demand upon the environment in terms of nutrient, water and energy use, which are adapted to changing climates, and are also resistant to new pests and diseases.

It is in analysing these threats that the importance of PGRFA and the need for their conservation allowing continued yet sustainable use is recognised. As stated by Maxted *et al.* (1997a) the principle aim when conserving these assets must be to "*ensure that these resources and their gene pools are secure, efficiently held, and readily available for* *sustainable utilisation*". This is achieved through various methods of *in situ* or *ex situ* conservation, the pros and cons of which are aptly discussed by Maxted *et al.* (1997a).

Legislatively, the need for efficient and effective conservation of PGRFA is widely acknowledged. For example, one of the Aichi Biodiversity Targets adopted by the tenth meeting of the COP for the CBD (see section 1.1) in their revised and updated Strategic Plan for Biodiversity states:

> ***"By 2020, the loss of genetic diversity of cultivated plants and farmed and domesticated animals and of wild relatives, including other socio-economically as well as culturally valuable species is maintained and strategies have been developed and implemented for minimizing genetic erosion and safeguarding their genetic diversity."***
>
> *Strategic goal C, Target 13,* CBD (2012)

The GSPC is a programme of the CBD that includes 16 global targets for 2011- 2020, which incorporates the conservation of CWR and other components of PGRFA:

> ***"70 per cent of the genetic diversity of crops including their wild relatives and other socio-economically valuable plant species conserved, while respecting, preserving and maintaining associated indigenous and local knowledge"***
>
> *Objective II: Target 9,* CBD (2012)

The ITPGRFA is a key global framework for PGRFA conservation (GSPC, n.d.) which aims to uphold:

> ***"…the conservation and sustainable use of plant genetic resources for food and agriculture and the fair and equitable sharing of benefits derived from their use, in harmony with the Convention on Biological Diversity, for sustainable agriculture and food security."***
>
> FAO (2009)

The ITPGRFA was negotiated by the Commission on Genetic Resources for Food and Agriculture (CGRFA) - a subdivision of the Food and Agricultural Organisation of the United Nations (FAO) that have now adopted the Second Global Plan of Action for PGRFA (FAO, 2011). This is an agreed set of priority activities that reaffirms the commitment of governments to PGRFA conservation and fulfilling the aims of the ITPGRFA. The FAO also released the Second Report on the State of the World's Plant Genetic Resources for Food and Agriculture (SoWPGR-2) in 2010 which served as a firm basis for the updated Second Global Plan of Action for PGRFA by providing a comprehensive overview of recent trends in PGRFA diversity, conservation and use around the world (FAO, 2010a, 2010b). One of the key messages from this report is that despite progress being made in securing PGRFA diversity *ex situ* (mainly in national genebanks), more needs to be done to conserve the diversity of many CWR and other underutilised species for present and future use. Further information is available in the synthesis of this report (FAO, 2010b).

Other aspects of PGRFA conservation are considered within the framework of the GSPC, such as the preservation of traditional knowledge in accordance with Article 8(j) of the CBD (2012) and Target 18 of the Aichi targets of the Strategic Plan for Biodiversity 2010-2020 (GSPC, no date):

> ***"Indigenous and local knowledge innovations and practices associated with plant resources maintained or increased, as appropriate, to support customary use, sustainable livelihoods, local food security and health care."***
>
> *Objective III: Target 13,* CBD (2012)

Implementation of this target is supported by the Global Diversity Foundation (GDF) which coordinates the Biocultural Diversity Learning Network (BDLN) and maintains an Online

Guide to Biocultural Diversity. However, progression for this target is difficult to monitor and may be considered an *"enabling target"* which supports the progression of other targets (GSPC no date).

1.4 Threat assessment

1.4.1 Role and Importance of Threat Assessment in Conservation

Conservation efforts are generally in response to threats to biodiversity; therefore the identification and ranking of threats is finely integrated into the systematic approach to conservation planning. This facilitates the most effective distribution of finite resources (money, time, labour or other precious assets) in order to minimise biodiversity loss and maximise the potential successes of conservation actions. This vital role is reflected in key legislation which will be discussed later in this section.

Within this approach, threat assessment is often a primary or secondary criterion contributing to conservation management at both the contextual/planning stages, and monitoring/evaluating stages. Its specific role can vary and is often uniquely tailored to suit the project, but in a more general sense the principle aim of threat assessment can be determined by the scale of the conservation target (Rao *et al.,* 2007; Hocking *et al.,* 2000). Broadly, this can be split into assessment at the either the level of a species or their habitat, or at an eco-geographical or spatial scale. Ecogeographical threat assessment can be applied on many different scales, from course assessment at the global range to fine scale assessment at more local or site levels. Another alternative that applies more specifically to PGRFA is the assessment of the threat of genetic erosion.

1.4.2 Threat assessment of species/taxa or their habitat

At the species level, the IUCN have had a huge success in creating the IUCN Red List of Threatened Species (IUCN Red List); a comprehensive and objective inventory of the global conservation status of biological species (IUCN, 2014). It has grown to be widely relied upon by governments, NGOs and scientific institutions in conservation planning and management, with this success promoting the establishment of additional initiatives applied at different scales to global Red List assessments such as ecosystem level assessments, national level assessments, and assessments for taxonomic groups (see IUCN (2014) for further details).

The IUCN Red List uses threat assessment as one of many carefully defined diagnostic criteria in order to give a qualitative estimation of species extinction risk and assign each species a 'category' based on the results (outlined in Figure 1.10). The main criteria assess extinction risk at the species level through population size (number of mature individuals) and trends (increase, decrease or fluctuation), geographic range, fragmentation, and presence of plausible threat (past, present, or future). Available information is assessed under the IUCN Red List Criteria to give a threat category appropriated to risk of extinction. A 'Least Concern' (LC) species has a small risk of extinction, being widespread (large extent of occurrence and/or area of occupancy), and/or having a stable population trend. If this is not the case, a species is deemed threatened, and assigned one of three threatened categories: Vulnerable (VU), Endangered (EN) or Critically Endangered (CR) (Figure 1.10). Data Deficient (DD) species are those that have insufficient information to assign a threat category. For DD species it is important to remember that no assessment of extinction risk has been made and so these taxa should **not** be treated as non-threatened species as this cannot be confirmed until enough information is available to assign a category. Not Evaluated species (NE) are those that have not yet been assessed using IUCN Red List Categories and Criteria, while Extinct (EX) is applied when '*there is no reasonable doubt that the last individual has died*', while Extinct in the Wild (EW) means '*the taxon is extinct in its natural habitat*' (IUCN, 2001). The IUCN Red List Methodology is to be discussed in more detail in the 'Methods' section.

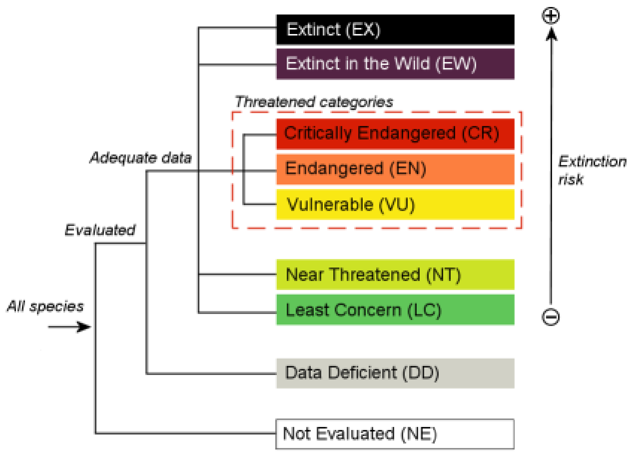


Figure 1.10 Structure of the IUCN Red List Categories into which assessed species are placed based on relative extinction risk determined by five quantitative criteria.

Source: IUCN 2012

Traditionally, the goal of the IUCN Red List was to identify species at highest risk of extinction, and regularly review and update these species assessments at ten year intervals; thereby communicating a clear role of threat assessment in priority setting for single species, both at the contextual and monitoring levels of conservation management. However, this has been modified to allow for multi-species analysis and monitoring of "*a representative selection of species (as biodiversity indicators) that cover all ecosystems of the world*"; an important step which has facilitated the aggregation of species-specific threat information to provide additional support for conservation through the comprehensive recognition of threatening processes and trends (Groom *et al*., 2006; also see next page for related information about the Sample Red List Index (SRLI)).

The benefits of this modified goal and the use of threat assessment as a contributory criterion for prioritisation of globally vulnerable species can be seen in programs such as Birdlife International's Important Bird areas (IBAs) Programme, which aims to identify small conservation sites, that are often part of a protected area network, containing significant numbers of one or more globally threatened, migratory or congregatory species thus protecting the species at the habitat level (Birdlife International, 2013; Rao *et al.*, 2007). It can also be seen in Key Biodiversity Areas approach (Eken *et al*., 2004; Rao *et al.* 2007), which builds on Red List assessments to identify, document and protect networks of sites that are critical for the conservation of global biodiversity – targeting species known to be threatened and/or geographically concentrated. And lastly in range level assessment for individual species such as those applied to Tigers and Jaguar, where priority areas and actions are identified using scoring indices inclusive of Red List assessment information and threat analyses (Dinerstein *et al*., 1997; Sanderson *et al*., 2002b; Rao *et al.* 2007). An apt comparison of these approaches can be seen in the publication of Rao *et al.* (2007) in Table 1 on page 50.

The IUCN Sampled Red List Index (SRLI) is another interesting approach to taxon level assessment that combats previous criticism of the IUCN Red List in that historically, priority has been given to assessment of taxa that are suspected to be at risk of extinction; giving a biased view of the state of biodiversity. As previously stated, biodiversity is a vast and complex entity and its assessment for the IUCN Red List is a mammoth task, especially given that new taxa are constantly being discovered. SRLI aims to give an overall view of the state of certain taxonomic groups by projecting findings from assessment of a random sample of taxa from that group. For example, it is estimated that 380, 000 plant species exist today, yet only 6% of these have been assessed by the IUCN Red List. The SRLI assessed 1, 500 plants from each of the five major groups and found that one in five of the world's plants are threatened with extinction, and a further 8% are Near Threatened (NT) so may become threatened without conservation actions (Plants under pressure, 2012).

In terms of CWR, it is unknown exactly how many species have been assessed within the IUCN Red List (Kell *et al.,* 2011a). However Kell *et al.* (2008) found that the 2004 IUCN Red List included 161 CWR that occur in Europe and the Mediterranean, while the 2006 IUCN Red List included a further 62 Euro-Mediterranean species- only one of which was related to a major food crop. Bilz *et al.* (2011) undertook regional assessments for 572 European CWR species within 25 crop gene pools, finding that at the European level at least 11.5% of the CWR species assessed were considered threatened, while a further 4.5% are considered Near Threatened.

It must be reiterated that threat assessment is not a standalone method of prioritising conservation targets, but rather a tool that evaluates current extinction risk and so contributes to complementary, strategic conservation planning; being meant for use alongside many other considerations such as biological characteristics of the species and ecosystem, cost of action, logistics to name but a few. To this effect, it is necessary to mention the Harlan & de Wet CWR Inventory (Vincent *et al.* 2013) – an annotated inventory of global priority CWR species that has already proven itself as a valuable baseline resource for systematic conservation planning (for examples please see Vincent *et al.,* 2012;

Shehadeh *et al.,* 2013; Khoury *et al.,* 2013; Vincent *et al.,* 2013). The Harlan & de Wet CWR Inventory has been crucial in the completion of this project and its use will be further discussed in Section 2: Methods.

1.4.3 Threat assessment at an eco-geographical or spatial level

Threat assessment for conservation targets on a geographical or spatial scale is also well analysed by Rao *et al.* (2007) and will be discussed/expanded upon in the following paragraphs.

As previously stated, threat assessment at this level can consist of either coarse scale assessment at the global range to fine scale assessment at more local or site levels. Although fine scale analysis is possible at a global scale (8 x 8 km), the vastness of the earth's total surface area means that course scale global threat assessment is usually a precursor to determine large conservation targets where further, finer scale assessment may be required at a later date.

In the scope of these finer scale analyses, the role of threat assessment can vary from further prioritisation of one or more potential conservation targets within an ecologically distinct area (intermediate, regional assessment) to analysing the requirement for threat specific conservation action either on a site specific scope or across multiple areas (for recurring threats at regional levels). As with species level assessments, in addition to initial prioritisation and detailing how to conserve biodiversity, another role of threat assessment at intermediate or fine scales is in conservation monitoring and evaluation of whether conservation strategies are effective (see Table 1.1 for a brief summary of the potential roles of threat assessment).

Table 1.1 A Summary of the role of threat assessment within conservation management and the scale at which this role is applicable.

Stage of Conservation Management	Specific role of Threat Assessment	Scale on which could be applied
Contextual/planning	Identification and prioritisation of conservation targets with higher risk of biodiversity loss	Global (Coarse) Regional (Intermediate)
	Prioritisation and optimisation of conservation actions in relation to threat	Regional (intermediate) Local (fine)
Monitoring and Evaluation	Observing change in threat status over time to see whether conservation has been effective or plans needs reviewing	Regional (intermediate) Local (fine)

Global 200 Ecoregions project (Olsen and Dinerstein, 1998) is a good example of a global scale assessment applied at the contextual stage of conservation. This project identified ecosystems through ecological and biogeographical criteria and then used total habitat loss, degree of fragmentation, water quality, and estimates of future threat to measure overall threat as a secondary criterion for prioritising ecosystems as conservation targets (Dinerstein *et al.,* 1995; Olsen and Dinerstein, 1998; Rao *et al.,* 2007).

The Nature Conservancy (TNC) has established an 'ecoregional planning process' that aims to set priorities for conserving biodiversity at the regional level (TNC 2000; 2003; Groves *et al.* 2002; Rao *et al.* 2007). The principle aim of this framework is similar to that of the Global 200 Ecoregions Project, being: ***"to identify conservation strategies and to gauge urgency of action"*** (Rao *et al.,* 2007). Five criteria are used to fulfil this aim, these being degree of existing protection, conservation value, threat, feasibility, and potential to affect other sites; where threat assessment is the most important component of this as it gives a relative measure of urgency as well as identifying the potential for multi-area conservation strategies to combat threats that may recur across the region (Groves, 2003; Rao *et al.,* 2007).

As already stated, local scale threat assessment is usually more orientated towards establishment of site level conservation strategies as opposed to priority setting (which is usually the focus of global and regional assessments). Generally, thorough knowledge of the area being studied in terms of its biodiversity and the scope and severity of its threats is essential, as the principle aim is usually to identify threats to conservation targets and rank them. This facilitates the appropriation of conservation strategies within the area (Rao *et al.* 2007). A good example of local scale conservation planning is the WWF's Rapid Assessment and Prioritization of Protected Area Management (RAPPAM) which is designed to provide protected area authorities and policy makers with a relatively quick and easy way to analyse major threats within their protected area structure and reform management systems accordingly. This is intended for use at numerous levels (national, regional, ecoregional, or local levels) as it is easily accessible to those with limited funds (Hockings *et al.,* 2000).

1.4.4 Threat assessment of genetic erosion

As previously discussed, PGRFA and CWR are vital resources for future food security as their genetic diversity acts as a potential reservoir of adaptability to changing environments for the crops on which we so heavily depend. Genetic erosion is concerned with the loss of genetic diversity, or more specifically:

> ***"…a permanent reduction in richness (or evenness) of common local alleles, or the loss of combinations of alleles over time in a defined area"***
>
> Maxted and Guarino (2006)

This definition recognises the levels at which genetic diversity occurs (number of different entities or 'richness', and relative frequency of entities or 'evenness') and identifies the significance of locally adapted alleles as it is unlikely that these can be replaced by genes from other populations.

Genetic erosion occurs in both wild and cultivated plants and principle causes tend to align with threats to biodiversity. Habitat disturbance (loss, degradation, and fragmentation) and small population size are agreed to compound the process of genetic erosion in wild material (Bijlsma and Loeschcke, 2012), however these factors can themselves be attributed to numerous causes or synergistic effects. Modern breeding practices and the replacement of traditional landraces by modern, genetically uniform varieties are thought to be the main causes of genetic erosion in cultivated material (Mathur 2011; Van de Wouw, 2009). Additionally, periodic regenerations and improper management practices can lead to genetic erosion of *ex situ* resources kept in genebanks or germplasm collections (Maxted and Guarino, 2006; Mathur, 2011).

Molecular analysis of genetic diversity is the key to measurement of current levels of erosion. However, this technology is not always readily available for routine testing as it remains expensive. Rough estimates of current genetic erosion can be made by assessing taxonomic (or species) loss as it is highly likely that this is correlated with loss of genetic diversity within the taxon. Alternatively, indicators of genetic diversity such as those outlined by Brown and Brubaker (2002) and Brown (2008, or those adopted by the FAO (2013a; 2013b) to monitor implementation and progress towards targets of the Second Global Plan of Action for PGRFA (FAO, 2011). The work of Brown and Brubaker (2002) and Brown (2008 is summarised in Table 1.2 (page 32) to demonstrate the types of information pertaining to genetic erosion. These, alongside other indicators from other publications such as those outlined above (FAO, 2013a; 2013b) may be used either individually or in combination to directly assess past genetic erosion and predict future loss.

Ideally, to assess the risk of genetic erosion, comparable measures at different points in time must be taken. This may involve direct comparisons which measure genetic diversity itself using molecular studies to assess change (del Rio *et al.* 2007; Ford-Lloyd *et al.,* 2006 ;Provan *et al*. 1999; Jordan *et al.,* 1998; Bikilsma *et al,.* 1994*;* Akinoto *et al*., 1999; De Oliveira and Martins, 2002).This can be difficult as despite containing many accessions representative of different genotypes, *ex situ* collections of PGRFA often only represent a fraction of a crops genetic diversity or can alternatively involve indirect observations that indicate change through proxies such as local knowledge of farmers and other relevant stakeholders (for example Hammer *et al.* 1996; Wilkes 1972; Mazzani *et al*. 1999; De Oliveira and Martins, 2002), ecogeographical diversity assessments (Parra-Quijano *et al.,* 2008) and other spatial/temporal comparisons of CWRs (Ford-Lloyd *et al.*, 2006). These measures may be applied on a temporal scale to estimate past erosion or on a spatial scale, and thus allow prediction of future losses and facilitation of informed conservation actions.

Measures taken need to be consistent and comparable. To this effect, Guarino (1995) modified a model developed by Goodrich (1987) in order to quantify genetic erosion by the scoring of various biological, environmental and socioeconomic factors that may or may not be influencing a particular taxon within a defined area. When put into practice (Frese *et al.*, 2009) it is suggested that this model does not sufficiently account for species biology, for

Table 1.2 Indicators to estimate genetic diversity in PGRFA. The secondary or support indicators are measures to aid interpretation of the values of the primary variables. Measures of processes that affect diversity are shown in italics. Source: adapted from Brown and Brubaker (2002), and Brown (2008).

Gene pool	*Level of indicator*	*In situ*	*Ex situ*
Cultivated	**LEAD/PRIMARY INDICATORS**	• **Number and frequency of landraces, and proportion of the area planted that is growing them**	• **Number of crop species, subspecies or geographic categories adequately sampled in gene banks** • **Number of accessions held in the gene bank** • **Number of collections or gene banks**
	SUPPORT/ SECONDARY INDICATORS	• Environmental amplitude of crop area • Number of farmer selection criteria, and evolution of farmer management	• Country distribution of seed gene banks • Coverage in collections of crop diversity
	MEASURES OF PROCESSES	• *Security of traditional knowledge*	• *Backup duplication provisions* • *Extent of usage and representation in core collections* • *Collection health, accession viability* • *Documentation and evaluation of collection*
Wild	**LEAD/PRIMARY INDICATORS**	• **Number of species, subspecies or geographic subdivisions of taxa distributed in protected areas, that cover the species environmental range**	• **Number of wild species, subspecies or geographic subdivisions of taxa related to crops adequately sampled in the gene bank**
	SUPPORT/ SECONDARY INDICATORS	• Abundance as population numbers and sizes, particularly of rare wild crop relatives • Gene diversity, divergence and distribution	• Coverage of species range • Evolutionary relationships and taxonomic resolution • Accession viability, documentation and duplication
	MEASURES OF PROCESSES	None	• *Number and frequency of accessions used* • *'Prebreeding' activities, including evaluation*

example some descriptors associated with disturbance (accidental fires, grazing, and irrigation schemes to name a few) may be beneficial to certain taxa and included within conservation management plans. De Oliveira and Martins (2002) also successfully applied the model of Guarino (1995) to identify areas more prone to genetic erosion within their study area. In this publication, the original model was modified to include 10 factors that directly affected the conservation target within the region of study, relating to ecological requirements, traditional uses as a medicinal plant, and current conservation status (*in situ* and *ex situ* resources).

After measuring and comparing relative genetic diversity to determine rates of genetic erosion, it is important to apply this to the greater framework of conservation action. For example, as detailed by Maxted and Guarino (2006), Guarino (1995) suggested a programme for monitoring genetic erosion at a national level which is composed as follows:

1) Study past genetic erosion in priority gene pools through spatial and temporal comparisons of indicators
2) Identify major factor(s) contributing to genetic erosion in the target gene pool
3) Map strength of identified alleged causative factor(s), or some other closely correlate feature over mandate region
4) Fieldwork in areas identified as high risk of genetic erosion, so as to gather baseline genetic diversity data (use of indicators), verify level of risk and plan possible conservation interventions, in partnership with affected local communities
5) Setting up a network of community based correspondents for continuous monitoring of genetic diversity and genetic erosion risk

In this way threat assessment of genetic erosion (which here consists of measuring past rate of genetic erosion, identifying major causes of genetic erosion and their relative strength/contribution) is linked to targeting of conservation actions. This sort of assessment is vital for halting biodiversity loss, especially and should be routine practice for the conservation of CWR and other components of PGRFA.

1.4.5 Legislation and Conservation Policy for Threat Assessment

Prioritisation of conservation targets with the highest risk is vital for systematic planning and effective distribution of limited resources for conservation. Within this context, threat status is one of the most commonly utilised biotic criteria to assess species risk of extinction (CBD, 2012; Johnson, 1995) and is therefore integral to the majority of conservation policy and legislation.

For example, within the targets of the GSPC 2020, all components of Objective II: ***"Plant diversity is urgently and effectively conserved"*** have a strong focus on effective conservation planning and management. This objective's dependence on priority setting and assessment of biotic criteria (such as threat) for determining taxon status makes threat assessment integral to success. Target 10 which aims to put ***"Effective management plans in place to prevent new biological invasions and to manage important areas for plant diversity that are invaded"*** (CBD 2010b) is also indirectly linked to threat assessment as invasive species are thought to be a main threat of wild plants and PGRFA (see section 1.3.2 for further detail).

Other GSPC 2020 targets incorporate threat assessment more directly, for example:

> ***"An assessment of the conservation status of all known plant species, as far as possible, to guide conservation action"***
>
> *Objective I: Target 2, GSPC,* CBD (2012)

> ***"Information, research and associated outputs, and methods necessary to implement the Strategy developed and shared"***
>
> *Objective I: Target 3, GSPC,* CBD (2012)

Here a requirement for threat assessment and associated methodologies for plant taxa at global and regional levels is clearly recognised.

It is notable that Targets 7 and 8 (objective II) are specifically aimed at complementary *in situ* and *ex situ* conservation of **threatened** plants, making the determination of taxon threat status and success in targets 2 and 3 vital for achieving these subsequent targets.

Targets 2 and 3 of the GSPC are also critical in achievement of other policies, notably Target 19 of the Aichi target of the Strategic Plan for biodiversity 2011-2020:

> ***"By 2020, knowledge, the science base and technologies relating to biodiversity, its values, functioning, status and trends and the consequences of its loss, are improved, widely shared and transferred, and applied."***
>
> *Strategic goal C: Target 13,* CBD (2010a)

As well as the Convention on the International Trade in Endangered Species of Wild Fauna and Fauna (CITES) which depends on species assessment (including threat status) to review and amend taxa included on the list of endangered species.

Article 5 of the ITPGRFA, entitled **"*Conservation, Collection, Characterization, Evaluation and Documentation of PGRFA*"**, incorporates threat assessment for systematic conservation and encourages monitoring and maintenance of conservation strategies and their associated resources (FAO, 2009). In addition to this, the FAO Second Global Plan of Action for PGRFA (FAO, 2011) incorporates threat assessment in many areas, for example in surveying and inventorying PGRFA for *in situ* conservation and management:

> ***"To identify, locate, inventory and assess threats to PGRFA, particularly from land-use and climate changes."***
>
> FAO (2011)

To achieve this objective, it is established that research is needed to study:

> ***"…the extent and nature of possible threats to existing diversity on farm and in situ, particularly climate and land-use change, including their effects on pollinators…"***
>
> FAO (2011)

Threat assessment is also implicated in assisting farmers to restore their crop systems in disaster situations, for prioritisation, management and monitoring both *in situ* and *ex situ*:

> ***"Special efforts are needed to identify the species and populations that are most at risk and that carry potentially important traits."***
>
> FAO (2011)

> ***"Countries need to establish or strengthen genetic erosion monitoring systems, including easy-to-use indicators. Support should be given to collecting farmers' varieties/landraces in particularly vulnerable or threatened areas, where these are not already held ex situ, so that these genetic resources can be multiplied for immediate use and conserved for future use."***
>
> FAO (2011)

1.5 Project Aims & Objectives

To summarise, CWR are an important subset of biodiversity that are vital for future food security, principally through plant breeding programmes. Unfortunately these valuable resources are highly threatened and are in dire need of conservation. Threat assessment is an important component of conservation planning and, alongside other considerations, facilitates prioritisation of conservation targets to minimise biodiversity loss as well as having applications in managing and monitoring progress of conservation strategies. The IUCN Red List is a widely accepted, evidence based methodology to assess species' extinction risk and will be used within this project to analyse threat for 267 CWR species on a global scale. Given that few CWR species are known to have global IUCN Red List assessments in place, this work is an important step towards filling the gap in our knowledge of CWR global threat status and will be an important resource for strategic conservation plans and the safeguarding of future food security.

The primary aim of this work is to use available data to conduct a Global IUCN Red List assessment for 267 selected CWR species.

The main objectives towards this are:

1) Literature reviews and background research to collate raw data and produce draft IUCN Red List assessments for submission to the IUCN Red List Unit (RLU).
2) Critical analysis of results, particularly concerning threat status, spatial patterns of threat, prominent threats to project taxa, and population trends.
3) Discussion of results and likely implications of this as well as potential application towards targeted conservation and future research.

If the results from previous projects such as the SRLI project (Plants under pressure 2012) are taken into account, it can be predicted that around 20% of CWR assessed within the scope of this project are threatened with extinction. The implications of this work for the target species (priority CWR) are important as this research is novel and will give an indication of extinction risk for priority CWR while amalgamating important and diverse data that can be applied to a wide range of conservation projects.

2 Methods

The principle aim of this project is to present a preliminary global IUCN Red List assessment of a representative sample of CWR from the Harlan and de Wet CWR inventory (Vincent *et al.*, 2013) as well as the associated analysis and discussion of results. This section is therefore concerned firstly with compilation of the project checklist (including a brief summary of The Harlan and de Wet CWR inventory (Vincent *et al.,* 2013)), and secondly with IUCN Red List Categories and Criteria. The latter is described in relation to the project while other potential threat assessment methodologies will be discussed in the results and discussion sections where necessary.

2.1. The Harlan and de Wet CWR Inventory

All taxa included in this project have, at some point, been delineated as 'priority taxa' by Vincent *et al.* (2013) in the Harlan and de Wet CWR inventory. In this publication, the authors used three principle sources to select 173 priority crops based on their socio-economic importance. These were: Annex 1 of the ITPGRFA (FAO, 2009), Groombridge and Jenkins' major and minor food crops of the world (Groombridge and Jenkins 2002), and Mansfeld's encyclopaedia of agricultural and horticultural crops (Hanelt and Institute of Plant Genetics and Crop Plant Research, 2001). After this process, one of three potential prioritisation concepts was used to further delineate priority CWR for each crop complex. These consisted of:

1) the Gene Pool Concept (GPC) which was determined using published material on crossing experiments;
2) the Taxon Group Concept (TGC) which is used as a proxy when GPC is unavailable and assumes that taxonomic relationships strongly reflect genetic relatedness;

3) the provisional gene pool concept (PGPC), which was used when published material of potential yet unconfirmed crossability between the crop and related taxa was available and no confirmed GPC or subordinate taxonomic information was available (see section 1.3.1 in the Introduction of this project for further detail concerning GPC and TGC).

Additionally, more distantly related taxa which have historically shown promise for crop improvement (see Maxted and Kell, 2009) were also deemed priority CWR. The resulting 1667 taxa (1392 species) are presented in a web enabled format for ease of access and to reflect the most recent advances and the most relevant literature in plant breeding (Vincent *et al.,* 2013, online inventory accessible at http://www.cwrdiversity.org/checklist/). The Harlan and de Wet CWR inventory aims to address the lack of systematic identification of CWR that has previously acted as a barrier to effective and systematic CWR conservation (Vincent *et al.*, 2013). It has already proven its worth in this role (see Vincent *et al.,* 2012; Shehadeh *et al.,* 2013; Khoury *et al.,* 2013; cited by Vincent *et al.,* 2013 and in section 1.4.2) and was used within this project as a crucial baseline for building a checklist of CWR species that, having already been identified as a global priority for food security, would highly benefit from global IUCN Red List assessment.

As the Red Listing project was commenced while the Harlan and de Wet CWR inventory was still in preparation, a preliminary version of the inventory was used to create a project checklist. Additionally, this project will not reflect the 'dynamic' quality of the online inventory, which is continuously updated to reflect the most recent plant breeding and taxonomic research. This means that although some taxa may no longer be a global priority for food security, all have been identified as such by the preliminary static checklist of Vincent *et al.* (2013).

2.2. Project checklist

Initially, assessment of the entirety of the Harlan and de Wet CWR inventory was discussed; however time constraints of the project would not allow this and 267 CWR species from 21 different genera were selected for global assessment and can be found in the final project checklist in Appendix 1.

All 267 species were selected from the 1667 taxa (108 genera) contained in the provisional Harlan and de Wet CWR inventory (Vincent *et al.,* 2013). Eighteen genera were randomly selected from this list of 108 genera by alphabetising them and assigning each one a number which increased from A to Z, before generating 18 random, unique numbers using the 'RANDBETWEEN' function in Microsoft Excel and extracting the corresponding genus. The resultant 546 CWR taxa were then filtered according to four main criteria:

1) Taxa that were already involved in other global Red Listing projects were eliminated as assessment at this level already existed or had already been undertaken- undermining the novel aspect of this work.
2) Taxa that were not included in Annex 1 of the ITPGRFA (FAO, 2009) were eliminated.
3) Taxa with no known experts were eliminated to maximise potential for information and to facilitate expansion of the project results through expert consultation.
4) Sub-specific taxa and hybrids were eliminated unless they were found to be a taxonomic synonym of a species according to The Plant List (2013) as the IUCN Red List is mostly restricted to species level assessments.

Taxonomic standardisation of the project checklist was necessary for consistency with the IUCN Red List and input of information into IUCN Species Information System (SIS). SIS is the online database used by contributors and assessors to store information towards draft Red List assessments and to submit final draft assessments to the IUCN RLU. IUCN SIS is standardised using The Plant List (2013) and so it was suggested by the IUCN RLU that the taxonomy of species taken from the Harlan and de Wet CWR inventory (which is standardised using GRIN Taxonomy (USDA, ARS, National Genetic Resources Program, 2015)) to create the project checklist were edited to agree with IUCN SIS. This was discussed with the IUCN RLU and taxonomy altered appropriately, a full project checklist which can be found in Appendix 1 and while this may not reflect all recent developments in taxonomic knowledge, taxonomy was accurate at the time of assessment. Further information concerning taxonomic decisions of the IUCN RLU can be found in the IUCN's 'Information Sources and Quality' document (IUCN, 2014).

This process resulted in a checklist of 267 CWR species from 21 different genera suitable for global assessment, while 279 taxa were eliminated through the process outlined above and so were 'Not Evaluated' (NE). Increase in number of genera from the initial selection of 18 to the final number of 21 was due to taxonomic standardisation where stone fruits designated *Prunus* by GRIN taxonomy were split into *Amygdalus*, *Armeniaca*, *Cerasus*, and *Padus* (see Table 2.1).

Table 2.1 Synonymic taxonomy of genera included in project checklist and crop complexes to which they belong.

GRIN Taxonomy Family	GRIN Taxonomy Genus	The Plant List Taxonomy Family	The Plant List Taxonomy Genus	Crop complexes to which genus belongs
Amaryllidaceae	Allium	**Alliaceae**	Allium	Onion (*Allium cepa*)
				Allium chinense (*Chinese scallion*)
				Allium fistulosum (*Welsh onion*)
				Allium porrum (*Leek*)
				Allium sativum (*Garlic*)
				Allium schoenoprasum (*Chives*)
				Allium tuberosum (*Chinese chives*)
Anacardiaceae	Mangifera	Anacardiaceae	Mangifera	Mango (*Mangifera indica*)
	Pistacia		Pistacia	Pistacio (*Pistacia vera*)
Aquifoliaceae	Ilex	Aquifoliaceae	Ilex	Yerbe maté (*Ilex paraguariensis*)
Asparagaceae	Asparagus	Asparagaceae	Asparagus	Asparagus (*Asparagus officinalis*)
Asteraceae	Helianthus	Compositae	Helianthus	Sunflower (*Helianthus annuus*)
Fabaceae	Lupinus	**Leguminosae**	Lupinus	White lupin (*Lupinus albus*)
				Blue lupin (*Lupinus angustifolius*)
				Sandplain lupin (*Lupinus cosentinii*)
				Yellow lupin *(Lupinus luteus*)
				Andean lupin *(Lupinus mutabilis)*
	Medicago		Medicago	Alfalfa/Lucerne (*Medicago sativa)*
				Barrel medic *(Medicago truncatula)*
	Vicia		Vicia	Monantha vetch *(Vicia articulata)*
				Bitter vetch *(Vicia ervilia)*
				Faba bean (*Vicia faba)*
				Narbon bean (*Vicia narbonensis)*
				Hungarian vetch *(Vicia pannonica)*
				Common vetch (*Vicia sativa)*
	Vigna		Vigna	Adzuki bean *(Vigna angularis)*
				Black gram/Urd bean *(Vigna mungo)*
				Mung bean *(Vigna radiata)*
				Bambara groundnut *(Vigna subterranea)*
				Rice bean *(Vigna umbellata)*
				Cowpea *(Vigna unguiculata)*
Poaceae	Aegilops	**Gramineae**	Aegilops	Wheat (*Triticum aestivum* L.)
	Avena		Avena	Common oat (*Avena sativa*)
	Eleusine		Eleusine	Finger/African millet (*Eleusine coracana*)
	Hordeum		Hordeum	Barley (*Hordeum vulgare*)
	Pennisetum		Pennisetum	Pearl millet (*Pennisetum glaucum)*
Rosaceae	Malus	Rosaceae	Malus	Apple (*Malus pumila*)
	Prunus		**Amygdalus**, **Armeniaca**, **Cerasus**, **Padus**	Almond *(Prunus dulcis,* Apricot *(Prunus armeniaca),* Sweet cherry *(Prunus avium),* Sour cherry (Prunus cerasus), Myrobalan plum (*Prunus cerasifera),* Plum *(Prunus domestica),* Japanese plum *(Prunus salicina),* Peach *(Prunus persica)*

2.3. Red List Assessment Methodology

The IUCN Red List was briefly discussed in section 1.4.2 of this project, while a detailed description of assessment methodology and terminology is available in the document 'Guidelines for Using the IUCN Red List Categories and Criteria and Rules of Procedure IUCN Red List assessment process 2013-2016' (IUCN, 2012b), and details for an external project are described below and outlined in Figure 2.1. External projects are those that originate from outside of the IUCN Species Survival Commission (SSC) network or the IUCN Global Species Programme, including assessments undertaken by individuals, academic institutions, or other external organizations, as well as national Red List initiatives (IUCN, 2012b).

As previously discussed, each species 'assessment' requires an analysis of all available, relevant information against a set of quantitative criteria in order to estimate risk of extinction and assign an appropriate Red List Category to the species in question. There are nine Red List Categories that are described within the introduction and presented in figure 1.10. These are assigned based on the following five criteria taken from IUCN (2001):

> ***"A. Declining population (past, present and/or projected)***
>
> ***B. Geographic range size, and fragmentation, decline or fluctuations***
>
> ***C. Small population size and fragmentation, decline, or fluctuations***
>
> ***D. Very small population or very restricted distribution***
>
> ***E. Quantitative analysis of extinction risk (e.g., Population Viability Analysis)"***
>
> IUCN (2001); see **Figure 2.2** for summary sheet of IUCN Red List Categories and Criteria version 3.1

Additionally, each criterion has a quantitative threshold that enables the assessor to assign an appropriate threat category. For example: for criterion A1, the population reduction thresholds for VU, EN, and CR are more than or equal to 50%, 70% and 90% respectively. Thus if 75% population reduction is observed, estimated, inferred, or suspected in the past then the species in question is classified as EN as it surpasses the threshold value for EN yet is not equal to the threshold category for CR. Similarly, if population reduction is 45% then this species is not classified as threatened as reduction is lower than the threshold value for VU (however this species may be considered for NT as it is close to qualifying for a threatened category). See Figure 2.2 for a summary of IUCN Red List Categories and Criteria including quantitative thresholds for each criterion.

Only one of the five criteria need to be met in order to classify a species as threatened, however species can qualify for numerous criteria, in which case the highest category of threat and the criteria used for this category is used for species status while additional criteria is noted in supporting documents (IUCN, 2001).

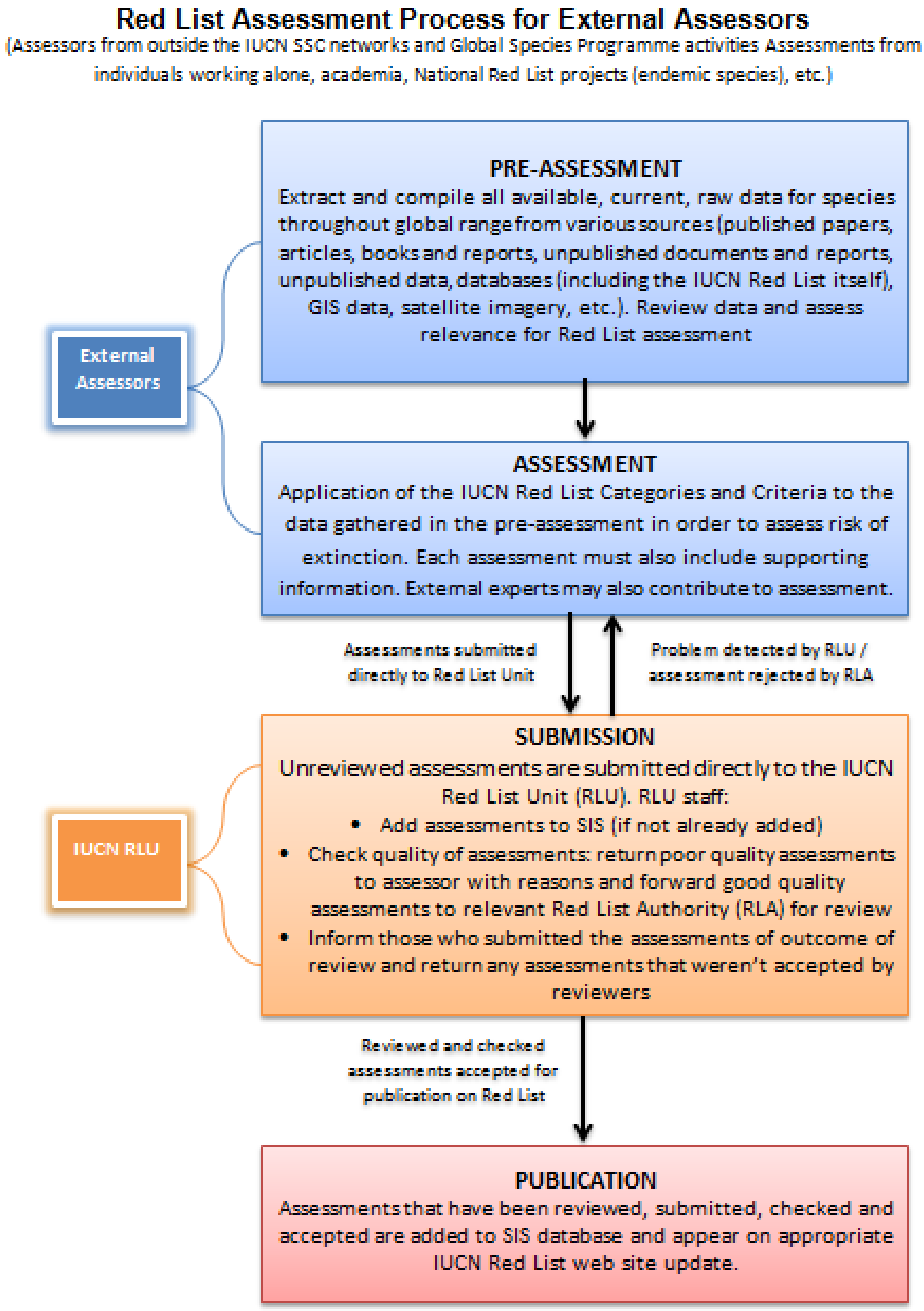


Figure 2.1 Red List assessment process for external assessors which includes five principle stages: pre-assessment, assessment, submission, and publication of accepted assessments. Source: IUCN (2012b).

A. Population size reduction. Population reduction (measured over the longer of 10 years or 3 generations) based on any of A1 to A4

	Critically Endangered	Endangered	Vulnerable
A1	≥ 90%	≥ 70%	≥ 50%
A2, A3 & A4	≥ 80%	≥ 50%	≥ 30%

A1 Population reduction observed, estimated, inferred, or suspected in the past where the causes of the reduction are clearly reversible AND understood AND have ceased.

A2 Population reduction observed, estimated, inferred, or suspected in the past where the causes of reduction may not have ceased OR may not be understood OR may not be reversible.

A3 Population reduction projected, inferred or suspected to be met in the future (up to a maximum of 100 years) *[(a) cannot be used for A3]*.

A4 An observed, estimated, inferred, projected or suspected population reduction where the time period must include both the past and the future (up to a max. of 100 years in future), and where the causes of reduction may not have ceased OR may not be understood OR may not be reversible.

based on any of the following:

- **(a)** direct observation *[except A3]*
- **(b)** an index of abundance appropriate to the taxon
- **(c)** a decline in area of occupancy (AOO), extent of occurrence (EOO) and/or habitat quality
- **(d)** actual or potential levels of exploitation
- **(e)** effects of introduced taxa, hybridization, pathogens, pollutants, competitors or parasites.

B. Geographic range in the form of either B1 (extent of occurrence) AND/OR B2 (area of occupancy)

	Critically Endangered	Endangered	Vulnerable
B1. Extent of occurrence (EOO)	< 100 km²	< 5,000 km²	< 20,000 km²
B2. Area of occupancy (AOO)	< 10 km²	< 500 km²	< 2,000 km²
AND at least 2 of the following 3 conditions:			
(a) Severely fragmented OR Number of locations	= 1	≤ 5	≤ 10
(b) Continuing decline observed, estimated, inferred or projected in any of: (i) extent of occurrence; (ii) area of occupancy; (iii) area, extent and/or quality of habitat; (iv) number of locations or subpopulations; (v) number of mature individuals			
(c) Extreme fluctuations in any of: (i) extent of occurrence; (ii) area of occupancy; (iii) number of locations or subpopulations; (iv) number of mature individuals			

C. Small population size and decline

	Critically Endangered	Endangered	Vulnerable
Number of mature individuals	< 250	< 2,500	< 10,000
AND at least one of C1 or C2			
C1. An observed, estimated or projected continuing decline of at least (up to a max. of 100 years in future):	25% in 3 years or 1 generation (whichever is longer)	20% in 5 years or 2 generations (whichever is longer)	10% in 10 years or 3 generations (whichever is longer)
C2. An observed, estimated, projected or inferred continuing decline AND at least 1 of the following 3 conditions:			
(a) (i) Number of mature individuals in each subpopulation	≤ 50	≤ 250	≤ 1,000
(ii) % of mature individuals in one subpopulation =	90–100%	95–100%	100%
(b) Extreme fluctuations in the number of mature individuals			

D. Very small or restricted population

	Critically Endangered	Endangered	Vulnerable
D. Number of mature individuals	< 50	< 250	**D1.** < 1,000
D2. *Only applies to the VU category* Restricted area of occupancy or number of locations with a plausible future threat that could drive the taxon to CR or EX in a very short time.	-	-	**D2.** typically: AOO < 20 km² or number of locations ≤ 5

E. Quantitative Analysis

	Critically Endangered	Endangered	Vulnerable
Indicating the probability of extinction in the wild to be:	≥ 50% in 10 years or 3 generations, whichever is longer (100 years max.)	≥ 20% in 20 years or 5 generations, whichever is longer (100 years max.)	≥ 10% in 100 years

Figure 2.2 Summary of the five IUCN Red List Criteria used to assess species extinction risk (IUCN, 2001).

The basic process towards this involves four or five stages and for external projects this includes; pre-assessment by 'Contributors' and/or 'Assessors', assessment by 'Assessors', direct submission to the IUCN RLU for checking, review and corrections or improvement if necessary, and finally, publication of accepted assessments on the IUCN Red List of Threatened Species.

Delineation of the project checklist was included within the pre-assessment phase as this involved extensive background research, the results of which were subsequently utilised as raw data for assessment. Supporting information for IUCN Red List assessments can be split into required information, recommended information, and discretionary information, all of which have a detailed description in tables 1-3 of the 'Documentation standards and consistency' document released by the IUCN (2013). All required information was filled out for the species of this project, alongside additional fields wherever possible. For most assessments within this project that were not assessed as Data Deficient (DD), the following information was entered into SIS (information required either indefinitely or under specific conditions is **emboldened**):

1) **Taxonomy** (Common names, known synonyms, **taxonomic notes**)
2) **Distribution** (**Narrative text about geographic range**, Area of Occupancy (AOO), Extent of Occurrence (EOO), **Locations information**, elevation, biogeographic realms, **georeferenced distributional map**)
3) **Countries of Occurrence (Presence and origin)**
4) **Population information** (**Narrative text about population**, **current population trend**, population size, fluctuation, **fragmentation**, past/ongoing/ future population reduction)

5) **Habitat and ecology** (**Narrative text about habitat and ecology**, **classification under the IUCN Habitats Classification Scheme (IUCN, 2012c),** continuing decline in habitat, **generation length, plant growth form**)
6) Use and Trade (Narrative text about use and trade, classification, offtake trends)
7) **Threats** (**Narrative text about threats**, **classification under the IUCN Threats Classification Scheme (IUCN, 2012c))**
8) Conservation (written description, Conservation actions in place/needed, research needed)
9) **Red List Assessment** (**category, criteria, rationale, date, assessors, contributors, reviewers)**
10) **Bibliography**

Data collation was undertaken throughout the project to ensure that the most recent literature was taken into account where possible. Lack of data for certain taxonomic groups often proved problematic, this will be expanded upon in the discussion.

Data for each of the sections listed above was extracted from a range of sources, with any one resource usually yielding information useful for more than one subject area. The Plant List (2013) was the principle taxonomic reference for synonyms and common names; however this was often cross referenced with GRIN Taxonomy (USDA, ARS, National Genetic Resources Program, 2015)) and the World Checklist of Selected Plant Families (WCSP, 2014) to acknowledge any taxonomic debate which was then referenced in the 'Taxonomic notes' section. Establishing native range (including country list) was done by combining information from GRIN Taxonomy (USDA, ARS, National Genetic Resources Program, 2015)), the Harlan and de Wet CWR online Inventory (Vincent *et al.,* 2013), and WCSP (2014) with information from national floras and Red Lists. The National Red List project (NRLWG, 2012 to present) was an invaluable source and contributed to most areas of assessment for species with regional species assessments available. Some issues of data availability for regional Red Lists were present and will be discussed later. The European Red List of Vascular Plants (Bilz *et al.,* 2011) proved a very useful resource when assessing species native to Europe. Floras and online plant databases were also a primary source of information for all subject areas, a few examples being : eFloras (2008) which provided the Flora of China, North America, and Chile amongst others; Jepson eflora for California (2014); the African Plant Database (Conservatoire et Jardin botaniques & South African National Biodiversity Institute, 2012); USDA PLANTS database (USDA, NRCS, 2014); FloraGREIF - Virtual Flora of Mongolia (University of Greifswald, Institute of Botany and Landscape Ecology, Institute of Geography and Geology, Computer Centre, 2010 to present); NatureServe Explorer for information on species of the United States and Canada (Natureserve. 2014); and Plants For A Future, (1996-2012) which was mainly used to ascertain habitat and plant use. Monographs were used for certain taxa (Wheat relatives, for example, used van Slageren (1994)) however original publications were often not readily available so in most cases this information was indirectly accessed through online plant databases which had extracted and digitalised relevant information from these publications to contribute to the database. Some online plant databases also contained information about prominent threats, or directed the researcher to other relevant databases or Red Lists where this information was held. Where this was not the case, which occurred for many species with minor threats, publications (journal articles, reports, books) detailing threats to habitat types (both local and regional) were invaluable, for example in China some general threats to forest habitats were identified from USDA Forest Service (2013) while Zheng *et al.* (2012) discusses degradation of forest and grassland habitat in the province of Sichuan. The WWF Terrestrial Ecoregions website (Olson *et al.*, 2001; WWF, 2013) was well used as this describes threats and current status of habitats in moderate detail. Best judgement, alongside any additional available information, was then used to infer whether the species was likely to be subject to any threats described by the WWF.

IUCN SIS was used to store and collate raw data, review information and undertake species assessment, as well as for submission of final draft assessments and supporting documentation to the IUCN RLU.

2.4. Spatial data to accompany Red List assessments

Distributional data is an important contributor to an IUCN Red List assessment as it provides a visual representation of species' distribution, helps to identify areas where conservation action would be most effective, and directly informs Red List assessments. A summary of the IUCN Red List Categories and Criteria (version 3.1; IUCN, 2001) is given in Figure 2.2 and demonstrates that geographical range is implicated in several criteria. Criterion A evaluates species population size reduction and can be based on direct observation or a series of indicators including "*c) a decline in area of occupancy (AOO), extent of occurrence (EOO) and /or habitat quality"*. Criterion B evaluates the geographic range of species, and uses two measurements derived from this range- EOO or AOO, also taking into account severe fragmentation or small number of locations and continuing decline in EOO, AOO, number of locations, or subpopulations. Criterion D evaluates very small or restricted population, with species that have an AOO of 20km^2 (or less than 5 locations) being assessed as VU under subcriterion D2.

Georeferenced data for species on the project checklist was extracted from the Harlan and de Wet CWR inventory (Vincent *et al.,* 2013) where available, and quality control was undertaken for each species. This raw, georeferenced data was only available for 84 of the 267 assessed species, however through the use of literature searches and knowledge of habitat preferences, species' approximate global native distribution was established for 136 species and shapefiles were created for each of these to accompany IUCN Red List assessments IUCN 2013). An example of a completed preliminary assessment for which this was possible is *Allium altaicum* Pall. which can be found in Appendix 2. These shapefiles were created using ArcMAP (ArcGIS) and are accompanied by an attribute table that delineates population level information (presence, origin and seasonality of species within an area), as well as information concerning the source of the data, when it was compiled, and by whom.

Where possible, the Geospatial Conservation Assessment Tool (GeoCAT; Bachman *et al.,* 2011) was used to calculate EOO and AOO as this online platform is consistent, intuitive, and performs automated EOO and AOO analysis. The polygon shapefiles created to accompany the IUCN Red List assessments were converted from polygon to point data using the 'conversion' tool in ArcMAP which allowed automated calculation of the EOO when uploaded to GeoCAT. The AOO created from the same method was presumed to be an overestimate as plants are not normally uniformly and consistently present across the entirety of their range. The exception to this is often when plants are limited or specially adapted to a certain area, in which case AOO is often a similar value to EOO. Calculating AOO was only possible where site specific, georeferenced occurrence data was available from the Harlan and de Wet CWR Inventory (Vincent *et al.*, 2013). As discussed above this data was subject to quality control checks and uploaded directly to GeoCAT for automated calculation of AOO where appropriate.

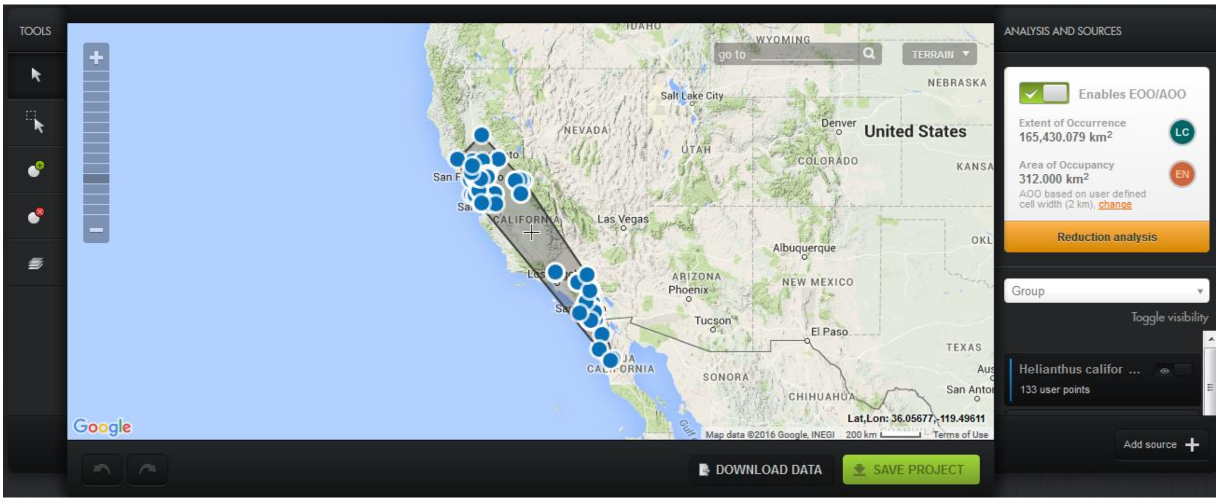


Figure 2.3 Occurrence data for *Helianthus californicus* uploaded to GeoCAT demonstrating automated calculation of EOO and AOO where georeferenced data is available.

2.5. Additional spatial analysis

In addition to creating shapefiles to accompany Red List assessments and estimating EOO and AOO, once native distribution had been established and accurate occurrence data had been extracted from the Harlan and de Wet CWR inventory (Vincent *et al.,* 2013), species richness was mapped for threatened and near threatened species (NT, VU, EN, CR), and all assessed species (LC, NT, VU, EN, CR species- excluding DD and EW species). Where information regarding native range was absent or uncertain (131 species), or occurrence data was not available (184 species), species could not be included in the richness analysis.

This resulted in only 8 of the 25 threatened or near threatened species being included in the former species richness analysis and 82 of the 187 species assessed as LC, NT, VU, EN, or CR being included in the latter species richness analysis.

Measuring species richness is one of the most straightforward ways of measuring alpha diversity (*"community's richness in species"*- Whittaker, 1972) and was mapped using DIVA-GIS software (version 7.5) - a freely available GIS tool for mapping and querying geographic data. The two principle steps in this process were: conversion of processed occurrence data (CSV files) to vector files (shapefiles with point data) using the 'point to shapefile' function and conversion of those vector files to raster files (gridfiles with discrete presence data) by using the 'point to grid' function. The parameter field was set to distinguish between different species, the output variable was set to distinguish 'number of different classes (richness)', and the 'circular neighbourhood' option was applied to consider diversity in areas adjacent to each cell as well as within each cell (diameter 1 map unit which is equal to 1 degree for maps based on latitude/longitude coordinates). The product was a grid file with a cell size of 1 decimal degree (approximately equal to 60 minutes or 111km at the equator, see Scheldeman and von Zonneveld (2010)) and a circular neighbourhood of 1.5 decimal degrees diameter for threatened and near threatened species, or a cell size of 0.5 decimal degrees and a circular neighbourhood of 0.75 decimal degrees diameter for assessed species that gave a global map of species richness for the desired sample of taxa.

In addition to this, the same method was used to create a map of observation richness by altering the output variable of 'richness' to 'number of observations' instead of 'number of different classes (richness)'. This allows a geographical comparison of species richness and sampling intensity to help identify areas where over or under sampling may have occurred. It is expected that some positive correlation should occur between these two variables as the majority of the data used originated from a variety of sources including herbaria and genebanks and so will in some cases represent unsystematic and uneven sampling of the target species (Scheldeman and von Zonneveld, 2010).

3 Results

3.1 Threat status

Of the 267 CWR species that had global assessments done for this project, around 6.3% (17 species) were considered to be Threatened, with 0.7% (two species) being Critically Endangered (CR), 3.4% (nine species) being Endangered (EN), and 2.2% (six species) being Vulnerable (VU). One species, *Mangifera casturi* Kosterm., was previously known from the wet climate area around Banjarmasin in Indonesia but has been identified as Extinct in the Wild (EW) in previous assessments (WCMC, 1998). As no evidence to contend this could be found, this category is maintained and the species is now only thought to be found in cultivation. It is necessary to mention that this species should be reviewed and potentially reclassified as Extinct, or taken off the Red List as it is unsure whether this species was previously known as a wild or a cultivated species. Around 3.0% (eight species) of the assessed species were considered Near Threatened (NT), while the large majority (60.7% or 162 species) were considered Least Concern (LC), and a further 29.6% (79 species) were deemed Data Deficient (DD). This is summarised in Table 3.1 and Figure 3.1 while a list of extinct, threatened and near threatened species, and the threat criteria they meet, can be found in Table 3.2 (see IUCN Red List Categories and Criteria summary sheet (Figure 2.2) or (IUCN, 2001) for detailed explanation of IUCN Categories and Criteria).

IUCN Red List Category	No. species
Extinct in the Wild (EW)	1
Critically Endangered (CR)	2
Endangered (EN)	9
Vulnerable (VU)	6
Near Threatened (NT)	8
Least Concern (LC)	162
Data Deficient (DD)	79
Total Evaluated species	**267**

Table 3.1 Summary of numbers of CWR within each IUCN Red List threat Category

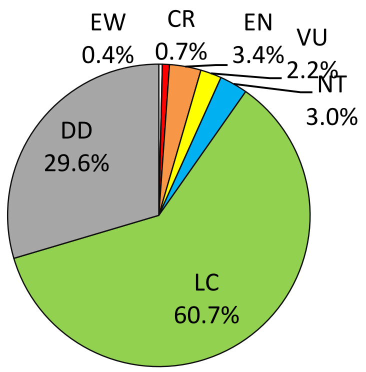


Figure 3.1 Red List Category of assessed CWR species

The summaries given in the previous paragraph are minimum estimates of threat, a more realistic view may be considered if those species that are no longer extant or those for which we do not have enough data (EW and DD species) are excluded (Bilz *et al.,* 2011). EW and DD CWR account for a total of 80 species in this study, excluding these CWR and assuming that proportion of threatened species is consistent within the DD group, 9.1% of the remaining 187 CWR species assessed are considered globally threatened.

Family	Species	Category	Criteria
ANACARDIACEAE	*Mangifera casturi*	EW	NA
LEGUMINOSAE	*Vigna monantha*	CR	B1ab(iii)
ROSACEAE	*Prunus murrayana*	CR	D
ANACARDIACEAE	*Mangifera austro-indica*	EN	B1ab(iii,iv,v)
ANACARDIACEAE	*Mangifera dongnaiensis*	EN	A2c
ANACARDIACEAE	*Mangifera minutifolia*	EN	B1ab(ii,iii)+2ab(ii,iii)
ANACARDIACEAE	*Pistacia mexicana*	EN	A2c
ASPARAGACEAE	*Asparagus kiusianus*	EN	B1ab(iii,iv,v)
LEGUMINOSAE	*Vicia hyaeniscyamus*	EN	B1ab(iii,iv)+2ab(iii,iv)
LEGUMINOSAE	*Vicia kalakhensis*	EN	B1ab (iv)+2ab(iv)
LEGUMINOSAE	*Vigna keraudrenii*	EN	B2a(i-v)
ROSACEAE	*Malus komarovii*	EN	B1ab(iii)
ANACARDIACEAE	*Mangifera andamanica*	VU	B1ab(iii)
ANACARDIACEAE	*Mangifera collina*	VU	B1ab(iii)
ANACARDIACEAE	*Mangifera flava*	VU	B1ab(i,ii,iii)+2ab(i,ii,iii)
ANACARDIACEAE	*Mangifera pentandra*	VU	B1ab(i,ii,iii,iv)+2ab(i,ii,iii,iv)
COMPOSITAE	*Helianthus paradoxus*	VU	A2c
LEGUMINOSAE	*Vicia tigridis*	VU	D2
ALLIACEAE	*Allium roylei*	NT	VU A2(d)
COMPOSITAE	*Helianthus anomalus*	NT	VU B1ab(iii,v)+ 2ab(iii,v)
COMPOSITAE	*Helianthus exilis*	NT	EN B2ab(iv,v)
GRAMINEAE	*Hordeum guatemalense*	NT	EN B2a
LEGUMINOSAE	*Vicia esdraelonensis*	NT	VU B1ab(i, iii)
LEGUMINOSAE	*Vicia qatmensis*	NT	EN B1ab(i-iv)+2ab(i-iv)
ROSACEAE	*Amygdalus texana*	NT	VU B1ab(iv)
ROSACEAE	*Prunus maritima*	NT	B2a

Table 3.2 All 18 CWR species globally assessed as Extinct in the Wild (EW), Threatened (Critically Endangered (CR), Endangered (EN), and Vulnerable (VU)) and the additional eight CWR species globally assessed as Near Threatened (NT).

Genus	Crop complexes to which genus belongs	No. spp. assessed	Red List Status of assessed species							% Threatened species
			EW	CR	EN	VU	NT	LC	DD	
Aegilops	Wheat	15	0	0	0	0	0	**14**	**1**	0.0%
Allium	Onion, Leek Garlic etc.	24	0	0	0	0	**1**	**10**	**13**	0.0%
Amygdalus	Stone fruits	8	0	0	0	0	**1**	**2**	**5**	0.0%
Armeniaca	Stone fruits	2	0	0	0	0	0	0	**2**	0.0%
Asparagus	**Asparagus**	**15**	0	0	**1**	0	0	**11**	**3**	**6.7%**
Avena	Oat	5	0	0	0	0	0	**3**	**2**	0.0%
Cerasus	Stone fruits	10	0	0	0	0	0	**3**	**7**	0.0%
Eleusine	Finger Millet	5	0	0	0	0	0	**3**	**2**	0.0%
Helianthus	**Sunflowers**	**26**	0	0	0	**1**	**2**	**19**	**4**	**3.8%**
Hordeum	Barley	30	0	0	0	0	**1**	**28**	**1**	0.0%
Ilex	Yerbe mate	1	0	0	0	0	0	0	**1**	0.0%
Lupinus	Legume forage	3	0	0	0	0	0	**3**	0	0.0%
Malus	**Apple**	**24**	0	0	**1**	0	0	**11**	**12**	**4.2%**
Mangifera	**Mango**	**12**	**1**	0	**3**	**4**	0	**3**	**1**	**58.3%**
Medicago	Legume forage	16	0	0	0	0	0	**14**	**2**	0.0%
Padus	Stone fruits	2	0	0	0	0	0	**1**	**1**	0.0%
Pennisetum	Pearl Millet	5	0	0	0	0	0	**4**	**1**	0.0%
Pistacia	**Pistacio**	**6**	0	0	**1**	0	0	**4**	**1**	**16.7%**
Prunus	**Stone fruits**	**34**	0	**1**	0	0	**1**	**15**	**17**	**2.9%**
Vicia	**Faba bean/vetch**	**20**	0	0	2	**1**	**2**	**13**	**2**	**15.0%**
Vigna	**Cowpea et al.**	**4**	0	**1**	**1**	0	0	**1**	**1**	**50.0%**
Totals		**267**	**1**	**2**	**9**	**6**	**8**	**162**	**79**	**6.4%**

Table 3.3 Red list status of assessed CWR classified by crop complex, showing percentage of 'threatened' species (Critically Endangered (CR), Endangered (EN), and Vulnerable (VU)). Information on rows for genera with threatened species is emboldened.

It is necessary to note that the scope of assessment is very different for each genus and this must be remembered when identifying proportional threat (Table 3.3). It must be stressed that this may be partially due to selection criteria for inclusion in the Red List project and may have presented bias in the results- an issue that will be explored in the discussion section. For 13 of the 21 genera included in the project, no species were assessed as threatened. The two genera with the highest proportions of threatened species were

Mangifera and *Vigna* with 58.3% (seven out of 12 species) and 50.0% (two out of four species) respectively. There were only two other genera with values over 10%, which were *Pistacia* (16.7% or one out of six species), and *Vicia* (15.0% or three out of 20 species). While *Asparagus, Malus, Helianthus, Prunus* all had one species deemed threatened which was proportionally equal to 6.7%, 4.2%, 3.8%, and 2.9% of the assessed species for each genus respectively (Table 3.3).

Maxted *et al.* (1997a) highlighted that conservation of PGRFA and CWR must be aimed at safeguarding genetic diversity. Thus, despite IUCN Red List assessment methodologies being principally aimed at evaluation on a species level, threats to genetic diversity or indicators thereof must be considered. As no genetic data contributed to threat assessment, species extinction risk must be presumed to be equal to or lower than loss of genetic diversity as postulated by Maxted *et al.* (1997a) and Maxted (2003).

3.2 Major threats

Within the scope of the IUCN Red List assessment, prominent threats to each species were recorded and coded against the IUCN Threats Classification scheme, version 3.2 (IUCN, 2012c). While only 17 species were assessed as threatened, 144 species had recorded threats with an average number of threats per species being around six and ranging from one to 25.

As can be seen in Figure 3.2, 'Housing and urban areas' (103 species), 'livestock farming and ranching' (85 species), and 'logging and wood harvest' (79 species) are the most prominent threats amongst CWR species studied in this project. However a relatively low proportion of species affected by these threats were given a threatened status (17.5%, 20.0%, and 12.7%

of the total species count for each respective threat), while for certain other threats the proportion of affected species that are threatened is much higher (53.3% of the 15 species threatened by wood and pulp plant plantations, 50.0% of the four species threatened by dams and water management/use, and 42.6% of the 47 species threatened by annual and perennial non timber crops). While this suggests that these threats are more likely to result in a high species extinction risk, care must be taken when interpreting threat data such as this because most species are subject to more than one threat at any given time and the cumulative effect of different combinations of these may produce different effects.

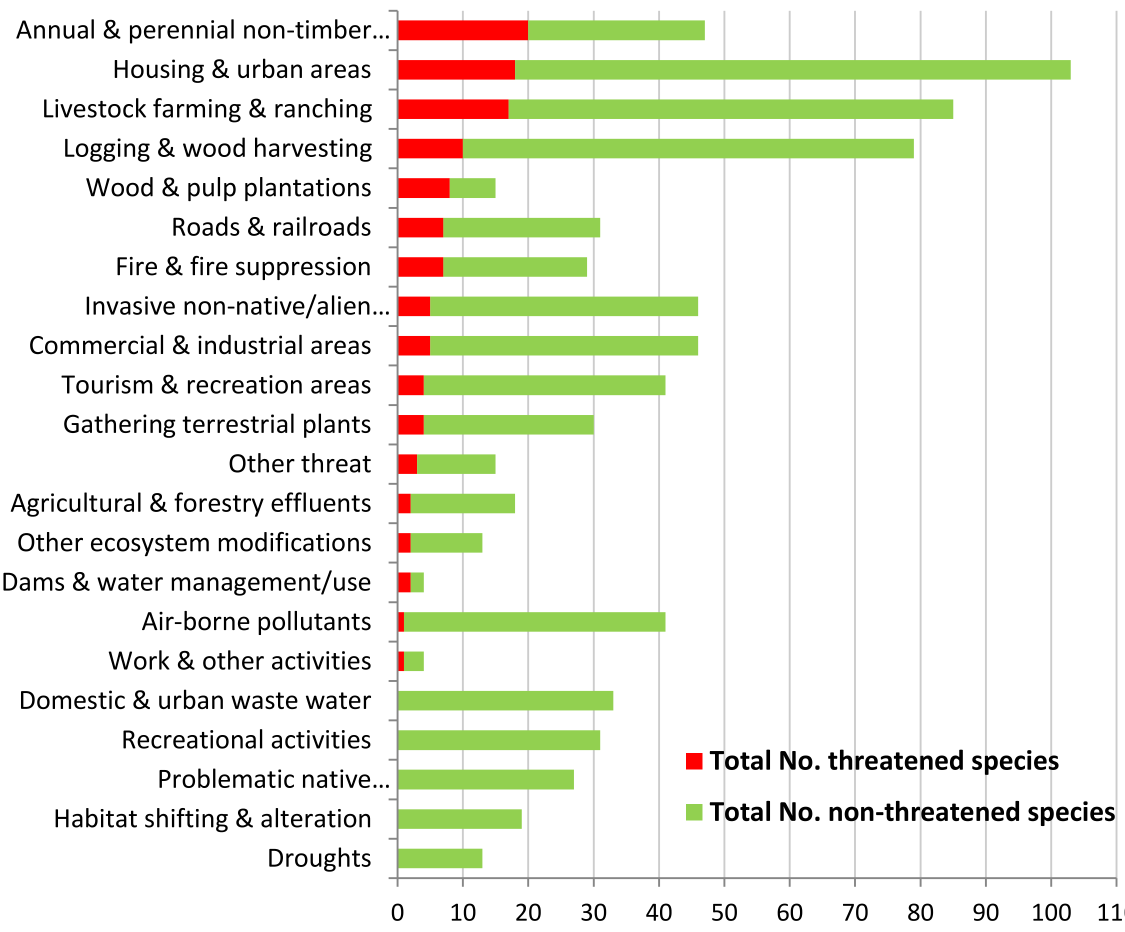


Figure 3.2 The most prominent, ongoing threats to CWR on a global scale (only threats recorded more than 10 times within project were included in this analysis).

3.3 Habitat types

The IUCN Habitat Classification Scheme (Version 3.1) (IUCN, 2012d) was used for the purposes of assessment. Definitions and synonyms for each habitat type can be found in the 'draft working document' for this classification (IUCN, 2012d). The third, more detailed level of the classification hierarchy was not applicable to CWR taxa used in this project due to the limited level of detail available from the literature concerning species' habitat preferences.

For the CWR assessed within this project, grassland is the most species rich habitat containing a total of 148 species from the project checklist, while forest and marine intertidal habitats are the second and third most species rich containing 125 and 88 CWR species respectively. Habitat type is unknown for one species (*Medicago lesinsii*) and the lowest species richness is found in desert habitat, 'other' and marine coastal/supratidal habitat with six, 14, and 15 species respectively (Figure 3.3).

Seventy-one species are found only to occur in one habitat type; the habitat types with the highest proportion of these unique species are: Rocky areas (27%), Marine Coastal/Supratidal (27%), Forest (19%), and Desert (17%) (Figure 3.3).

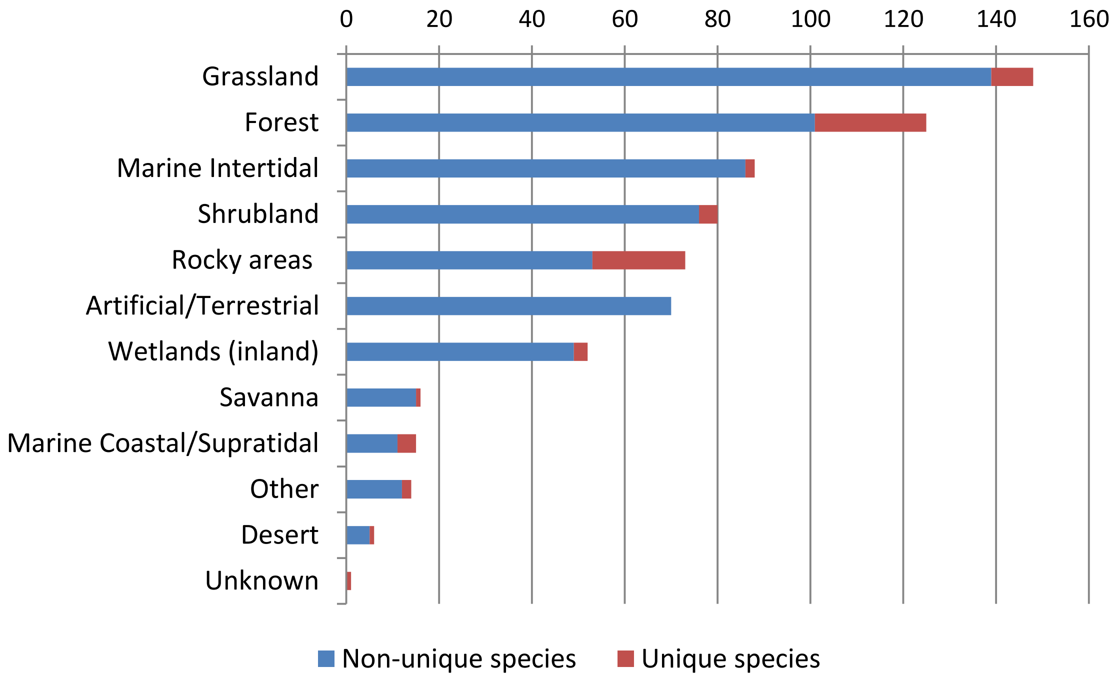


Figure 3.3 Species richness for each habitat type, with number of species unique to habitat type highlighted in red.

For all habitats, the majority of recorded species are assessed as LC or DD, which is unsurprising given that these are the most commonly occurring categories within the project checklist. Grassland contains the highest number of LC CWR with 103 species, which makes up 70% of total species count for this habitat. However in proportional terms, wetlands (inland) and Artificial/terrestrial habitats comprise 87% and 84% LC species respectively. The same is true for DD species; numerically grassland contains the highest number of DD species, but proportionally savanna and rocky areas are comprised of 44% and 38% DD species respectively.

Threatened species are recorded in all habitats excluding desert, savanna, ‘other’ and ‘unknown’, while two NT species, *Amygdalus texana* and *Helianthus anomalus,* occur in dry savanna and temperate desert respectively. Forest habitat contains a total of 125 species from all Red List Categories, including 35 DD species, 74 LC species, three NT species, 12 threatened species (one CR, seven EN, and four VU) and *Mangifera casturi* which is EW. Grassland habitat also contains CWR species with a wide range of threat statuses comprising 37 DD, 103 LC, two NT, and six threatened species (one VU, four EN, and one CR). These two habitat types (forest and grassland) also contain the highest number of threatened species, however the two habitats containing highest proportion of threatened (VU, EN, CR) to non/near threatened (LC, NT) species are forest, rocky areas, and marine coastal/supratidal habitats comprising 10%, 7%, and 7% threatened species respectively.

3.4 Population trends

Population trend was noted for 266 of the 267 CWR species assessed within the scope of this project. *Mangifera casturi* was not included in this as it is assessed as EW with no extant wild populations, so population trend cannot be applied. As can be seen from Figure 3.4, global population trend is stable for 54.5% (145) of the 266 species, the majority of which are assessed as LC (140 species or 96.6%). Four species are DD despite having a stable population trend, while *Helianthus paradoxus* is VU with a stable population trend. Three species (1.1%) have an increasing population trend and all of these are globally assessed as LC. Population trend is unknown for 81 species (30.5%), 61 of which are DD, while decreasing population trend is recorded for 37 species (13.8%) and comprise all levels of the IUCN Red List Categories. Of the 37 species with decreasing population trend, 40.5% are also assessed as threatened (VU, EN, CR) or NT, while 37.8% are globally assessed as DD and only 10.8% are assessed as LC.

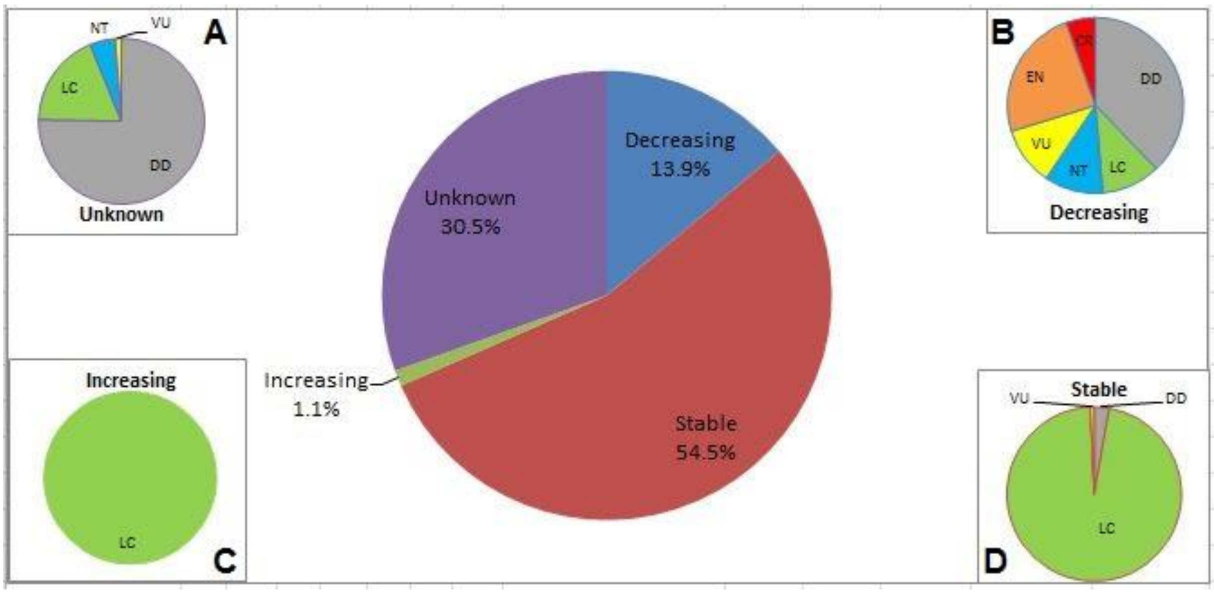


Figure 3.4 Global population trend for the 266 CWR species assessed within this project (central pie chart). Proportional representation of Red List Categories for species classified as having A) an unknown global population trend, B) a decreasing global population trend, C) an increasing global population trend, or D) a stable global population trend.

3.5 Spatial distribution

3.5.1 Red List assessments: maps and geographic range

As previously stated, shapefiles denoting native distribution accompanied 136 of the 267 globally assessed species within this project. This was achieved using occurrence data taken from preliminary Harlan and de Wet CWR Inventory (Vincent *et al.,* 2013) which was present for a total of 84 species from the project checklist, alongside information from literature searches and known habitat preferences to estimate or calculate native range. Shapefiles denoting native range were then converted from polygon to point data using ArcMap and uploaded to GeoCAT to analyse AOO and EOO for each species.

While native distribution maps were only created for 136 CWR, EOO is recorded for a higher proportion of the 267 assessed CWR species (215 CWR or 80.5%). This is because EOO could be estimated and inferred from more vague written descriptions of native distribution, ecology, and habitat. The creation of distribution shapefiles to accompany these EOO estimates required more precision and so was not possible in all cases. AOO was only recorded for 109 (40.8%) of the 267 assessed CWR species, as even though attempts were made to estimate this value, less information was available and estimation of this value is more complex than estimating EOO so this was not possible for the large majority of species. Figure 3.5 shows proportional Red List Category for species where EOO is known and where AOO is known and it can be seen that the majority of these species are LC.

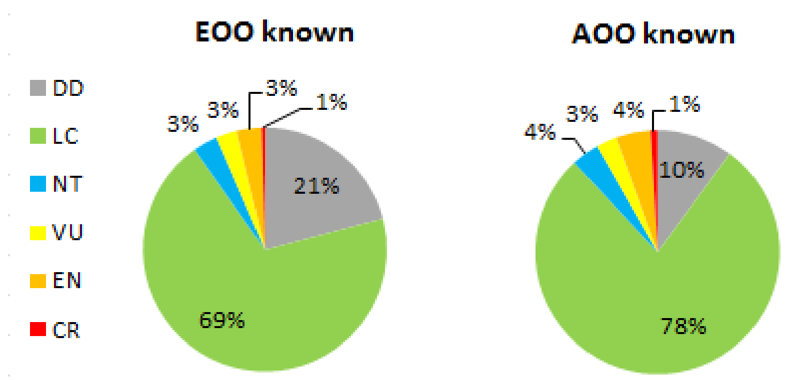


Figure 3.5 Proportional Red List Category of species where Extent of Occurrence (EOO) and Area of Occupancy (AOO) are known.

Of the 53 species with unknown EOO, 66.0% are assessed as DD, while 24.5% are assessed as LC, while for the 159 species with unknown AOO proportion of DD and LC species are 43.4% and 48.4% respectively. The 14 species presented in Table 3.4 are those for which EOO and/or AOO is unknown, and threat status is threatened or NT. For four of the 14 species neither EOO nor AOO is known, the first of which is classified as EW (*Mangifera casturi*), the second NT (*Allium roylei*), the third EN (*Mangifera dongnaiensis*), and the fourth species is CR (*Prunus murryana*).

Table 3.4 Fourteen species from the project checklist that have one of either AOO or EOO unknown (U) yet are also globally assessed as threatened or near threatened.

Species	Taxonomic authority	Category	Criteria	EOO	AOO
Mangifera andamanica	King	VU	B1ab(iii)	6500	U
Mangifera casturi	Kosterm.	EW		U	U
Mangifera dongnaiensis	Pierre	EN	A2c	U	U
Malus komarovii	(Sarg.) Rehder	EN	B1ab(iii)	3500	U
Mangifera collina	Kosterm.	VU	B1ab(i,ii,iii)	17000	U
Mangifera austro-indica	Kosterm.	EN	B2ab(i,ii,iii,iv,v)	U	100
Pistacia mexicana	H.B.K.	EN	A2c	1553129	U
Vicia esdraelonensis	Warb. & Eig	NT	VU B1ab(i, iii)	30000	U
Allium roylei	Stearn	NT	VU A2d	U	U
Asparagus kiusianus	Makino	EN	B1ab(iii,iv,v)	3000-5000	U
Helianthus anomalus	S.F.Blake	NT	B1ab(iii,v)+2ab(iii,v)	60000-200000	U
Helianthus paradoxus	Heiser	VU	A2c	80000	U
Amygdalus texana	(D.Dietr.) W.Wright	NT	VU B1ab(iv)	30000	U
Prunus murrayana	E.J.Palmer	CR	D	U	U

3.5.2 Species richness

A global map of species richness is shown in Figure 3.6, inclusive of 82 CWR from the project checklist for which spatial data was available and that were assessed as LC (74 species), NT (three species), VU (one species), EN (three species), or CR (one species).

Global species richness ranges from one to 26 species per grid square (0.25 decimal degrees^2, considering circular neighbourhood 0.75 decimal degrees in diameter) and is unevenly distributed across global range. A larger scale map of the global species richness map is given in Figure 3.7, showing European Mediterranean and Middle East regions. It is noteworthy that species richness does not exceed 10 species per grid square in any area outside of the region delineated by this figure, and observation richness is also highest within this geographical area (see Figure 3.8).

Highest species richness is concentrated in the Middle East, from northern parts of Jordan through Lebanon and Syria along the Fertile Crescent. Apart from the high species richness value of 21 species found in central Spain, species richness values as high as 20 were unique to this area, with 35 species found in the 10 most species rich grid squares within this region (where species richness is greater than or equal to 20). These are mainly *Aegilops* (13 species), *Medicago* (eight species), and *Vicia* (nine species), but also include *Allium ampeloprasum, Avena fatua, Horduem bulbosum, Lupinus angustifolius,* and *Pistacia khinjuk.* Apart from *Vicia hyaeniscyamus* which is EN and *V. qatmensis* which is NT, all species in these 10 grid squares are LC.

High species richness in central Spain is very close to two large cities (Madrid and Toledo). This circular neighbourhood includes 21 species, all of which are LC, comprising *Aegilops* (three species), *Allium* (two species), *Lupinus* (two species), *Medicago* (seven species), *Vicia* (four species), *Asparagus acutifolius, Avena fatua, Cerasus mahaleb*. Observation richness is relatively low throughout Spain and Northern Morocco, generally not exceeding 56 occurrences per grid square, even in southern regions of Spain and Portugal near the Mediterranean where a moderately high species richness of 14 species per grid square is found.

Transcaucasia (Georgia, Armenia, and Azerbaijan) also shows high levels of species richness per grid square. The 21 species that occur in the two most species rich grid squares in this region, all of which are LC, include: *Aegilops* (eight species), *Vicia* (eight species), *Allium schoenoprasum, Avena fatua, Cerasus mahaleb, Hordeum bulbosum,* and *Medicago rigidula*.

Observation richness for species rich areas in this region is generally high, with 315 and 161 occurrences in the two most species rich grid squares.

Smaller areas of species richness can be seen in Greece and Turkey, mostly in coastal areas along the Mediterranean with one additional area in central Turkey. Apart from these concentrated areas of species richness, values within this region are generally within the range of one to eight species per grid square.

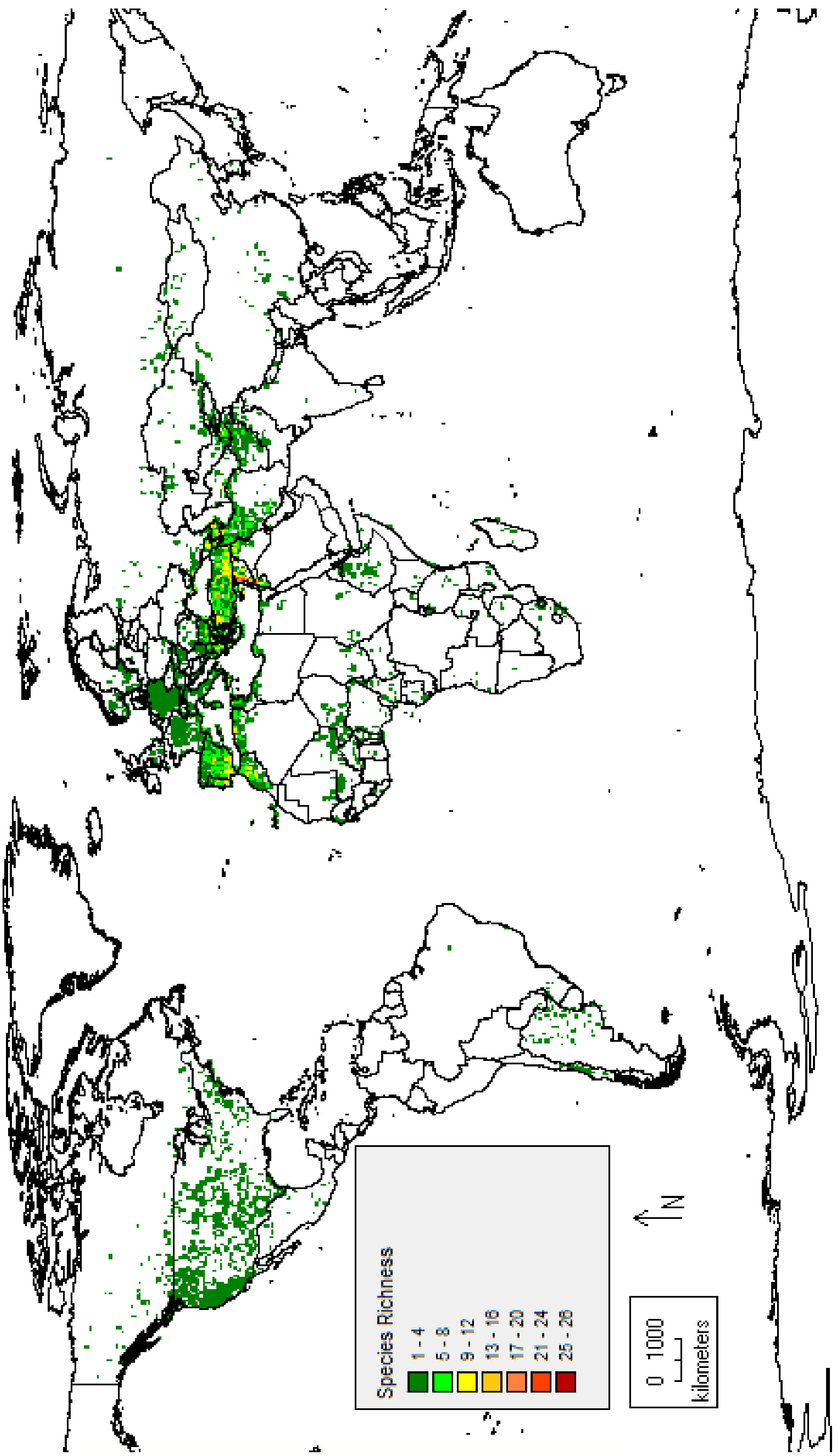


Figure 3.6 Global map of species richness for the 83 CWR included within this project that had sufficient spatial data to estimate species' native range and were assessed as LC, NT, VU, EN, or CR.

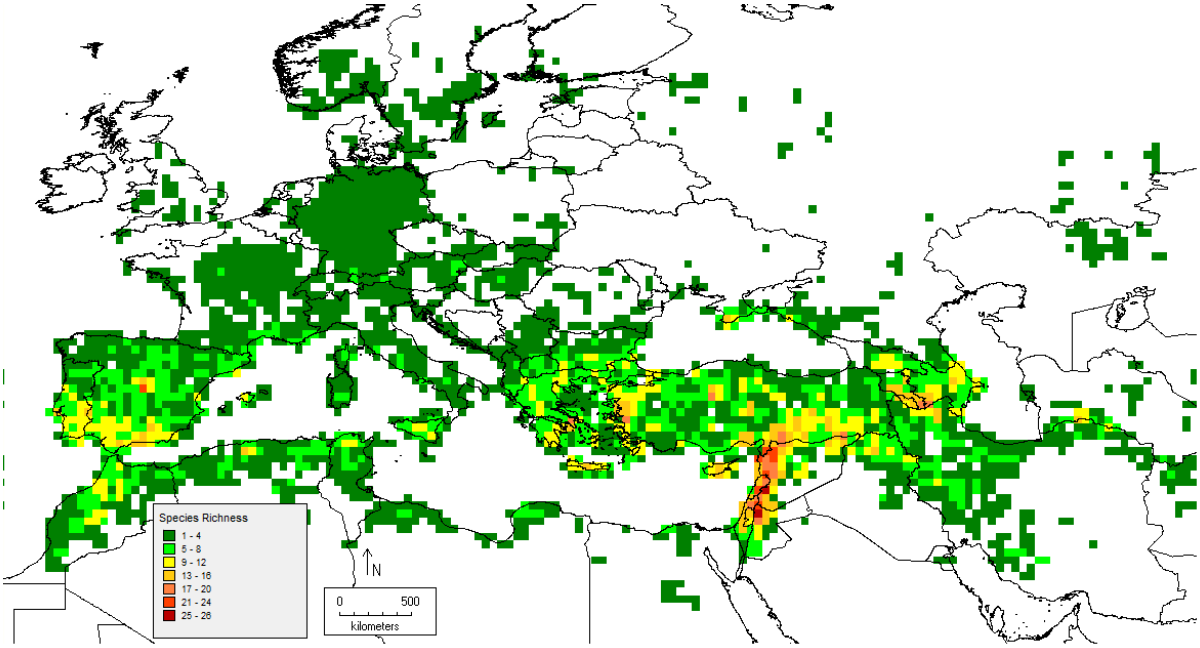


Figure 3.7 Transect of global map showing areas with highest CWR species richness.

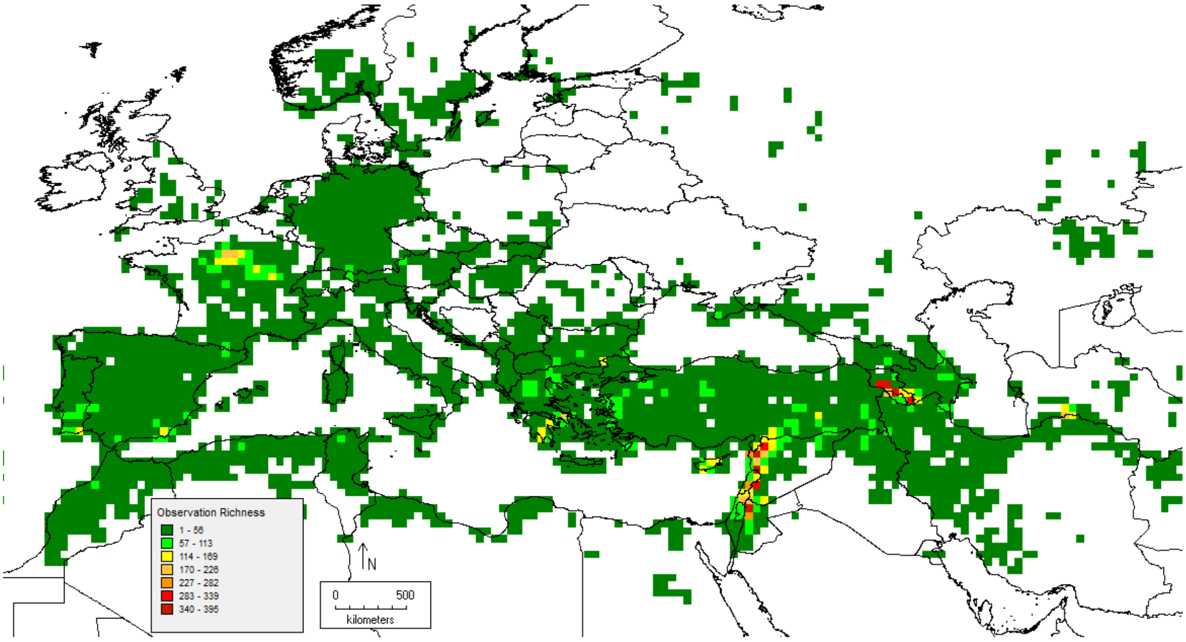


Figure 3.8 Observation richness for areas with highest CWR species richness.

3.5.3 Distribution of threatened CWR

Figure 3.9 shows global species richness per one decimal degree grid square (circular neighbourhood two decimal degrees in diameter) for the eight CWR included within this project for which spatial data was available and that were assessed as NT (three species), VU (one species), EN (three species), or CR (one species).

Maximum threatened species richness of two was recorded for two adjacent grid squares in western Syria (Figure 3.10), while elsewhere richness did not exceed one species per grid square. This high species richness accounts for two populations of *Vigna* species found in this area of the Fertile Crescent: *Vicia hyaeniscyamus* (EN) and *Vicia qatmensis* (NT), which are found on the Syria-Lebanon border and the Syria- Turkey border respectively. High observation richness (57 occurrences per grid square) is also observed in this area corresponding with high threatened species richness (Figure 3.11) as well as species richness for all 86 species observed in the previous sub section (Figure 3.10).

Figure 3.12 shows richness of threatened species eligible for spatial analysis in North and Central America. While species richness never exceeds one, occurrences for three threatened CWR species are recorded in this area: *Helianthus paradoxus*(VU) which is found in Texas, *Pistacia mexicana* (EN) which is endemic to Mexico, and *Prunus maritima* (NT) which is found on the eastern coast of the United States. Observation richness does not exceed seven for *P. maritima,* five for *H. paradoxus,* and two for *P. mexicana*.

In Africa, threatened species with sufficient spatial information were *Vigna keraudrenii* (EN) and *Vigna monantha* (CR) for which occurrence records were found on the coastline of Somalia and central Madagascar (Figure 3.13). Observation richness was between one and four for *V. keraudrenii* and between one and five for *V. monantha.*

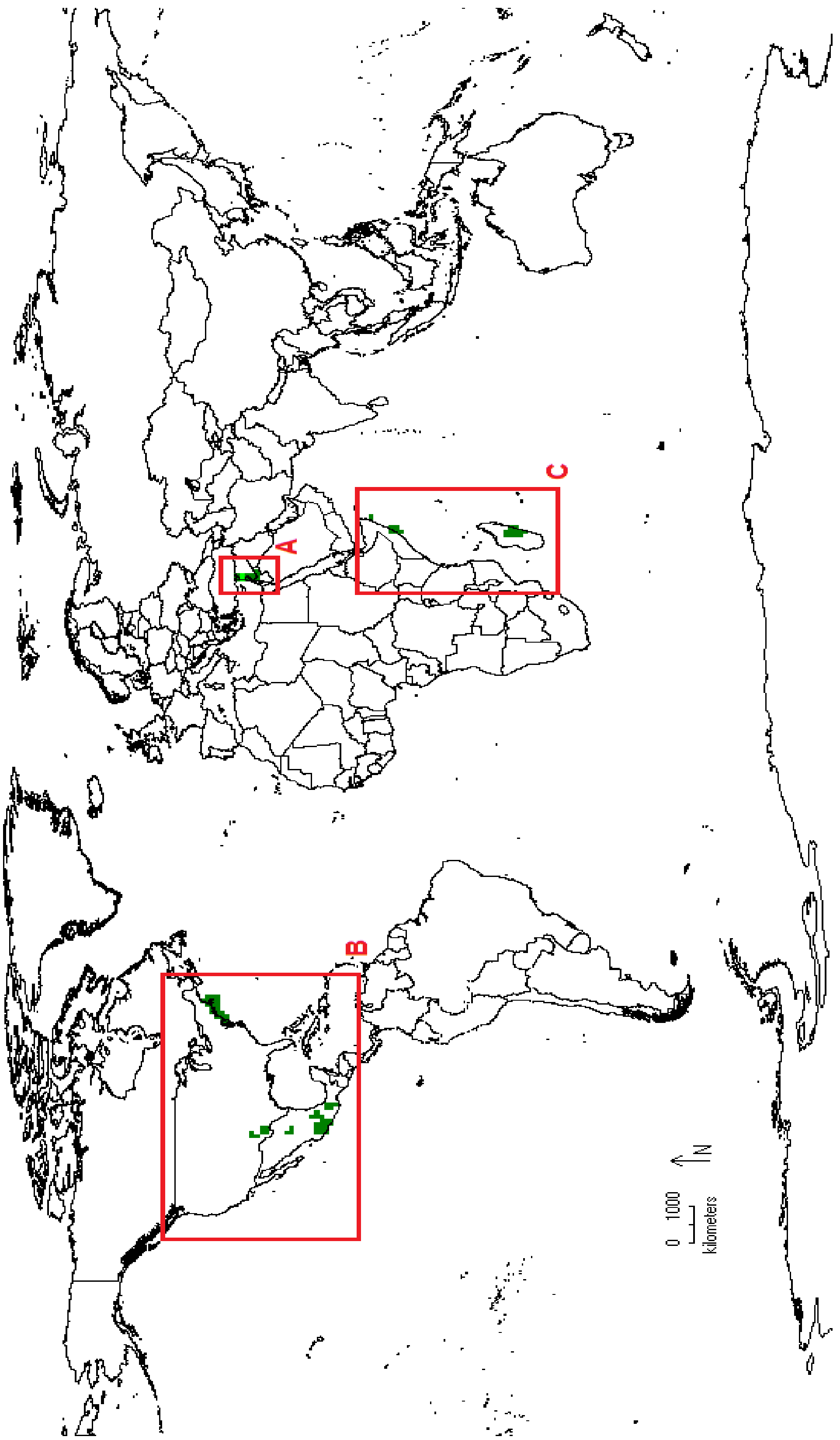


Figure 3.9 Global map of the eight threatened and Near Threatened CWR included within this project that had sufficient spatial data to estimate species' native range. Red boxes A-C will be presented at a larger scale in subsequent figures.

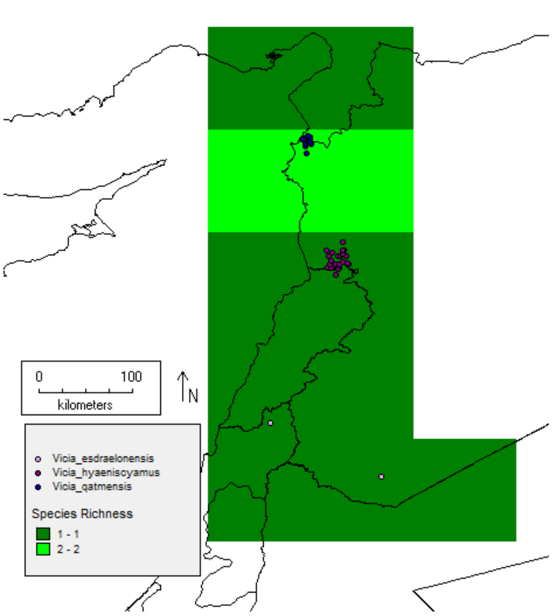


Figure 3.10 Inset B of **Figure 3.9** showing highest area of species richness (2) per grid square for assessed CWR.

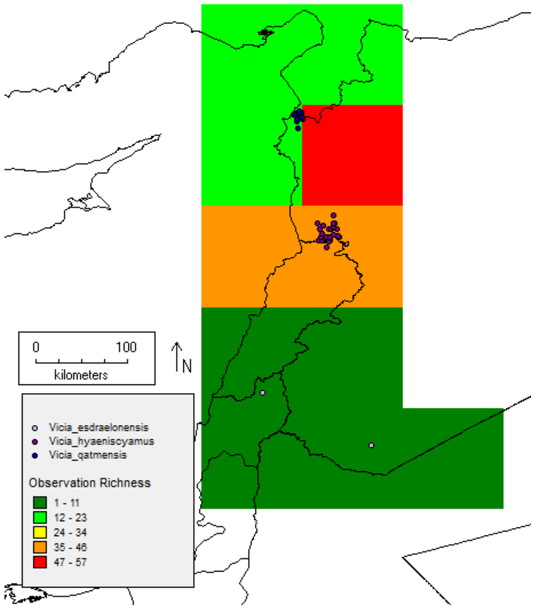


Figure 3.11 Inset B of **Figure 3.9** showing highest area of observation richness (57) per grid square for assessed CWR.

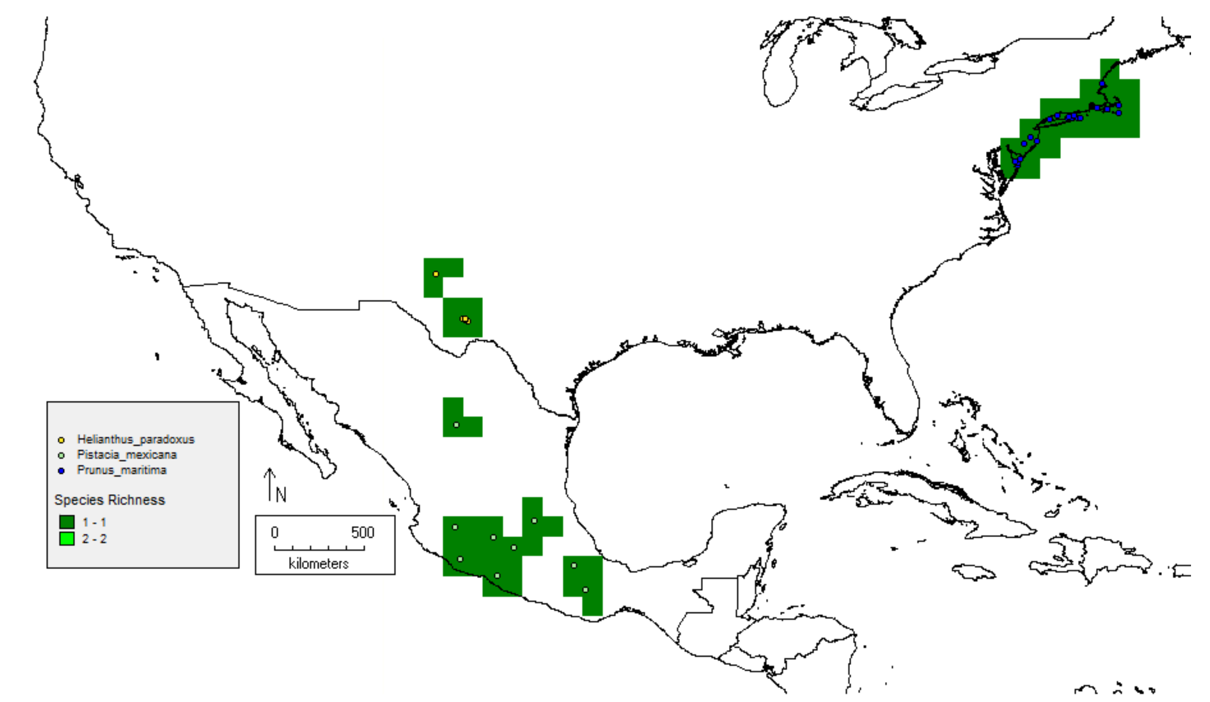


Figure 3.12 Inset A of **Figure 3.9** showing species richness for assessed CWR which occur in northern and central America.

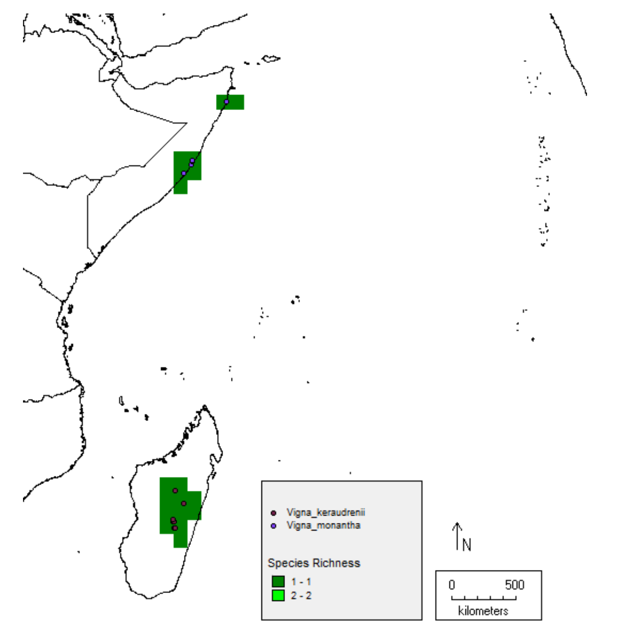


Figure 3.13 Inset C of **Figure 3.9** showing species richness for assessed CWR which occur in Madagascar and Somalia.

4 Discussion

4.1 Threat Status and population trends

Threat statuses and population trends for the 267 CWR species assessed using IUCN Red List Categories and Criteria (IUCN, 2001) are presented in the results section of this project (Figure 3.1 and Figure 3.4 also see Appendix 1 for project checklist) and discussed and compared to the results of other IUCN Red List assessments here (see **Table 4.1**). The two main comparative projects will be Sampled Red List Index, or SRLI (Brummitt and Bachman, 2010) and the European Red List of Vascular Plants (Bilz *et al.,* 2013). The SRLI aims to assess a representative sample of plants from different groups in order to give a generalised estimation of risk of extinction for all plants. Within the European Red List of Vascular Plants, regional Red List assessment was undertaken for 1826 plants, 572 of which are CWR of priority crops. Therefore these two publications are used for comparative analysis as they are both good examples of IUCN Red List assessment undertaken for plant species, while providing valuable insight concerning global assessment (SRLI) and CWR assessment (European Red List). Results from the SRLI and the European Red List are summarised alongside results for this project in **Table 4.1**.

Publication	% species for each Red List Category						Total no. spp. assessed
	DD	LC	NT	VU	EN	CR	
SRLI	4.5%	64.0%	10.0%	10.5%	7.0%	4.0%	7000
European Red List	29.0%	54.7%	4.5%	3.8%	4.4%	3.3%	572
Cactus species	8.7%	58%	5.1	9.4%	12%	6.7%	1478
Current project	29.6%	60.7%	3.0%	2.2%	3.4%	0.7%	267

Table 4.1 Comparison of project results (threat status, excluding extinct species) with three other IUCN Red List projects: SRLI (Brummitt and Bachman, 2010) European Red List of Vascular Plants Bilz *et al.,* 2013), and Cactus species (Goettsch *et al.,* 2015).

4.1.1 LC species

It can be immediately seen that the majority of assessed species were classified as LC for each of the four compared projects, ranging between 54% and 64%. For this project, all individual genera had a minimum of 25% LC species per genus, with lowest values occurring for two of the 21 genera: *Mangifera* and *Vigna*. *Aegilops, Hordeum,* and *Medicago* had over 85% LC species per genus, while all three assessed *Lupinus* species were LC.

As can be seen from Figure 3.4 in the results section of this project, all species with an increasing population trend and the majority of species with a stable population trend are LC. A further four species with a decreasing population trend are LC, these are *Hordeum comosum, H. secalinum, Mangifera minor,* and *M. quadrifida.* These species are classified as LC as, despite population decline, *Hordeum comosum* is noted as a common species occurring in protected areas, while the latter three are noted to be widespread species for which population decline does not significantly increase risk of extinction (von Bothmer et al., 1995) However this should be monitored to ensure that population decline does not increase or reach a level where it does pose a significant threat to these species.

It is necessary to note that global population trend was not always a direct measure of change in population count for the CWR species within this project, but was often a proxy measure based on known threats, habitat decline, or documented population decline at regional or sub regional levels. This was based on the assumption that recorded regional population trends were an accurate reflection of global data when combined, compared and reviewed. While it is recognised in the European Red List of Vascular Plants (Bilz *et al.,* 2011) that defining individuals within plant populations is extremely difficult due to factors such as clonal reproduction, naturally fluctuating annual species, and subterranean growth and so usefulness of physical population counts is often limited, the authors utilise proxy measure as described above and so this was emulated in the current project as accepted practice.

4.1.2 DD species

Where species do not have adequate information to determine a threat category they are classified as Data Deficient (DD); this was true for 29.6% of assessed species, which was slightly higher than that of the European assessment (29.0%) and significantly higher than that of SRLI (4.5%). However, it is necessary to note that actually a third of all species assessed within SRLI '*remain insufficiently known to be able to carry out a conservation assessment*' and, of these 94.5% are '*awaiting further investigation'* while 4.5% were classified as DD. In terms of population trends, 77.2% of DD species have an unknown population trend.

As highlighted by Goettsch *et al.* (2015), very few complete plant groups have been assessed using the IUCN Red List Categories and Criteria. This publication reports the results of IUCN Red List Assessments for Cacti (family: Cactaceae) stating that within this group 8.7% of species were listed as DD, a significantly lower level than the current work. As emphasised by Goettsch *et al.* (2015) this is consistent with other plant groups (examples given by the authors are: conifers, 1%; cycads, 1%; mangroves, 4%; and sea grasses, 12%) but is significantly lower than most vertebrate groups (15% for mammals, 25% for amphibians, and 46% for sharks and rays) (Goettsch *et al.*, 2015).

The low proportion of threatened species and the high proportion of DD species of this project in comparison to SRLI and assessments of other plant groups (see Goettsch *et al.,*

2015) may be a result of different attitudes when interpreting uncertain data. The IUCN Red List advises a '*precautionary but realistic attitude to uncertainty when applying the criteria*', where a 'precautionary attitude' involves assessing species as having a high risk of extinction unless it can be proven that this risk is absent. Where uncertain data was present for the current project, attempts were made to emulate this attitude when applying criteria in order to make the most of available information and to minimise DD classification as far as possible. However, as 'attitude' is a somewhat subjective variable, it may be that assessors involved in this project did not fully achieve the advised precautionary attitude as much as assessors for other projects, in which case more emphasis will have been put on having evidentiary support for classification of threatened species than in other projects, resulting in a higher proportion of DD species. An investigation to compare relative attitudes taken when undertaking assessments for different projects would give useful insight into project results and could prove useful for future assessors; however it is unsure how this would be achieved. Roberts *et al.* (2016) undertook research to discern the accuracy of IUCN Red List assessments that are based on biological collections and geographic range (EOO and AOO). In this publication, the authors conclude that even with limited data (a minimum of three georeferenced data points- the minimum to estimate EOO) these can lead to reliable preliminary assessments of extinction risk and Data Deficient status should only be assigned as a last resort.

Additionally, the high level of DD species within this project was also affected by other factors such as the collation of conflicting information due to taxonomic disagreements. For many of the species studied, taxonomic debate was a prominent issue and while information under synonymous taxonomy was incorporated wherever possible this often resulted in conflicting information for one or more fields in which case certain information had to be disregarded as unreliable and could not contribute to assessment. For example, Townsend (1967) and Meikle (1977), based on observations of herbarium material, consider *Vicia assyriaca* to be a synonym of *V. noeana*. Davis and Plitmann (1970), however, retained the two as distinct species, while noting the existence of intermediate forms. There have been found no introgressive specimens and the specific distinction is warranted (Maxted 1995). Also, while information concerning sub specific taxa was included in species assessments wherever possible, this added another level of taxonomic debate and potentially conflicting information. Taxonomic issues were noted in the 'Taxonomic Notes' section of each assessment which should facilitate wider use of assessments as although The Plant List was used for ultimate taxonomic decisions, other taxonomic views are accounted for. It is noted that expansion of the project to include expert consultation for CWR species assessments may be useful in addressing taxonomic issues.

Information availability and quality was also a prominent issue, with many data sources providing potentially valuable information that could not be built upon due to supporting documentation being unavailable or inaccessible. It is noteworthy that the level of DD species is very similar between this project and the European Red List of Vascular Plants (Bilz *et al.,* 2011) which suggests that CWR as a group of plants may have more uncertainty or less data available than other plants that might be included in the SRLI or for which whole groups have been fully assessed. Indeed Maxted *et al.* (2008b) stress that the existence of CWR populations both within formally protected areas and outside of these areas in habitats such as field borders and roadsides has led to them being largely overlooked for both *in situ* and *ex situ* conservation. On the other hand one would think that the commercial value of CWR would increase the likelihood of CWR taxa being chosen as a subject of study.

Data availability issues were especially prominent when accessing national Red Lists; as local, national, and regional assessments are not included directly on the IUCN Red List (unless the species is endemic to the specified region and so assessment is also global) many national Red Lists are stored at institutions that produced them (universities, libraries, government and non-government facilities, and environmental ministries to name a few examples) and so are not widely accessible. Additionally many of these reports and publications do not provide any more detailed information than each species' Red List Category. The National Red List project (NRLWG, 2012 to present) is taking an important step towards improving accessibility and thus facilitating use of national Red Lists through a centralised online hub. This resource proved a very useful tool throughout the duration of this project, and while plant assessments for an impressive 55 countries, regions and sub national entities are included within this resource, at least 43 regional and sub regional Red Lists have not yet been added and so remain largely inaccessible. Additionally, many sub global Red List projects are undertaken through independent institutions and so a lack of standardisation and supporting documentation for these projects means that information is not always of adequate quality or useful towards global IUCN assessments. For example, 18% of data within this database use non-IUCN Red List Criteria and a further 11.3% use modified IUCN Red List Criteria for threat assessment (NRLWG, 2012 to present) which potentially limits the relevance of this information towards application of current IUCN Red List Categories and

Criteria (version 3.1, IUCN, 2001). Furthermore, this resource show a high level of threat (47.8%) for plants assessed at a sub global level using IUCN Red List Categories and Criteria, but also notes potential bias within the database as only 46 of 73 national Red List for plants (including repeat assessments) where comprehensive assessments of entire plant groups that also included non-threatened species (NRLWG, 2012 to present). The limited application of information from national Red Lists was also noted as an issue for the European Red List of Vascular Plants (Bilz *et al.*, 2011).

A more specific data availability issue that may have led to the high percentage of DD species within the project was a lack of quantitative information available for species on the project checklist. This is especially true for population information (size, status and trend), which is also identified as lacking information by Bilz *et al.* (2011), as well as information concerning continuing decline in geographic area and/ or population. Red List methodology partially compensates for this through accepted use of estimation, inference and projection where quantitative data is absent or of poor quality, however while this was relied upon in many cases for the current project (for example see Figure 4.1), the high proportion of ‘unknown’ records for these data fields highlights the astounding lack of quantitative data for wild populations of CWR species.

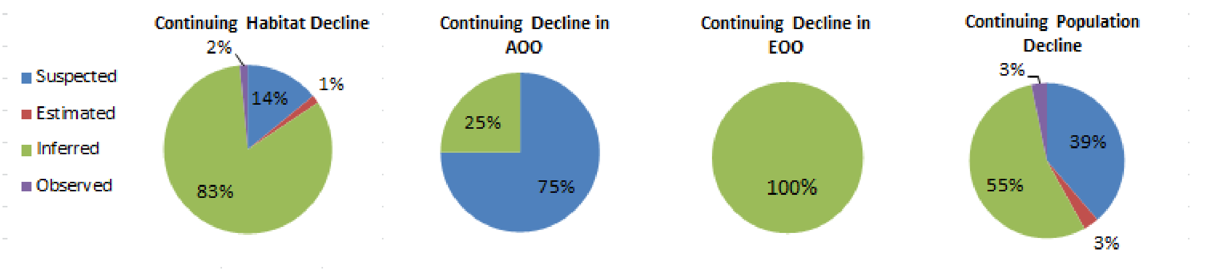


Figure 4.1 Proportionate representation of different methodologies used to apply IUCN Red List Criteria in the current project including use of suspected, estimated, inferred or observed patterns for three example fields of continuing decline: habitat, area of occupancy (AOO), and extent of occurrence (EOO).

Additionally the explicit use of decline in habitat quality as an indicator of criterion A (population reduction) for threatened species, and the prominent use (41.0% of threatened species) of continuing decline in '*area, extent and/or quality of habitat'* as an indicator of criterion B (geographic range in the form of EOO or AOO) reaffirms the lack of quantitative data for the species in this project and the consequent reliance on indirect indicators of threat and stresses.

Expert review of species assessments may have provided additional information that would have allowed application of IUCN Red List Criteria to assess DD species and assign them a suitable threat category. This is advised for expansion of the project, however while this action would undoubtedly prove useful, the European Red List notes issues in application of expert consultation to wide ranging species given that expertise is normally focused on populations from a single country. Considering this, collecting knowledge in this way for global level assessments would require a massive international collaboration of botanists and plant experts which may prove difficult to arrange and manage.

Only one genus, *Lupinus*, has no DD species while 12 of the 21 genera assessed within this project comprise 25% or more species classified as DD within each genus (see table 3.3 in results section for Red List status per genus). This is most prominent for stone fruits (*Amygdalus, Armeniaca, Cerasus, Padus,* and *Prunus*) for which 57.1% are DD, *Allium* species- 54.2% of which are DD, and *Malus* species- 50.0% of which are DD. It is interesting to note that taxonomy for stone fruits is well debated (for example see Rehder, 1940; Takhtadzhian, 1997; Wu *et al.,* 2006; Spooner *et al.,* 2003; The Plant List, 2013) and so this is likely to have been a prominent contributor to high proportion of DD species, as described earlier in this section, and expert consultation for these species would have proved extremely useful.

4.1.3 NT and Threatened species

When taxa are close to qualifying for a threatened category or are likely to become threatened in the near future they are classified as NT, which is the case for 3.0% of all 267 assessed CWR species, from four different genera assessed within this project. These species, alongside DD species, are priority for reassessment at appropriate intervals (IUCN, 2001) and the genera with the highest proportion of NT species are *Vicia* and *Helianthus.* Proportion of NT taxa is higher for both SRLI (10.0%) and the European Red List (4.5%) than for the current project. Unsurprisingly, no species with increasing or stable population trend were NT; while four NT species had decreasing population trend and the other four NT species had unknown population trend.

Percentage of threatened species (VU, EN, or CR) for this project (6.3%) is lower than that of SRLI (21.5%) and the European Red List (11.5%). This could be linked to the high proportion of DD species and the reasons for this high proportion that are postulated in the previous section, as DD species may have been classified as threatened with a more precautionary attitude and better data availability. However these species could also be LC and so this link cannot be verified until enough data is available for DD species to be reassessed. Monitoring and management is recommended for all threatened species within this project to ensure that the situation does not worsen. Within this, all but 2 of the 17 threatened CWR species within this project have a decreasing population trend and so particular attention should be payed to these CWR species.

For the 17 threatened species within this project criterion B (Geographic range size, and fragmentation, decline or fluctuations) was the most prominent criterion applied (70.0%) as seen in Figure 4.2. As postulated for DD species above, this suggests that information availability is lower for population data as well as quantitative data.

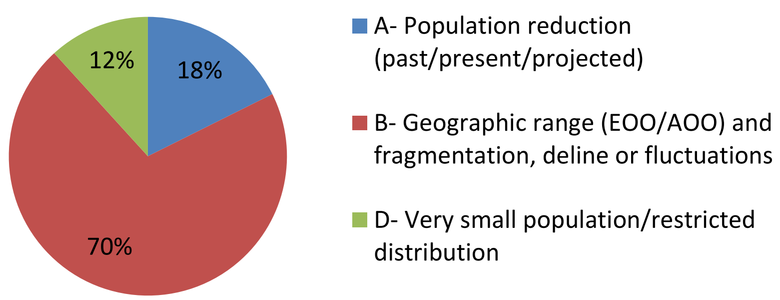


Figure 4.2 Proportional criteria used to assess the 17 threatened species within this project.

4.2 Major threats

A summary of major threats to CWR species assessed within this project is given in the results section; these include 'housing and urban areas', 'livestock farming and ranching', and 'logging and wood harvest'.

This is consistent with SRLI which identifies major threats to plants as agriculture, harvesting development, and logging (Brummitt and Bachman, 2010). The European Red List identifies intensified livestock farming (particularly intensive grazing), and recreational activities and infrastructure development related to tourism and urbanisation, and invasive alien species (Bilz *et al.*, 2011). It is necessary to note that while intensive grazing is identified as a prominent threat as noted above which could extinguish the studied population, lack of grazing also consists a threat for various species included on the European Red List of Vascular Plants as grazing may be necessary to halt succession- an important distinction that has implications for habitat management plans where relevant (Bilz *et al.*, 2011).

Logging and wood harvesting is likely to be a more prominent threat outside of Europe because tropical forests yield less merchantable timber per unit area than temperate forests such as those found in Europe; therefore, to gain a given volume of wood, the area of tropical forest disturbed by logging is larger than that of temperate forests (FAO- Regional Office for Asia and the Pacific, 2002). Additionally, logging of tropical forests is thought to have greater total impact as working over extensive areas requires greater infrastructure (roads etc.) and increases habitat fragmentation as well as habitat degradation and destruction (FAO- Regional Office for Asia and the Pacific, 2002). Furthermore, Europe has low rates of illegal logging compared other areas of the world (WWF, 2005) which only adds to the differential magnitude of threat from logging between European and tropical forests.

It is identified by Bilz *et al.* (2011) that the IUCN Red List measures threat at species level, and does not consider intraspecific diversity which is a very important asset when discussing CWR due to their potential application in plant breeding for crop improvement. Bilz *et al.*

(2011) also suggest that supported assumptions of genetic erosion cannot be made without "*regular and long term monitoring of genetic diversity within and between a broad range of CWR species*". Establishing an assessment of genetic diversity would be very beneficial to the conservation of CWR in particular due to their aforementioned use as a potential reservoir of adaptive traits for cultivated species and the dire consequences for future food security should this reservoir suffer extensive genetic erosion. Furthermore, loss of genetic diversity is thought to be equal to or higher than loss of species diversity as extant species still suffer genetic erosion (Maxted *et al.*, 1997b); however while it is thought that all CWR will be suffering from genetic erosion to some extent, the magnitude of this cannot be estimated without long term monitoring of genetic diversity or a demonstrated, valid proxy thereof (Bilz *et al.,* 2011).

Climate change is not one of the most frequently recorded threats for the current project, SRLI, or the European Red List. This is mainly because despite this being recognised as a major threat to all species, including CWR (Jarvis *et al.,* 2008) it is the indirect effects of climate change that manifest themselves while direct impacts of climate change usually remain unseen (Maxted *et al.*, 2013). Considering this climate change is not directly represented within the results of this project for many reasons, being at least partially due to the complex and multifaceted effects of climate change on different species and the lack of information available to make supported assumptions within species assessments. Many of the threats recorded for CWR species within this project (see figure 3.2) are indirectly implicated within the overall threat of climate change; for example invasive alien species are predicted to experience increased range and establishment opportunities (Masters and

Norgrove, 2010) while extreme weather events such as floods, fire regimes, and droughts are predicted to become more frequent with climate change (WWF, 2014). CWR are critical in ensuring our future food security as they provide vital potential for the provision of new crop cultivars adapted to marginal or extreme conditions which climate change is predicted to present (Ford-Lloyd *et al.,* 2011; Maxted *et al.,* 2013). It is ironic that, given their importance in adapting to rapidly changing environments predicted due to climate change, CWR are themselves also threatened by climate change.

4.3 Habitat types

CWR occur in a wide variety of habitats, which is partly why they have such great potential use in plant breeding as they have such a broad range of adaptation. Having said this, many CWR species prefer disturbed habitats such as roadsides and along field margins (Stolton *et al.*, 2006; Jarvis *et al.*, 2015). In the UK, grassland has been found to be rich in CWR priority species relating to forage and fodder crops while weedy areas, fertile grassland, and lowland woodland were rich in CWR species related to food crops (Jarvis *et al.,* 2015). The most CWR rich habitat types for the current project were found to be grassland and forest habitats (see figure 3.3).

A summary of habitat types and proportions of threatened to non-threatened CWR species occurring within them is given in the results section of this project. However it is necessary to note that while these results may highlight patterns of threat between and within habitat types, results must be interpreted with care as threat at the species level may not be directly proportional with threat at the habitat level. The reason for this is twofold: many of the species assessed in this project occur in more than one habitat type and so may be threatened in other habitat types than the one being analysed. For example *Vicia hyaeniscyamus* is globally assessed as EN but this is more due to its association with agricultural and semi agricultural land than its occurrence in open temperate forest as for this species, urbanisation and overgrazing is a prominent threat. A second consideration is, given the complexity of ecosystems and the limited scope of this project in that only a segment of the diversity and interactions within each habitat type is analysed, these results should be used as indicators as opposed to direct measures of threat status of habitat type. To gain a fuller picture of habitat threat, assessment particularly designed to gauge threat at habitat level would be more appropriate but for the current project conservation effort should be focused on variability of CWR and crop complexes, not habitats (Kell *et al.*, 2008).

SRLI found that tropical wet forest is home to the highest proportion of threatened species (63.0%), with rocky areas (13.4%) and temperate forest (12.7%) having the second and third highest percentage of threatened species within the study. However when species richness per habitat type is also considered within the SRLI project, forest habitat contains a much higher number of species (over 3000) compared to the second and third most species rich habitats (shrubland with around 1000 recorded species and grassland with around 750 recorded species) and so a general correlation between habitat richness and number of species may be present. In the current project, the habitat types with the highest proportion of threatened species are forest, rocky areas, and marine coastal/supratidal habitats comprising 10%, 7%, and 7% threatened species respectively. It is necessary to note that different levels of habitat classification are used between SRLI and the current project, so forest habitats with threatened species within this project include four subtypes of

Subtropical/Tropical Moist Lowland, Subtropical/Tropical Moist Montane, Subtropical/Tropical Dry, and temperate forests. The majority of threatened species within these forests are mango relatives (*Mangifera*) native to the tropical forests of Southeast Asia where significant habitat loss has already occurred and continues at a rate of about 1.2% per annum (UNEP, FAO, UNFF, 2009). Conversion to agriculture principally for the establishment of palm oil plantations is thought to be the main driver of forest loss in this region (UNEP, FAO, UNFF, 2009).

Three threatened species from the project, *Vicia hyaeniscyamus*, *Prunus murrayana*, and *Malus komarovii,* are all documented to occur in open temperate woodland. None of these species are unique to this habitat type, also occurring in shrubland (*P. murrayana*, and *M. komarovii*) and arable or pastureland (*V. hyaeniscyamus*). The principle threat to temperate forests seems to be urbanisation which is recorded for *V. hyaeniscyamus* (Keisa *et al.,* 2008), *M. komarovii* (Shao-Xian *et al*. 2011) and *P. murryana* (National Park Service, 2014) despite them occurring in very different geographical localities (China and Texas in North America respectively). *M. komarovii* is also subject to habitat fragmentation and degradation from large scale road construction and expansion, pressures from tourism development, and illegal logging activities which are present in the Changbai Shan Mountain Nature Reserve where this species occurs (Shao-Xian *et al*. 2011). As previously mentioned, threats to *V. hyaeniscyamus* are more due to its association with agricultural and semi agricultural land than its occurrence in open temperate forest.

P. murryana also occurs in rocky habitats alongside two other threatened species: *Pistacia mexicana,* and *Vigna keraudrenii*. As previously stated, urbanisation is a threat to all habitat types for *P. murryana,* while *P. mexicana* which also occurs in tropical dry forest and shrubland, is threatened by growing agriculture and pastoralism (Ramirez-Marcial and González-Espinosa, 1998). *V. keraudrenii* is native to rocky hillsides and high altitude woodland of Madagascar (Maxted *et al.,* 2004) which face ongoing threats from encroaching agriculture, exploitation by growing human populations, and fire (Crowley, 2013).

Similarly to the results of SRLI, desert habitat has one of the lowest proportions of threatened species, and the general rule that habitat types less suited to conversion for agriculture is also common to the two projects, suggesting that this threat makes a major contribution to both CWR and plants in general. This is also supported by the findings of Goettsch *et al.* (2015) who state that land conversion to agriculture and aquaculture is one of the most predominant threatening processes for cacti.

4.4 Spatial Distribution

In addition to the spatial data that was produced to accompany Red List assessments, where occurrence data was available and native range was known species richness maps were produced for two groups of CWR species from the project checklist: all assessed species, and threatened/Near Threatened species. These are presented in section 3.5 and will be discussed in further detail here.

The Euro-Mediterranean was identified as the most CWR species rich area for all assessed species (Figure 3.6 and 3.7) and contained CWR for all the major crops for which it is thought to be a major centre of CWR diversity including relatives of: wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.), oats (*Avena sativa* L.), faba bean (*Vicia faba* L.), Lucerne (*Medicago sativa* L.), and pistachio (*Pistacia vera* L.) (Maxted *et al.*, 2008b). This region is thought to be floristically rich in CWR as it includes two Vavilov centres of diversity (Vavilov, 1935). These centres (shown in Figure 4.3) are geographic regions where important crops are thought to have been domesticated and where genetic diversity for these crops is still thought to be focused (Vincent *et al*., 2013). Vincent *et al.* (2013) found that 63.0% of priority CWR are found within these Vavilov centres, with the highest concentrations being in China, the Near East, and Euro-Mediterranean (areas one, four, and five respectively in Figure 4.3). It is also interesting to note that observation richness is also high in this area and so species richness could be a result of sampling bias or better data availability for this region. However some correlation between species and observation richness is unavoidable

	Key:
1	China
2	India
2a	Indo-Malayan region
3	Central Asia, including Pakistan, Punjab, Kashmir, Afghanistan and Turkestan
4	the Near East/Asia minor
5	the Mediterranean
6	Ethiopia
7	Southern Mexico and Central America
8	Ecuador, Peru, Bolivia
8a	Chile
8b	Brazil-Paraguay

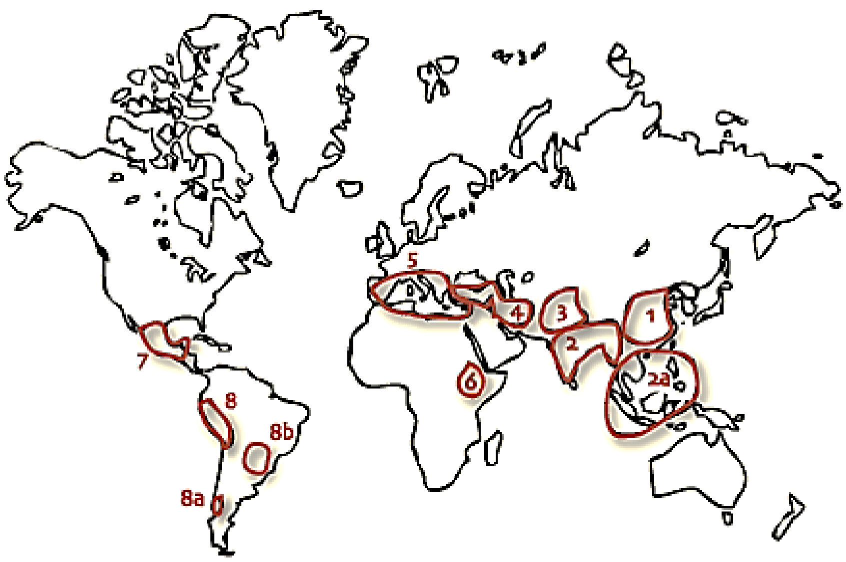


Figure 4.3 Vavilov's centres of origin (Vavilov, 1935; adapted by Harlan, 1971).

and thorough knowledge of original dataset and collection details in relation to taxon distribution is the only way to truly recognise a genuine uneven species distribution as in this case intense and homogenous sampling throughout the species range could be verified or disproved (Scheldeman and von Zonneveld, 2010).

When mapped on a larger scale, highest species richness is similar for both groups of mapped species (two groups being all assessed species and threatened and NT species), occurring in Syrian and Lebanese areas of the Fertile Crescent in the Middle East. This is consistent with findings of Maxted *et al.* (2012) who also found this to be a species rich area for temperate forage and pulse legumes (specifically the area around the Lebanese/Syrian border near Tel Kalakh in Homs province for priority species within the publication). A total of three threatened or NT species from the project checklist occur in this region: *Vicia hyaeniscyamus* (EN) and *V. qatmensis* (NT), and *V.esdraelonensis* (NT). Maxted (1995) suggests the establishment of *in situ* reserves within the Eastern Mediterranean where species of this genus are concentrated as the region as a whole is threatened with genetic erosion. When viewed on protectedplanet.net (IUCN and UNEP-WCMC, 2015), it can be seen that little to no formal *in situ* conservation is recorded within this region and while this may suggest that passive conservation (coincidental occurrence of CWR populations in areas with active conservation from which they might benefit) is not present for CWR occurring in this species rich area, it is necessary to note that as CWR often occur in disturbed habitats their conservation outside of protected areas is encouraged (Stolton *et al.*, 2006; Jarvis *et al.,* 2015) for example through agri-environmental schemes that would provide incentives for farmers and land owners to manage and monitor certain populations or areas of their land

(Jarvis *et al.,* 2015). Genetic reserves are reported to have been established: a major Global Environment Facility (GEF)/World bank funded project towards the conservation of genetic diversity through genetic reserves *in situ* was undertaken from the year 2000 to 2006 in the Fertile Crescent, however it is unknown whether this project was sustainable or whether CWR populations in these natural or semi natural areas are being actively monitored or managed (Maxted and Bennett, 2001; Hunter *et al.*, 2012). It is necessary to mention that ongoing conflict and civil war in Syria (Rodgers *et al.*, 2015) comprises a prominent threat to flora of this region as even if management and monitoring of *in situ* genetic reserves has been established it is unlikely that this will continue through the challenges of civil unrest.

The SRLI has produced an interactive map of threat level of different plants around the world available online from http://www.kew.org/science/plants-at-risk/plants-worldwide.htm#. However this resource is currently unavailable and could not be accessed so detailed comparison with results of the current project was not possible. However the main findings summarised on the site and by Brummitt *et al.* (2015) state that: species of Europe and Asia are largely not threatened on a regional scale but may be suffering localised threat from changes in land use; the same is true of North American species however localised threats comprise expansion of existing agricultural services and residential developments; Madagascar and Southeast Asia are suffering devastating forest loss from slash and burn cultivation and oil palm cultivation respectively. Within SRLI, 33 species were assessed within Syria and around 3% of these were assessed as threatened, while no species were classified as DD. Further detail and comparison of findings and threats specifically for the Middle East and the Fertile Crescent would have been useful; however the findings outlined above are similar to the results of the current project and reiterate the vital importance of strategic conservation especially as numerous factors such as the habitat degradation outlined above can cause continued loss of genetic diversity even if a species is formally assessed as stable.

4.5 Implications of the present work

As highlighted throughout, threat assessment and its products, such as the IUCN Red List assessments produced for the current project, are not meant to be used on their own to prioritise conservation action but are a highly effective tool when used in conjunction with knowledge of other factors to prioritise and plan strategic conservation action. These include but are not limited to: ecological and cultural attributes of the conservation target (which could be at any level of biodiversity, see figure 1.1), financial cost and availability of funds, effective use of resources (financial and otherwise), and predicted success and sustainability of conservation action. In this way, the products of this project offer a valuable contribution to strategic, holistic conservation prioritisation and planning for CWR species. Furthermore, supporting documentation gathered towards Red List assessment is also useful in the capacity of informing conservation planning and to this end research for each individual species assessment was as thorough as possible with aims to present a high level of detail in a clear and concise manner.

More specifically, the results of this project highlight gaps in our knowledge of CWR which need to be addressed, or areas of research for which digitalisation to increase data accessibility would be useful towards improving conservation planning. Population data was the most difficult to source, and while native distribution in the form of EOO was often established from the literature, occurrence data and estimations of AOO were difficult or impossible to establish for many CWR species. The Harlan and de Wet online CWR inventory (Vincent *et al.,* 2013) and the National Red List database (NRLWG, 2012 to present) are important examples of online databases that proved invaluable to this project and that are continually being improved and updated to facilitate continued use towards conservation planning.

For the species included in this project, more research including fieldwork and data collection is an important implication for those which are classified as DD, especially considering some are known to be suffering from population or habitat decline. CWR species suffering decline should have management and monitoring put in place wherever possible even when assessed as LC, as these species could potentially become threatened if negative population trend continues to be disregarded. For threatened and NT species, the species assessed are all exposed to a unique melange of threats and occur in various different habitat types with dissimilar biological requirements that produces potentially conflicting management needs. However in most cases more general recommendations for active CWR conservation include population monitoring and management *in situ* alongside collection of germplasm resources for complementary *ex situ* conservation to facilitate future use by plant breeders and other stakeholders.

With these general recommendations in mind, a table of *in situ* and *ex situ* priority CWR species based on the current work is given in Table 4.2. These 38 species consist of CR, EN, VU, NT, LC, and DD species that also have decreasing population trend. Recommendations of *ex situ* and *in situ* conservation are given based on 'conservation actions' filled out for each individual species assessment; however it must be reiterated that threat assessment is meant for use as a tool of strategic conservation and so these recommendations should be viewed alongside other factors influential to successful and effective conservation planning as previously discussed.

Complementarity and the establishment of both *in situ* and *ex situ* conservation is important: *ex situ* conservation is currently thought to be more prominent for CWR species than *in situ* conservation, however the lack of systematic conservation in gene banks and other *ex situ* establishments means that both taxonomic and genetic diversity is grossly under-conserved (Maxted *et al.,* 2008a; 2011; Bilz *et al.,* 2011). Sampling and *ex situ* conservation of species over a wide range of their ecogeographic diversity is also one way to increase scope of genetic diversity that is conserved where patterns of genetic diversity remain unknown and so ecogeographic diversity provides a proxy measure (Bilz *et al.,* 2011; Kell *et al.*, 2011b). In addition to these benefits of *ex situ* conservation, *in situ* conservation facilitates continued adaptation of CWR to changing environments and conservation of biotic interactions and other ecosystem services in addition to the target taxa (Maxted *et al.,* 2008a).

Table 4.2 *In situ* and *ex situ* priority CWR species based on threat category, decline in habitat and/or population, and advised conservation actions based on individual Red List assessments.

Taxonomy	Taxonomic authority	Category	Criteria	Ex situ?	In situ?
Vigna monantha	Thulin	CR	B1ab(iii)	Y	Y
Prunus murrayana	E.J.Palmer	CR	D	Y	Y
Mangifera dongnaiensis	Pierre	EN	A2c	Y	Y
Mangifera minutifolia	Evrard	EN	B1ab(ii,iii)+2ab(i i,iii)	Y	Y
Malus komarovii	(Sarg.) Rehder	EN	B1ab(iii)	Y	Y

Mangifera austro-indica	Kosterm.	EN	B2ab(i,ii,iii,iv,v)	Y	Y
Pistacia mexicana	H.B.K.	EN	A2c	Y	Y
Vigna keraudrenii	Du Puy & Labat	EN	B2ab(i,ii,iii,iv,v)	Y	Y
Vicia hyaeniscyamus	Mouterde	EN	B1ab(iii,iv)+2ab(iii,iv)	N	Y
Vicia kalakhensis	A.Khattab, N.Maxted & F.A.Bisby	EN	B1ab(iv)+2ab(iv)	Y	Y
Asparagus kiusianus	Makino	EN	B1ab(iii,iv,v)	Y	Y
Mangifera andamanica	King	VU	B1ab(iii)	Y	Y
Mangifera pentandra	Hook.f.	VU	B1ab(i,ii,iii,iv)+2ab(i,ii,iii,iv)	Y	N
Mangifera flava	Evrard	VU	B1ab(i,ii,iii)+2ab(i,ii,iii)	Y	Y
Mangifera collina	Kosterm.	VU	B1ab(i,ii,iii)	N	N
Helianthus paradoxus	Heiser	VU	A2c	N	Y
Allium roylei	Stearn	NT		Y	N
Helianthus anomalus	S.F.Blake	NT		N	Y
Helianthus exilis	A.Gray	NT		Y	N
Amygdalus texana	(D.Dietr.) W.Wright	NT		Y	N
Mangifera quadrifida	Jack	LC		N	N
Hordeum secalinum	Schreb.	LC		N	Y
Mangifera minor	Blume	LC		Y	Y
Hordeum comosum	J.Presl	LC		N	Y
Mangifera applanata	Kosterm.	DD		Y	Y
Vigna hosei	Backer ex K.Heyne	DD		Y	N
Vicia assyriaca	Boiss.	DD		Y	N
Pistacia weinmannifolia	J.Poiss. ex Franch.	DD		Y	Y
Eleusine intermedia	(Chiov.) S.M.Phillips	DD		Y	Y
Amygdalus minutiflora	(Engelm. ex A Gray) W.Wright	DD		Y	Y
Amygdalus mira	(Koehne) Ricker	DD		Y	Y
Amygdalus pedunculata	Pall.	DD		Y	N
Armeniaca mandshurica	(Maxim.) Skvortsov	DD		Y	Y
Cerasus pseudocerasus	(Lindl.) Loudon	DD		Y	Y
Cerasus serrula	(Franch.) T.T.Yu & C.L.Li	DD		Y	N
Malus chitralensis	Vassilczenko	DD		Y	Y
Prunus bifrons	Fritsch	DD		Y	N
Medicago papillosa	Boiss.	DD		Y	N

Legislation towards conservation of CWR is discussed in the introduction to this project, including delineation of targets in which threat assessment is implicated for relevant policies such as the CBD (2012), the GSPC (CBD, 2010a), the ITPGRFA (FAO, 2009), and the FAO Second Global Plan of Action for PGRFA (FAO, 2011). For example, within the FAO Second Global Plan of Action for PGRFA (FAO, 2011) threat assessment is implicated in the surveying and inventorying PGRFA for *in situ* conservation and management:

> ***"To identify, locate, inventory and assess threats to PGRFA, particularly from land-use and climate changes."***
>
> FAO (2011)

The IUCN Red List assessments presented in this project are an important asset towards reaching the aims of the legislation highlighted in the introduction and thus towards safeguarding PGRFA for sustainable use.

4.6 Limitations of work

It is necessary to note that although genera selected from the Harlan and de Wet CWR inventory were extracted at random, selection criteria as detailed in the methods section of this project may have biased the selection of CWR and therefore the results and making them a non-representative sample. It can be seen from Table 3.3 that number of species assessed in the project is not uniform across all genera; additionally it is acknowledged that the entirety of each featured crop complex has not been accounted for by this project. This results from two stages of selection, firstly- crop complexes can include numerous genera and while some crop complexes are represented by more than one genus (for example legume species and stone fruits) this is not the case for all complexes (wheat relatives for which only *Aegilops* species are included). Secondly, for many crops and crop complexes diversity is held at a subspecific level and so by undertaking Red List assessment at only the species level any diversity below this level is not accurately represented in the project checklist or the results. However while this bias may limit implications of the project results, global Red List assessment of priority CWR species that had no previous threat assessment is valuable and these novel results provide a platform for future research in this important area of CWR research.

As stated, while this project gives an idea of threat to priority CWR species, Red List assessment for the entirety of the Harlan and de Wet CWR checklist would be extremely useful to those trying to safeguard CWR taxa through conservation planning. It would also combat any bias that may have arisen in the results of this project as a product of the selection criteria as mentioned above.

Occurrence data was from a provisional version of the Harlan and de Wet CWR inventory and, as well as not being available for all species, quality control was necessary as anomalous occurrence points were included within the dataset. This was somewhat difficult and time consuming, however these issues of data quality have been since reviewed by the authors of the Harlan and de Wet CWR inventory and a comprehensive occurrence dataset for a large proportion of priority CWR is in preparation. Use of this dataset, when compiled, to review assessments would be useful to confirm or improve the quality of individual assessments and spatial analysis.

Additionally, a lack of external review and input from plant experts for each species assessment makes these Red List assessments limited to the amount of data that can be gained uniquely through literature review. Additionally, this input may have been useful to clarify some of the taxonomic issues that were presented through the project. Advice and comment would be welcomed to build upon and improve assessments where this is deemed necessary, and establishment of a network of plant experts to this end would be a consideration for expansion of the project.

Threat assessment at different levels was discussed in the introduction and while indications of threat at the habitat level can be inferred from project results, this assessment does not measure of threat at a genetic level. As genetic diversity is one of the main assets of CWR species this would be useful to know for strategic and targeted conservation planning.

4.7 Future research

A few possible expansions of the project have been mentioned in the previous section, this includes: improvement of Red List assessments through review by plant experts and establishment of a network to facilitate this and for use in other relevant projects, and increased scope of the Red List assessments to include all taxa of the Harlan and de Wet CWR inventory. Furthermore on the note of increasing the number of CWR assessed, the authors of the Harlan and de Wet CWR inventory are also in the process of compiling a global database of quality checked occurrence data which would facilitate the red listing of CWR species included on their priority checklist by addressing some of the issues of data availability. It would also provide a firm informational basis for distributional modelling of CWR species and facilitate other project such as a gap analysis (see Maxted *et al.* (2008c) for an in depth description of gap analysis) for global priority CWR, to determine where CWR conservation efforts should be focussed, where this has not been undertaken.

It is also noted that continuous reassessment of all CWR species included in this project will be necessary at regular intervals in the future (the IUCN recommends reassessment every 5-10 years, (IUCN, 2001)) or when important information concerning threat and extinction risk becomes available (especially for DD species). Where possible, the establishment of sustainable monitoring and management for these species would prove useful as this would facilitate evaluation of trends over time and these species could be added to the Red List Index (RLI) where these trends would serve as indicators for the diversity of CWR as a set of species (Bubb *et al.,* 2009).

There is speculation as to whether current IUCN Red Listing methodology is entirely reliable in assessing loss of genetic diversity, as its principle application is meant to assess risk of loss at a species level and not a genetic level. While some measurements included in the IUCN Red List Categories and Criteria such as population, number of individuals, and fragmentation are thought to address this, the results of this work could provide useful insight into the development of threat assessment of genetic diversity for genetic resources such as PGRFA and CWR and the efficiency of the IUCN Red List assessment process in this capacity.

5 Conclusions

This project has undertaken IUCN Red List assessment for a sample of 267 priority CWR species extracted from the static Harlan and de Wet CWR inventory compiled by Vincent *et al.* (2013). Seventeen CWR species (6.3%) were found to be threatened with high risk of extinction, while 3% of those assessed were classified as NT, 60.7% were found to be LC, and a further 29.6% were deemed DD.

CWR are valuable socio-economic resources that provide a genetic reservoir of potential and proven desirable adaptability for our crops. Without CWR and PGRFA our future food security is fatally compromised by the lack of genetic diversity of cultivated species and their consequential inability to adapt to changes in environments such as: the predicted effects of global climate change, new pest species or other pressures from the changing demands of the agricultural market. It is for this reason that CWR are in dire need of sustainable and strategic conservation both *in situ* and *ex situ*.

The high proportion of data deficiency in this project suggests a basic lack of information and research concerning CWR, which is a significant barrier to the strategic conservation that they so desperately need. Considering their vital importance for agriculture, CWR are not given enough attention by conservationists and expansion of the knowledge base for CWR through further research is critical for the future of our crops. Integration of CWR and agricultural conservation into biodiversity conservation would improve both knowledge and implementation (Bilz *et al.,* 2011).

This is reflected in the low level of active conservation documented for CWR despite the recognition of numerous threats to CWR species and habitats. However this may be partially due to encouraged conservation of CWR outside of formal protected area networks.

Combatting this lack of research is supported by targets within relevant legislation that promote threat assessment as a tool of strategic conservation as well as the application of this to PGRFA and CWR. To this end, this work is a valuable assessment of a sample of global priority CWR; providing indications of threat levels and species with urgent conservation needs. In addition to this, the current project has brought together diverse information on priority CWR species within the project checklist to further facilitate CWR conservation planning.

The current project and its products are heavily implicated in future conservation planning efforts to protect CWR and facilitate their continued availability for use in crop improvement programmes. For the reasons outlined above, research of this nature is vital in improving our future food security.

Appendix 1 Project checklist of selected priority CWR species and IUCN Red List Category and Criteria

Species Taxonomy	Taxonomic authority	IUCN Red List Category	IUCN Red List Criteria
Aegilops biuncialis	Vis.	LC	
Aegilops columnaris	Zhuk.	LC	
Aegilops crassa	Boiss.	LC	
Aegilops cylindrica	Host	LC	
Aegilops geniculata	Roth	LC	
Aegilops juvenalis	(Thell.) Eig	DD	
Aegilops kotschyi	Boiss.	LC	
Aegilops neglecta	Bertol.	LC	
Aegilops peregrina	(Hack.) Maire & Weiller	LC	
Aegilops sharonensis	Eig	LC	
Aegilops speltoides	Tausch	LC	
Aegilops tauschii	Coss.	LC	
Aegilops triuncialis	L.	LC	
Aegilops umbellulata	Zhuk.	LC	
Aegilops vavilovii	(Zhuk.) Chennav.	LC	
Allium altaicum	Pall.	DD	
Allium altyncolicum	N.Friesen	LC	
Allium ampeloprasum	L.	LC	
Allium asarense	R.M.Fritsch & Matin	DD	
Allium atrosanguineum	Schrenk	LC	
Allium atroviolaceum	Boiss.	DD	
Allium bourgeaui	Rech.f.	DD	
Allium galanthum	Kar. & Kir.	DD	
Allium karelinii	Poljakov	DD	
Allium ledebourianum	Schult. & Schult.f.	LC	
Allium macrostemon	Bunge	LC	
Allium maximowiczii	Regel	LC	
Allium oliganthum	Kar. & Kir.	DD	
Allium oschaninii	O.Fedtsch.	DD	
Allium praemixtum	Vved.	DD	
Allium pskemense	B.Fedtsch.	DD	
Allium ramosum	L.	LC	
Allium roylei	Stearn	NT	
Allium sacculiferum	Maxim.	LC	
Allium scabriscapum	Boiss.	DD	
Allium schoenoprasum	L.	LC	
Allium semenowii	Regel	LC	

Allium thunbergii	G.Don	DD	
Allium weschniakowii	Regel	DD	
Amygdalus andersonii	(A.Gray) W.Wight	DD	
Amygdalus davidiana	(Carrière) de Vos ex Henry	LC	
Amygdalus kansuensis	(Rehder) Skeels	LC	
Amygdalus minutiflora	(Engelm. ex A Gray) W.Wright	DD	
Amygdalus mira	(Koehne) Ricker	DD	
Amygdalus nana	L.	DD	
Amygdalus pedunculata	Pall.	DD	
Amygdalus texana	(D.Dietr.) W.Wright	NT	
Armeniaca mandshurica	(Maxim.) Skvortsov	DD	
Armeniaca mume	Siebold	DD	
Asparagus acutifolius	L.	LC	
Asparagus aphyllus	L.	LC	
Asparagus cochinchinensis	(Lour.) Merr.	LC	
Asparagus dauricus	Fisch. ex Link	DD	
Asparagus filicinus	Buch.-Ham. ex D.Don	LC	
Asparagus horridus	L.	LC	
Asparagus inderiensis	Blume ex Ledeb.	LC	
Asparagus kiusianus	Makino	EN	B1ab(iii,iv,v)
Asparagus macowanii	Baker	LC	
Asparagus maritimus	(L.) Mill.	DD	
Asparagus officinalis	L.	LC	
Asparagus oligoclonos	Maxim.	DD	
Asparagus schoberioides	Kunth	LC	
Asparagus tenuifolius	Lam.	LC	
Asparagus verticillatus	L.	LC	
Avena abyssinica	Hochst.	LC	
Avena fatua	L.	LC	
Avena hybrida	Peterm.	DD	
Avena sterilis	L.	LC	
Avena strigosa	Schreb.	DD	
Cerasus cerasoides	(Buch.-Ham. ex D.Don) S.Y.Sokolov	LC	
Cerasus dielsiana	(C.K.Schneid.) T.T.Yu & C.L.Li	DD	
Cerasus glandulosa	(Thunb.) Sokoloff	DD	
Cerasus nipponica	(Matsum.) H.Ohba	DD	
Cerasus pleiocerasus	(Koehne) T.T.Yu & C.L.Li	DD	
Cerasus	(Lindl.) Loudon	DD	

pseudocerasus			
Cerasus pumila	(L.) Michx.	LC	
Cerasus serrula	(Franch.) T.T.Yu & C.L.Li	DD	
Cerasus subhirtella	(Miq.) S.Y.Sokolov	DD	
Cerasus tomentosa	(Thunb.) Wall. ex T.T Yu & C.L.Li	LC	
Eleusine africana	Kenn.-O'Byrne	LC	
Eleusine floccifolia	Spreng.	LC	
Eleusine intermedia	(Chiov.) S.M.Phillips	DD	
Eleusine kigeziensis	S.M.Phillips	DD	
Eleusine tristachya	(Lam.) Lam.	LC	
Helianthus annuus	L.	LC	
Helianthus anomalus	S.F.Blake	NT	
Helianthus argophyllus	Torr. & A.Gray	LC	
Helianthus arizonensis	R.C.Jacks.	DD	
Helianthus atrorubens	L.	LC	
Helianthus bolanderi	A.Gray	LC	
Helianthus californicus	DC.	LC	
Helianthus debilis	Nutt.	LC	
Helianthus deserticola	Heiser	DD	
Helianthus divaricatus	L.	LC	
Helianthus exilis	A.Gray	NT	
Helianthus giganteus	L.	LC	
Helianthus grosseserratus	M.Martens	DD	
Helianthus hirsutus	Raf.	LC	
Helianthus maximiliani	Schrad.	LC	
Helianthus neglectus	Heiser	DD	
Helianthus niveus	(Benth.) Brandegee	LC	
Helianthus nuttallii	Torr. & A.Gray	LC	
Helianthus paradoxus	Heiser	VU	A2c
Helianthus pauciflorus	Nutt.	LC	
Helianthus petiolaris	Nutt.	LC	
Helianthus praecox	Engelm. & A.Gray	LC	
Helianthus resinosus	Small	LC	
Helianthus salicifolius	A.Dietr.	LC	
Helianthus silphioides	Nutt.	LC	
Helianthus tuberosus	L.	LC	
Hordeum arizonicum	Covas	LC	
Hordeum bogdanii	Wilensky	LC	
Hordeum brachyantherum	Nevski	LC	
Hordeum	(Trin.) Link	LC	

brevisubulatum			
Hordeum bulbosum	L.	LC	
Hordeum capense	Thunb.	LC	
Hordeum chilense	Roem. & Schult.	LC	
Hordeum comosum	J.Presl	LC	
Hordeum cordobense	Bothmer, N.Jacobsen & Nicora	LC	
Hordeum depressum	(Scribn. & J.G.Sm.) Rydb.	LC	
Hordeum erectifolium	Bothmer, N.Jacobsen & R.B.Jørg.	DD	
Hordeum euclaston	Steud.	LC	
Hordeum flexuosum	Steud.	LC	
Hordeum fuegianum	Bothmer, N.Jacobsen & R.B.Jørg.	LC	
Hordeum guatemalense	Bothmer, N.Jacobsen & R.B.Jørg.	NT	
Hordeum halophilum	Griseb.	LC	
Hordeum jubatum	L.	LC	
Hordeum lechleri	(Steud.) Schenck	LC	
Hordeum marinum	Huds.	LC	
Hordeum murinum	L.	LC	
Hordeum parodii	Covas	LC	
Hordeum patagonicum	(Hauman) Covas	LC	
Hordeum procerum	Nevski	LC	
Hordeum pubiflorum	Hook.f.	LC	
Hordeum pusillum	Nutt.	LC	
Hordeum roshevitzii	Bowden	LC	
Hordeum secalinum	Schreb.	LC	
Hordeum stenostachys	Godr.	LC	
Hordeum tetraploidum	Covas	LC	
Hordeum vulgare	L.	LC	
Ilex argentina	Lillo	DD	
Lupinus angustifolius	L.	LC	
Lupinus luteus	L.	LC	
Lupinus micranthus	Guss.	LC	
Malus asiatica	Nakai	DD	
Malus baccata	(L.) Borkh.	LC	
Malus chitralensis	Vassilczenko	DD	
Malus doumeri	(Bois) A.Chev.	LC	
Malus fusca	(Raf.) C.K.Schneid.	LC	
Malus halliana	Koehne	LC	
Malus honanensis	Rehder	DD	

Malus hupehensis	(Pamp.) Rehd.	LC	
Malus kansuensis	(Batalin) C.K. Schneid.	DD	
Malus komarovii	(Sarg.) Rehder	EN	B1ab(iii)
Malus mandshurica	(Maxim.) Kom. ex Juz.	LC	
Malus muliensis	T.C.Ku	DD	
Malus ombrophila	Hand.-Mazz.	DD	
Malus orientalis	Uglitzk.	LC	
Malus prattii	(Hemsl.) C.K.Schneid.	DD	
Malus prunifolia	(Willd.) Borkh.	DD	
Malus sikkimensis	(Wenz.) Koehne	LC	
Malus spectabilis	(Aiton) Borkh.	LC	
Malus toringo	(Siebold) Siebold ex de Vriese	LC	
Malus toringoides	(Rehder) Hughes	DD	
Malus transitoria	(Batalin) C.K. Schneid.	DD	
Malus tschonoskii	(Maxim.) C.K.Schneid.	DD	
Malus yunnanensis	(Franch.) C.K.Schneid.	LC	
Malus zumi	(Matsum.) Rehder	DD	
Mangifera andamanica	King	VU	B1ab(iii)
Mangifera applanata	Kosterm.	DD	
Mangifera austro-indica	Kosterm.	EN	B2ab(i,ii,iii,iv,v)
Mangifera casturi	Kosterm.	EW	
Mangifera collina	Kosterm.	VU	B1ab(i,ii,iii)
Mangifera dongnaiensis	Pierre	EN	A2c
Mangifera flava	Evrard	VU	B1ab(i,ii,iii)+2ab(i,ii,iii)
Mangifera gedebi	Miq.	LC	
Mangifera minor	Blume	LC	
Mangifera minutifolia	Evrard	EN	B1ab(ii,iii)+2ab(ii,iii)
Mangifera pentandra	Hook.f.	VU	B1ab(i,ii,iii,iv)+2ab(i,ii,iii,iv)
Mangifera quadrifida	Jack	LC	
Medicago arborea	L.	LC	
Medicago constricta	Durieu	LC	
Medicago doliata	Carmign.	LC	
Medicago falcata	L.	LC	
Medicago glomerata	Balb.	LC	
Medicago italica	(Mill.) Fiori	LC	
Medicago lesinsii	E. Small	LC	
Medicago littoralis	Loisel.	LC	
Medicago murex	Willd.	LC	
Medicago papillosa	Boiss.	DD	

Medicago rigidula	(L.) All.	LC	
Medicago rugosa	Desr.	LC	
Medicago scutellata	(L.) Mill.	LC	
Medicago soleirolii	Duby	DD	
Medicago truncatula	Gaertn.	LC	
Medicago turbinata	(L.) All.	LC	
Padus cornuta	(Wall. ex Royle) Carrière	DD	
Padus maackii	(Rupr.) Kom.	LC	
Pennisetum orientale	Rich.	LC	
Pennisetum polystachion	(L.) Schult.	LC	
Pennisetum purpureum	Schumach.	LC	
Pennisetum squamulatum	Fresen.	DD	
Pennisetum violaceum	(Lam.) Rich.	LC	
Pistacia eurycarpa	Yaltirik	LC	
Pistacia khinjuk	Stocks.	LC	
Pistacia lentiscus	L.	LC	
Pistacia mexicana	H.B.K.	EN	A2c
Pistacia terebinthus	L.	LC	
Pistacia weinmannifolia	J.Poiss. ex Franch.	DD	
Prunus americana	Marshall	LC	
Prunus angustifolia	Marshall	LC	
Prunus argentea	(Lam.) Rehder	DD	
Prunus besseyi	L.H.Bailey	DD	
Prunus bifrons	Fritsch	DD	
Prunus bokhariensis	Royle ex C.K.Schneid.	DD	
Prunus canescens	Bois	DD	
Prunus cocomilia	Ten	DD	
Prunus concinna	Koehne	DD	
Prunus emarginata	(Douglas) Eaton	LC	
Prunus fenzliana	Fritsch	DD	
Prunus ferganensis	(Kost. & Rjab.) Y.Y.Yao	DD	
Prunus fruticosa	Pall.	DD	
Prunus gracilis	Engelm. & Gray	LC	
Prunus harvardii	(W.Wight) S.C.Mason	LC	
Prunus hortulana	L.H.Bailey	LC	
Prunus incana	(Pall.) Batsch	DD	
Prunus incisa	Thunb.	DD	
Prunus jaquemontii	Hook. f.	LC	
Prunus mahaleb	L.	LC	

Prunus maritima	Marshall	NT	
Prunus mexicana	S.Watson	LC	
Prunus munsoniana	W.Wight & Hedrick	LC	
Prunus murrayana	E.J.Palmer	CR	D
Prunus padus	L.	LC	
Prunus pensylvanica	L.f.	LC	
Prunus prostrata	Labill.	DD	
Prunus rivularis	Scheele	DD	
Prunus salicina	Lindl.	LC	
Prunus spinosa	L.	LC	
Prunus subcordata	Benth.	LC	
Prunus umbellata	Elliott	DD	
Prunus ussuriensis	Kovalev & Kostina	DD	
Prunus webbii	(Spach) Vierh.	DD	
Vicia articulata	Hornem.	LC	
Vicia assyriaca	Boiss.	DD	
Vicia barbazitae	Guss. & Ten.	DD	
Vicia ciliatula	Lipsky	LC	
Vicia ervilia	Willd.	LC	
Vicia esdraelonensis	Warb. & Eig	NT	
Vicia galeata	Boiss.	LC	
Vicia grandiflora	Scop.	LC	
Vicia hyaeniscyamus	Mouterde	EN	B1ab(iii,iv)+2ab(iii,iv)
Vicia hybrida	L.	DD	
Vicia hyrcanica	Fisch. & C.A.Mey.	LC	
Vicia johannis	Tamamsch.	LC	
Vicia kalakhensis	A.Khattab, N.Maxted & F.A.Bisby	EN	B1ab(iv)+2ab(iv)
Vicia lutea	L.	LC	
Vicia melanops	Sibth. & Sm.	LC	
Vicia narbonensis	L.	LC	
Vicia pannonica	Crantz	LC	
Vicia qatmensis	Gomb.	NT	
Vicia sericocarpa	Fenzl	LC	
Vicia serratifolia	Jacq.	LC	
Vicia tigridis	Mouterde	VU	D2
Vigna hosei	Backer ex K.Heyne	DD	
Vigna keraudrenii	Du Puy & Labat	EN	B2ab(i,ii,iii,iv,v)
Vigna monantha	Thulin	CR	B1ab(iii)
Vigna schlechteri	Harms	LC	

Appendix 2 Example of preliminary IUCN Red List assessment with map of approximate global native distribution

Allium altaicum - Pall.

PLANTAE - TRACHEOPHYTA - LILIOPSIDA - LILIALES - ALLIACEAE - Allium - altaicum

Common Names: Altai Onion (English), Altain Songino (Mongolian), Zerleg Songino (Mongolian)
Synonyms: Allium ceratophyllum Besser ex Schult. & Schult.f.

Red List Status
DD - Data Deficient, (IUCN version 3.1)

Red List Assessment

Assessment Information

Assessor(s): Rhodes, L. & Maxted, N.

Assessment Rationale

Despite being a widespread species, *Allium altaicum* is documented to be either suffering from sub population declines or to be rare in both its Russian and Mongolian ranges (FAO 2011, Smekalova 2007, Oyuntsetseg *et al.* 2011). Some *ex situ* conservation in place for the species, and all known sub populations from Russia are passively conserved in protected areas, with recommendations for more active conservation having already been stated (Smekalova 2007). Throughout the rest of it's range, information regarding direct or indirect threats, population size and trends, *in situ* conservation, and habitat quality is lacking. This species is therefore globally assessed as Data deficient as further research is required to ensure that stable sub populations of this species are extant and under appropriate conservation measures.

Distribution

Geographic Range

Allium altaicum Pall. is said to be the most widely distributed species within its section (Fritsch & Friesen 2002). It is native to Asia, ranging from the mountains of southern Siberia (Altai, Sayan Mountains, Tuva, Trans-Baikal region) through Middle Asia, (Dzungarian Ala Tau, Tarbagatai) the Far East (the upper Amur region and the Amur river, 30 km above Ignashino Village), north and central Mongolia (Khubsugul, Khentei, Khangai, Khobdo, Mongolian Altai, Middle Khalka, Depression of

Great Lakes, Gobi-Altai, Dzungarian Gobi) (Gubanov 1996), and Northern China (Chukhina 2009, Fritsch & Friesen 2002). It is also cultivated as a minor crop in Southern and Western Siberia (Brewster 2008, USDA, ARS, National Germplasm Resource Program 2013).

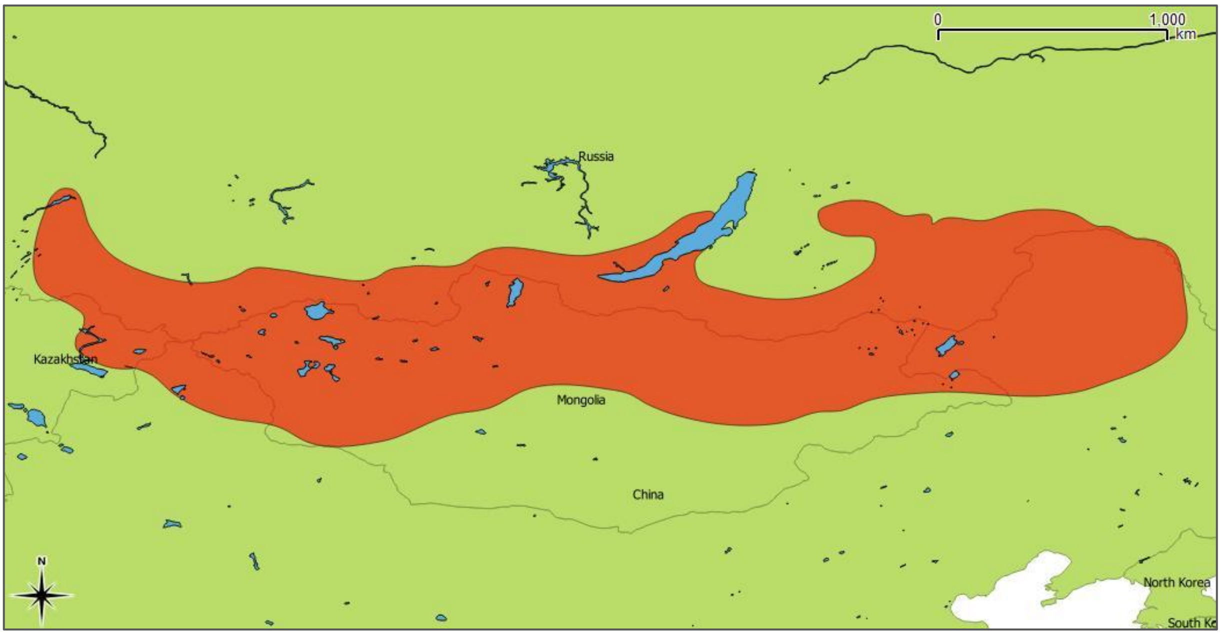
Elevation / Depth / Depth Zones

Elevation Lower Limit (in metres above sea level): 1900

Elevation Upper Limit (in metres above sea level): 2400

Map Status

Map Status	Data Sensitive?	Justification	Geographic range this applies to:	Date restriction imposed:
Done	-	-	-	-



Biogeographic Realms

Biogeographic Realm: Indomalayan, Palearctic

Occurrence

Countries of Occurrence

Country	Presence	Origin	Formerly Bred	Seasonality
China	Extant	Native	-	Resident

China -> Heilongjiang	Extant	Native -	Resident
China -> Nei Mongol	Extant	Native -	Resident
China -> Xinjiang	Extant	Native -	Resident
Kazakhstan	Extant	Native -	Resident
Mongolia	Extant	Native -	Resident
Russian Federation	Extant	Native -	Resident
Russian Federation -> Central Asian Russia	Extant	Native -	Resident
Russian Federation -> Central Asian Russia -> Amur	Extant	Native -	Resident
Russian Federation -> Central Asian Russia -> Buryatiya	Extant	Native -	Resident
Russian Federation -> Central Asian Russia -> Chita	Extant	Native -	Resident
Russian Federation -> Central Asian Russia -> Tuva	Extant	Native -	Resident
Russian Federation -> Eastern Asian Russia	Extant	Native -	Resident
Russian Federation -> Eastern Asian Russia -> Altay	Extant	Native -	Resident
Russian Federation -> European Russia	Extant	Native -	Resident
Russian Federation -> European Russia -> Irkutsk	Extant	Native -	Resident

Population

Fritsch and Friesen (2002) describe this species as the most widely distributed of its section, while Brewster (2008) states that *Allium altaicum* Pall. is 'widespread' in the mountains of northern and central Mongolia and southern Siberia.
However, in the 2011 Mongolian Red list (Oyuntsetseg *et al.* 2011), although regional population size is unknown, continuing decline was recorded for area of occupancy, quality of habitat, number of locations and number of mature individuals.
Furthermore, within it's Russian range, although found uniquely in Biosphere reserves (Petrosyan *et al.,* 2006) *Allium altaicum* is reported as rare or uncommon within these reserves and has 'special status' in at least 2 biosphere reserves (Information Center for the Environment at the (University of California, Davis) and Collaborators 2013).Population information across the rest of the species range is unknown and so research in this area to determine whether stable sub populations exist is important for this species.

Population Information

Continuing decline in mature individuals?	Qualifier	Justification
Unknown	-	-

Habitats and Ecology

Allum altaicum Pall. is a petrophyte that is most often found in dry, open plant formations such as rock crevices, stony slopes, gravelly deposits or similarly rocky areas in sub-alpine zones with a shallow soil (Fritsch & Friesen, 2002, Chukhina 2009). In Mongolia these species also grow in stone fields and screes as well as waterside pebbles (Oyuntsetseg *et al.* 2011). Their occurrence is not strongly correlated to soil mineral content, pH or vegetation type and so while large sub populations have been reported distribution is often as groups of small sub population (Fritsch & Friesen 2002).

IUCN Habitats Classification Scheme

Habitat	Season	Suitability	Major Importance?
6. Rocky areas (eg. inland cliffs, mountain peaks)	-	-	-

Systems

System: Terrestrial

Use and Trade

General Use and Trade Information

The leaves and large frost resistant bulb of *Allium altaicum* Pall. are are a source of vitamins and so often consumed as a table vegetable, especially in Southern Siberia (Fritsch and Friesen 2002, Chukhina 2009). This species is a Taxon Group 3 relative of *A. fistulosum* (Welsh onion), *A. schoenoprasum* (Chives), *A. chinense* (Chinese scallion) and *A. cepa* (Onion). It is also a primary genetic relative of *A. fistulosum* and therefore has potential application in crop breeding and improvement (Vincent *et al.* 2012; USDA, ARS, National Germplasm Resource Program 2013).

In Kazakhstan this species is thought to be an under-utilised crop, requiring thorough study, breeding, and well-adjusted marketing to achieve sustainable exploitation of this species as an economic resource (Scientific and Production Center of Farming and Plant Growing Ministry of Agriculture of Kazakhstan Republic 2007).

Subsistence:	Rationale:	Local Commercial:	Further detail including information on economic value if available:
No	-	-	-

National Commercial Value: No

International Commercial Value: No

Is there harvest from captive/cultivated sources of this species? Yes

Threats

Fritsch & Friesen (2002) identify that sub populations of this species are often threatened by mass collection for food consumption.

The FAO (2011) have reported a reduction in sub populations within the Russian Federation this species has been included in the Red data book of Russia (1988) and the IUCN Red List, with 'increasing anthropogenic effect' being identified as a national cause of Crop wild relative population reduction (Smekalova 2007).

In the 2011 Mongolian Red List assessed regional sub populations as Vulnerable based on habitat degradation and decline of occurrence, documenting the following regional threats; human induced habitat loss and degradation (extraction, mining, harvesting, food, subsistence use and local trade, sub national/national trade), changes in native species dynamics (prey/food base), intrinsic factors (limited dispersal poor recruitment reproduction and regeneration, high juvenile mortality, low densities, population fluctuations, restricted range) (Oyuntsetseg *et al.* 2011).

Conservation

Allium altaicum Pall. has been recognised as being threatened in Russia and is considered within the 'National Crop Wild Relative Conservation Strategy' as requiring urgent *in situ* conservation measures (Smekalova 2007). According to the Information Retrieval System for Fauna and Flora in Protected Natural Areas of the Russian Federation (Petrosyan *et al.* 2006) all known sub populations within the Russian Federation occur within protected areas (Altaisky and Katunskiy Biosphere reserves of the World Heritage Site Golden Mountains of Altai, Baikalo-Lenskiy and Baikalskyi Biosphere reserves of the World Heritage Site Lake Baikal, and the Sokhondinskiy biosphere reserve). However they are thought to be passively conserved in these protected areas and so Smekalova (2007) recommends promotion of active conservation through several actions; talking to staff of reserves to raise the status of CWR within nature reserves, preparing supporting documentation for nature protecting authorities and establishing sub population monitoring systems.

Mongolian sub populations are listed in the Mongolian Red Book (Jamsran *et al.* 1987, Gal *et al.* 1997, Oyuntsetseg *et al.* 2011) and in the Mongolian Law on Natural Plants 1995 as 'very rare' (Oyuntsetseg *et al.* 2011). Furthermore, 14 accessions (7,100 seeds) are conserved *ex situ* in the Svalbard Seed vault in 2 genebanks (SGCV Data Portal 2013), 7 of which originate from the IPK genebank and 7 of which are from the Centre of Genetic Resources (CGN, Netherlands). According to Botanical Garden Conservation International (BCGI 2013) this species has living collections in 41 botanical gardens worldwide, although origin and location of collection are not detailed in this resource (garden locations are undisclosed to protect rare and valuable plant species).

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