1 Introduction

1.1 Context

The conservation and sustainable use of plant genetic diversity is the basis of human well-being and food security. Today we face a stark challenge – either we learn to conserve biological diversity and practice sustainable use of its components or we ourselves are likely to face extinction. Thus, as biologists our specific challenge is to classify existing biological diversity and halt ecosystem, habitat, species and genetic diversity loss, while feeding the ever-increasing human population. Further as scientists we would be failing if we did not also warn society about the excessive consumption rates of a relatively small proportion of humankind, and the resulting gross inequality and poverty. World population is projected to grow from 6.1 billion in 2000 to 9.8 billion in 2050, an increase of 38% (Figure 1.1). Future population growth is highly dependent on the path that future fertility takes. The average annual population growth rate over this half-century will be 0.77%, substantially lower than the 1.76% average growth rate from 1950 to 2000. Future population growth is highly dependent on the path that future fertility takes. If fertility levels continue to decline, the world population is expected to reach 10.1 billion in 2100, increasing by about 35 million persons each year, according to the medium variant (United Nations, 2011). Even if human population levels do begin to level off, it can be argued that the planet is already beyond its human carrying capacity as evidenced by the current over-exploitation of our natural resources and the dominance of unsustainable environmental management practices.

The exponential loss of plant diversity that is currently occurring has been well documented: habitats, species, gene combinations and alleles are being lost. The State of the World's Plants 2016 report (RBG Kew, 2016) estimates that 21% of global plant species fall into the threatened IUCN Red list criteria, and they conclude in their 2017 report (RBG Kew, 2017) that 'Despite ongoing efforts to increase the rate at which plants are evaluated for their extinction risk, there is widespread recognition that many plants may become extinct before they have been recognized as being at risk, and perhaps even before they have been discovered'. It is perhaps easiest to undertake threat assessment at the plant species level because species are relatively discrete, and, in many cases, the necessary data sets are available. Conversely, loss of genetic diversity may be characterized as a 'silent risk', because unlike habitats and species the loss of genetic diversity is difficult to observe and quantify and often passes unnoticed. Yet loss of genetic diversity will always be greater than habitat and species loss because genetic diversity will be entirely lost from extinct habitat and species but there will also be genetic diversity loss from the habitats and species that remain extant (Maxted *et al.*, 1997a). However, the conservation of plant genetic diversity is of critical importance to the survival of humanity itself due to the pivotal role plants play in the functioning of all natural ecosystems and the direct benefits to humanity that can arise from their sustainable exploitation of plant diversity (Frankel *et al.*, 1995). Humankind has since the earliest times exploited plant diversity in numerous ways, such as the development of new agricultural and horticultural crops, and medicinal drugs, as well as the numerous other ways humans use plants (Lewington, 1990). In contrast to the economic, political and social benefits of active plant conservation linked to sustainable exploitation, the consequences of our careless disregard for loss of diversity or unsustainable exploitation, combined with population growth, will be catastrophic for the planet, our fellow creatures and humanity itself.

The importance of biological diversity conservation, its sustainable utilization and the link to human development were central to the United

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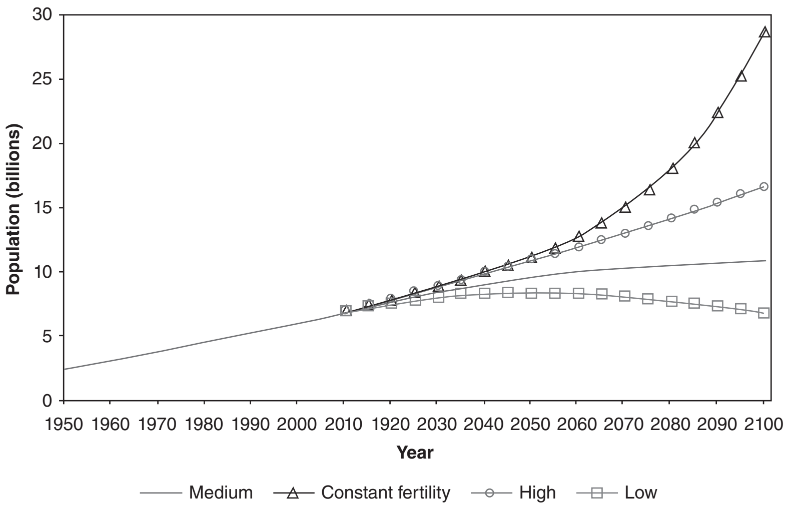

Figure 1.1 Human population 1950–2100.
(United Nations, 2011)

Nations Conference on the Environment and Development (UNCED) held in Rio de Janeiro, Brazil, in 1992. The Conference saw the adoption of the Convention on Biological Diversity (CBD, 1992), whose three key objectives, stated in Article 1, remain a cornerstone of plant genetic conservation today:

> The objectives of this convention . . . are the conservation of biological diversity, the sustainable use of its components and the fair and equitable sharing of the benefits arising out of the utilization of genetic resources. . .

Subsequent to signing and ratification of the Convention, steps were taken toward conserving microbial, animal and plant species and genetic diversity, as well as the habitats and ecosystems in which they live. In April 2002, the CBD Conference of the Parties (COP) made a commitment to achieve by 2010 a 'significant reduction of the current rate of biodiversity loss at the global, regional and national level as a contribution to poverty alleviation and to the benefit of all life on Earth' (CBD, 2002). However, it must be admitted that this target was not or even nearly met. In response to this failure, in October 2010, the CBD COP adopted a revised and updated Strategic Plan for Biodiversity, including the Aichi Biodiversity Targets, for the 2011–2020 period (CBD, 2010b). The vision was that humankind should be 'Living in Harmony with Nature' and 'By 2050, biodiversity is valued, conserved, restored and wisely used, maintaining ecosystem services, sustaining a healthy planet and delivering benefits essential for all people'. The rationale for the new plan was that biological diversity underpins ecosystem functioning and these ecosystem services are essential for human well-being. Furthermore, it provides for food security, human health, and the provision of clean air and water, and is essential for the achievement of the Sustainable Development Goals, including poverty reduction. Target 13 of the Aichi Biodiversity Targets specifically addresses genetic conservation:

> Target 13: By 2020, the 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.

Intermediate progress was assessed in the Global Biodiversity Outlook 4 (CBD, 2014) (Table 1.1).

In parallel to the recent development of the new Strategic Plan, the CBD has also developed the Global Strategy for Plant Conservation 2011–2020 (CBD, 2010a), which aims to achieve the three objectives of the Convention particularly for plant diversity. It should be implemented within the broader framework

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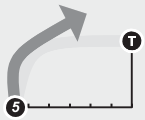
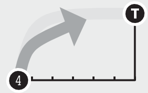
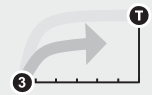
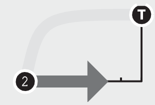
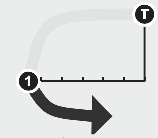
Table 1.1. **Target 'dashboard'—a summary of progress towards the Aichi Biodiversity Targets, broken down into their components (CBD, 2014). Note The assessment uses a five-point scale and the assessment of level of confidence is indicated by stars (★★★).**

				
On track to exceed target (we expect to achieve Target by deadline)	On track to achieve target (if we continue on our current trajectory, (we expect to achieve target by 2020)	Progress towards target but at an insufficient rate (unless we increase efforts target will not be met by deadline)	No significant overall progress (overall, we are neither moving towards nor away from target)	Moving away from target (things are getting worse rather than better).

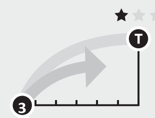
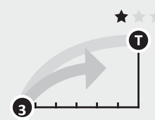
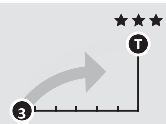
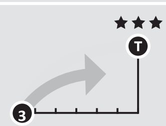
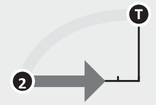
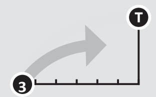
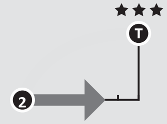
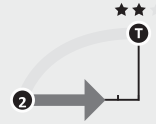
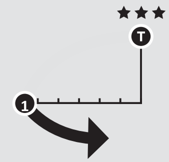
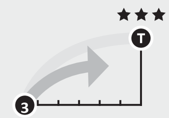
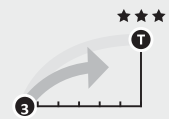
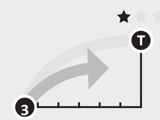
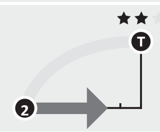
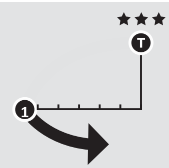
		TARGET ELEMENT	STATUS	COMMENT
	Target 1	People are aware of the values of biodiversity		Limited geographical coverage of indicators. Strong regional differences
		People are aware of the steps they can take to conserve and sustainably use biodiversity		Evidence suggests a growing knowledge of actions available, but limited understanding of which will have positive impacts
	Target 2	Biodiversity values integrated into national and local development and poverty reduction strategies		Differences between regions. Evidence largely based on poverty reduction strategies
		Biodiversity values integrated into national and local planning processes		The evidence shows regional variation and it is not clear if biodiversity is actually taken into consideration
		Biodiversity values incorporated into national accounting, as appropriate		Initiatives such as WAVES show growing trend towards such incorporation
		Biodiversity values incorporated into reporting systems		Improved accounting implies improvement in reporting

Table 1.1. (*cont.*)

Target 3	Incentives, including subsidies, harmful to biodiversity, eliminated, phased out or reformed in order to minimize or avoid negative impacts	★★★ 	No significant overall progress, some advances but some backward movement. Increasing recognition of harmful subsidies but little action
	Positive incentives for conservation and sustainable use of biodiversity developed and applied	★★★ 	Good progress but better targeting needed. Too small and still outweighed by perverse incentives
Target 4	Governments, business and stakeholders at all levels have taken steps to achieve, or have implemented, plans for sustainable production and consumption . . .	★★★ 	Many plans for sustainable production and consumption are in place, but they are still limited in scale
	. . . and have kept the impacts of use of natural resources well within safe ecological limits	★★★ 	All measures show an increase in natural resource use
Target 5	The rate of loss of forests is at least halved and where feasible brought close to zero	★★☆ 	Deforestation significantly slowed in some tropical areas, although still great regional variation
	The loss of all habitats is at least halved and where feasible brought close to zero	★★☆ 	Varies among habitat types, data scarce for some biomes
	Degradation and fragmentation are significantly reduced	★★☆ 	Habitats of all types, including forests, grasslands, wetlands and river systems, continue to be fragmented and degraded.

Target 6	All fish and invertebrate stocks and aquatic plants are managed and harvested sustainably, legally and applying ecosystem based approaches	★★★ 3 T	Great regional variation, positive for some countries but data limited for many developing countries
	Recovery plans and measures are in place for all depleted species	★★★ 3 T	Variable, progress in some regions
	Fisheries have no significant adverse impacts on threatened species and vulnerable ecosystems	★★ 2 T	Some progress e.g. on long-lining used in tuna fisheries, but practices still impacting vulnerable ecosystems
	The impacts of fisheries on stocks, species and ecosystems are within safe ecological limits, i.e. overfishing avoided	★★ 2 T	Overexploitation remains an issue globally, but with regional variation
Target 7	Areas under agriculture are managed sustainably, ensuring conservation of biodiversity	★★ 3 T	Increasing area under sustainable management, based on organic certification and conservation agriculture. Nutrient use flattening globally. No-till techniques expanding
	Areas under aquaculture are managed sustainably, ensuring conservation of biodiversity	★★ 3 T	Progress with sustainability standards being introduced, but in the context of very rapid expansion. Questions about sustainability of expansion of freshwater aquaculture
	Areas under forestry are managed sustainably, ensuring conservation of biodiversity	★★ 3 T	Increasing forest certification and criterion indicators. Certified forestry mostly in northern countries, much slower in tropical countries

Table 1.1. (*cont.*)

	Target 8	Pollutants (of all types) have been brought to levels that are not detrimental to ecosystem function and biodiversity	*No clear evaluation*	Highly variable between pollutants
		Pollution from excess nutrients has been brought to levels that are not detrimental to ecosystem function and biodiversity		Nutrient use levelling off in some regions, e.g. Europe and North America, but at levels that are still detrimental to biodiversity. Still rising in other regions. Very high regional variation
	Target 9	Invasive alien species identified and prioritized		Measures taken in many countries to develop lists of invasive alien species
		Pathways identified and prioritized		Major pathways are identified, but not efficiently controlled at a global scale
		Priority species controlled or eradicated		Some control and eradication, but data limited
		Introduction and establishment of IAS prevented		Some measures in place, but not sufficient to prevent continuing large increase in IAS
	Target 10	Multiple anthropogenic pressures on coral reefs are minimized, so as to maintain their integrity and functioning		Pressures such as land-based pollution, uncontrolled tourism still increasing, although new marine protected areas may ease overfishing in some reef regions
		Multiple anthropogenic pressures on other vulnerable ecosystems impacted by climate change or ocean acidification are minimized, to maintain their integrity and functioning	*Not evaluated*	Insufficient information was available to evaluate the target for other vulnerable ecosystems including seagrass habitats, mangroves and mountains

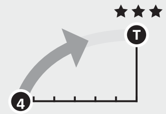
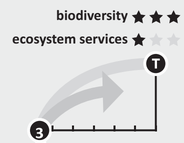
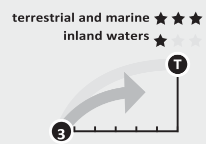
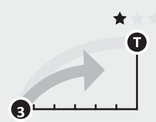
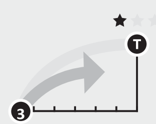
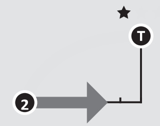
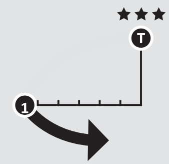
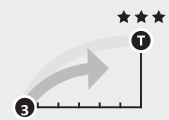
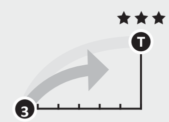
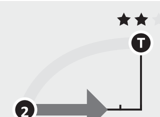
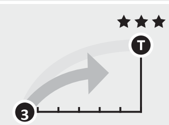
Target 11	At least 17 per cent of terrestrial and inland water areas are conserved		Extrapolations show good progress and the target will be achieved if existing commitments on designating protected areas are implemented. Inland water protection has distinct issues.
	At least 10 per cent of coastal and marine areas are conserved		Marine protected areas are accelerating but extrapolations suggest we are not on track to meet the target. With existing commitments, the target would be met for territorial waters but not for exclusive economic zones or high seas
	Areas of particular importance for biodiversity and ecosystem services conserved		Progress for protected Key Biodiversity Areas, but still important gaps. No separate measure for ecosystem services
	Conserved areas are ecologically representative		Progress, and possible to meet this target for terrestrial ecosystems if additional protected areas are representative. Progress with marine and freshwater areas, but much further to go
	Conserved areas are effectively and equitably managed		Reasonable evidence of improved effectiveness, but small sample size. Increasing trend towards community involvement in protection. Very dependent on region and location
	Conserved areas are well connected and integrated into the wider landscape and seascape		Initiatives exist to develop corridors and transboundary parks, but there is still not sufficient connection. Freshwater protected areas remain very disconnected

Table 1.1. (*cont.*)

	Target 12	Extinction of known threatened species has been prevented		Further extinctions likely by 2020, e.g. for amphibians and fish. For bird and mammal species some evidence measures have prevented extinctions
		The conservation status of those species most in decline has been improved and sustained		Red List Index still declining, no sign overall of reduced risk of extinction across groups of species. Very large regional differences
	Target 13	The genetic diversity of cultivated plants is maintained		*Ex situ* collections of plant genetic resources continue to improve, albeit with some gaps. There is limited support to ensure long term conservation of local varieties of crops in the face of changes in agricultural practices and market preferences
		The genetic diversity of farmed and domesticated animals is maintained		There are increasing activities to conserve breeds in their production environment and in gene banks, including through *in-vitro* conservation, but to date, these are insufficient
		The genetic diversity of wild relatives is maintained		Gradual increase in the conservation of wild relatives of crop plants in *ex situ* facilities but their conservation in the wild remains largely insecure, with few protected area management plans addressing wild relatives
		The genetic diversity of socio-economically as well as culturally valuable species is maintained	*Not evaluated*	Insufficient data to evaluate this element of the target
		Strategies have been developed and implemented for minimizing genetic erosion and safeguarding genetic diversity		The FAO Global Plans of Action for plant and animal genetic resources provide frameworks for the development of national and international strategies and action plans

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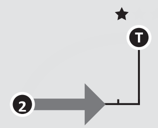
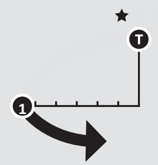
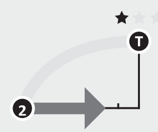
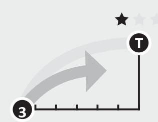
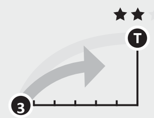
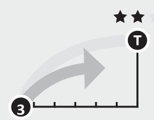
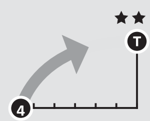
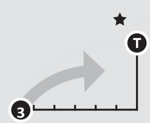
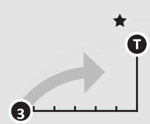
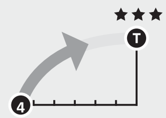
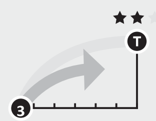
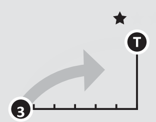
Target 14	Ecosystems that provide essential services, including services related to water, and contribute to health, livelihoods and well-being, are restored and safeguarded . . .		High variation across ecosystems and services. Ecosystems particularly important for services, e.g. wetlands and coral reefs, still in decline
	. . . taking into account the needs of women, indigenous and local communities, and the poor and vulnerable		Poor communities and women especially impacted by continuing loss of ecosystem services
Target 15	Ecosystem resilience and the contribution of biodiversity to carbon stocks have been enhanced through conservation and restoration		Despite restoration and conservation efforts, there is still a net loss of forests, a major global carbon stock
	At least 15 per cent of degraded ecosystems are restored, contributing to climate change mitigation and adaptation, and to combating desertification		Many restoration activities under way, but hard to assess whether they will restore 15% of degraded areas
Target 16	The Nagoya Protocol is in force		The Nagoya Protocol will enter into force on 12 October 2014, ahead of the deadline set.
	The Nagoya Protocol is operational, consistent with national legislation		Given progress that has been made, it is likely that the Nagoya Protocol will be operational by 2015 in those countries that have ratified it

Table 1.1. (*cont.*)

	Target 17	Submission of NBSAPs to Secretariat by (end of) 2015		For those Parties for which information is available, about 40% are expected to have completed their NBSAP by October 2014 and about 90% by the end of 2015
		NBSAPs adopted as effective policy instrument		The adequacy of available updated NBSAPs in terms of following COP guidance is variable
		NBSAPs are being implemented		The degree of implementation of updated NBSAPs is variable
	Target 18	Traditional knowledge, innovations and practices of indigenous and local communities are respected		Processes are under way internationally and in a number of countries to strengthen respect for, recognition and promotion of, traditional knowledge and customary sustainable use
		Traditional knowledge, innovations and practices are fully integrated and reflected in implementation of the Convention . . .		Traditional knowledge and customary sustainable use need to be further integrated across all relevant actions under the Convention
		. . . with the full and effective participation of indigenous and local communities		Efforts continue to enhance the capacities of indigenous and local communities to participate meaningfully in relevant processes locally, nationally and internationally but limited funding and capacity remain obstacles

	Target 19	Knowledge, the science base and technologies relating to biodiversity, its values, functioning, status and trends, and the consequences of its loss, are improved		Significant effort on delivery of information and knowledge relevant to decision makers is being made, and relevant processes and institutions are in place
		Biodiversity knowledge, the science base and technologies are widely shared and transferred and applied		Improvements in analysis and interpretation of data gathered from disparate collecting and monitoring systems. However, coordination to guarantee models and technologies that can integrate this knowledge into functional applied systems needs to be improved
	Target 20	Mobilization of financial resources implementing the Strategic Plan for Biodiversity 2011–2020 from all sources has increased substantially from 2010 levels		Limited information on many funding sources, including domestic funding, innovative financial mechanisms, and the private sector. General increase in bilateral ODA against 2006–2010 baseline.

From CBD (2014).

of the Strategic Plan for Biodiversity 2011–2020 and establishes 16 plant-related Targets to be achieved by 2020:

Objective I: Plant diversity is well understood, documented and recognized
- Target 1: An online Flora of all known plants.
- Target 2: An assessment of the conservation status of all known plant species, as far as possible, to guide conservation action.
- Target 3: Information, research and associated outputs, and methods necessary to implement the Strategy developed and shared.

Objective II: Plant diversity is urgently and effectively conserved
- Target 4: At least 15% of each ecological region or vegetation type secured through effective management and/or restoration.
- Target 5: At least 75% of the most important areas for plant diversity of each ecological region protected with effective management in place for conserving plants and their genetic diversity.
- Target 6: At least 75% of production lands in each sector managed sustainably, consistent with the conservation of plant diversity.
- Target 7: At least 75% of known threatened plant species conserved *in situ*.
- Target 8: At least 75% of threatened plant species in *ex situ* collections, preferably in the country of origin, and at least 20% available for recovery and restoration programmes.
- Target 9: 70% 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.
- Target 10: Effective management plans in place to prevent new biological invasions and to manage important areas for plant diversity that are invaded.

Objective III: Plant diversity is used in a sustainable and equitable manner
- Target 11: No species of wild flora endangered by international trade.
- Target 12: All wild-harvested plant-based products sourced sustainably.
- Target 13: 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 IV: Education and awareness about plant diversity, its role in sustainable livelihoods and importance to all life on Earth is promoted
- Target 14: The importance of plant diversity and the need for its conservation incorporated into communication, education and public awareness programmes.

Objective V: The capacities and public engagement necessary to implement the Strategy have been developed
- Target 15: The number of trained people working with appropriate facilities is enough according to national needs to achieve the targets of this Strategy.
- Target 16: Institutions, networks and partnerships for plant conservation established or strengthened at national, regional and international levels to achieve the targets of this Strategy.

Target 9 addresses the genetic conservation of crop-related diversity and firmly places the conservation of the genetic diversity associated with socio-economically important species within the broader plant conservation agenda.

Allied to the development of biodiversity conservation policy has been initiatives within the Food and Agriculture Organization (FAO) of the United Nations (UN) to promote parallel policies that specifically relate to plant genetic resource conservation. The Global Plan of Action (GPA) for the Conservation and Sustainable Utilization of PGRFA was formally adopted in 1996 by representatives of 150 countries during the Fourth International Technical Conference on Plant Genetic Resources in Leipzig, Germany (FAO, 1996) and was revised in 2011 (FAO, 2011e). It provides a strategic framework for the conservation and sustainable use of the plant genetic diversity on which food and agriculture depends, provides a means of identifying priority actions, to ensure the conservation of plant genetic resources for food and agriculture (PGRFA) as a basis for food security, sustainable agriculture and poverty reduction, and promotes sustainable use and exchange of PGRFA and the fair and equitable sharing of the benefits arising from their use. Further it provides a basis for international collaboration, the strengthening of national PGRFA programmes and information sharing. The Second GPA has 18 priority activities organized into four key subjects: *In Situ* Conservation and Management, *Ex Situ* Conservation, Sustainable Use, and Building Sustainable Institutional and Human Capacities.

The GPA is complemented by the International Treaty on Plant Genetic Resources for Food and Agriculture (FAO, 2001), which aims to promote the conservation and sustainable use of PGRFA and the fair and equitable sharing of the benefits arising out of their use, in harmony with the Convention on Biological Diversity (CBD), for sustainable agriculture and food security. Generally, it has a similar structure to the CBD but in relation to PGRFA. Specifically, in Article 9, it recognizes the enormous contribution that the local and indigenous communities and farmers make to the conservation and development of PGRFA and requests governments to implement Farmers' Rights that ensure the protection of their traditional knowledge, their right to equitably sharing benefits arising from PGRFA utilization and their right to participate in national PGRFA-related issues. Articles 10–14 establish the Multilateral System of Access and Benefit Sharing (MLS). This provides scientific institutions and private sector plant breeder's with access and opportunity to exploit materials stored in gene banks or fields by providing a framework for research, innovation and exchange of information, while at the same time safeguarding the rights of genetic resource providers. The coverage of the International Treaty is not universal but applies to 35 food staples, 15 forage legumes, 12 forage grasses and 2 other forage complexes selected on a basis of food security and interdependence and listed in Annex I. As a means of assessing the current condition of PGRFA and monitoring the impact of the Global Plan and International Treaty, FAO periodically produces a report that summarizes the current status of PGRFA conservation and use globally based on country reports, information gathering, regional syntheses, thematic background studies and the literature. The first State of the World's PGRFA (SoW) report was published in 1998 (FAO, 1998), the second in 2010 (FAO, 2010a) and the first State of the World Report on Biodiversity for Food and Agriculture in 2019 (FAO, 2019).

1.2 Plant Biodiversity

'Biological diversity' or 'biodiversity' is the result of 3000 million years of biotic evolution on Earth; the term being initially associated with the American conservationist Edward Wilson (Wilson, 1992). His definition of biodiversity is:

> The variety of organisms considered at all levels, from genetic variants belonging to the same species through arrays of species to arrays of genera, families, and still higher taxonomic levels; including the variety of ecosystems, which comprise both communities of organisms within particular habitats and the physical conditions under which they live.

While the CBD uses the following definition in Article 2:

> 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.

Such biodiversity includes ecosystems, which encompass both living organisms and their physical environment, species and the genetic diversity within species (Figure 1.2). Diversity at the community level may be referred to as ecogeographic diversity, at the species level as taxonomic diversity and at the gene level as genetic diversity. However, at whatever level biological diversity is considered, it is vast; a fact that may be illustrated by the numbers of described and estimated plant species (Table 1.2). Plants can be defined as multicellular eukaryotes (organisms with

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Table 1.2 **Kingdom Plantae**

Sub-kingdom	Division	Common name	Number of species	Proportion of group known	Size	Mode of life
BRYATA (non-vascular plants)	Bryophyta	Mosses	ca. 10 000	Moderate/ high	Low growing	Terrestrial (moist habitats)
	Hepatophyta	Liverworts	ca. 6000	Moderate	Low growing	Terrestrial (moist and dry habitats)
	Anthocerophyta	Horned liverworts	ca. 100	Moderate	Low growing	Terrestrial (moist habitat)
TRACHEATA (vascular plants) Pteridophytes (fern allies)	Lycophyta	Club mosses	ca. 1300	Moderate	Mainly low growing	Terrestrial, (moist and dry habitats)
	Psilophyta	Whisk fern	10	Moderate/ high	Small herbs	Terrestrial
	Sphenophyta	Horsetails	15	High	Herbs	Terrestrial
	Filicinophyta	Ferns	ca. 12 000	High	Few centimetres to 25 m	Terrestrial (few freshwater taxa)
GYMNOSPERMS (naked seed plants)	Cycadophyta	Cycads	145	High	Shrubs to small trees $\leq$18 m tall	Terrestrial
	Ginkgophyta	Ginkgo	1	High	Tree $\leq$30 m tall	Terrestrial
	Coniferophyta	Conifers	630	High	Shrub or tree $\leq$100 m tall	Terrestrial
	Gnetophyta	Gnetophytes	ca. 70	High	Shrubs, vines and small trees	Terrestrial
ANGIOSPERMS (enclosed seed plants)	Anthophyta	Flowering plants, Angiosperms	ca. 369 000	High	$<$1 mm to $>$100 m tall	Most habitats

Adapted from Groombridge and Jenkins (2000) and RBG Kew (2017).

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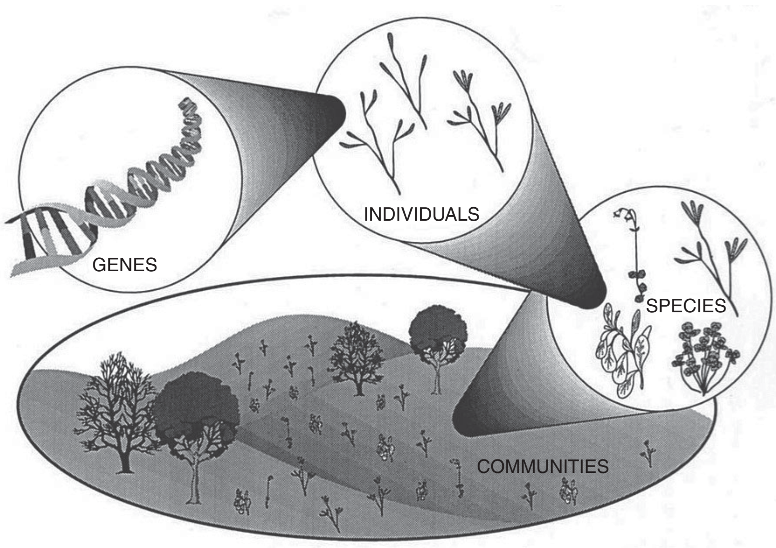

Figure 1.2 Diversity – from genes to communities.
(Reproduced from Frankel *et al*., 1995)

nucleated cells and membrane-bound organelles), where the fertilized egg develops into a diploid multicellular embryo, there are alternating spore-producing and haploid egg- or sperm-producing generations, and virtually all are terrestrial, photosynthetic autotrophs.

Biological diversity is not only apparent in the numbers of different species and the types of different ecosystems in which they exist but can also be observed between individual of a species. The measurement of biodiversity is related to the various levels of biological organization – genetic, taxonomic and ecological diversity (Table 1.3). Genetic diversity is the heritable variation that is observed within and between populations. The basic genetic component is the gene, and they are found in the nuclei of all cells of all organisms: plants, fungi, bacteria, viruses and animals. Genes are made up of DNA and are situated along chromosomes. Ultimately, it is the variation in the sequence of four nucleotide base pairs (A, T, C and G), which, as components of nucleic acid, constitute the genetic code, which is passed from generation to generation. New genetic variation arises in individuals from gene and chromosome mutations, and in organisms that reproduce sexually, by recombination. There can be various distinct forms of the same gene, referred to as alleles.

Individuals in a plant population or species vary genetically for a range of characteristics or traits. Such genetically significant traits might include: height, fecundity, pathogen or pest resistance, or tolerance/adaptation to extreme environmental conditions such as drought. This variation, which may for instance be expressed morphologically, behaviourally or physiologically, is referred to as the phenotype. The phenotype results from a combination of the individual's genotype (its genetic composition), interacting with the environment in which it is found. The genetic pool of variation present within an inter-breeding population is acted upon by selection. Genetic diversity is not constant for all species; individuals and species vary in the amount and geographic pattern of their genetic variation. Interestingly generally the more highly 'bred' the individual, the less genetic (allelic) diversity is encountered, because bred organisms have passed through the domestication bottleneck where only a limited number of individuals are domesticated from the original ancestral stock. Perhaps the record for the number of alleles per gene locus goes to red clover (*Trifolium pratense*), where self-incompatibility is controlled by a single, multi-allelic gene expressed in the pollen, and it has been estimated that more than 200 alleles exist for this one gene (Lawrence, 1996). It

Table 1.3 **The composition and levels of plant biodiversity**

Genetic diversity	Taxonomic diversity	Ecological diversity
	Kingdom	
	Division	
	Class	Biomes
	Order	Bioregions
	Families	Landscapes
	Genera	Ecosystems
	Species	Habitats
	Subspecies/ varieties	Niches
Populations	Populations	Populations
Individuals	Individuals	
Chromosomes		
Genes		
Alleles		
Nucleotides		

From Heywood and Watson (1995).

is the genetic variation within and between individuals and populations of the same species that ensures the species can adapt and change in response to natural (e.g. changing environment) and artificial (e.g. breeder's selection criteria) selection pressures. Therefore, if a virulent form of a pathogen evolves, such as Ug99, a race of wheat stem rust (*Puccinia graminis* Pers. f. sp. *tritici* Eriks. & Henn.) to which 80–90% of global wheat cultivars are susceptible, it can cause catastrophic loss of wheat grain yield of 70% or more (FAO, 2013b). However, natural genetic diversity within wheat populations means some individuals will be resistant. Notably some resistant individuals have been found to help maintain wheat production (Endresen *et al.*, 2012; Tadesse *et al.*, 2012). Hence, genetic diversity enables natural evolution and adaptation of species within a changing environment and provides a source of traits for breeders to overcome new virulent strains of pathogens. It is essential for the long-term survival of any species in the wild and for providing food security for humankind.

Taxonomic diversity is diversity at the taxonomic level where organisms are grouped into classes, families, tribes, genera and species using the taxonomic hierarchy. Central to the concept of taxonomic diversity is the species, and for practical purposes, species are the most common targets for biodiversity research and management. The species is however not a standard unit of measurement, since there are several different concepts of what constitutes a species and the level of distinction that constitutes a species in one plant group may be different to that accepted in another group. While genes provide the blueprint for the construction of organisms, they are only expressed through the form and function of species. Similarly, ecosystems are essentially manifestations of the interactions between organisms. It follows that neither genes nor ecosystems can be manipulated or managed without attention to the requirements of species; they are the entities in nature that adapt and evolve, occupy space and become extinct.

Ecological diversity describes biodiversity in terms of the relationship between organisms from population level and upwards through niches, habitats, ecosystems, landscapes and bioregions, to biomes (Table 1.3). At the largest scale, a 'biome' describes any of a group of major regional terrestrial communities with its own type of climate, vegetation and animal life. They are not sharply separated but merge gradually into one another. Examples include tundra, temperate deciduous forest and desert. At the smallest scale, ecological diversity can describe 'populations', which are local communities of potentially inter-breeding organisms. Conservationists refer to habitat, ecosystem or landscape conservation, although these terms are unfortunately often used interchangeably; the ecosystem is the most widely accepted unit of ecological conservation. An ecosystem is defined by the CBD as:

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a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit.

Each level of diversity has its own specific measure: communities, such as savannah grassland, mangrove swamp or steppe, are measured in terms of ecogeographic characteristics, species diversity, and biotic and abiotic interaction; species are measured in terms of representative population density, frequency and cover; individual populations or organisms are measured in terms of their intrinsic genetic diversity; and genes are measured in allelic diversity. Although when people consider plant diversity, they often think in terms of number of higher plant species, but it is important to consider all levels of biodiversity. However, species are commonly considered to have special intrinsic validity because they can be more objectively defined, as a potentially inter-breeding group of individuals, therefore numbers of species are often used to compare diversity with communities or higher taxonomic groups.

Kingdom Plantae is composed of 10 major divisions with approximately 300 000 species, the vast majority of which are flowering plants (or angiosperms), and these are the species most widely exploited by humankind. The diversity within angiosperms has been classified by numerous eminent botanists over the centuries into orders, classes, families and tribes; each classification has its advantages and disadvantages. However, as our knowledge of plant diversity progresses, so successive classification will it is hoped provide a better approximation of the underlying natural classification that exists in nature. Currently a collaborative group of taxonomists, the Angiosperm Phylogeny Group, are producing and iteratively refining a classification of the angiosperms utilizing DNA sequence data. The classification (Angiosperm Phylogeny Group, 2016) recognizes 64 orders and 416 families (Figure 1.3). More information can be obtained from the Angiosperm Phylogeny Group (APG) website (www.mobot.org/mobot/research/apweb/).

1.3 Plant Genetic Resources for Food and Agriculture

Traditionally, plant genetic conservation has focused almost explicitly on crops and, lately, their wild related species. The diversity within these species has been recognized as a tangible, economic resource, thus they were referred to initially as 'plant genetic resources', which may be defined as:

> Plant genetic resources are the taxonomic and genetic diversity of plants that is of value as a resource for the present and future generations of people.
>
> (IPGRI, 1993)

Crops may here be broadly defined as any cultivated species, so including those used for food, food additives, feed (animal food), fibre, fuel, feedstocks, bio-based materials, fun (ornamentals and turf-grass), medicine, environmental uses, poisons and gene sources (Cook, 1995). For millennia, humans have exploited the variation within these species. Subsistence farmers would, for example, annually save plants that had larger heads or pest resistance to sow in the following year. This process is as important today as it was for the earliest farmers. However, more recently, to narrow the focus of conservation and exploitation PGRFA have been distinguished from the broader plant genetic resources (PGR) for those species most directly associated with feeding humankind. PGR may also be defined by the nature of the resource utilized that form a continuum between the most advanced cultivars and wild species (Figure 1.4). These include:

- **Modern cultivars**: Genetically uniform or clonal crop varieties bred by plant breeders and currently sown by farmers that become a genetic resource once commercially obsolete.
- **Obsolete cultivars**: Former cultivars that are no longer commercially grown and do not appear on national variety lists, but which may possess genes useful to plant breeders.
- **Breeding lines, clones, populations and genetic stocks**: Material used by plant breeders to develop modern cultivars by means of crossbreeding or use of biotechnology tools.

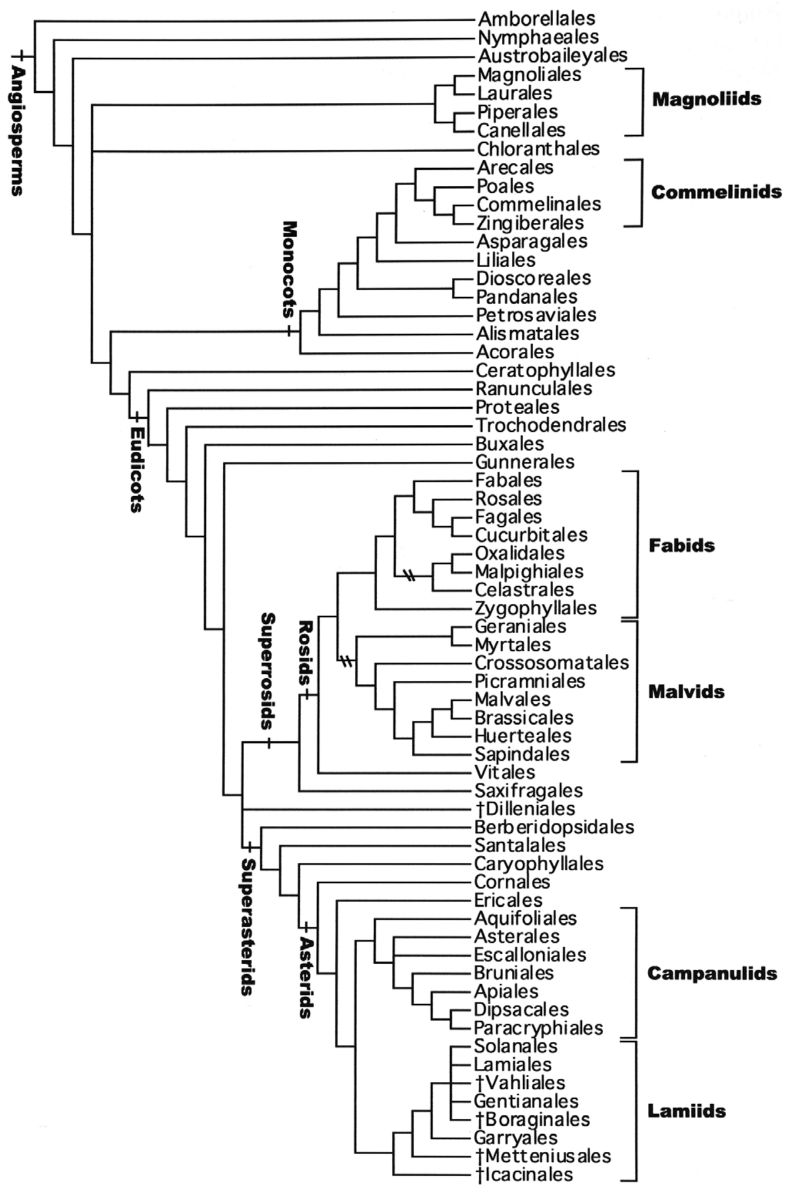

Figure 1.3 Classification of flowering plants.
(Reproduced from Angiosperm Phylogeny Group, 2016)

- **Crop landraces**: Genetically diverse crop varieties that are the product of traditional seed saving systems rather than modern plant breeding, commonly associated with local adaptation, and traditional agricultural practices in more marginal agricultural environments.
- **Weedy races**: Wild species that occur as part of crop–weed complexes as result of hybridization between the crop and wild species, the crop and wild species being evolved from the same ancestor or as the crop's progenitor, often found in gene centres but which hybridize freely with the crop and may introgress useful genes from wild species.
- **Related wild species**: Wild species that are relatively closely related to a crop and may be crossed with the crop either using conventional or genetic engineering techniques to introduce desirable traits from the wild species to the crop.

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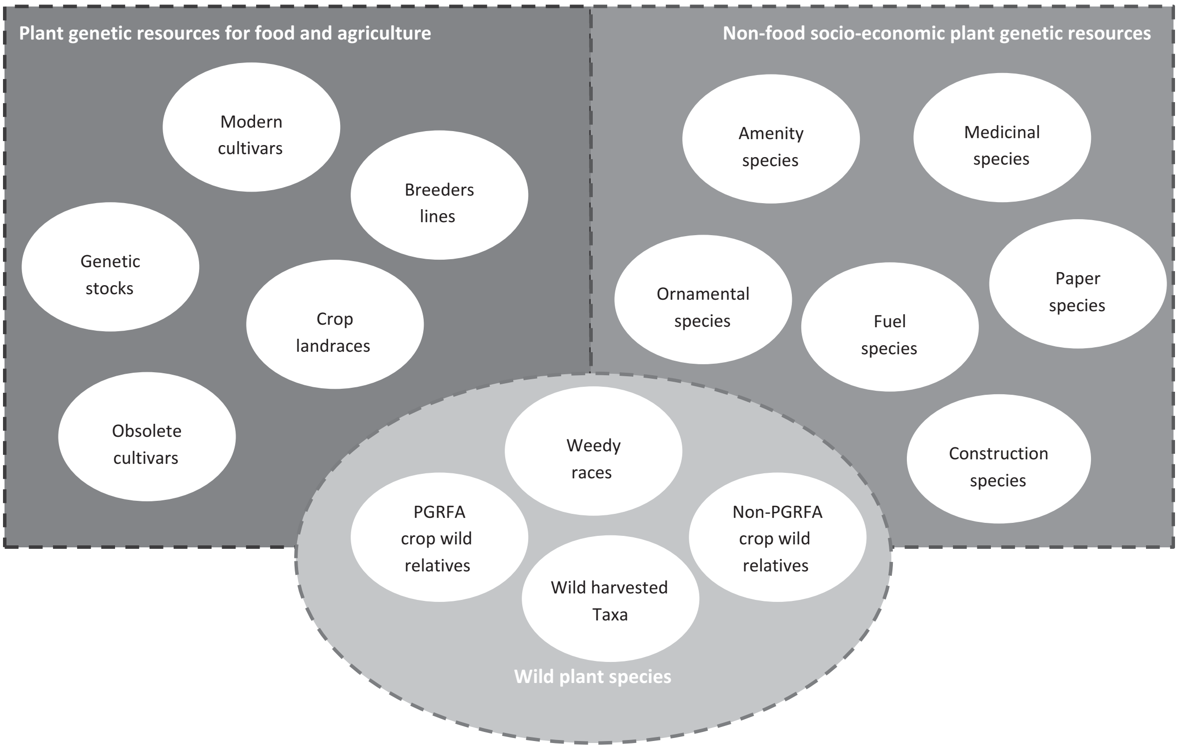

Figure 1.4 The diversity of plant genetic resources.

- **Non-food socio-economic species**: Species whose value is associated with non-agricultural exploitation, such as species with medical, forestry, recreational or ornamental value.
- **Other wild species**: Species of less immediate utilization potential in terms of trait acquisition but which form the basis of natural communities.

Although domesticated plant species represent only a small proportion of the Earth's total biodiversity, they are of fundamental importance to humankind. We have been selecting plants from the wild, domesticating them and adapting them to our needs for around 10 000 years. This process of domestication has led to the existence of an enormous number of different cultivars (product of plant breeding) and landraces (product of farmer-based selection and breeding). Many landraces have been grown in specific localities for extended periods and so grow to withstand local conditions, e.g. altitude, rainfall, drought; they are genetically adapted to the local environment and are referred to as an ecotype.

Increasingly the techniques developed initially for plant genetic resource characterization and genetic conservation are being applied to the broader conservation of wild plant species that are only remotely related to any form of human utilization. The application of biotechnology and systematic bioprospecting has also meant that any plant species has the potential to be of use to humankind in the future. Thus, the boundary between what may and may not be regarded as a plant genetic resource is breaking down and becoming of limited semantic importance. In the future a more appropriate definition might be the total genetic diversity found both between and within all plant species.

1.4 Where Are Plants Found?

The initial response to this question might be throughout the world, but plant diversity and more specifically plant genetic resources are not distributed evenly across the surface of the world, let alone across

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the terrestrial regions. Their distribution tends to be shaped by four main criteria:

- Historical: organisms that have evolved in isolation from other groups due to historic geographic changes, such as shifts in tectonic plates leading to changes in land mass formation, the rise of mountain ranges or sinking of an isthmus.
- Causal: organisms respond and adapt to specific environmental factors where they are located, e.g. temperature, precipitation and soil conditions.
- Casual: when organisms originally arrive in a location by accident or human intervention, once in that location they evolve to fill all available ecological niches, such as Darwin's finches on the Galápagos Islands or alien introductions.
- Functional: when organisms live together in certain areas, they interact and form communities, each organism within the community playing a specific role, e.g. primary producers, which produce organic material from nutrients in the soil and in the atmosphere with the help of light.

Table 1.4 **Biogeographic factors influencing plant concentration**

Biogeographic factor	More biodiversity	Less biodiversity
Latitude	Near equator	Away from equator
Temperature	Warmer	Colder
Rainfall	Wetter	Drier
Seasonality	Less seasonal	More seasonal
Topography	More varied	More uniform
Altitude	Lower	Higher
Area size	Larger	Smaller
Geographic isolation	More endemics	Fewer endemics
Geologic isolation	More endemics	Fewer endemics

Complicated patterns of biodiversity can originate from the operation and interaction between these four criteria. But if plant diversity is measured in terms of species richness then they tend to vary geographically according to a series of rules applicable for terrestrial environments (Table 1.4). Therefore, plant diversity tends to be concentrated in particular regions near the equator and decreases towards the poles (Figures 1.5). Table 1.5 indicates the distribution of higher plants on a continental basis, and it can be clearly seen that plant diversity increases as you move away from the poles towards the equator.

The concentration of biodiversity in certain regions was noted by Norman Myers, who proposed the concept of biodiversity hotspots (Myers, 1988), defined for plants as an area with a high level of plant species and endemism (0.5% of all vascular plants or 1500 endemic species) and threat (25% or less of original vegetation left intact). He argued that plants should be the baseline for hotspot selection because all other life depends on them. Originally Myers designated 10 hotspots, but following further study Myers (1990) added eight additional hotspots. Thereafter these have been further expanded to the 34 hotspots currently recognized by Mittermeier *et al.* (1999) (Table 1.6). These biodiversity hotspots hold 50% of the world's plant species and especially high numbers of endemic species yet covers only 2.3% of the Earth's land surface. Each hotspot is facing extreme threat from habitat mismanagement and has already lost ≥70% of its original natural vegetation. Myers *et al.*'s (2000) definition of diversity within hotspots is based on species assessment, but even if we consider habitat diversity, these same regions are also rich in habitat diversity, containing tropical rain forest, tropical montane forest, tropical moist forest, warm temperate and Mediterranean vegetation. Further, if plant hotspots (Figure 1.5) are compared to biodiversity hotspots (Figure 1.6) they are correlated with highest plant species concentrations being primarily found in the montane regions of the tropics. But are these areas also rich in genetic diversity?

Generally, we do not yet have enough genetic diversity data to answer this question, except perhaps for PGRFA. The Russian geneticist N.I. Vavilov was one of the first scientists to make the connection between the conservation of genetic diversity and its use in underpinning food security. He also noted that the genetic diversity of PGRFA was

Table 1.5 **Regional distribution of higher plants**

		Number of Species		Endemics	
Continent	Sub-Region	Continent	Sub-Region	Number	%
Europe		12 500		3 500	28
Americas		133–138 000			
	North America		20 000	4,198	21
	Middle America		30–35 000	14–19 000	46–54
	South America		70 000	55 000	78.5
	Caribbean Is.		13 000	6,555	50
Africa		40–45 000		35 000	77–87.5
	North Africa		10 000		
	Tropical Africa		21 000		
	Southern Africa		21 000		
Asia					
	Southwest Asia & Middle East		23 000	7,100	31
	Central & North		17 500	2,500	14
	Indian Subcontinent		25 000	12 000	48
	Southeast Asia (Malesia)		42–50 000	29–40 000	70–80
	China & East Asia		45 000	18 650	41.5
Australasia	Australia & New Zealand	17 580		16 202	90
Oceania	Pacific islands	11–12 000		7,000	58–63

Adapted from Davis *et al.* (1995).

concentrated in certain regions (Vavilov, 1917), but his formulated the fundamental concept of the 'Centres of Origin' of crop diversity was published a few years later following extensive field observation and plant collecting across five continents (Vavilov, 1926, 1951). He recognized eight centres (Table 1.7 and Figure 1.7) based on crop presence, within crop landrace and crop wild relative diversity. Vavilov (1965) noted:

The regions of maximum variation, usually including a number of endemic forms and characteristics, can usually also be considered as the centre of type-formation . . . The presence in northern Africa and south-western Asia of large groups of endemic plants, both species and varieties of cultivated plants, based on which independent agricultural civilizations arose.

He used the term 'Centres of Origin' himself extending Willis's age and area hypothesis (1922), stating that the greater the number of related species occurring in an area, the greater their genetic diversity in that location and the more likely that this was the crop's centre of ancient origin. As Hawkes (1983) notes this is an oversimplification in terms of crop origin, but it proved a very useful concept in terms of identifying that crop species and genetic diversity are distributed unevenly across the terrestrial surface of the Earth but in eight relatively restricted locations. It is also interesting to note that biodiversity in general and

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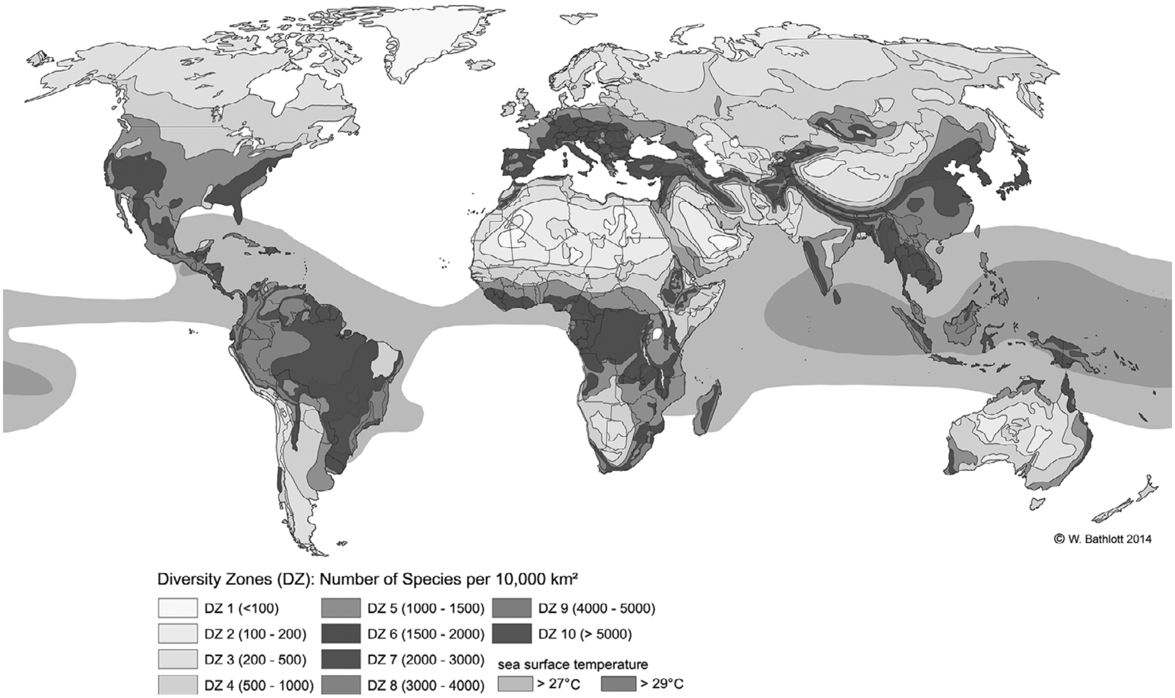

Figure 1.5 Species diversity globally of vascular plants. (A black and white version of this figure will appear in some formats. For the colour version, refer to the plate section.)
(Reproduced from Barthlott *et al.*, 2014)

plant species diversity are not congruent with the 'Centres of Crop Diversity'; the Vavilov centres do not include the Polynesian and Micronesian Islands, Brazilian Atlantic Forest, Caribbean Antilles, South African Cape region, Madagascar, Southwestern Australia and New Caledonia, but they do include Chiloe in Chile, Ethiopia, Central Asia and China all of which are not biodiversity or plant diversity hotspots.

Whether conserving plant diversity or more specifically plant genetic resources, hotspots are a natural foci of conservation activity, because they contain:

- relatively high species numbers
- high endemicity, whether of common or unusual lineages
- unusual combinations of community ecological characteristics
- super speciose taxa (e.g. the high number of fruit flies in Hawaii)

It might be expected that genetic diversity within a species is spread evenly throughout its range, but it seems that the pattern of genetic diversity is at least partially independent of geographic patterns. Therefore, it is necessary to have genetic and geography knowledge for efficient conservation.

1.5 Why Does Plant Biodiversity Need Conservation?

The answer to this fundamental question is: plant biodiversity has economic, social and ethical value for humankind, it is a finite natural resource and it is currently being eroded or lost by careless, unsustainable human practices (FAO, 2019; IPBES, 2019). This loss of plant biodiversity can occur at each biodiversity level: genes, species and communities. If we use species extinction to illustrate the point, estimates of the precise number of species and precise rates of species extinction vary, but Lugo (1988) produced a consensus view based on a multiple estimate that 15–20% of all species would become extinct between 1988 and the turn of the century.

Table 1.6 **The 34 hotspots, their characteristics and plant diversity**

		Geographic Area					Indicative biodiversity		
		Original extent	Remaining intact		Area protected		Vascular plant species		
Hot spots	Biome(s)	(km^2)	(km^2)	(%)	(km^2)	(%)	Diversity	Endemism	% Endemic
Tropical Andes	Tropical and subtropical moist broadleaf forests; montane grassland and shrubland	1 542 644	385 661	25.0	246 871	16.0	30 000	15 000	50
Tumbes-Chocó-Magdalena	Tropical and subtropical moist broadleaf forests	274 597	65 903	24.0	34 338	12.5	11 000	2750	25
Atlantic forest	Tropical and subtropical moist broadleaf forests	1 233 875	99 944	8.0	50 370	4.1	20 000	8000	40
Cerrado	Tropical dry forest, woodland savannah, open savannah	2 031 990	432 514	22.0	111 051	5.5	10 000	4400	44
Chilean Winter Rainfall-Valdivian Forest	Mediterranean forests; woodlands and shrubs; temperate broadleaf and mixed forests	397 142	119 143	30.0	50 745	12.8	3892	1957	50
Mesoamerica	Tropical and subtropical moist broadleaf forests	1 130 019	226 004	20.0	142 103	12.6	17 000	2941	17
Madrean Pine-Oak Woodlands	Tropical and subtropical coniferous forests	461 265	92 253	20.0	27 361	5.9	5300	3975	75
Caribbean islands	Tropical and subtropical dry broadleaf forests	229 549	22 955	10.0	29 605	12.9	13 000	6550	50
California Floristic Province	Mediterranean forests; woodlands and shrubs; temperate coniferous forests	293 804	73 451	25.0	108 715	37.0	3488	2124	61
Guinean forest of West Africa	Tropical and subtropical moist broadleaf forests	620 314	93 047	15.0	108 104	17.4	9000	1800	20
Cape Floristic Province	Mediterranean forests; woodlands and shrubs	78 555	15 711	20.0	10 859	13.8	9000	6210	69
Succulent Karoo	Deserts and xeric shrubland	102 691	29 780	29.0	2567	2.5	6356	2439	38
Maputaland-Pondoland-Albany	Tropical and subtropical moist broadleaf forests; montane grassland and shrubland	274 136	67 163	25.0	23 051	8.4	8100	1900	23

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Table 1.6 (*cont.*)

		Geographic Area					Indicative biodiversity		
		Original extent	Remaining intact		Area protected		Vascular plant species		
Hot spots	Biome(s)	(km²)	(km²)	(%)	(km²)	(%)	Diversity	Endemism	% Endemic
Coastal Forests of Eastern Africa	Tropical and subtropical moist broadleaf forests	291 250	29 125	10.0	50 889	17.5	4000	1750	44
Eastern Afromontane	Tropical and subtropical moist broadleaf forests; montane grassland and shrubland	1 017 806	106 870	11.0	154 132	15.1	7598	2356	31
Horn of Africa	Tropical and subtropical grassland; savannas, and shrublands	1 659 363	82 068	5.0	145 322	8.8	5000	2750	55
Madagascar and the other Indian Ocean Islands	Tropical and subtropical moist broadleaf forests	600 461	60 046	10.0	18 482	3.1	13 000	11 600	89
Mediterranean Basin	Mediterranean forests, woodlands and shrubs	2 085 292	98 009	5.0	90 242	4.3	22 500	11 700	52
Caucasus	Temperate broadleaf and mixed forest	532 658	143 818	27.0	42 721	8.0	6400	1600	25
Irano-Anatolian	Temperate broadleaf and mixed forest	899 773	134 966	15.0	56 193	6.2	6000	2500	42
Mountains of Central Asia	Temperate grassland; savannas, and shrublands; montane grassland and shrubland	863 362	172 672	20.0	59 563	6.9	5500	1500	27
Western Ghats and Sri Lanka	Tropical and subtropical moist broadleaf forests	189 611	43 611	23.0	26 130	13.8	5916	3049	52
Himalaya	Tropical and subtropical coniferous forests; montane grassland and shrubland	741 706	185 427	25.0	112 578	15.2	10 000	3160	32
Mountains of Southwest China	Temperate coniferous forests	262 446	20 996	8.0	14 034	5.3	12 000	3500	29
Indo-Burma	Tropical and subtropical moist broadleaf forests	2 373 057	118 653	5.0	235 758	9.9	13 500	7000	52
Sundaland	Tropical and subtropical moist broadleaf forests	1 501 063	100 571	7.0	179 723	12.0	25 000	15 000	60

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Table 1.6 (*cont.*)

Hot spots	Biome(s)	Geographic Area: Original extent (km²)	Remaining intact (km²)	Remaining intact (%)	Area protected (km²)	Area protected (%)	Indicative biodiversity: Vascular plant species: Diversity	Endemism	% Endemic
Wallacea	Tropical and subtropical moist broadleaf forests	338 494	50 774	15.0	24 387	7.2	10 000	1500	15
Philippines	Tropical and subtropical moist broadleaf forests	297 179	20 803	7.0	32 404	10.9	9253	6091	66
Japan	Temperate broadleaf and mixed forest	373 490	74 698	20.0	62 025	16.6	5000	1950	35
Southwest Australia	Mediterranean forests, woodlands and shrubs	356 717	107 015	30.0	38 379	10.8	5.571	2948	53
East Melanesian Islands	Tropical and subtropical moist broadleaf forests	99 384	29 815	30.0	5677	5.7	8000	3000	38
New Zealand	Temperate broadleaf and mixed forest	270 197	59 443	22.0	74 260	27.5	2300	1865	81
New Caledonia	Tropical and subtropical moist broadleaf forests	18 972	5122	5.0	4192	22.1	3270	2432	74
Polynesia/ Micronesia	Tropical and subtropical moist broadleaf forests	47 239	10 015	21.0	2436	5.2	5330	3074	58
Galápagos	Xerophytic shrubland	7882	4931	62.6	7278	92.3	541	224	41
Juan Fernandez Islands	Temperate forest	100	–	–	91	91.0	209	126	60
Totals		**23 498 083**	**3 384 177**	**–**	**2 382 636**	**–**			
Total endemics								**131 399**	
% Global diversity								**43.8**	

From Mittermeier *et al.* (1999, 2004).

More recent estimates suggest 20% of species will become extinct within the 30-year period between 1998 and 2028 (American Museum of Natural History, 1998). However, proving a species is extinct is very difficult, particularly for a plant with the possibility of a long-lived soil seed bank, and the IUCN prefer to highlight the fact that species extinction is occurring at unprecedented levels – currently it is estimated that extinction rates are up to 1000 and 10 000 times the 'background' or natural rate (Chivian and Bernstein, 2008).

It is even more difficult, if not impossible, to estimate the precise rates of the loss of genetic diversity from within species. It must, however, always be faster than the loss of species, because there will be some genetic erosion (loss of genetic diversity) from the species that remain extant and complete loss of genetic diversity from species that become extinct.

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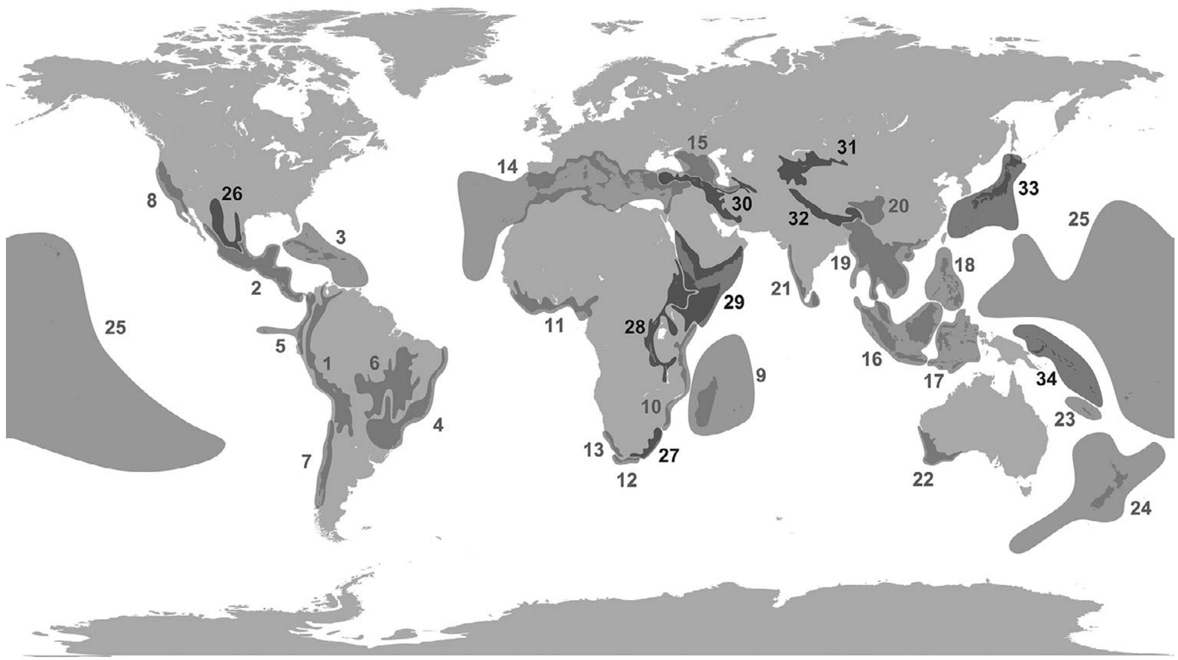

Figure 1.6 The location of areas of exceptionally high biodiversity richness – biodiversity hotspots. (A black and white version of this figure will appear in some formats. For the colour version, refer to the plate section.)
(Reproduced from Mittermeier *et al.*, 1999)

Table 1.7 **World centres of cultivated plant diversity**

Centre	Countries	Crop diversity
I China	Central and West China, Korea, Japan and Taiwan	*Panicum miliaceum* – Chinese millet; *Sesamum indicum* – sesame *Avena nuda* – naked oat; *Fagopygrum esculentum* - buckwheat; *Glycine hispida* - soybean; *Phaseolus angularis* – adzuki bean; *Raphanus sativus* - radish; *Brassica* species; *Colocasia esculenta* – taro yam; *Allium* species; *Cucurbita moschata* – butternut squash; *Phyllostachys* spp. – small bamboos; many temperate (*Pyrus*, *Malus*, *Prunus*, *Chaenomeles* spp.) and tropical fruit trees (*Citrus* spp.); *Camellia sinensis* – Chinese tea; as well as plants producing oils, spices, medicines and fibres
II India	India	*Oryza sativa* – rice; *Eleusine corocana* – finger millet; *Cicer arientinum* – chickpea; *Cajanus cajan* – pigeon pea; *Phaseolus acontifolius* – moth bean, *P. calcaratus* – rice bean; *Vigna sinensis* – asparagus bean; *Dolichos biflorus* – horse gram; *Trigonella foenum-graecum* – fenugreek; *Solanum melongena* – eggplant; several *Amaranthus* species; *Colocasia esculenta* – taro yam; *Dioscorea alata* – yam; tropical fruits (*Citrus* spp., *Musa* spp., *Mangifera* spp.); oil-producing species, fibres (*Corchorus olitorius* – jute), spices (*Piper nigrum* – pepper), stimulants and dye plants; sugar plants such as *Saccharum officinarum* – sugarcane.
IIa Indo-Malaya	South China, South-East Asia	*Dioscorea* spp. – yams; *Citrus maxima* – pomelo; *Musa* spp. – banana; *Cocos nucifera* – coconut
III Inner Asia	Afghanistan, Central Asia and Northwest India	*Triticum vulgare* – wheat; *Pisum sativum* – garden pea; *Lens culinaris* – lentil; *Brassica*, *Eruca* and *Lepidium* species; *Linum*, *Sesamum* and *Coriandrum* (one of their centres); *Carthamus tinctorius; Cannabis indica*; *Gossypium herbaceum*; various vegetables and melon species, spice crops, etc.; fruit and nut trees in the genera *Malus*, *Pyrus*, *Prunus*, *Pistacia*, *Amygdalus*, *Juglans*, *Corylus*, etc.
IV Asia Minor	Turkey, Transcaucasia, Turkmenistan and Iran	*Triticum monococcum*, *T. durum*, *T. turgidum* and *T. aestivum* – wheats; *Secale cereale* – rye; *Avena byzantina* – red oat, *A. sativa* – oat; *Cicer arietinum* – chickpea; *Lens culinaris* – lentil; *Vicia ervilia* – bitter vetch; *Pisum sativum* – garden pea; forages (*Medicago sativa* – lucerne, *Trifolium resupinatum* – strawberry clover, *Trigonella foenum-graecum* – fenugreek, *Onobrychis* viciifolia – sainfoin, *Lathyrus cicera* – chickling vetch and *Vicia sativa* – common vetch); oil-producing plants (*Sesamum*, *Linum*, *Brassica*, *Camelina*, *Eruca* spp.); melons (*Cucumis* and *Cucurbita* spp.); vegetables (*Lepidium*, *Brassica*, *Daucus*, *Eruca*, *Allium*, *Petroselinum*, *Lactuca* and *Portulaca* spp.); fruit crops (*Malus*, *Pyrus*, *Punica*, *Ficus*, *Cydonia*, *Cerasus*, *Amygdalus*, *Vitis*, *Pistacia* spp.); dye plants (*Crocus sativus* and *Rubia tinctorum*)

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Table 1.7 (*cont.*)

Centre	Countries	Crop diversity
V Mediterranean	Countries bordering the Mediterranean Sea	*Vicia faba* – fababean, *Lathyrus ochrus* – Cyprus vetch, *Vicia sativa* – common vetch, large-seeded *Cicer arientinum* – chickpea, *Hedysarum coronarium* – Italian sainfoin, *Ornithopus vicifoliia* – sainfoin; various oil-producing plants and spices; *Olea europaea* – olive and *Ceratonia siliqua* – carob; *Beta vulgaris* – beets, *Brassica oleracea* – cabbages, *Portulaca oleracea* – purslane, *Allium* spp. – onions, *Asparagus* – asparagus, *Lactuca* – lettuce, *Pastinaca* – parsnip, *Tragopogon* – salsify; ethereal oil species and spices
VI Abyssinia	Ethiopia, Eritrea	*Triticum aestivum* – wheats, *Hordeum vulgare* – barley, *Sorghum bicolor*– sorghum, *Cicer arietinum* – chickpea; *Lens culinaris* – lentil; *Vicia ervilia* – bitter vetch; *Pisum sativum* – garden pea, *Trigonella foenum-graecum* – fenugreek, *Brassica oleracea* – cabbages, *Allium* spp. – onions, *Lepidium latifolium* – peppergrass, *Vigna unguiculata* – cowpea, *Lupinus* spp. – lupins, *Linum usitatissimum* – flax; plus indigenous cereal *Eragrostis tef* – teff and *Eleusine coracana* – African millet; oil-bearing *Guizotia abyssinica* – Niger; *Coffea arabica* – coffee, *Catha edulis* – khat and *Musa ensete* – Abyssinian banana
VII Mesoamerica	South Mexico and Central America	*Zea mays* – corn/maize; *Phaseolus vulgaris* – common bean, *P. coccineus* – runner bean, *P. acutifolius* – tepary bean; *Chenopodium berlandieri* – hauzontle and *Amaranthus cruentus* – purple amaranth; *Cucurbita*, *Sechium* and *Capsicum* spp. (*C. annum*) bell and mostly mild hot pepper; *Pachyrhizus tuberosa* – yam bean, *Ipomaea batatas* – sweet potato and *Maranta arundiacea* – arrowroot; *Gossypium hirsutum* – cotton; many tropical and temperate fruits; *Nicotiana tabacum* – tobacco, *Bixa orellana* – annatto and *Theobroma cacao* – cocoa
VIII South America	Peru, Ecuador and Bolivia	*Solanum tuberosum* – potato, *Oxalis tuberosa* – oca, *Tropaeolum tuberosum* – anu and *Ullucus tuberosus* – ulluco; *Solanum lycopersicum* – tomato, *Solanum muricatum* – Peruvian pepino, *Cyclanthera pedata* – achocha or caigua, *Physalis peruviana* – Cape gooseberry and *Cucurbita maxima* – pumpkin; Phaseolus *vulgaris* – common bean, *P. lunatus* – Lima bean, *Lupinus mutabilis* – pearl lupin, *Capsicum* spp. (*C. baccatum*, *C. chinense* and *C. pubescens*) – hot peppers, *Gossypium barbadense* – cotton *Chenopodium quinoa* – quinoa, *Chenopodium pallidicaudale* – kañiwa, *Amaranthus caudatus* – foxtail amaranth, *Erythroxylum coca* – coca and *Lepidium meyeii* – maca
VIIIa Chiloe	Chile	*Solanum tuberosum* – potato; *Madia sativa* – Chilean oilplant, *Bromus mango* and *Fragaria chiloensis* – beach strawberry
VIIIb Brazil and Paraguay	Brazil and Paraguay	*Manihot utilissima* – manioc, *Arachis hypogaea* –peanut, *Theobroma cacao* – cocoa, *Hevea brasiliensis* – rubber plant and *Ilex paraguayense* – mate

From Vavilov (1926).

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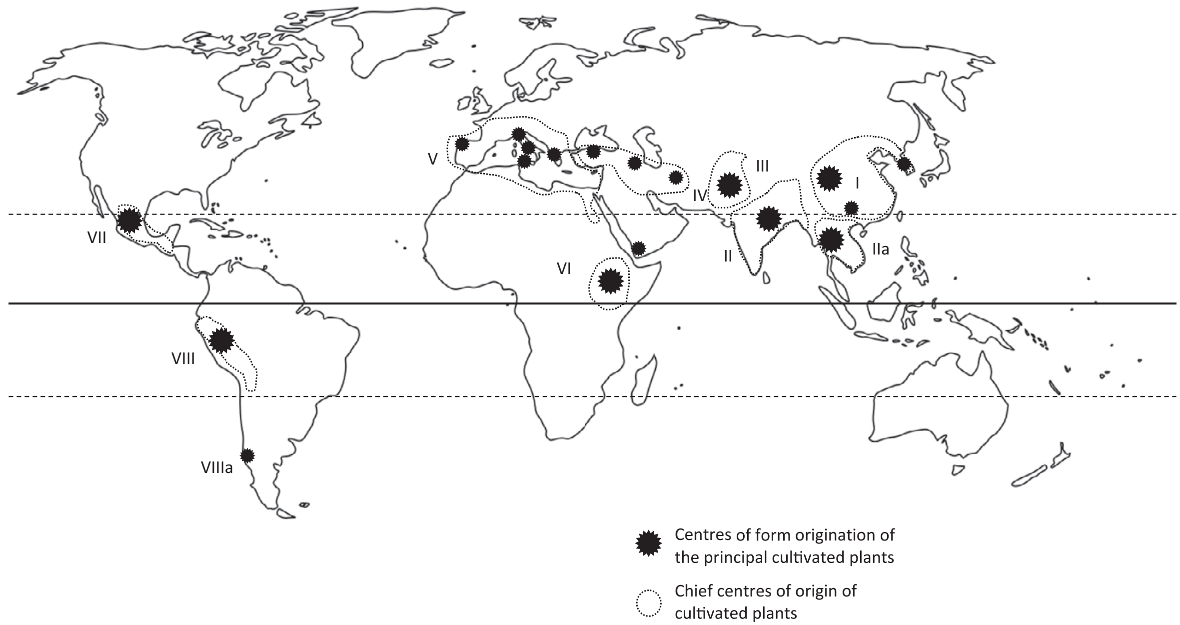

Figure 1.7 The centres of crop diversity.
(From Vavilov, 1951: amended by Hawkes, 1983)

Loss of any genetic diversity means that plants may not be able to adapt to changing conditions quite so readily in the future. Although, as already stressed, rates of genetic erosion cannot be quantified accurately, it seems likely that virtually all species are currently suffering loss of genetic variation to varying degrees. If the figures are correct for species extinction, where 100% of genetic diversity will be lost, then approximately a further 10–15% of plant and animal genetic diversity could be lost over the same period due to genetic erosion (Maxted *et al.*, 1997a).

Obviously, plant diversity has many forms of value and the aesthetic and ethical values cannot be underestimated, particularly as these values are easily identifiable by the public who ultimately fund most conservation action and research. But it is difficult to quantify the economic value of aesthetic and ethical reasons to conserve plant diversity. One estimate of the value of the introduction of new genes from wild relatives to crops is $115 billion per year worldwide (Pimentel *et al.*, 1997), more recently PWC (2013) estimated a similar value for use of CWR in breeding of the 26 top global crops alone. This estimate of the value of wild species for one form of direct use highlights why we need plant diversity. It also underlines the continued need plant breeders have for access to plant genetic diversity if they are to keep their breeding options open. Plant diversity that is lost through genetic erosion or extinction means that diversity is unavailable for exploitation. It also remains the case that 90% of the world's calorie consumption is still based on 30 crops and that all these species originated in the Vavilov centres of diversity primarily located in developing countries (FAO, 1998). Many of these countries are both the home of such critically important plant diversity and are also at risk of food insecurity (Figure 1.8). The Food Security Risk Index is an indication of relative risk of famine based on an evaluation of the accessibility and availability of food and the stability of food supplies across 197 countries. It also takes into consideration the nutritional and health elements of populations (Maplecroft, 2013).

There is a continual requirement for plant breeders to produce novel cultivars that combat evolving pests and pathogens, and less overt demands such as climate change and changing consumer requirements. If the plant breeder is to retain the upper hand, he or she must maintain access to as wide a genetic gene pool as possible. Hence it is important to note that no single country is sufficiently wealthy in native genetic diversity to make it independent of this requirement for the genetic resources of other countries. The reason is that the most species cultivated in any country are rarely native to that country; they were imported historically from the diverse centres of crop diversity worldwide. Take, for example, the botanically rich country of Brazil; more than three-quarters of its calorie consumption is based on crops originating in another continent (Table 1.8). Therefore, there is a need for plant conservation and continued access to the conserved diversity for each country no matter how botanically rich that country may be.

1.6 Threats to Plant Biodiversity

Species extinction and genetic erosion are natural events, just as species and genetic evolution are natural; nature is, and it seems has always been, dynamic in this respect. However, the contemporary situation concerning species extinction and genetic erosion is quite different from that which existed in the past. Humankind now can drastically alter the world environment in ways not previously possible, and it is these anthropogenic changes that have increased the speed of species extinctions and genetic loss. Many species are unable to naturally evolve sufficiently quickly to adapt to the new changing environments created by humans.

The kind of anthropogenic changes that may lead to extinction of taxa (taxonomic erosion) or genetic diversity (genetic erosion) may be broadly grouped under the following general headings:

- Habitat destruction, degradation and fragmentation of natural habitats – leading to direct eradication of taxa as a result of road and reservoir building, changes in land usage, etc.

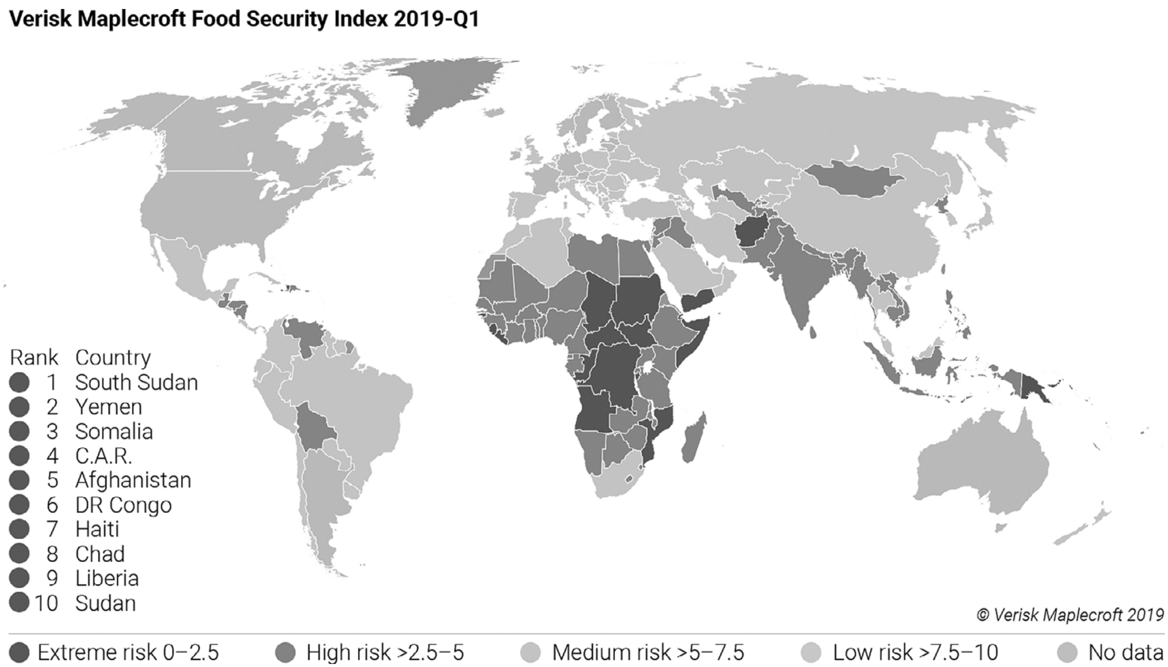

Figure 1.8 Food security risk index 2013. (A black and white version of this figure will appear in some formats. For the colour version, refer to the plate section.) (From Maplecroft, 2013)

Table 1.8 **Source of plant-derived calories consumed in Brazil**

Crop	Share of plant-derived calories (%)	Centre of origin
Sugar	15.76	Indochina
Wheat	15.76	West and Central Asia
Rice (paddy)	14.45	Asia
Soybean	13.79	China–Japan
Maize	8.58	Central America
Beans	6.20	Andes
Cassava	4.06	Brazil–Paraguay
Coconut	2.09	Indomalaya
Bananas	2.05	Indochina
Oil palm	1.77	West Africa

From FAO (2016).

- Over-exploitation – plant extraction from the wild for food, material, medicines and fuel-wood or overgrazing of plants *in situ*.
- Invasive alien species – human-mediated introduction of exotic species to areas outside of their native range where they compete with, prey on or hybridize with native species. The human-mediated introduction of exotic diseases to areas where the taxa have not previously been subject to the disease can also have devastating effects on susceptible populations.
- Human socio-economic changes and upheaval – resulting in extinction of tribal cultures, urban sprawl, land clearances, wars and human food shortages all of which can negatively impact on local taxa.
- Unsustainable changes in agricultural practices and land use – which can lead to the displacement of landraces by modern cultivars, a shift to monoculture or cash cropping where previously weeds were tolerated is now unacceptable. Other changes may cause incidental extinction, for example where land drainage leads to the unintentional loss of marsh-loving taxa from drained habitats.
- Calamities – anthropogenic changes that are often not a direct consequence of human action but are an unforeseen by-product resulting in a dramatic effect on biodiversity such as droughts, floods, landslides and of course climate change, which is already having a dramatic global impact.

Finally, climate change is a significant driver of threats to all forms of biodiversity and results from anthropogenic mismanagement of the environment, but its impact is seen through each of the changes listed above rather than having a discrete impact of its own.

It should be noted that the threat to botanical diversity as a result of anthropogenic changes is not universal for all species. Some species are under greater threat of genetic erosion or even of complete extinction than others. Rare and geographically or ecologically restricted species are more highly threatened and likely to become extinct or eroded; that is why the flora of oceanic islands are so vulnerable. Threat is also dynamic, meaning that levels of threat often change rapidly and unexpectedly. Thus, an endemic species or habitat may, for example, suddenly come under the threat of industrial development, road building or logging.

The IUCN has developed a means of assessing relative threat to a taxon and categories of perceived threat, the so-called IUCN Red Data List Categories (Figure 1.9). The assessment is based on the numbers of mature individuals, population size trends, population fluctuations and distributions of populations, demographic patterns, and extinction probabilities in the wild. The IUCN Red List Categories for individual plant species at global (IUCN, 2001) and regional levels (IUCN, 2003) are held in a web-enabled database, the IUCN Red List of Threatened Species (www.iucnredlist.org/). These categories can be applied at local regional as well as global scales to assess comparative threat and so help in prioritizing where conservation effort should be focused.

IUCN Red List Assessment is a widely accepted means of assessing relative threat to species; the Red

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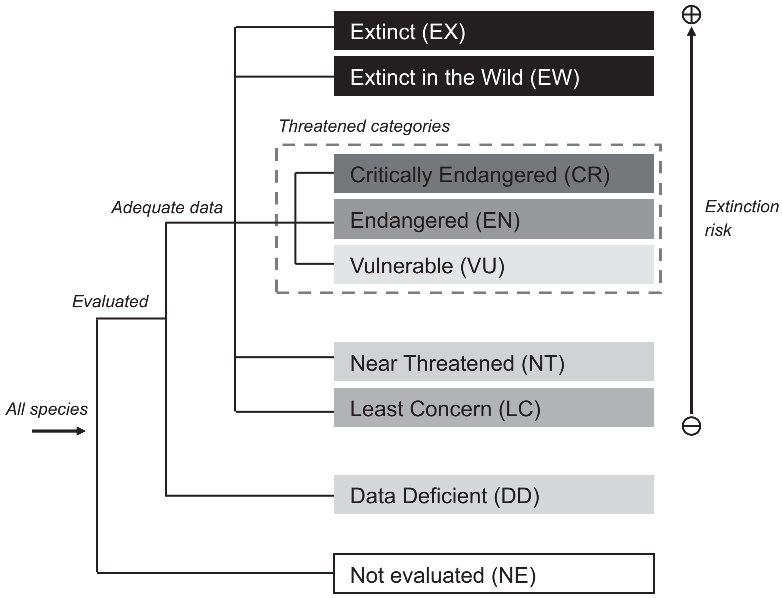

Figure 1.9 Structure of IUCN Red List Categories. (A black and white version of this figure will appear in some formats. For the colour version, refer to the plate section.)
(Reproduced from IUCN, 2001)

List Criteria have been applied to 17 604 plant species, and of these, 9829 are listed as threatened (Table 1.9). Hence, 56% of the species assessed are regarded as threatened, and 95% of all plant species have yet to be assessed. However, in terms of the number of species threatened the percentage threatened figure should not be extrapolated to all plant species as the species selected were not selected randomly and they are likely to have been selected because they were known *a priori* to be threatened. A more reliable statistic is the Sampled Red List Index for Plants (Brummitt and Bachman, 2010). This index was generated by selecting approximately 1500 species at random for each of four major plant groups, monocotyledons, legumes, pteridophytes and conifers/cycads (bryophytes are to be added subsequently), and assessing each species against the IUCN Red List Categories and Criteria. The result was that 21.5% of the index plants are currently threatened with extinction, with 4% of them being Critically Endangered, 7% Endangered, 10.5% Vulnerable, 10% Near Threatened and 64% Least Concern, with 4.5% Data Deficient meaning there was insufficient data available to undertake an assessment. In the broader biodiversity context these figures indicate plants are more threatened than birds, experience a similar level of threat to mammals but are less threatened than amphibians.

IUCN Red List Assessment could not be used for domesticated species as their occurrence is dependent on humankind but there has recently been a comprehensive assessment of 572 European crop wild relative species (Bilz *et al.*, 2011; Kell *et al.*, 2012). Results of this study show that at least 11.5% (66) of the species are threatened, with 3.3% (19) of them being Critically Endangered, 4.4% (22) Endangered and 3.8% (25) Vulnerable. A further 4.5% (26) of the species are classified as Near Threatened and one species (*Allium jubatum* J.F. Macbr.) is Regionally Extinct. The remaining species were regionally assessed as Data Deficient (DD) (29%) or Least Concern (LC) (54.7%). As a group, the most threatened crop complex was the brassica complex, but multiple wild relatives of beet, lettuce, wheat and alliums were also threatened. Kell *et al.* (2012) analyzed the factors threatening CWR diversity and reported 31 distinct threats, the most frequent being 'livestock farming and ranching', 'tourism and recreation areas' and 'housing and urban areas'. However, the authors note that we should not conclude that farming *per se* is

Table 1.9 **Summary of IUCN Red List Category for plant divisions**

Class[a]	EX[b]	EW	Subtotal (EX+EW)	CR	EN	VU	Subtotal (threatened spp.)	NT	LR/ cd	DD	LC	Total
Anthocerotopsida	0	0	0	0	2	0	2	0	0	0	0	2
Bryopsida	2	0	2	12	13	7	32	1	0	3	3	41
Charophyaceae	0	0	0	0	0	0	0	0	0	3	8	11
Chlorophyceae	0	0	0	0	0	0	0	0	0	1	0	1
Cycadopsida	0	4	4	53	65	74	192	63	0	3	45	307
Florideophyceae	1	0	1	6	0	3	9	0	0	44	4	58
Ginkgoopsida	0	0	0	0	1	0	1	0	0	0	0	1
Gnetopsida	0	0	0	0	1	3	4	7	0	10	76	97
Jungermanniopsida	1	0	1	10	11	12	33	1	0	0	10	45
Liliopsida	9	4	13	501	812	717	2030	352	10	669	2585	5659
Lycopodiopsida	0	0	0	13	11	16	40	9	0	8	29	86
Magnoliopsida	107	26	133	2192	3453	4889	10 534	1372	174	1456	6443	20 112
Marchantiopsida	0	0	0	1	3	2	6	0	0	4	1	11
Pinopsida	0	0	0	29	96	79	204	98	0	7	298	607
Polypodiopsida	2	1	3	62	69	78	209	26	0	54	180	472
Sphagnopsida	0	0	0	0	0	2	2	0	0	0	0	2
Takakiopsida	0	0	0	0	0	1	1	0	0	0	0	1
Ulvophyceae	0	0	0	0	0	0	0	0	0	1	0	1
Total	**122**	**35**	**157**	**2879**	**4537**	**5883**	**13 299**	**1929**	**184**	**2263**	**9682**	**27 514**

[a] Anthocerotopsida (hornworts); Bryopsida, Sphagnopsida and Takakiopsida (true mosses); Charophyaceae, Chlorophyceae and Ulvophyceae (green algae); Cycadopsida (cycads); Florideophyceae (red algae); Ginkgoopsida (ginkgo); Gnetopsida (gnetums); Jungermanniopsida and Marchantiopsida (liverworts); Liliopsida (monocotyledons); Lycopodiopsida (club mosses and spike mosses); Magnoliopsida (dicotyledons); Polypodiopsida (ferns, horsetails and quillworts); Pinopsida (conifers).

[b] IUCN Red List Categories: EX – Extinct, EW – Extinct in the Wild, CR – Critically Endangered, EN – Endangered, VU – Vulnerable, LR/cd – Lower Risk/conservation dependent, NT – Near Threatened (includes LR/nt – Lower Risk/ near threatened), DD – Data Deficient, LC – Least Concern (includes LR/lc – Lower Risk, Least Concern).

From IUCN (2018).

threatening CWR diversity; in fact, farmed areas (including arable land and pasture) are one of the primary habitats of CWR species. Rather it is unsustainable farming practices, such as severe overgrazing, conversion of land to monocultures, and the heavy application of fertilizers and herbicides, that are the major threats to CWR that grow in agricultural areas (Kell *et al*., 2012). IUCN Red List assessments do not directly assess threats posed by climate change as the impacts are often less direct and so cannot be unequivocally attributed to climate change. What is recorded is overgrazing, increased fires or competition from alien species, each of which may have at its foundation changes in the biotic or abiotic environment themselves attributable to climate change.

Using the IUCN Red List Categories and Criteria does have a limitation: it only applies to threat assessment at the taxonomic (primarily species) level, and it cannot be used for assessment at the ecosystem or genetic levels. Ecosystem threat assessment is gradually being developed both at the global and national scales, but thus far there is no widely agreed methodology. The most comprehensive global assessment was the Millennium Ecosystem Assessment (MEA, 2005), which found human mismanagement of the world's ecosystems are already causing significant harm to humankind and diminishing the potential long-term benefits we obtain from ecosystems. It noted that approximately 60% (15 out of 24) of the ecosystem services examined during the Millennium Ecosystem Assessment are being degraded or used unsustainably, including fresh water, capture fisheries, air and water purification, and the regulation of regional and local climate, natural hazards and pests. There is also some evidence that changes being made in ecosystems are increasing the likelihood of nonlinear changes in ecosystems (including accelerating, abrupt and potentially irreversible changes) that have important consequences for human well-being, such as changes in pest and disease emergence dates. Further harmful effects of the degradation of ecosystem services (the persistent decrease in the capacity of an ecosystem to deliver services) are being borne disproportionately by the poor, resulting in growing inequities and disparities between global regions. Perhaps not surprisingly the ecosystems that are being most rapidly eroded are those of highest exploitation value to humankind, such that virtually 100% of natural grasslands in the USA have been lost since 1942 and more than 90% of natural wetlands in New Zealand have been lost since European settlement (Spellerberg, 1996). Furthermore, between 1900 and 2005 the annual rate of forest loss was 14.5M hectares or 145 000 km^2 per year (FAO, 2011b).

While in terms of loss of genetic diversity there are very few examples that quantify the loss of genetic diversity, normally the population numbers or size is taken as a proxy for genetic diversity but there is unlikely to be a direct relationship between loss of populations and loss of genetic diversity. The evidence that is available is largely drawn from loss of diversity in agro-biodiversity where within a crop the disappearance of landraces is likely to be strongly correlated with loss of diversity. In the State of the World's PGRFA report (FAO, 1998) it is noted that the proportion of the wheat grown in Greece contributed by old, indigenous landraces declined from 80% in 1930 to less than 10% in 1970. Furthermore, in Kampuchea rice landraces were lost in the 1970s when war disrupted agricultural production, but in this case a partial duplicate had been preserved in the International Rice Research Institute gene bank in the Philippines and so could be repatriated. While in Mexico and Guatemala, urbanization has displaced about 50% of the populations of teosinte (*Zea mexicana*), the closest relative of maize (Wilkes, 2007), and in the USA there has been loss of vegetable and fruit landraces (Figure 1.10).

Much of this domesticated diversity is being lost due to the replacement of older inherently diverse varieties with modern, high-yielding cultivars (either inbred lines or F_1 hybrids), but the high-yielding cultivars are genetically uniform, thus gradually, locally adapted variation is lost and the domesticate gene pool is shrinking. The aim of domesticated crop conservation is to conserve these landraces and their wild relatives, which retain the essential genetic diversity that is required for breeding new cultivars. We cannot hope to counter or mitigate the effect of climatic change without this breadth of diversity.

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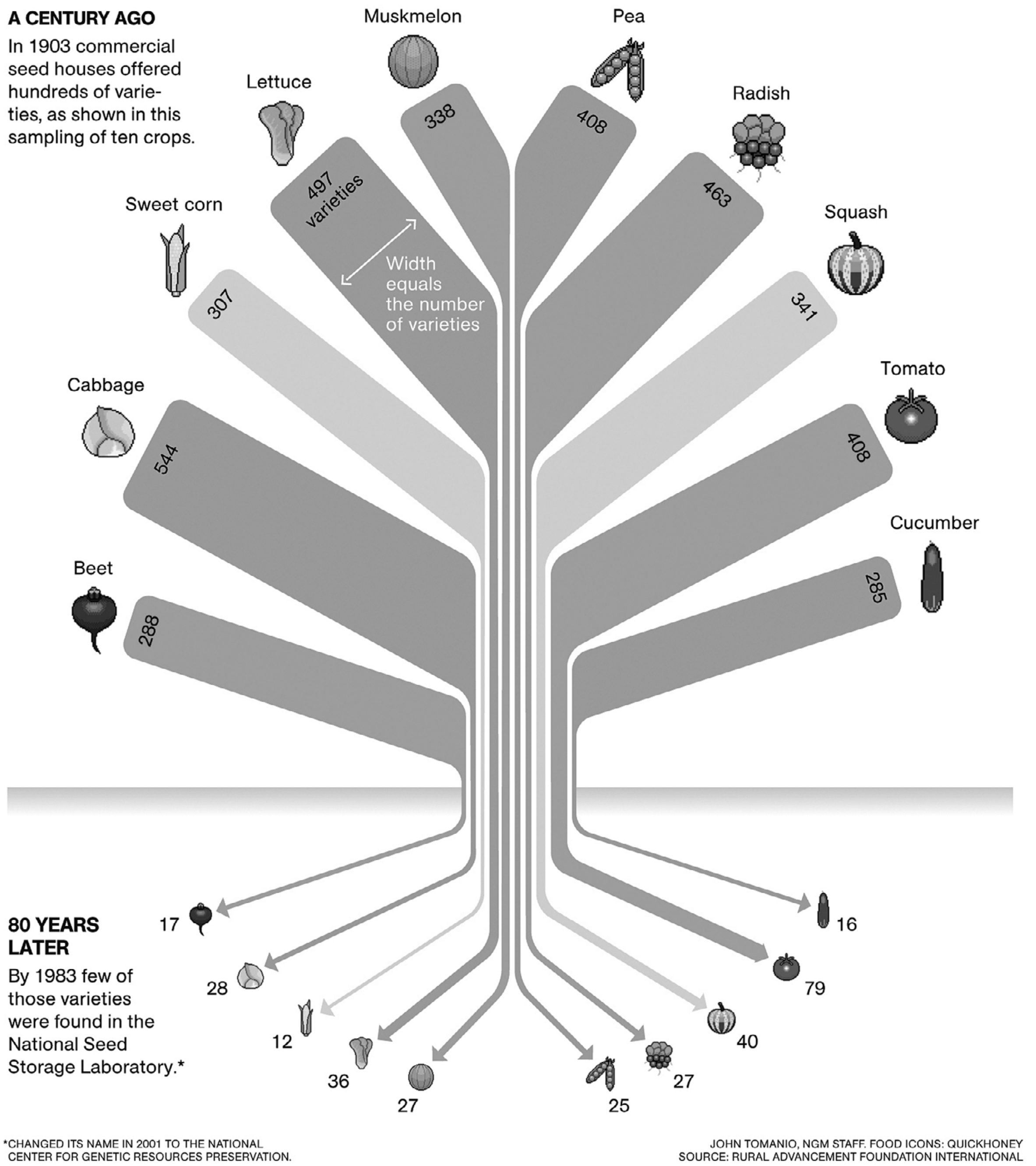

Figure 1.10 Loss of vegetable varieties in the United States.
(From RAFI, 1983; National Geographic, 2013)

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1.7 Why Do We Need PGRFA?

Genetic vulnerability is a term used to describe the adverse effects of a lack of genetic diversity, and this deficit means that a species or population is unable to respond to change in its biotic or abiotic environment. For example, in an area where soil salinity is increasing gradually those individuals that are less able to survive will be lost from the population and the allele frequency will change to reflect this selection pressure; it is only possible for this to occur if there was genetic variation in the original population and the needed salinity resistance was present. Genetic vulnerability is often a problem for agricultural crops, which are deliberately bred for uniformity to ensure yield and performance stability. These genetically uniform varieties may not have the inherent genetic diversity necessary to withstand adverse pest and pathogen attack or environmental hazards, and they are therefore uniformly susceptible. Genetic diversity is necessary to decrease vulnerability to new races of pest or pathogen, or environmental or cultural changes. The problems resulting from genetic uniformity are highlighted in the following examples:

- The history of potato cultivation in Europe illustrates the necessity for diversity. Potato breeders in the 19th century were worried about the narrow genetic base of the potato in Europe; they used phrases expressing the need for 'new blood' and lamenting the potato's 'degeneration'. It is believed that this resulted from the fact that all European potatoes existing in the 19th century resulted from selection over two centuries earlier of two initial introductions. It is not surprising therefore that the potato crop in Ireland was devastated by epidemics of late blight in the 1840s.
- A more recent, but less publicized, example of genetic vulnerability was that of the Soviet wheat cultivar 'Bezostaja', which was grown on about 15 million hectares in 1972. The cultivar originated in the Ukraine during a period of relatively mild winters. Then in 1972 a very severe winter occurred causing losses of millions of tonnes of winter wheat throughout the Soviet Union. The genetic uniformity of the cultivar meant it was universally unable to cope with cold conditions.
- The value of local landraces or long-established cultivars and the diversity of genes they may hold often remain unappreciated until they compete against new foreign cultivars. The genetically uniform semi-dwarf wheat cultivars of the Green Revolution when first grown in Mexico were overcome by the fungal diseases black stem rust and stripe rust, while the tried and tested local varieties with their intrinsic genetic diversity were able to resist the attack.
- Genetically uniform upland cotton introduced from the USA to western Tanzania in the early 20th century was deemed unproductive as a result of the insect pest cotton jassid and bacterial blight. Cotton breeders were only able to solve these problems when resistance to jassid attack was found to be related to the length and density of hairs on the underside of the leaves. In Tanzania, genetic variation for hairiness was found to be present in the locally adapted cottons and was rapidly exploited to give jassid-resistant varieties. Genetic variation in local landraces for resistance to bacterial blight was also exploited to produce new and highly successful cultivars.

1.8 How Do We Conserve Plant Genetic Diversity?

Plant genetic conservation aims to maintain the taxonomic and genetic diversity of plants, the habitats or ecosystems in which they live, and the interrelationships between plants, other organisms and their environment. It aims to enhance or maintain diversity and halt habitat, species and genetic erosion by establishing and implementing conservation programmes. To achieve this goal the conservationist must clearly define and understand the processes involved, and then develop practical techniques to achieve taxonomic and genetic stability, maximizing the likelihood of allelic diversity maintenance. Conservationists, when undertaking conservation, use their knowledge of genetics, ecology, geography, taxonomy and many other disciplines to understand

and manage the biodiversity they wish to conserve. It is important to stress that genetic conservation is not just about maintaining alleles or individual plant populations but includes all levels of biodiversity from ecosystems (a community of organisms and its abiotic environment), through communities (collection of species found in a common environment or habitat), species and populations to genetic diversity within populations. To conserve maximum diversity in a species, populations of the species are likely to require protection in diverse locations, and in each of these the habitat must be maintained that contains the target population.

The practice of conservation tends to diverge between those that take an ecosystem and those that take a genetic approach, though these approaches are viewed as extremes in a continuum of overlapping techniques. Ecological conservation focuses on the conservation of whole communities. Individual survival and extinction are a major concern but are seen in the context of overall community health. This form of whole community conservation was basic to the International Biological Programme in the 1960s and early 1970s and was later exemplified by the 'Man and the Biosphere' programme of UNESCO. The latter established a network of biosphere reserves, representing distinct biomes and ecosystems throughout the world. The clear emphasis is on conservation of overall ecosystems and particularly keystone species that dominate that ecosystem. Other individual species are conserved as part of the entire ecosystem, but it is possible that individual species may be lost within a conserved ecosystem. Genetic conservation focuses more explicitly on individual taxa (most commonly species) and attempts to conserve the full range of genetic (allelic) variation within those taxa. The realization of the importance of conserving genetic diversity arose from the work of early geneticists, such as W. Bateson and N.I. Vavilov, who travelled the world in the 1920s and 1930s collecting the wide genetic variation available of crops and their wild relatives. International genetic conservation of crops and crop relatives gained momentum in the 1960s, spearheaded by the FAO of the UN and a series of technical meeting, which they hosted. In 1974 the International Board for Plant Genetic Resources was established to help develop and promote national and international PGR activities. The aim of genetic as opposed to ecological conservation is often explicitly utilitarian, and the conservation of genetic diversity is often linked directly to human utilization, as occurred with Vavilov's original work.

The aim of genetic conservation is to maximize the maintenance of genetic diversity, but further it is explicitly utilitarian: there is an intimate link between plant genetic diversity, conservation and utilization (Figure 1.11). The model includes a series of steps starting with the full range of genetic diversity for all plant species, through the prioritization of target taxa, the planning of conservation action and the implementation of the conservation action, and leading through characterization and evaluation to utilization. The application of this model is at the core of food security, poverty alleviation and the well-being of humankind.

Central to the model of plant genetic conservation are two general strategies for conservation, each composed of a range of specific techniques. The two strategies are *ex situ* and *in situ* conservation defined by the Convention on Biological Diversity (CBD, 1992) thus:

Ex situ conservation means the conservation of components of biological diversity outside their natural habitats.

In situ conservation means the conservation of ecosystems and natural habitats and the maintenance and recovery of viable populations of species in their natural surroundings and, in the case of domesticates or cultivated species, in the surroundings where they have developed their distinctive properties.

There is an obvious fundamental difference between these two strategies: *ex situ* conservation involves the location, sampling, transfer and storage of the species away from the original location where they were found, whereas *in situ* conservation involves the location, designation, management and monitoring of species at the location where they grow naturally or are cultivated. The two general strategies may be subdivided into several specific techniques (Table 1.10).

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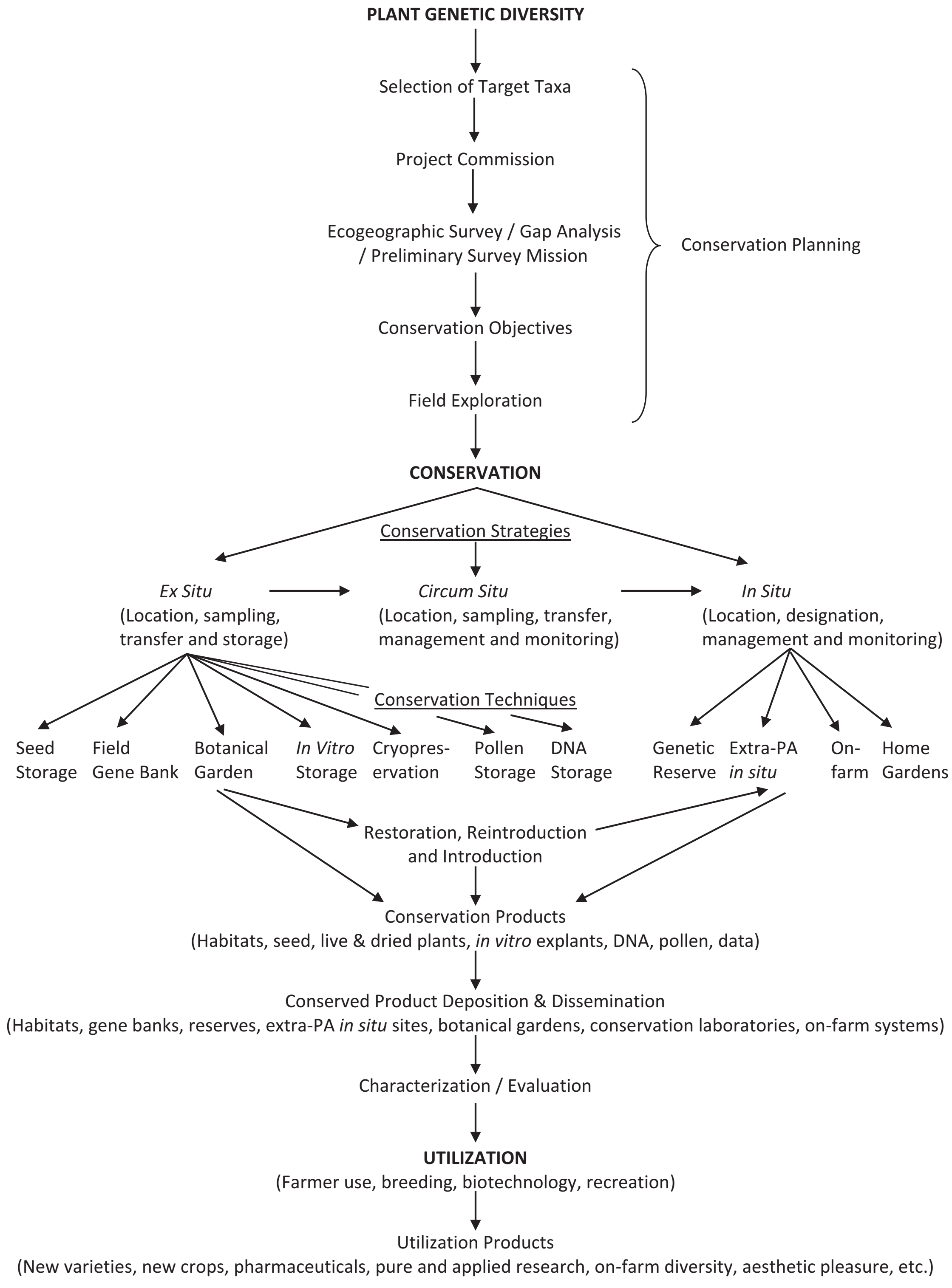

Figure 1.11 Model of plant genetic conservation.
(Adapted from Maxted *et al.*, 1997b)

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Table 1.10 **Genetic conservation strategies and techniques**

Strategies	Techniques	Definition
Ex situ conservation	Seed storage	The sampling, transfer and storage of seed samples at a suitably low moisture content (≈5%), and sub-zero temperatures (≈−20°C)
	Cryopreservation	The sampling, transfer and storage of seed samples at ultra-low temperature (−196°C)
	In vitro storage	The sampling, transfer and maintenance of explants in a sterile, pathogen-free environment
	DNA/pollen storage	The sampling, transfer and storage of DNA or pollen in sub-zero temperatures (≈−20°C)
	Field gene bank storage	The sampling, transfer and maintenance of living plants under field or plantation conditions
	Botanic garden/ arboretum	The sampling, transfer and maintenance of living plants (tree species for arboreta) in a garden
In situ conservation	Genetic reserve conservation	The location, management and monitoring of genetic diversity of natural wild populations within defined areas designated for active, long-term conservation
	Extra PA *in situ* sites	The location, management and monitoring of genetic diversity of natural wild populations in informal *in situ* conservation sites
	On-farm conservation	The location, management and monitoring of genetic diversity of locally developed traditional crop varieties, with associated wild and weedy species or forms, by farmers within traditional agricultural, horticultural or agri-silvicultural cultivation systems for commercial sale
	Home garden	The location, management and monitoring of genetic diversity of locally developed traditional crop varieties or forms by householder within their individual garden, backyard or orchard cultivation systems for home consumption

Although *in situ* and *ex situ* techniques have been defined and the distinction between the two general strategies emphasized, in practice it may not be possible to make such a clear distinction. Take, for example, the conservation of the legume tree genus, *Leucaena*, where germplasm is often collected from native habitats and then taken *ex situ* to be more easily managed by local communities. The trees are not conserved using field gene bank or arboreta techniques, but within local communities, they are managed using traditional silvi-cultural techniques within an *in situ* on-farm system. This form of ‘hybrid’ conservation has been termed *circa situm* conservation and is often found in the management of fruit trees in subsistence communities.

The point should be stressed that although nine basic *in situ* and *ex situ* conservation techniques have been outlined, no single technique alone can adequately and completely conserve the genetic diversity found within any single species. A more appropriate methodology is to apply multiple techniques, applied in a complementary fashion to ensure the long-term safety of the entire gene pool of

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genetic diversity of the target taxon. This is referred to as complementary conservation.

1.9 How Do We Use Plant Genetic Diversity?

As has already been emphasized genetic conservationists often emphasize the link between conservation and use or exploitation. It can be further argued that the ultimate reason for conserving biodiversity, whether 'living' or 'suspended', is to make it available for use by humankind, either now or in the future. However, the ways in which humans use plant diversity are themselves very diverse; plant genetic resources are not just simply used as trait donors by plant breeders. Plants may be used as:

- food, crop species including beverages;
- food additives, including processing agents and other additives used in food and beverage preparation;
- feed (animal foods), the fodder or forage species eaten by vertebrate and invertebrate animals;
- materials, such as wood, fibres, cork, cane, tannins, latex, resins, gums, waxes, oils, etc.;
- fuels, wood, charcoal, etc.;
- poisons;
- medicines, human and veterinary;
- environmental: these will include species that are ornamentals, recreational, hedges, shade plants, windbreaks, soil improvers, plants for regeneration, erosion control, indicator species (e.g. pollution, underground water);
- gene donors: plants that contain desirable traits that can be transferred to other species to improve their use.

As well as these clear examples of human exploitation, there are also more nebulous but equally valid uses, such as those derived from ethical and aesthetic convictions. These may, for example, be as simple as wishing to walk your dog in open countryside, as such diverse habitats provide a pleasant environment – which is a further and valid use of biodiversity. Similarly, you may have been born in a beautiful valley and wish that the valley retains its basic character, or hopefully you agree that it is wrong for humans to carelessly eradicate species. Defined in these terms all species have a use in some form even if it defined in purely aesthetic or ethical terms. A recent paper in the *British Medical Bulletin* demonstrated the positive effect of biodiversity on human health, as well as the mechanisms and evidence of the positive health effects on humans of diversity in nature and green spaces (Honnay and van Nieuwenhuyse, 2018). These so-called ethical and aesthetic uses are commonly established by the general public and will often be focused on 'flagship' species, for example orchids or cacti for plants, or 'picturesque' environments. This type of value is more difficult to define, but that does not make its worth any less valid, and as much conservation is funded from public sources, it cannot be ignored.

The most fundamental use of plant genetic diversity remains as food crops. In certain cases, the conserved material can be used directly, as is often the case in the selection of new accessions of forage species, where little breeding is undertaken, or in the case of the reintroduction of primitive landrace material following their local extinction. More commonly, however, the first stage of utilization will involve the recording of genetically controlled characteristics (characterization) and the material may be grown out under diverse environmental conditions to evaluate and screen for, say, drought or salt tolerance, or the deliberate infection of the material with diseases or pests to screen for biotic resistance (evaluation).

Having briefly discussed how humankind uses plant diversity, the key point should be stressed here that any form of plant exploitation must be sustainable and non-exploitive. Sustainability, in the sense of continuance, is a fundamental concept for both conservation and utilization within the biosphere, the finite system in which we all live. It is ignorance of this fundamental concept that has resulted in many acute environmental disasters, e.g. desertification of the African Sahel or shrinkage of the Aral Sea in Central Asia. Non-exploitive, in the sense of a subsistence farmer providing a sample of the traditional landrace their family has maintained by cycles planting, cultivation harvesting and seed selection for millennia and finding the landrace had a unique allele for an adaptive trait, then when bred into an elite breeder's line made a new cultigen that had global sales of US$ millions. The signing of a now Standard Material Transfer Agreement by the donating farmer and recipient organization ensures that today benefit would flow back to the farmer, his family and his community. Each of these negative examples is a consequence of policy-makers not thinking sustainably and focusing on selfish short-term benefits, which is not fit practice for the 21st century.