Chapter 11
Genetic Diversity, Genetic Erosion, Conservation of Genetic Resources, and Cultivation of Medicinal Plants

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Abstract Wild or cultivated plants used in traditional and modern medicines are categorized as medicinal plants (MPs). Out of over 70,000 MPs, 3000 are traded and 900 are cultivated. Fragmentation/loss of habitats, unsustainable harvests, excessive grazing, invasive species, pollution, and climate change are destroying genetic diversity. Regular use of MPs in modern medicines, consumer/industrial merchandises, and increasing popularity of complementary and alternate (CAM) therapies are expanding national/global trade inciting irrational wild collections beyond regeneration potential of wild populations consequently losing species and genetic diversity. Investigations on endangered species indicated frightening levels of genetic erosion and dwindling population densities/sizes below minimum viable limits. Only a small fraction of known MPs have been evaluated for their genetic diversity and genetic erosion. Morphoagronomic, biochemical and molecular marker, and enzyme studies on wild and cultivated genotypes, populations, species, and geographical regions revealed genetic diversity with varied levels of polymorphism (14–100 %), number of alleles (2–14/locus), observed (0.0–1.0) and expected (0.06–0.84) heterozygosities, Nei's gene diversity (0.12–0.36), Shannon's index (0.08–0.51), gene flow (0.22–4.69), genetic distances (0.02–0.54), and similarities (0.02–0.98). Recovery, conservation, and cultivation programs initiated by governments have slowed down genetic erosion. Cultivation helped in relieving harvest pressure on wild flora and in preserving genetic diversity of some species. Existence of large number of species, paucity of adequate research funds, loss/degradation of forests, ever increasing local/world demand, genetic resource utilization with benefit sharing, and patent conflicts are the concerns that need to be resolved for conserving genetic diversity and preventing genetic erosion.

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11.1 Introduction

Plants have been used for their curative property since antiquity. Plants possessing therapeutic activity are known as medicinal plants (MPs) or pharmaceutical botanicals or healing herbs or minor forest or underutilized or industrial crops. The earliest record of MPs use by human beings dates back to around 7000 years (Kathe 2006). A medicinal plant is defined as "a plant (wild or cultivated) used for medicinal purposes" (http://apps.who.int/medicinedocs/pdf/s4928e/s4928e.pdf. Viewed June 17, 2014) or "all higher plants that have been alleged to have medicinal properties, i.e., effects that relate to health or which have been proven to be useful as drugs by western standards or which contain constituents that are used in drugs" (Farnsworth and Soejarto 1991) or "the term medicinal as applied to a plant indicates that it contains a substance or substances which modulate beneficially the physiology of sick mammals and that has been used by humans for that purpose" (http://wwwlib.teiep.gr/images/stories/acta/Acta%20500/500_1.pdf. Viewed June 17, 2014) or "those that are commonly used in treating and preventing specific ailments and diseases and that are generally considered to play a beneficial role in healthcare" (Srivastava et al. 1996) or "a plant which has been used for medical purposes at one time or another and which, although not necessarily a product or available for marketing is the original material of herbal medicines" (http://www.wpro.who.int/publications/docs/Guidelines_Appropriate_Use_of_Herbal_Medicines.pdf. Accessed June 17, 2014) or "useful plants for primary healthcare, as remedy for diseases and injury, plants used traditionally for foods and drinks and which are believed that they are good for health; the MPs include foods, drinks, herbs, and spices" (Bekele 2007). For the purpose of this chapter, MPs include aromatic, dye-yielding, pesticidal plants, and many spices. Plants are natural factories producing thousands of primary and secondary metabolites. The curative property of MPs is attributed to low-molecular weight secondary metabolites such as alkaloids, steroids, glycosides, phenolics, flavonoids, coumarins, saponins, stilbenoids, lactones, terpenoids, tannins, lignans, etc. accumulated in one or more parts in varying concentrations in response to stress, predation, competition, for attracting pollinators and conversion to primary metabolites. Being chemical repositories or libraries, MPs are wild-collected or cultivated for their prized phytochemicals in contrast to food, fodder, fuel, flower, fruit, foliage, fiber, timber, and other crops (Heywood 1999; Lubbe and Verpoorte 2011). The phytochemicals are biosynthesized through mevalonate, shikimate, and methyl erythritol phosphate pathways. In addition to majority (70–80 %) of citizens of developing nations, increasing number of denizens of developed countries (37 % Americans, 31 % Germans) are relying on traditional (TM), complementary, and alternate (CAM) medicines for healthcare steadily boosting demand for MPs. The global search (bioprospection) for biologically active, therapeutically effective, stable, and safe phytochemicals has pushed them into transnational patent conflicts. Several modern medicines that treat constipation (e.g., *Cassia senna*, *Plantago psyllium*) to cancer (e.g., *Camtotheca acuminata*, *Catharanthus roseus*, *Podophyllum hexandrum*, *Prunus africana*, *Taxus* species) are made from phytochemicals. Between 1959 and 1980, 25 % of prescription medicines worth US$ 8.1 billion dispensed through USA community pharmacies had one or more MP derived biochemicals. In 1981, 121 prescription medicines containing phytochemicals of 95 MPs were used worldwide (Farnsworth and Soejarto 1991). More than 25 % of pharmaceutical medicines in use (Lubbe and Verpoorte 2011) and 26–50 % of new medicines that entered markets in recent years are plant based. Estimates indicate that tropical forests can yield 328 more plant medicines worth US$147 billion (Memdelsohn and Balick 1995). Plant-based medicines or herbal medicines or botanical drugs or phytomedicines or phytopharmaceuticals are in use in China, India, Germany (30–40 % of prescription medicines), Japan (15–20 % of prescription medicines), Ukraine (20–50 % of prescription medicines), Organization for Economic Cooperation and Development (OECD) countries, African and Asian countries (Principe 1991). Human and environmental factors namely, habitat change (habitat loss, fragmentation, degradation or conversion to other uses such as human habitation, agriculture, slash and burn cultivation, ranching, timber logging, ecotourism, mining and industry), climate change (global warming, tsunamis, erratic rainfall, forest fires, glacier melting), invasive species (intentionally or accidentally introduced native or exotic species which compete out native species and invasive pests that damage wild flora), over-harvesting (frequent wild harvests at wrong phenological stages beyond species' regeneration capacities, wasteful wild collections exceeding market needs, and destructive harvests exterminating plants), pollution (caused by human activities, agricultural chemicals, sewage, traffic, industrial effluents), overgrazing, and booming world trade (8–15 % growth per annum; Grünwald and Büttel 1996) are the driving forces of genetic erosion (depletion or loss of genetic diversity and gene pool wealth over time) and extinction of MPs. International organizations such as United Nations Environment Program (UNEP), United Nations Educational, Scientific and Cultural Organization (UNESCO), United Nations Industrial Development Organization (UNIDO), World Health Organization (WHO), International Union for Conservation of Nature and Natural Resources (IUCN), World Wide Fund for Nature (WWF), Food and Agriculture Organization (FAO), Convention on Biological Diversity (CBD), Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES), Trade Record Analysis of Fauna and Flora in Commerce (TRAFFIC), MPs Specialist Group of the Species Survival Commission of IUCN, G-15 Gene Bank for Medicinal and Aromatic Plants, Asian Network on Medicinal and Aromatic Plants, Asia Pacific Information Network on Medicinal and Aromatic Plants, International Council for Medicinal and Aromatic Plants, Biodiversity International (formerly, International Plant Genetic Resources Institute), International Trade Center (ITC), etc. are providing guidelines, directions to governments on scientific information, recovery, conservation, cultivation, sustainable utilization, quality control, and international trade in threatened MPs for protecting genetic diversity and resources.

11.2 Global Genetic Resources

Forests, wooded lands, banks of water sources, wastelands, roadsides, and agricultural lands are the natural habitats. Medicinal herbs that grow in agricultural fields are weeded out by farmers ignorant of their economic significance or due to lack of local market. Forests are the primary habitats where MPs grow as undergrowth and in open grasslands (subjected to overgrazing). The present forest area is 4.033 billion hectares or 31 % of world's land area relative to earlier 6.2 billion hectares. Primary forests (rich in native species) account for 36 % (1.4 billion hectares), naturally regenerated forests for 57 %, and planted forests for 7 % of total area. American Samoa, French Guiana, Gabon, Micronesia, Palau, Pitcairn, Seychelles, Solomon Islands, Suriname, Turks, and Caicos Islands are endowed with 79–98 % of their land area covered under forests. In Brazil, Brunei, Darussalam, French Guiana, Gabon, Micronesia, Papua New Guinea, Peru, Singapore, Suriname, and Tajikistan, 65–100 % forest cover is primary forests (FAO 2010). UNEP World Conservation Monitoring Centre (http://www.unep-wcmc.org/) has identified 17 mega-biodiversity countries that support bulk of global ecosystem, species, genetic and molecular diversity. These are: Australia, Brazil, China, Colombia, Democratic Republic of Congo, Ecuador, India, Indonesia, Madagascar, Malaysia, Mexico, Papua New Guinea, Peru, Philippines, South Africa, USA, and Venezuela.

Out of 370,000 (900,000 species including outdated names and synonyms; Paton 2009) to 422,000 estimated plants; 72,000–77,000 are MPs (Schippmann et al. 2006; Rajeswara Rao et al. 2012). With several countries inventorying, digitizing, and investigating their MPs resources this number may get revised from time to time. Bulgaria (750 MPs, 200–300 in common use), China (11,146), Ethiopia (1000, 300 often used), Finland (100), France (900), Hungary (270), India (7500–8000, 960 regularly used), Italy (1500), Jordan (363), Macedonia (700, 150 in frequent use), Malaysia (1200), Malta (458), Nepal (1950), Pakistan (1500), Philippines (850), Republic of Korea (1000), Romania (283), Serbia (400), Slovenia (400), Sri Lanka (1414, 208 commonly used), Thailand (1800), Turkey (500), USA (2564), Vietnam (1800), Yugoslavia (>700), and other countries recorded their MPs resources (Schippmann et al. 2006; Guo et al. 2009). WHO has published monographs on 118 MPs and information on MPs of Myanmar (59), Mongolia (92), South Pacific (102), Papua New Guinea (126), Republic of Korea (150), and Vietnam (200). Plant families Apiaceae, Apocynaceae, Araliaceae, Asclepiadaceae, Asteraceae, Canellaceae, Euphorbiaceae, Guttiferae, Lamiaceae, Lauraceae, Leguminosae, Menispermaceae, and Rosaceae have higher number of MPs. For most MPs information on centers of their origin, biology, genetic diversity, population sizes, distribution, trade volumes/value, and threat levels is scanty.

11.3 Assessment of Genetic Diversity

The survival, evolutionary capability, and agility of wild flora to adjust to changing ecological and environmental conditions are determined by genetic diversity developed over millennia. Genetic diversity among and within populations in a habitat is a result of natural selection, gene flow, genetic drift, inbreeding, and mutation. Genetic diversity assessment helps in designing conservation and crop improvement strategies (Sheng et al. 2004; Rahimmalek 2012). Past research recorded ethnomedical (folklore/tribal medicine) uses by ethnic/tribal communities. Concurrently, taxonomists prepared district, province, and country floras to assess species diversity, abundance, and distribution. These floras served as baseline surveys for conservation and utilization programs. Morphoagronomic, biochemical variations within and among genotypes, populations, species, and regions were subsequently studied. Researchers are currently employing enzymes and molecular markers for assessing and preserving genetic diversity, establishment of phylogenetic relations of populations or related species, identification of species and varieties (DNA fingerprinting) or discrete genetic units within species, DNA bar coding, marker-assisted selection for crop improvement, authentication of herbal materials, detecting adulteration in commercial herbal products, predicting from which wild population or geographical location a commercial sample has been sourced, estimating variation between in vitro and conventionally propagated plants or wild and cultivated populations, estimating gene flow, estimating disease susceptibility, and assessing geographical variation at genetic level (Atangana 2010; Lal et al. 2011). The literature survey indicated that not even a small fraction of known MPs have been evaluated for genetic diversity and gene pool wealth. To the best of author's knowledge no attempt has been made so far to prepare genome map of any MPs although morphotypes, chemotypes, genotypes, and ecotypes differing in morphology, physiology, categories, and contents of phytochemicals have been recorded. Polymorphism (14–100 %) is evident in the investigated species with 2–14 alleles/locus. Observed (0.0–1.0) and expected (0.06–0.84) heterozygosities, genetic distances (0.02–0.54) and similarities (0.02–0.98), Shannon's index (0.08–0.51), Nei's gene diversity (0.12–0.36), gene flow (0.22–4.69), AMOVA (Analysis of Molecular Variance), UPGMA (Unweighted Pair Group Method with Arithmetic Mean) clustering, PCoA (Principal Coordinate Analysis), and PCA (Principal Component Analysis) revealed that genetic diversity is high in the existing populations (Table 11.1). Genetic variations in leaf (e.g., *Achillea* species, *Aloe vera*, *Hemidesmus indicus*, *Ocimum sanctum*), flower (e.g., *A. vera*, *C. roseus*, *Clitoria ternatea*), fruit (e.g., *Emblica officinalis*), seed (e.g., *Abrus precatorius*, *Mucuna cochinchinensis*, *Withania somnifera*), tuber (e.g., *Chlorophytum borivilianum*, *Curculigo orchioides*) and stem (e.g., *Phyllanthus amarus*, *O. sanctum*) characteristics, plant architecture (e.g., *Artemisia annua*, *Piper longum*), chemical profile (e.g., *A. annua*, *A. dracunculus*, *A. judaica*, *Atractylodes lancea*, *C. galioides*, *Hypericum triquetrifolium, P. hexandrum*, *Primula ovalifolia*), and ploidy levels (e.g., *Artemisia dracunculus*, *C. roseus*) have been reported.

Table 11.1 Genetic diversity reported in several medicinal plants from different countries employing morphological, agronomical, biochemical, and molecular markers and enzymes

Botanical name	Country	Method	Genetic diversity	Reference
Achillea bieberstenii	Iran	Morphoagronomic	25 populations from 12 provinces were clustered into 11 groups with significant variation in studied marker characters	Seyed et al. (2012)
Achillea fragrantissima	Jordan	RAPD	Five populations from five locations showed genetic diversity with similarity values ranging from 0.02 to 0.58 and were grouped into four clusters	Rawashdeh (2011a)
Achillea millefolium subsp. *millefolium/Elbursensis*	Iran	Morphology, ISSR	Accessions from various regions showed 87.3 % polymorphism, 32.6 % genetic variation among groups, 40.9 % among populations and 26.9 % within populations. Gene diversity over loci varied among regions and accessions were grouped according to regions. Morphological and molecular markers produced similar results	Gharibi et al. (2011)
Achillea santolina, A. tenuifolia	Iran	RAPD, ISSR	16 accessions of both species showed genetic diversity. Genetic similarity ranged from 60 to 86 % in *A. tenuifolia* and 40–84 % in *A. santolina* with low similarity (0.36) between them	Ebrahimi et al. (2012)
Achillea tenuifolia	Iran	ISSR	Genotypes from diverse regions exhibited 86.8 % polymorphism, clustered into three groups with 68.7 % variation among and 31.3 % within groups. Varied in morphological characters	Rahimmalek (2012)
Actaea racemosa (Black cohosh)	USA, Canada	AFLP	Principal component analysis (PCA) distinguished distant populations and pointed out genetic similarity within geographic regions	Motley et al. (2004)

(continued)

Table 11.1 (continued)

Botanical name	Country	Method	Genetic diversity	Reference
Allanblackia floribunda, A. stanerana, A. gabonensis	Cameroon	Microsatellites	70 trees from four sites showed no significant difference between wild and cultivated trees with inbreeding in cultivated trees of *A. floribunda*. Seven microsatellite loci displayed polymorphism in *A. stanerana* and *A. gabonensis*	Atangana (2010)
Allium sativum (Garlic)	Different countries	Isozymes, AFLP	High heterogeneity was noticed within Central Asian gene pool	Kamenetsky et al. (2007)
Aloe vera	Iran	RAPD	10 accessions from different regions showed 70.3 % polymorphism and were grouped into two clusters	Barandozi et al. (2012)
Arnica montana	Romania	RAPD	Six genotypes from two regions were grouped into two clusters which recorded high genetic distance coefficients	Pop et al. (2008)
Artemisia annua	India	Chemical, RAPD	Eight individuals of a population exhibited chemotypic and genetic variation (96 % polymorphism, 0.79 polymorphic information content) with no similarity (0.64 dissimilarity)	Sangwan et al. (1999)
Artemisia dracunculus	USA	Biochemical	Genetic diversity varied from 22 % between and 78 % within populations. Diploid to decaploid ecotypes differed in chemical composition	Eisenman (2010)
Artemisia judaica	Egypt	RAPD	Egyptian populations showed 57.5 % polymorphism and genetic distance	Badr. et al. (2012)
Artemisia judaica	Jordan	RAPD	10 primers gave 165 polymorphic bands with 0.61–0.02 similarity index. No similarity in some samples	Rawashdeh (2011b)
Asparagus racemosus	India	RAPD	Accessions of *A. racemosus* and ornamental species showed 48.3 % intra and 51.7 % interspecies variation. Two accessions were related to unknown *A.* species	Shasany et al. (2003)

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Table 11.1 (continued)

Botanical name	Country	Method	Genetic diversity	Reference
Asparagus racemosus, *A. officinalis*, *A. springeri*, *A. plumosus*, *A. densiflora myersii*	India	RAPD	Species displayed 94.5 % polymorphism with no similarity	Lal et al. (2011)
Blumea balsamifera	China	AFLP	35 plants from 5 provinces had 99.5 % polymorphism. They were grouped into four clusters with less variation within provinces	Pang et al. (2014)
Butea monosperma	India	RAPD	16 accessions from five provinces recorded 0.43 mean genetic divergence, 0.53–0.79 similarity coefficients and were grouped into four clusters	Khan et al. (2008)
Bunium persicum (Black cumin)	Iran	RAPD, AFLP	20 populations of black cumin had 75–86 % polymorphism, 0.39–0.96 similarity coefficients. Genetic distances among populations did not correlate with geographical distances	Pezhmanmehr et al. (2009)
Cassia occidentalis	India	RAPD	10 accessions from different districts had 71.2 % polymorphism, 0.54–0.73 similarity coefficients. They were grouped into two clusters	Arya et al. (2011)
Calligonum polygonoides	India	Chemical, RAPD	54 wild plants from eight locations of Thar desert showed 90.2 % polymorphism, 0.43–0.89 similarity coefficients. Plants differed in nutrient composition. Anthropogenic activity in one location led to low diversity and affected genetic composition	Vyas et al. (2012)
Carapichea/Cephaelis ipecacuanha (Ipecac)	Brazil	ISSR	50 wild clusters with 291 aerial stems showed no genetic differentiation at the cluster level	de Oliveira et al. (2010)
Catharanthus roseus	India	RAPD, ISSR	14 cultivars displayed 82 % polymorphism in 17 loci and were classified into two clusters where some cultivars were closely related	Shaw et al. (2009)

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Table 11.1 (continued)

Botanical name	Country	Method	Genetic diversity	Reference
Chamomilla recutita	European countries	ISSR	Seven cultivars, eight accessions showed 85.4 % polymorphism, 0.65 mean genetic similarity. Genetic similarity was high in cultivars	Okoń and Magdziak (2011)
Changium smyrnioides	China	RAPD	Five populations recorded 69 % polymorphism with 51.2 % diversity among and 48.8 % within populations	Fu et al. (2003)
Chimonanthus praecox	China	RAPD, ISSR	72 clones from two regions showed 63.6–78.3 % polymorphism. Distribution of clones was consistent with regions. Genetic variation among clones of a region was 85.6–86.7 %	Zhao et al. (2007)
Cibotium barometz	China	SRAP	79 plants from seven populations showed 86 % polymorphism, 0.23 Nei's gene diversity index, and 0.36 Shannon's information index. Genetic diversity within and among populations was 58.9 and 41.1 %. Gene flow was low (0.72) and geographical distribution was not distinctive	You and Deng (2012)
Coleus amboinicus, C. aromaticus, C. forskohlii	India	RAPD	Three species exhibited genetic diversity	Govarthanan et al. (2014)
Commiphora wightii	India	RAPD	Accessions collected from different locations recorded 83.5 % polymorphism with 0.55–0.79 similarity coefficients	Suthar et al. (2008)
Coptis chinensis	China	ISSR	214 plants from seven wild and three cultivated populations revealed that polymorphism in wild (52.4 %) and cultivated (65.2 %) and genetic variation (10.9 %) between them was not significantly different. Cultivation did not result in genetic erosion	Shi et al. (2008)
Crocus sativus	Iran	Microsatellites	Observed and expected heterozygosities varied from 0.07 to 0.92 and 0.10 to 0.58, respectively, with 2.6 alleles/locus	Nemati et al. (2012)

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Table 11.1 (continued)

Botanical name	Country	Method	Genetic diversity	Reference
Cuminum cyminum	Iran, Syria, Afghanistan	ISSR, RAPD, morphoagronomic	44 accessions recorded 54.9–67.3 % polymorphism, 0.25–0.94 similarity coefficients in different analyses. Morphoagronomic and molecular markers differentiated the accessions differently	Ahmadvandi et al. (2013)
Cunila galioides	Brazil	RAPD	Three chemotypes with wide genetic variation were recognized. Two chemotypes were closely related while the third chemotype represented a different genetic pool	Fracaro et al. (2005)
Cuscuta reflexa	India	ITS nrDNA	30 populations from nine geographical locations showed high degree of diversity as they evolved in reproductive isolation. Two locations indicated genetic exchange among populations	Ali et al. (2011)
Dacydium pierrei	China	RAPD	Nine plants from Hainan province showed 33.3 % polymorphism and 0.11 genetic distance	Su et al. (1999)
Dendrobium species	India	RAPD, SSR	30 individuals of five species recorded polymorphism with 4–7 alleles per locus. SSR markers were better than RAPD markers	Chattopadhyay et al. (2012)
Dioscorea opposita	China	ISSR	28 cultivars exhibited 83 % polymorphism and were grouped into four clusters	Zhou et al. (2008)
Dracocephalum kotschyi, D. multicaule, D. polychaetum, D. surmandinum Lallemantia sp.	Iran	RAPD	17 accessions of *Dracocephalum* and 1 of *Lallemantia* displayed high genetic diversity. *D. polychaetum* and *D. surmandinum* were closely related to *D. kotschyi*. RAPD markers differentiated the species at molecular level and were useful in estimation of inter- and intraspecific variations	Sonboli et al. (2011)
Dysosma pleiantha	China	Microsatellites	38 plants from three populations recorded 2–14 alleles per locus with 0.54–0.85 heterozygosity values. Homozygosity was recorded in 10 loci	Guan et al. (2011)

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Table 11.1 (continued)

Botanical name	Country	Method	Genetic diversity	Reference
Echinacea angustifolia	USA	AFLP	10 populations exhibited genetic divergence with restricted gene flow along north–south climatic gradient with 60 % genetic variation within populations, 20 % among populations, and 20 % among groups	Still et al. (2005)
Echinacea species	USA	AFLP	Nine species and three varieties displayed 90 % polymorphism and were closely related. *E. purpurea*, *E. sanguinea,* and *E. simulata* were grouped in one clade and the others in the second clade	Kim et al. (2004)
Epimedium pubescens, E. sagittatum, E. wushanense	China	Isozymes	471 plants from 11 populations exhibited 69.2–84.6 % polymorphism with 2–3 alleles/locus and 0.27–0.38 heterozygosity. *E. pubescens* was closely related to *E. sagittatum*. Results indicated mixed breeding system, gene flow among populations and genetic relationship among the species	Xu et al. (2007)
Epimedium sagittatum	China	SSR	16 synthesized primer pairs transferred to 52 species showed high genetic diversity with 0.35 observed and 0.65 expected hyterozygosities and 11.9 alleles per locus	Zeng et al. (2010)
Fritillaria cirrhosa	China	AFLP	159 individuals of nine wild populations recorded 91.9 % polymorphism with 0.27 estimated heterozygosity in population and 0.37 at species levels. Genetic differentiation among populations was 0.28. Genetic diversity among some populations was high while in others it was low	Zhang et al. (2010)
Gymnema sylvestre	India	ISSR	Plants collected from 12 geographical regions recorded 85 % polymorphism	Mouna et al. (2014)

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Table 11.1 (continued)

Botanical name	Country	Method	Genetic diversity	Reference
Gardenia jasminoides	China	AFLP	Eight wild or cultivated populations registered 67.6 % polymorphism at species and 36.9–59.4 % in population levels. Genetic diversity within populations was 0.21–0.31. Genetic differentiation among populations was 64.8–76.6 %. Regions did not show differences. Gene flow (1.74) was consistent with mean genetic identity (0.93) among populations. Genetic and geographic distances were correlated between populations	Han et al. (2007)
Gastrodia elata	China	AFLP	27 accessions from five provinces exhibited 78 % polymorphism, genetic distance varied from 0.54 to 0.018. One province indicated high diversity and can serve as germplasm source for improvement	Guan (2013)
Ginkgo biloba	China	RAPD	Nine populations recorded 97.9 % polymorphism, expected heterozygosities of 0.24–0.36, Shannon's information index of 0.34–0.51, genetic differentiation of 0.16 and 89 % within population genetic variation. They were classified into two groups	Fan et al. (2004)
Haloxylon ammodendron	China	ISSR, RAPD	Four populations exhibited 89.7 % polymorphism and 0.33–0.37 Shannon's index. There was no genetic differentiation and variation among populations was low (10.6 %) due to high rates of gene flow	Sheg et al. (2004)
Heliotropium indicum	India	ISSR	In five wild populations 34 loci displayed 79.1 % polymorphism, 1.8 observed and 1.5 effective number of alleles, 0.43 Shannon's index, 0.29 estimated heterozygosity, 0.19–0.50 genetic distance between and 0.60–0.82 genetic similarity within populations	Kumar and Britto (2011)
Hippophae spp. (Sea buckthorn)	Different countries	Isozymes, RAPD, AFLP, ISSR, cpDNA, ITS	Genetic diversity high among populations, origins, and subspecies	Cheng et al. (2007)

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Table 11.1 (continued)

Botanical name	Country	Method	Genetic diversity	Reference
Hydrastis canadensis (Golden seal)	USA	RAPD	Cultivated and wild plants collected from different regions revealed genetic diversity within and among populations but not between cultivated and wild plants	Kerry (2009)
Hypericum perforatum (St. John's wort)	Croatia	RAPD	109 samples collected from eight locations recorded 0.12–0.31 Nei's gene diversity. Two populations had low and high genetic diversity. One population was polymorphic due to outcrossing. High fixation index (0.33) indicated low gene flow due to apomixes	Pilepic et al. (2008)
Launaea arborescens	China	Microsatellites	10 polymorphic (2–6 alleles/locus) and 9 monomorphic microsatellite loci recorded 0.00–0.83 observed and 0.06–0.71 expected heterozygosities	Li et al. (2012)
Lepidium sativum	India	RAPD	18 genotypes displayed polymorphism with 23–66 % genetic relatedness.	Bansal et al. (2012)
Justica adhatoda	Pakistan	PBA, chemical	Genetic diversity was high (90 %) within populations due to absence of genetic drift than among populations (10 %) though habitats were fragmented with limited number of plants. Chemical variation was higher among populations	Gilani et al. (2011)
Manilkara hexandra, *Averrhoa carambola*	India	RAPD	25 accessions of the species produced six highly polymorphic bands and exhibited genetic variation at amplicon level. Both the species are related indicating ancestral linkage	Goraniya et al. (2013)
Melissa officinalis (Lemon balm)	Iran, Germany, Japan	Morphoagronomic, chemical	Nine populations from Iran and one each from Germany and Japan revealed significant variation in morphoagronomic traits. Phenotypic diversity was not associated with geographical region in Iranian populations. Phenotypic variation was high among populations of different countries. German population displayed low diversity	Aharizad et al. (2012)

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Table 11.1 (continued)

Botanical name	Country	Method	Genetic diversity	Reference
Mentha aquatica	Iran	RAPD	51 wild populations exhibited 93.9 % polymorphism, 0.21–0.79 similarity coefficients and were grouped into 13 clusters. RAPD effectively distinguished populations, estimated genetic variation and distance	Kazemi and Hajizadeh (2012)
Mentha cervina	Iberian Peninsula	ISSR	18 populations exhibited 14.2–58.3 % polymorphic loci, 0.14–0.21 Nei's diversity, and 0.08–0.33 Shannon's index; high species diversity (98.3 %, 0.33 and 0.23, respectively) with 50 % variation within and 44 % among populations and 6 % between regions. Genetic differentiation coefficient was 0.53. Maximum number of populations needs to be conserved	Rodrigues et al. (2013)
Mucuna monosperma, M. atropurpurea, M. gigantea, M. bracteata, M. pruriens	India	AFLP	25 accessions of five species collected from seven provinces displayed high polymorphism. Genetic diversity was high in *M. pruriens* germplasm. *M. pruriens* var. *pruriens,* and var. *hirsuta* were closely related	Sathyanarayana et al. (2011)
Morinda citrifolia, M. tinctoria, M. pubescens	India	RAPD, ISSR	22 accessions collected from four regions showed polymorphism. Two accessions were closely related (0.94 similarity index) and two were distantly related (0.25–0.39 similarity index). Both markers were effective	Singh et al. (2011)
Myrtus communis	Tunisia	Isozymes RAPD	Six populations from three climatic zones disclosed high genetic diversity within populations, in populations of subhumid zone, and high differentiation among populations in relation to climatic zones and geographical distance	Messaoud et al. (2007)
Nothofagus nervosa, N. oblique, N. dombeyi	Chile	RAPD, ISSR	125 trees of three species recorded 80 and 97 % polymorphism with the two markers. The trees were grouped into three clusters	Mattioni et al. (2002)

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Table 11.1 (continued)

Botanical name	Country	Method	Genetic diversity	Reference
Ocimum basilicum, O. americanum, O. polystachyon, O. viride, O. gratissimum, O. sanctum	India	RAPD, SSR, ISSR	All markers recorded 100 % polymorphism in 41–329 loci. *O. basilicum* and *O. polystachyon* registered close similarity indexes and *O. viride* and *O. americanum* least similarity index. They were divided into two clusters	Lal et al. (2012)
O. gratissimum	Kenya	AFLP	139 samples from all provinces exhibited polymorphism with central Kenyan population recording highest genetic diversity. Genetic differentiation coefficient was 0.29. 71 % of variability was within populations. More plants need to be selected from few populations for conservation	Matasyoh et al. (2011)
Oroxylum indicum	India	RAPD	Accessions collected from eight locations indicated high similarity (87 %) with 49.6 % polymorphism	Jayaram and Prasad (2008)
Panax quinquefolius	USA	Allozymes	In 21 wild populations expected heterozygosity values were higher in protected populations (0.08) than in those permitted to be harvested (0.07). Coefficient of genetic differentiation was greater in unprotected (0.49) relative to protected (0.17) populations. Juvenile plants (0.07) had lower heterozygosity relative to reproductive plants (0.08)	Sanders and Hamrick (2004)
Paris polyphylla var. chinensis	China	Microsatellites	30 plants from a natural population possessed 2–5 alleles/locus with 0.00–0.47 observed and 0.38–0.66 expected heterozygosities	Zheng et al. (2012)
Podophyllum hexandrum	India	RAPD, chemical	12 accessions displayed high degree of genetic diversity. Chemical markers identified new chemotype	Sultan et al. (2010)
Phlomis olivieri, P. anisodonta, P. bruguieri, P. persica	Iran	RAPD, biochemical	*P. olivieri* plants exhibited genetic distances. This species was closely related to *P. anisodonta* and *P. persica*. Verbacoside content varied in species and was influenced by geographical locations and growing conditions	Sarkhail et al. (2014)

(continued)

Table 11.1 (continued)

Botanical name	Country	Method	Genetic diversity	Reference
Phyllanthus emblica	India	Isozymes	Four populations exhibited genetic diversity	Shaanker and Ganeshaiah (1997)
Phyllanthus emblica	India	Microsatellites	Two populations displayed polymorphism and heterozygosities of 0.36–0.76 (observed) and 0.49–0.81 (expected). Genetic resources depleted due to overexploitation and fragmentation	Pandey and Changtragoon (2012)
Podophyllum hexandrum (Indian may apple)	India	RAPD, biochemical	28 genotypes from 11 geographical regions exhibited 92.4 % polymorphism, 0.50 Shannon's information index, 0.69 mean coefficient of gene differentiation with limited gene flow (0.22). Variation among groups was 53 %, among genotypes 47 %, and within genotypes 33.8 %. Podophyllotoxin content varied in the genotypes and was positively correlated to altitude and regional ecological conditions	Alam et al. (2009)
Primula ovalifolia	China	Chemical, ISSR	Three chemotypes were recognized in five populations. Chemical and molecular markers yielded similar results	Nan et al. (2003)
Primula veris	Poland	Enzymes	Three natural (500–1200 plants) and three cultivated populations were evaluated. 1–2 loci were polymorphic with 2–3 alleles. Cultivated populations were more polymorphic. Heterozygosity was low (0.03–0.06)	Morozowska and Krzakowa (2003)
Rauvolfia serpentina	India	RAPD	Inter- and intrapopulation diversity was evident with 70 % polymorphism. Accessions were divided into two clusters	Padmalatha and Prasad (2007)
Rauvolfia tetraphylla	India	RAPD	Plants from five locations had 0.08–0.35 genetic distance between populations, 0.70–0.93 genetic identity, and Nei's gene diversity of 0.20	Mahesh et al. (2008)
Satureja bachtiarica	Iran	RAPD, ISSR	46 plants of five populations recorded 95.9–98 % polymorphism. 79 % genetic variation was within and 21 % among populations	Saidi et al. (2013)

(continued)

Table 11.1 (continued)

Botanical name	Country	Method	Genetic diversity	Reference
Retama raetam	Tunisia	RAPD	Three populations collected from different habitats recorded 68 % variation within populations with significant differentiation among them. Genetic distance varied from 0.10 to 0.51 and gene flow from 0.49 to 4.69	Abdelloui et al. (2014)
Rheum officinale	China	ISSR	12 populations revealed low population (28.9 %) and high species (95.2 %) genetic diversity. Genetic variation among populations was 74.4 % with limited gene flow (0.28). Genetic and geographic distances were positively correlated signifying the role of geographic isolation in shaping the population genetic structure. Conservation should aim at preserving all existing populations	Wang et al. (2012)
Rheum tanguticum	Tibet	ITS	Mean intraspecific distance was 0.13 with rich variation. 87 clones were closely related to *R. rhabarbarum*, 10 clones to *R. officinale* and 5 clones to *Fagopyrum esculentum*. *In situ* conservation was suggested	Ma et al. (2014)
Rhodiola dumulosa	China	AFLP	1089 individuals within 35 populations revealed high genetic diversity that decreased with increasing altitude. Closely related populations occurred in close proximity with significant gene flow. Two gene pools were identified. Gene diversity ranged from 0.20 to 0.22. Gene flow of distantly distributed populations was low	Yan and Anru (2011)
Rhodiola rosea (Roseroot)	Greenland Sweden, Faroe Islands	SSR, ISSR	91 samples recorded 83.8 % polymorphism for Sweden, 94.6 % for Greenland, and 48.7 % for Faroe Islands	Kylin (2010)
Rhodiola rosea	Russia, Kazakhstan	SSR, ISSR	Four geographically distant populations registered 85.9 % polymorphism (6.25 alleles/locus) with high species genetic diversity (gene diversity = 0.33, Shannon's index = 0.48) but low population diversity. Observed and expected heterozygosities ranged from 0.4 to 1.0 and 0.47 to 0.84, respectively	György et al. (2012)

(continued)

Table 11.1 (continued)

Botanical name	Country	Method	Genetic diversity	Reference
Semecarpus kurzi	India	RAPD	Plants collected from 12 areas displayed 86.8 % polymorphism and were grouped into three clusters. Genetic distances were low	Das and Mandal (2013)
Swertia chirayita	Nepal	RAPD	40 accessions from five populations registered 92.3 % polymorphism. Genetic distance varied from 33 to 68 % among populations	Shrestha et al. (2013)
Rhodiola rosea	India	RAPD, CAPS	RAPD markers produced 12 polymorphic loci in 30 genotypes from three regions while CAPS markers failed to do so. They were classified into three clusters. Genetic differentiation was considerably low with significant gene flow through seed dispersal	Soni et al. (2010)
Rhododendron species	China	RAPD	43 samples of 49 species belonging to three subgenera revealed 98 % polymorphism. Genetic similarity coefficient ranged from 0.26 to 0.91. Species of three subgenera could be distinguished with morphology and RAPD markers	Zhou et al. (2008)
Salvadora oleoides	India	Allozymes	500 plants of 11 populations exhibited high genetic diversity. Coefficient of genetic differentiation among populations was 0.02. Genetic similarities between population pairs were high (0.98)	Saini and Yadav (2013)
Salvadora persica	Egypt	AFLP, RAPD	Six wild populations of different areas exhibited 58–65 % polymorphism. Genetic distances and distances of collection sites were not correlated. Some individuals were different in spite of closeness of locations	Hegazi et al. (2011)

(continued)

Table 11.1 (continued)

Botanical name	Country	Method	Genetic diversity	Reference
Salvia miltiorrhiza	China	ITS nrDNA	Seven accessions of *S. miltiorrhiza* and 28 of other taxa revealed high genetic diversity. The taxa were classified into three clusters and one clade (three accessions). *S. bowleyana*, *S. yunnanensis*, *S. cavaleriei* var. *simplicifolia* are potential gene germplasm resources for *S. miltiorrhiza*	Zhang et al. (2012)
Sargentodoxa cuneata	China	RAPD	Three populations from three altitudes registered 84.1 % total polymorphism. Decrease in altitude reduced percentage polymorphic loci and increased similarity index. Genetic variation within and among populations was 43.7 and 56.3 %, respectively. Genetic differentiation was 0.54 and gene flow was low (0.40)	Li et al. (2004)
Scutellaria baicalensis	China	cpDNA	28 wild and 22 cultivated populations recorded similar genetic variation. Genetic differentiation of cultivated (0.22) was less then wild (0.70) populations. Genetic structure of wild populations was influenced by geographical distances	Qing et al. (2010)
Taxus brevifolia (Pacific yew)	Canada	RAPD	RAPD markers that revealed polymorphic loci were developed using 39 haploid megagametophytes from a single mother tree	Göçmen et al. (1996)
Thuja sutchuenensis	China	ISSR	Seven populations recorded 76.1 % polymorphism, 0.16 gene diversity, 0.25 Shannon's index in population and 0.17, 0.30 respectively, at species levels; low genetic differentiation (0.10), high gene flow (4.41) and were clustered into two classes. Genetic and geographical distances were not correlated	Liu et al. (2013)
Tinospora cordifolia	India	SCoT	21 accessions collected from two provinces recorded 87.0 % polymorphism and were grouped into two clusters. Genetic similarity varied from 1.0 to 0.68 with two accessions having 100 % similarity	Paliwal et al. (2013)

(continued)

Table 11.1 (continued)

Botanical name	Country	Method	Genetic diversity	Reference
Tylophora hirsuta, Wattakaka volubilis, Cryptolepis buchananii	Pakistan	RAPD	Intra- and interspecific diversity was low with 24.2 % polymorphism. The three species are closely related	Tariq et al. (2014)
Utrica parviflora	India	RAPD	Plants collected from different altitudes of Kumaun hills displayed 68.8 % polymorphism and were grouped into two clusters	Chirag et al. (2011)
Vaccinium macrocarpon (American cranberry)	USA	RAPD	A gradient of molecular diversity was found between central and marginal populations	Stewart and Excoffier (1996)
Vitex rotundifolia	China	ISSR	135 plants from 14 populations displayed 0.19 overall genetic diversity with 40 % variation within populations. Genetic differentiation among populations was relatively high (0.59) with limited gene flow	Hu et al. (2008)
Warburgia ugandensis	Kenya	AFLP	Trees within populations had higher genetic variation (59 %) than among populations (41 %). Genetic and geographic distances were not related among populations	Muchugi et al. (2012)
Withania somnifera	India	RAPD	Five accessions collected from a province registered 0.24–0.48 genetic distance, 0.62–0.78 genetic identity, 0.25 Nei's genetic diversity with 1.4–1.6 alleles/locus. One accession showed 83.8 % polymorphism	Dharmar and Britto (2011)
Withania somnifera	India	RAPD	Five accessions collected from a province registered 0.24–0.48 genetic distance, 0.62–0.78 genetic identity, 0.25 Nei's genetic diversity with 1.4–1.6 alleles/locus. One accession showed 83.8 % polymorphism	Dharmar and Britto (2011)

(continued)

Table 11.1 (continued)

Botanical name	Country	Method	Genetic diversity	Reference
Withania somnifera	India	RAPD	Five accessions collected from different sites of a province registered 0.24–0.48 genetic distance, 0.62–0.78 genetic identity, 0.25 Nei's genetic diversity with 1.4–1.6 alleles/locus. One accession showed 83.8 % polymorphism	Dharmar and Britto (2011)
Withania somnifera	India	Morphoagronomic, RAPD	30 genotypes collected from different provinces displayed high phenotypic variation in morphoagronomic parameters. Root yield was correlated with plant height. They recorded 87.3 % polymorphism, 0.18–0.90 genetic similarity. They could not be grouped into clusters	Khatak et al. (2013)
Withania somnifera	India	RAPD, ISSR	16 accessions collected from different locations showed 74.5 and 81.1 % polymorphism. They were grouped into two clusters. Similarity coefficient ranged from 0.42 to 0.94 (ISSR) and 0.44–0.94 (RAPD). Both markers differentiated the genotypes	Tripathi et al. (2012)
Withania somnifera, *W. coagulans*	India	AFLP	35 plants of *W. somnifera* and 5 of *W. coagulans* were classified into two clusters with similarity coefficient of 0.3 and high levels of polymorphism. Three morphotypes were recognized from plants sourced from different regions with low genetic variation within populations	Negi et al. (2000)
Withania somnifera, *Rauvolfia serpentina*	India	RAPD	Plants collected from seven locations of a province exhibited 92.3 % polymorphism in *W. somnifera* and 52.9 % in *R. serpentina*. The plants were classified into two clusters each	Sairkar et al. (2013)

RAPD Random amplification of polymorphic DNA, *AFLP* Amplified fragment length polymorphism, *RFLP* Restriction fragment length polymorphism, *SSR* Simple sequence repeat or microsatellite, *ISSR* Intersimple sequence repeat, *SCoT* Start codon targeted, *cpDNA* Cytoplasmic deoxyribonucleic acid, *ITS nrDNA* Internal transcribed spacer region of nuclear ribosomal DNA, *CAPS* Cleaved amplified polymorphic sequence, *SRAP* Sequence related amplified polymorphism, *PBA* P450-based analog

11.4 Genetic Erosion and Its Consequences

Habitat destruction, degradation, fragmentation or conversion for agriculture, ranching, horticulture, mining, ecotourism, industry, population fragmentation, commercial over-harvesting to satisfy urban and export demands, overgrazing (out of 11,146 MPs more than 3000 are facing genetic erosion in China; Guo et al. 2009), competing uses such as logging of medicinal trees for building material, fuel, paper, dyes are some of the human exerted pressures on native populations, their biology, and potential to respond to environmental shifts leading to dwindling population sizes (for many MPs, population size is directly related to genetic diversity), population densities, diminished fitness, enhanced isolation, genetic erosion, and species extinction. Population fragmentation, isolation, and decreased population densities/sizes force inbreeding within sites modifying patterns of gene exchange, pollen and seed movement between fragmented populations leading to genetic erosion. For wild-collected MPs the impact of over-harvesting depends on the part collected, biology, range, distribution, and economic value. Populations may disappear rapidly due to overcollection than from fragmentation or habitat destruction (Sanders and Hamrick 2004; Sanders et al. 2005). In crop improvement programs selecting and breeding MPs for a character under genetic control increases the frequency of specific alleles within population. Recurrent selection for that character in each breeding cycle disrupts the equilibrium among evolution forces and results in losing gene pools (Han et al. 2007). Chinese *Scutellaria baicalensis* suffered decline of wild populations during the past few decades. To sustain supplies large-scale cultivation was initiated. Cultivated populations experienced loss of 10 out of 25 identified alleles and became increasingly homozygous. Preserving wild populations therefore, is imperative (Quing et al. 2010). American ginseng (*Panax quinquefolius*) roots are extensively collected in the United States for sale as herbal panacea. Wild roots are regarded as more potent and valuable than cultivated roots. Harvest pressure declined wild populations to below minimum viable sizes accelerating species extinction (Sanders and Hamrick 2004). A simulation program on *P. quinquefolius* revealed that random harvests resulted in significant genetic erosion, especially its allelic wealth relative to initial levels. Harvesting fewer mature plants was suggested to minimize negative effects (Sanders et al. 2005). Such computer simulations based on remote sensing and ground data can help conserve critically endangered species. Demand and price are high for wild-gathered ginseng (*Panax ginseng*) roots considered stronger than cultivated roots. Illegal harvests of young plants wiped out wild populations from Asia (Behrens 2014). South Indian forests are treasure houses for costly sandalwood (*Santalum album*) and red sandalwood (*Pterocarpus santalinus*) trees. Illegal felling and smuggling wiped out large number of trees from several locations. In Brazil, leaves of *Lychnophora ericoides* are used for anti-inflammation. Human interference declined population density to 0.16 individuals/m^2 and put it at 73 % risk of genetic erosion (Almeida et al. 2012). *Ficus insipida* latex is used to treat intestinal parasites, as beer's chillproofing agent, meat tenderizer, and for digestion. Instead of tapping the trees for latex whole trees were indiscriminately felled drastically bringing down their numbers and increasing intestinal parasites in ethnic communities of Peru. Sustainable harvests should hence take into account the relationship between MPs and health needs of indigenous people (Behrens 2014). *E. officinalis* fruits rich in vitamin-C are plucked and traded by tribal communities of India. Of late, the tribal youth are axing trees for fruits inflicting genetic erosion (Rajeswara Rao 2012). In Côte d'Ivoire vines of *Griffonia simplicifolia*, trees of *Voacanga africana* and *V. thouarsii* are chopped down to gather fruits. In Chile woody branches of *Haplopappus taeda* (aids digestion) were cut to the ground level destroyng the shrubs. Extract of devil's claw (*Harpagophytum procumbens*) aids in treating rheumatic disorders. Erratic collections severely reduced wild population size and genetic diversity in South Africa, Botswana, and Namibia. Bark of *P. africana* is employed for curing prostatic hyperplasia. Excessive and destructive stripping of 59,000–90,000 trees/annum from African mountains and highlands led to near disappearance of wild trees from Mount Oku forest in Cameroon. The leaves of bearberry (*Arctostaphylos uva-ursi*) are medicinally useful. Uprooting whole plants disturbed other plants, inhibited regrowth, created space for other plants to takeover and caused soil erosion, landslides, and death of innocent people in Pohnpei in the South Pacific. Kava kava (*Piper methysticum*) populations inhabiting these mountains were uprooted to meet increasing demand instead of harvesting branches and leaves for anxiolytic kavalactones. This led to soil erosion. Over-harvesting of *Arnica montana* wild populations created space for the growth of *Rhododendron* plants in their place. Thus, faulty harvesting methods led to genetic erosion and socioenvironmental problems with a cascading effect on the biodiversity and ecology of the region (Behrens 2014). Orchid *Nervilia fordii* is known for its febrifuge and antitussive properties. The plant produces only one leaf/year. Being an export commodity, 7–8 tons of whole bulbs were dug every year diminishing wild populations and making it an endangered species (Heywood 1999). In China *Dendrobium* is rarely found in the wild. Chinese wild *Panax notoginseng* is believed to be extinct in the wild due to overcollection (Liu et al. 2011). Fortunately, cultivated *P. notoginseng* retained reasonable level of genetic diversity (Guo et al. 2009). In India *Gnidia glauca* var. *sisparensi,* a medicinal tree used in *Ayurveda* is believed to be extinct in the wild. Recently, three trees were found in the Western Ghats after 148 years. Overexploitation, unsustainable harvests, and population fragmentation severely depleted genetic diversity of *Phyllanthus emblica* (syn. *E. officinalis*) in India (Rajeswara Rao 2012; Singh et al. 2012). Forest-dwelling communities and rural people in forest fringe areas depend on the trade of fruits for their livelihoods. Loss of genetic resources adversely impacts their income. Chinese and Asian *Blumea balsamifera* yields borneol, a widely used phytopharmaceutical. Chinese wild resources have diminished at a rapid rate during recent years limiting supplies and endangering it (Pang et al. 2014). Populations of several Chinese MPs namely, *Acanthopanax senticosus*, *Asarum heterotropoides* var. *mandshuricum*, *A. lancea*, *Bupleurum chinense*, *Cistanche deserticola*, *Dioscorea zingiberensis*, *Ephedra sinica*, *Eucommia ulmoides*, *Gastrodia elata*, *Glycyrrhiza uralensis*, *Magnolia officinalis*, *Notoptetygium incisurn*, *Phellodendron chinense,* and *Swertia milensis* have declined due to over-exploitation. Several African and Indian species were rendered endangered through commercial harvesting. People living in Indian Thar desert depend on its fragile natural resources. *Calligonum polygonoides,* a perennial shrub is food for people and animals. Flower buds are effective in countering negative effects of sunstroke. Root decoction as a gargle cures sour gums. Aqueous extract is used as an antidote against poisonous effects of plants and opium. Human activities diminished populations of *C. polygonoides* at an alarming rate affecting their genetic composition and diversity in Bikaner province (Vyas et al. 2012). *Carapichea* (*Cephaelis*) *ipecacuanha* (ipecac) roots are known for their emetic, nauseant, expectorant, and diaphoretic properties. Plants are being commercially harvested in Brazil since eighteenth century. Deforestation, habitat fragmentation, and uncontrolled harvesting without replanting declined wild populations. In spite of limited cultivation in India, world demand is met through wild-gathering eroding its diversity and gene pool (de Oliveira et al. 2010). *Changium smyrnioides* is an endangered medicinal plant endemic to eastern China. Medicines of this plant quench thirst, moisten lungs, soothe the throat, and removes toxins that cause skin infections. Continuous wild collections constricted the size of natural populations and made them rare (Fu et al. 2003). Chinese *Fritillaria cirrhosa* bulbs are used as antitussive, expectorant, and hypotensive agent. Owing to its strict habitat needs, domestication and cultivation are difficult. Over-harvesting, habitat fragmentation, and overgrazing during the past decades decreased population sizes and their genetic diversity pushing it to the brink of extinction (Zhang et al. 2010). *Epimedium* species are used in traditional Chinese medicines. Commercial overexploitation relegated some of the species to endangered status (Zeng et al. 2010). Roots and leaves of Malabar nut *Justica adhatoda* (syn. *Adhatoda vasica*) are employed in treating bronchitis, asthma, fever, and jaundice in traditional medicine systems in the Indian subcontinent. The plant grows under harsh conditions in Pakistan. Over-harvesting to satisfy domestic and commercial needs and habitat loss fragmented and imperiled populations (Gilani et al. 2011). Rhizomes of *Paris polyphylla* var. *chinensis* are used in Chinese medicines for treating hemostasis, protitis, and snakebite. This plant has been on the verge of extinction due to severe deforestation, small population sizes, inbreeding and absence of alleles at some loci (Zheng et al. 2012). *Swertia chirayita* is a commercial medicinal plant of Nepal. Overexploitation to meet high trade demand depleted wild populations beyond their regeneration capacities losing genetic diversity and gene pool (Shreshta et al. 2013). Traditional healers use bark of *Warburgia ugandensis* against malaria, constipation, cough, candidiasis, and as skin cream. Overuse of the bark, the root, and indiscriminate tree felling for timber/wood over many decades wiped out populations in many African regions causing loss of genetic diversity (Muchugi et al. 2012). *Rhodiola dumulosa* population is fragmented across northern, central, and northwestern China. Two distinct gene pools were discovered, one in northern and the other in central and northwestern China with restricted gene flow among these populations. Conservation schemes should include samples containing both the gene pools to avoid genetic erosion (Yan and Anru 2011). *A. montana* is a poisonous medicinal plant endemic to Europe and is protected by European laws. In the absence of cultivation, unauthorized, illegal wild collections and overgrazing turned it into an endangered plant in Romania (Pop et al. 2008). Red lists of IUCN and different countries and CITES appendixes cite numerous MPs with varying levels of threat to their survival. It is not known how much genetic diversity or how many gene pools have been lost. The big question is can we protect the existing genetic diversity without inflicting further genetic erosion?

11.5 Influence of Loss or Fragmentation of Habitats on Genetic Diversity and Genetic Erosion

Human interference disturbs the equilibrium of evolutionary forces of selection, gene flow, mutation, genetic drift, inbreeding affecting adaptive capacities of species. The consequences of human atrocities such as fragmentation, degradation, or destruction of forests or their conversion for other uses result in irreplaceable loss of species, genetic, and ecosystem diversity as reforestation programs concentrate on timber/wood or commercial species. An overlooked problem of habitat fragmentation is the proliferation of other species spacing out MPs. Human introduced commercial species replace native MPs quickly depleting genetic diversity. In India forest bamboo plantations and invasive weeds *Lantana camara*, *Parthenium hysterophorus*, *Hyptis suaveolens,* etc. replaced native species. Exotic blue pine *Pinus wallichiana* has edged out local white oak and medicinal herb *Lilium polyphyllum* in Shimla. Logging and timber/rubber tree plantations destroyed large tracts of Amazon rain forests. Forest destruction leads to loss of microflora and fauna adversely affecting soil fertility (loss of organic matter, nutrients, and beneficial microorganisms) consequently limiting plant germination, growth, and survival. Loss of trees and shrubs that support climbing/trailing species, parasitic plants (e.g., *C. deserticola* on *Haloxylon persicum*/*ammodendron*), shade-loving species, beneficial flora and fauna poses problems for the survival of these species. Exposure of denuded forests to sun light, winds, heavy rains cause moisture and organic matter losses, loss of soil productivity, and lead to soil erosion and landslides. During 2000–2010, 13 million hectares/year of forests were lost (in comparison to >16 million hectares/year during 1990–2000) due to deforestation and natural disasters out of which primary forests accounted for 4.188 million hectares/year. Even after taking into account natural regeneration, afforestation, and reforestation, the net loss was 5.211 million hectares/year (i.e., the world lost 0.13 % of existing forests/year). Forest fires and insect pests and diseases damaged 1 and 2 % of forests, respectively (FAO 2010). Though FAO (2010) stated that US$ 628 million worth medicinal and aromatic plants (MAP) were collected as part of nonwood forest products, no details were given on the species collected or loss of species. Studies in Brazil and Peru showed that nonwood forest products yielded higher net returns/hectare than timber and were harvested with less damage to the ecosystem. Conservation International identified 34 biodiversity hot spots with high levels of species endemism (>1500 at each hot spot) and frightening levels of biodiversity depletion (70 % original habitat lost). Eight of them are in Africa, 13 in Asia Pacific, 4 in Europe and Central Asia, 5 in South America, and 4 in North and Central America (http://www.cepf.net/resources/hotspots/Pages/default.aspx. Viewed 17 June 2014). Two of them namely, Himalayas and Western Ghats are in India. Though these hot spots occupy only 2.3 % of Earth's surface, they are habitats for more than half of global endemic species, many of which are medicinally valuable. The frightening aspect is the increasing number of biodiversity hot spots (up from earlier 17) pointing to loss of species and genetic diversity. Walter and Gillett (1998) estimated that out of 49,000 plant species evaluated 34,000 species (8 % of global flora of 422,000) were threatened with extinction. Later, Bramwell (2003) enhanced it to 21 % of world flora. Based on these estimates, Schippmann et al. (2006) calculated that 21 % of 72,000 MPs, i.e., over 15,000 MPs are threatened globally. Edwards (2004) scaled down this number to 4000–10,000. In 2001, IUCN revised its criteria (version 3.1) for classifying plants into nine categories (http://www.iucnredlist.org/static/categories_criteria_3_1) such as extinct, extinct in the wild, critically endangered, endangered,

Table 11.2 Estimated number of plants, medicinal plants (MPs), and threatened MPs worldwide

Estimates	Number of species	Reference
Estimated number of plants	370,000–422,000	Schippmann et al. (2006) and Paton (2009)
Estimated number of MPs by WHO in 1970s	Over 21,000	Heywood (1999)
Estimated number of MPs	>35 000	Lewington (1993)
Estimated number of plants used ethnomedically	70 000–80 000 (>20,000 plants in NAPRALERT database)	Farnsworth and Soejarto (1991) and Heywood (1999)
Estimated number of MPs	72,000	Schippmann et al. (2006)
Estimated number of MPs	77,000	Rajeswara Rao et al. (2012)
Estimated number of MPs	80,000	Joy et al. (1998)
Estimated number of flowering plants of pharmacological value	125,000	Memdelsohn and Balick (1995)
Number of MPs threatened in 1997 (8 % of world flora)	5760–6160	Walter and Gillett (1998)
Number of MPs threatened in 2003 (21 % of global flora)	15,120–16,170	Bramwell (2003), Schippmann et al. (2006)
Number of MPs threatened in 2004	4000–10,000	Edwards (2004)
Number of MPs threatened in 2014 (2.5 % of world flora)	1800–1925	IUCN Red List of Threatened Species^{TM} version 2014.1

WHO World Health Organization, *NAPRALERT* Natural Product Alert (http://www.napralert.org/), *IUCN* International Union for Conservation of Nature and Natural Resources vulnerable, least concern, data deficient, and not evaluated. IUCN prepared Red List of Threatened Species™. In its version 2014.1, IUCN provided trends during the period 1996/1998–2014 (http://www.iucnredlist.org/). As per Table 3b: "Status category summary by major taxonomic group (plants)" 128 plant species are extinct, 104 are possibly extinct, 2000 are critically endangered, 3178 are endangered, 5205 are vulnerable (up to here 10,487 species or 2.5 % of global plant species are threatened + 128 are extinct), 1544 are nearly threatened, 210 at lower risk are conservation dependent, 5466 are of least concern, and for 1539 species' data are deficient (19,374 or 4.6 % of global species were comprehensively assessed). The details of threatened MPs are depicted in Table 11.2. In India 265 MPs, in Europe 150 MAP, in Croatia 17 MP, in Ukraine 202, in Estonia 16, in Finland 20 are threatened; in Malta 9 MPs are extinct and 34 are threatened; in Serbia 6 are extinct, 4 are thought to be extinct, and 24 species are critically endangered.

11.6 Effect of Wild Collections on Genetic Diversity and Genetic Erosion

Wild collection provides income and incentives for local communities for conservation and sustainable use of MPs resources. Wild collection for healthcare needs of indigenous people cause little damage to genetic diversity as the quantities collected are small. Commercial, destructive, or over-harvesting (low prices, un- or underemployment, lack of livelihood options force (majority women) collectors to mine rather than manage the resources; Lange 2006b; Schippmann et al. 2006) threaten MPs genetic diversity. Crude collection methods result in loss of yield, quality, and reduction in price. Habitat-specific, slow-growing, popular MPs with narrow geographic distribution and small population sizes are susceptible to overharvesting and are at a greater risk of genetic erosion due to demand–supply mismatch relative to fast-growing, widely distributed species with high population densities, reproductive rates, and regenerative capacities (e.g., *Peumus boldus* trees). Endemic species are particularly at a greater risk due to their restricted habitat and small population sizes. Collection pressures differ among species (trees vs. herbs, slow vs. fast growing, perennials vs. annuals, vegetatively vs. reproductively propagated MPs). Overcollection of fruits or seeds of a tree causes minimum harm, while annual herbs will be wiped out from a location if all their seeds are collected. Slow-growing trees that produce few seeds are however, susceptible to genetic erosion (Schippmann et al. 2006). Harvesting branches, leaves, flowers, fruits, and seeds do not destroy MPs. Stripping bark, cutting wood or main stem, and digging underground parts kill them causing genetic erosion, e.g., *Aconitum ferox/heterophyllum/spicatum*, *Nardostachys jatamansi*, *Neopicrorhiza scrophulariiflora*, *P. ginseng/quinquefolius*, *Saussurea costus*, *Valeriana jatamansi*, *Warburgia salutaris,* etc. Majority of MPs in trade are not cultivated and most material is forest gathered. The unscientific harvesting practices rapidly decline wild populations and accelerate their extinction (Sanders and Hamrick 2004; Sanders et al. 2005). Duke (1997) stated that human population pressure endangers species the most "the better a medicinal plant, the more it threatens itself." Further, overplaying (herbal hype) and intentional misrepresentation (herbal hoax) of claims of herbal medicines encourage over-harvesting. Since phytochemicals are widely distributed in the plant kingdom, he felt that alternate sources can be found in nature for threatened MPs and invasive weed MPs (*Hypericum perforatum* in western US) need to be contained rather than conserved. It is estimated that 70–90 % MPs and 50–70 % of their biomass traded internationally and regionally are wild-sourced (Edwards 2004; Balunas and Kinghorn 2005; Lange 2006a). About two-thirds of MPs were wild-procured (Edwards 2004). In Europe 90 % of over 1300 MPs were wild-harvested (Balunas and Kinghorn 2005). In China 60–80 % of 700,000 tons of MPs were used in 1990s and 80 % of the species were wild-gathered, in the United States 90 % herbs were wild-sourced, and in Germany 70–90 % of 1560 species traded were wild-harvested in Africa, America, Asia, and Europe (Heywood 1999). In Hungary 30–35 % (10,000–15,000 tons dry phytomass of 120–130 MPs), Spain 50 %, Ecuador 90 %, Albania 90–100 % MPs and in Romania 11,300 tons were wild-collected. In India 77 % MPs were wild collected (12 % from temperate forests, 40 % tropical forests, and 25 % roadsides; Ved and Goraya 2008), 72 % of them in a destructive manner. The scenario is the same in other countries. In addition to regulating wild collections, certification is being insisted (FairWild Standard version 2.0 for wild-collected plants, fungi, and lichen; http://www.fairwild.org/standard) for quality control, to discourage illegal collections, to ensure fair, ethical trade practices, and for social accountability (International Fair Trade Association http://www.ifat.org; Social Accountability International http://www.sa-intl.org; Fair Trade Labeling Organization International http://www.fairtarde.net). WHO (2003) outlined strategies and techniques for small and large-scale collection to ensure long-term survival of wild populations and their habitats. WHO pointed out that collection is associated with geographical, economical, sociocultural, environmental, and business issues that varies from region to region and have to be tackled locally. WHO stressed on the quality of wild-collected material avoiding contamination by men/women and machines. The strategies were given under five subheads emphasizing on correct identification (confusion arises due to common local names for different species, e.g., Punarnava for *Boerhaavia diffusa* and *Trianthema portulacastrum*; Sankhapushpi for *C. ternatea*, *Convolvulus microphyllus,* and *Evolvulus alsinoides* in India. Computer databases and traditional herbaria help in identification and authentication), inventorying population densities of targeted MPs for exempting threatened species from collection, preparing management plans for correct collection practices (sustainable, e.g., Hambledon Herbs, UK, sourced sustainably wild-harvested *H. procumbens* from Namibia through Oxfam) to encourage regeneration of source material, best time of collection to ensure quality and quantity of active constituents, avoiding polluted areas or collection of contaminated

MPs, protecting collected material from postharvest contamination (improper drying causes fungal contamination), ensuring proper storage (avoid pest contamination, phytochemical content degradation), transport, hygiene, and safety of the personnel. Subsequently, Medicinal Plant Specialist Group (2007) of the Species Survival Commission of IUCN published international standard (version 1.0) for sustainable wild collection of MAP containing six principles and 18 criteria which are briefly discussed. 1. Maintaining wild MAP resources (three criteria: conservation status of targeted species is to be periodically evaluated and reviewed as per IUCN version 3.1; collections should be monitored based on identification, inventory, and assessment discouraging collection of threatened species, minimizing waste collections; and collection intensity should match species' regeneration capacities). 2. Preventing negative environment impacts on other wild species, habitats, and surrounding areas (two criteria: protection of sensitive taxa, their habitats and ecosystem diversity; and services). 3. Complying with laws, regulations, and agreements (two criteria: tenure collection rights to be issued to authorized collectors; local, national, and international laws on collection and management should be strictly adhered to). 4. Respecting customary rights of ethnic communities and indigenous people to utilize and manage collection sites (two criteria: access rights, traditional use, and cultural heritage of ethnic communities are to be recognized and respected; benefits accruing from the use of wild-collected MAP should be shared with these people). 5. Applying responsible management practices (four criteria: management plans are to be drawn for sustainable collection, to maintain quality and prevent biotic and abiotic contamination and to conserve habitats; the impacts of collection are to be assessed and recorded; collection activities should be transparent with stakeholder participation; collection methods, storage, transportation, etc. should be documented). 6. Applying responsible business practices to support quality, financial, and workers needs of the trade without compromising on resource sustainability (five criteria: species with no market value should not be collected and collected species should conform to quality specifications of buyers; traceability of collected material should be ensured through proper labeling and certification concerning origin, collection site, year/time of collection, etc.; financial viability of collection, conservation of species and habitats, and management of resources should be ensured; collectors and managers should be trained for sustainable collections and to comply with this standard, national, and international laws; health and safety of collectors and managers should be safeguarded with adequate compensation). Several countries have complied and passed legislations for assuring quality and stopping illegal collections. In India Girijan (Tribal) Cooperative Corporations are permitted to purchase forest products from tribal collectors and market them. In Andhra Pradesh province the Corporation is permitted to collect about 35 MPs from forests. In spite of the efforts of governments and international organizations, irrational and illegal wild collections continue threatening genetic diversity and causing genetic erosion.

11.7 Impact of National and International Trade on Genetic Diversity and Genetic Erosion

Rapid urbanization and opening up of urban markets for traditional herbs placed large demand for MPs. In the old world countries MPs are used for warding off evil spirits/enemies/jealousy/competition; for good luck, blackmagic, attracting/retaining partners; as aphrodisiacs, fish/animal poisons, dyes, etc. enhancing market requirement and value. MPs are traded within countries, across nations within a continent, and exported across the world. From collectors/cultivators the material passes through complex trade channels before it is used or exported. Hong Kong, Tokyo, New York, and Hamburg are important trading centers (Lubbe and Verpoorte 2011). It is difficult to distinguish between wild-collected and cultivated materials. Correct market data and trends are scarce (Schippmann et al. 2006) and are difficult to ascertain as MPs are traded in vast array of products. Global trade data (http://comtrade.un.org/db/default.aspx. Accessed 5 June 2014) sourced from UN Comtrade database from HS (Harmonized Commodity Description and Coding System) 1992 classification and commodity 1211 ["plants and parts of plants (including seeds and fruits), of a kind used primarily in perfumery, in pharmacy or for insecticidal, fungicidal or similar purposes, fresh or dried, whether or not cut, crushed or powdered"] are presented in Table 11.3. The annual international trade is in excess of 500,000 tons during 2008–2012 which is higher than earlier figures (1991–2003: global annual average exports were 467,000 tons valued at US$ 1.2 billion with 12 countries making up ca 80 % of exports and imports; Lange 2006b) and the value of imports and exports are consistently increasing. Data for 2013 is incomplete as data for China, Hong Kong, and other countries are not available. The number of importing countries is more than exporting countries. The value of imports has risen by 30.2 % and exports by 42.1 % between 2008 and 2012. As a result unit prices of MPs have increased substantially (more than double in some cases) in the exporting countries (Larsen 2011). Poor, unskilled, unemployed, or low-wage earning gatherers overexploit MPs to shore up their income

Table 11.3 Global imports and exports of perfumery and pharmacy plants and plant parts during 2008–2013 (UN Comtrade database for the years 2008–2013 in HS 1992 for commodity 1211)

Year	Imports		Exports		Number of importing (exporting) countries
	Quantity (000 tons)	Value (US$ million)	Quantity (000 tons)	Value (US$ million)	
2008	513.8	1966.8	524.9	1793.7	157 (139)
2009	527.6	1867.7	533.9	1782.1	155 (133)
2010	546.1	2124.1	519.9	2087.3	153 (133)
2011	527.4	2488.2	633.2	2467.7	147 (131)
2012	575.0	2560.1	547.7	2548.8	139 (121)
2013	371.4	1750.2	338.2	1497.4	81 (74)

UN United Nations, *HS* Harmonized Commodity Description and Coding System
US United States

in countries exporting unprocessed, wild-sourced MPs at cheaper prices (Lange 2006b; Schippmann et al. 2006). In terms of value Belgium, Canada, China, France, Germany, Hong Kong, India, Italy, Japan, Malaysia, Mexico, Netherlands, Republic of Korea, Singapore, the United Kingdom, and USA are the main importing countries. Belgium, Canada, Chile, China, Egypt, France, Hong Kong, Germany, India, Mexico, Morocco, Poland, Republic of Korea, Singapore, and USA are the major exporting countries. Major markets are in developed countries but bulk of botanicals is exported from developing nations as unprocessed, raw material yielding low profits. International demand is confined to few regions leading to overexploitation (Lange 2006b). Profits of exporting developing nations can be improved by exporting processed botanicals. Indian exports grew from 48,525 to 87,745 tons and US$ 106.3 to 207.8 million (95.5 % increase) during this period. Chinese exports increased from 188,249 to 227,038 tons and US$ 450.0 to 844.8 million (87.7 % enhancement). Data on local consumption for different countries are sparse. In China, 1–1.6 million tons of MPs are used in traditional Chinese medicines compared to earlier 700,000 tons (Heywood 1999; Liu et al., 2011). Germany's use in 1996 was around 40,000 tons, Bulgarian's requirement (60–70 % for exports, 30–40 % for domestic consumption) was 12,000–15,000 tons (70–80 % wild-collected, 20–30 % cultivated), Croatian 109 tons was wild-collected from 87 species in 2001, in Nepal over 15,000 tons were wild-harvested from 100 species, and in Poland 8000–10,000 tons (>50 % exported) of 200 wild MAP were collected. Indian domestic demand was pegged at 263,000 tons in 2005–2006 (Ved and Goraya 2008). In Ukraine, 1000 tons (60 % wild, 40 % cultivated) of 44 MPs are used in the domestic market (Minarchenko 2011). If the domestic consumption of all importing countries is taken into account, the total annual demand runs into several million tons of MPs. Assuming 60–70 % moisture content in the plant parts, actual wild collections are 2–3 times higher than their trade volumes as most of the raw material is traded as dry biomass. Around 3000 (others estimated 4000–6000) MPs are globally traded with larger number in national markets (Schippmann et al. 2006). A flourishing trade with consistently increasing demand has devastating consequences on wild-collected MPs, their genetic diversity, and gene pools. Some of the species traded in large volumes are: *Actaea racemosa* (*Cimicifuga racemosa*), *Allium sativum*, *Aloe ferox*, *A. vera* (*barbadensis*), *A. montana*, *Atropa belladonna*, *Carapichea* (*Cephaelis*) *ipecacuanha*, *Cassia senna*, *Centella asiatica*, *Echinacea purpurea*, *E. angustifolia*, *E. sinica*, *Ginkgo biloba*, *Glycyrrhiza glabra*, *Hippophae rhamnoides*, *Hydrastis canadensis*, *H. perforatum*, *Matricaria chamomilla* (*recutita*), *Melissa nettle*, *Oenothera biennis*, *P. africana*, *P. ginseng*, *P. quinquefolius*, *Papaver somniferum*, *Pelargonium sidoides*, *P. methysticum*, *P. psyllium*, *Sabal serrulata*, *Serenoa repens*, *Silybum marianum*, *S. chirayita*, *Tanacetum parthenium*, *Taxus wallichiana*, *T. brevifolia*, *T. chinensis*, *Ulmus rubra*, *Vaccinium macrocarpum*, *V. myrtillus*, *Valeriana officinalis*, *V. wallichii*.

MPs are exported as fresh or dried plants or parts (leaf, stem, bark, wood, bud, flower, fruit, berry, seed, root, rhizome, tuber, bulb, corm) cut into pieces, crushed, or powdered. They are used as culinary herb, powder, paste, juice, decoction/

infusion, extract/tincture, macerate, cooked or fermented, phytochemicals, and as formulations in herbal teas, health/herbal/sports drinks, TM, CAM, over-the-counter medicines, functional foods, pharmaceuticals, nutraceuticals, cosmeceuticals, medicine adjuncts, dietary supplements, aromatherapy, flavors, fragrances, herbal pesticides, etc. The economic significance of MPs products sourced from several web sites is detailed in Table 11.4. With burgeoning world population (>7 billion) consumption of these products continues to rise.

The escalating trade in regional and transnational markets acts as a driving force for over-harvesting and illegal wild collection of threatened species. TRAFFIC, the wildlife trade monitoring network (http://www.traffic.org/overview/) analyzes trade trends, patterns, and impacts on wild animals and plants to manage wildlife trade and maintain wildlife populations and ecosystems to meet human requirements. CITES regulates and monitors global trade in threatened

Table 11.4 Global economic significance of products containing medicinal plants and their derivatives

International trade	Value
International market for herbal medicines	US$ 60 billion in 2000 (WHO 2003), US$ 43 billion in OECD countries in 1985. US$ 8 billion in USA in 1980 estimated at US$ 11 billion in 1985 (Principe 1991). With 10 % growth rate the current market size is over US$ 140 billion
Global market for herbal teas (around 300 species used in USA, China)	US$ 100 million
World market for nutraceuticals	US$ 142 billion in 2011 and is expected to be US$ 205 billion by 2017
International market for cosmeceuticals	US$ 27 billion in 2010 (US market in 2004 US$ 12.4 billion)
International trade in functional foods	US$ 57 billion
Market for dietary supplements	US$ 21.3 billion in 2005
World market for aromatherapy	US$ 400 million
Natural products for animal care	US$ 1 billion in 2009
Global pharmaceutical market	US$ 965 billion in 2012 and is expected to reach US$ 1.2 trillion by 2016–2017. It takes 10–15 years and US$ 1.38 billion to develop a medicine or vaccine (http://www.ifpma.org/)
US market for energy, sports, and functional drinks	US$ 12.87 billion during 2004–2006
Chinese trade in herbal medicines, functional foods, herbal extracts, etc	US$ >40 billion in 2011 (Liu et al. 2011)
Germany's herbal market	US$ 12.7 billion in 1989
Brazil's botanical market	US$ 160 million in 2007
Western Europe's herbal trade	US$ 5 billion in 2003–04
Indian traditional medicines trade	£88 billion in 2005–06 (Ved and Goraya 2008)

WHO World Health Organization, *OECD* Organization for Economic Cooperation and Development, *USA* United States of America species of animals and plants by educating customs officials and advising countries on banning commercial exports and imports of threatened species. CITES (http://www.cites.org/eng/disc/species.php) prepares species lists under three appendixes. Species can be added, deleted, or moved from one appendix to the other by Conference of the Parties to CBD (http://www.cbd.int/). Species threatened with extinction are listed in appendix 1. Out of 931 species and 47 subspecies of fauna and flora listed in this appendix, 301 (32.3 %) species belonging to 20 families and 4 (8.5 %) subspecies belonging to 2 families are plants. Appendix 2 lists species that may become extinct if neglected and are not protected. These species are permitted to be commercially traded provided they are legally acquired from sustainable sources. Out of 34,419 species and 11 subspecies in this appendix, 29,592 (74.4 %) species belonging to 46 families including 162 populations belong to the plant kingdom. Species whose trade is regulated by a country but require the cooperation of other nations to avert illegal trade are included in Appendix 3 on the request of that country. Out of 147 species, 13 subspecies, and 1 variety in this appendix, 12 (8.2 %) species including 2 populations and 1 variety belonging to 9 families are plants. Notwithstanding inclusion of a particular species in these appendixes, artificially grown or cultured plants or plantlets, hybrids developed by government or private agencies and cultivated species are permitted to be commercially traded. Several species of *Aloe*, *Cycas beddomei*, *Dendrobium cruentum*, *Saussurea costus* are some of the species listed in Appendix1. *Adonis vernalis*, *Aloe* species, *Aquilaria* species, *Cibotium barometz*, *Dalbergia* species, *Dionaea muscipula*, *Dioscorea deltoidea*, *Euphorbia* species, *Guaiacum* species, *Heydychium phillippinense*, *Hoodia* species, *H. canadensis*, *Nardostachys grandiflora*, *P. ginseng*, *P. quinquefolius*, *Picrorhiza kurrooa*, *P. hexandrum*, *P. africana*, *P. santalinus*, *Rauvolfia serpentina*, *Senna meridionalis*, *Swetenia* species, *Taxus* species are some of the species included in Appendix 2. *Dalbergia* species, *Gnetum montanum*, *Magnolia liliifera* var. *obovata* are some of the species shown in Appendix 3. These, IUCN and countries' red lists help in identifying MPs which need conservation, recovery, or cultivation.

11.8 Consequences of Climate Change on Genetic Diversity

Considering the major influence of environment on survival, growth, yield, and quality of MPs, climate change may impact ecosystem composition, function, population structure, dynamics and interspecific interactions. One of the consequences ascribed to climate change is the infestation of plants with virulent native or exotic species of insects and disease producing fungi, bacteria, or phytoplasma causing extensive damage to wild populations leading to loss of plants with valuable genes. The other change is the replacement of native plants with species more adapted to the modified climate and significant changes in growth, flowering, and reproductive capacities of native plants. Frequent or regular occurrence of forest fires (natural, accidental, or deliberate) destroying local flora and fauna is attributed to rising temperatures and dry conditions. Not all MPs with valuable gene pools revive after a major fire disaster. Loss of organic matter and microbiome (rhizoshere microorganisms and microbial biomass) adversely affects subsequent growth, yield, and quality of MPs. Changes in rainfall and wind patterns, occurrence, and prevalence of drought and moisture stress induce long-lasting effects on MPs survival and distribution. Landslides, soil erosion destroy local flora eroding genetic diversity. The increase in temperatures adds competitive edge to species that thrive at higher temperatures and adversely impact growth and reproductive capacities of MPs that prefer lower temperatures. Higher temperatures influence litter decomposition and soil organic matter content (Veteläinen et al. 2007). Earthquakes, volcanic eruptions, glacier melting, floods, and tsunamis destroy vast tracts eroding genetic diversity.

11.9 Conservation of Genetic Resources and Genetic Diversity

The aims of conservation are preservation of genetic diversity and promotion of evolutionary processes. Conservation programs should be ecology-friendly and indigenous people-friendly. UNEP World Conservation Strategy defined conservation as (http://www.unep.org/geo/geo3/english/049.htm. Viewed July 20, 2014) “the management of the human use of the biosphere so that it may yield the greatest sustainable benefit to the present generations while maintaining its potential to meet the needs and aspirations of future generations.” For many decades conservation of genetic resources of MPs was neglected. The impetus was given by the Chiang Mai declaration “Save the plants that saves lives” by health professionals who gathered at the WHO/IUCN/WWF international consultation on MPs conservation held at Chiang Mai, Thailand, from March 21 to 26, 1988. They called up on UN, its member states, government and nongovernment organizations for international cooperation and coordination for recognizing MPs importance in primary healthcare, their economic significance and the threat being faced by them owing to habitat loss and unsustainable harvests, and the vital inevitability of conserving to assure continuous supplies for future use. Subsequently, WHO et al. (1993) released guidelines for MPs conservation. Conservation of genetic resources requires team effort of national and international organizations such as IUCN, WWF, FAO, Botanic Garden Conservation International (BGCI, http://www.bgci.org/), UNIDO, UNESCO, etc. with the involvement of ethnic communities and indigenous people. WHO guidelines cover eight strategies: 1. To record and digitize traditional knowledge of local communities of each country on ethnobotanical uses and share the benefits arising out of commercial exploitation of such knowledge with the communities. India has digitized 220,268 medicinal formulations used in Indian systems of medicine through traditional knowledge digital library

(TKDL, www.csir.res.in) initiative that has helped the country to get some patents granted based on Indian traditional knowledge revoked. The Tropical Botanical Gardens and Research Institute (TBGRI), Thiruvananthapuram, Kerala, documented and patented the medicinal properties of *Trichopus zeylanicus* and shared the benefits arising out of commercial utilization of the traditional knowledge of *Kaani* tribal community with them. The agreement between the National Biodiversity Institute of Costa Rica and Merck for bioprospection of Costa Rica's 4 % world's biodiversity for benefit sharing from commercial products arising out of the bioprospection is another example. The problem is in recognizing ownership of genetic resources and the knowledge arising out of them. Some countries regard genetic resources as a nation's heritage and should be shared with financial compensation. Others opine them to be human heritage and should be freely shared. In both the cases the ecosystem and indigenous peoples' needs (who fear that governments and companies indulge in biopiracy) are largely ignored. Extreme arguments include bioprospection as a conservation measure to protect species from extinction. The guidelines provided by CBD on access to genetic resources and fair and equitable sharing of the benefits arising out of their utilization (Secretariat of the Convention on Biological Diversity 2002) and the 2010 Nagoya Protocol (www.cbd.int/nagoya/outcomes/) are useful in resolving this conflict. 2. To prepare countrywise databases of MPs, their distribution patterns, herbaria sheets, and identify threatened species for conservation. Remote sensing and GIS (Geographic Information System) technologies are currently used by many countries for assessing the distribution of MPs and their threat levels (Liu et al. 2011). 3. To encourage cultivation of MPs through development of high-yielding varieties, their agrotechnology, raising nurseries, and training the stakeholders. Cultivated MPs can then be used for trade. 4. To ensure sustainable wild collections, banning collection of threatened species and regulating their trade. Nepal has banned wild collection of rare species, India has banned export of wild-collected endangered species, Bulgaria prohibited wild collection of 14 species, Croatia protected 44 species from wild collection, in different regions of Italy wild-harvest of 15–174 species is prohibited, 2–51 species restricted, and 26 species regulated, in Lithuania wild-harvest of 21 threatened MPs is regulated, and in Poland 20 MPs strictly and 16 are partially protected. In India and China threatened MPs are substituted with species having the same medicinal properties (Liu et al. 2011). 5. To improve harvesting, storing, and production practices with emphasis on quality control. 6. In situ conservation of MPs and their populations in their habitats through biosphere reserves (621 biosphere reserves in 117 countries; http://www.unesco.org/new/en/natural-sciences/environment/ecological-sciences/biosphere-reserves/. Viewed July 22, 2014), nature/ecological/gene reserves, wildlife sanctuaries, national parks, sacred groves, heritage sites are collectively called protected areas (currently 200,589 terrestrial protected areas covering 14.3 % land area and 9612 marine protected areas covering 10 % marine area exist; http://www.protectedplanet.net/search; http://wdi.worldbank.org/table/3.4. Accessed July 22, 2014). In situ conservation preserves species, genetic and ecosystem diversity. Reintroduction (in situ seeding, in situ or ex situ nurseries, alginate encapsulated microshoots, etc.) of overexploited species into their natural habitats is recommended. IUCN is advising countries to identify and earmark MPs rich forests as Medicinal Plant Conservation Areas (MPCA). Several Indian provinces earmarked MPs rich forest areas (200–500 ha each) for their protection and conservation. About 40 MPCA have been established in South India. China has established in situ conservation networks such as Tibetan Plateau for alpine MPs, XinJiang province for MPs of northwestern China, ChangBai Mountain for MPs of northeastern China, and GuangXi province for MPs of southern China (Liu et al. 2011). In Samoa four village-owned and managed rain forest reserves were established in 50,000 acres. In Belize MPs extractive reserve has been created on 6000 acres. Forest gene bank where species can exchange gene pools within and among populations and evolve is another idea mooted for in situ conservation (Shaanker and Ganeshaiah 1997). 7. Ex situ conservation to complement in situ conservation and as an insurance policy but not to replace in situ conservation. Species whose habitats have been destroyed or cannot be protected or whose populations got severely depleted or that became locally extinct should be given priority for ex situ conservation. Selected species should be carefully collected to include broad genetic base for improvement, reintroduction, and recovery without endangering wild populations. Considering that 70 % genetic diversity of a species can be retained in a sample of less than 1000 accessions, many MPs can be conserved ex situ. The problem lies in sampling due to differing growth, flowering, fruiting times; geographical distances; population sizes; ecological requirements; morphotypes and chemotypes. The advantages include easy plant propagation, reintroduction, agronomic improvement, research and education on these species. Disadvantages are inability to conserve 100 % genetic diversity, conserved species suffer genetic erosion, and are dependent on human care. Every country is recommended to establish botanic gardens equipped with field gene banks (germplasm of live trees, shrubs, vegetatively propagated species) and seed banks (stored at −20 °C) of annuals and perennials. BGCI has added ex situ conservation status of 3000 MPs to its PlantSearch database and is involved in conservation of threatened MPs in Brazil, China (through community based approach), Cameroon, Costa Rica, India, Madagascar, Mexico, Morocco, Philippines, Sri Lanka, Uganda, and other countries. It has a network of >2500 botanic gardens worldwide with 7 patron gardens for ex situ conservation of species comprising over 100,000 species, 4 million living plant collections with 6.13 million accessions and 142 million herbaria. Some of the gardens are devoted to MPs such as Monastir medicinal botanic garden of Tunisia and medicinal botanic garden of Shanghai, China. With the help of modern technology (in vitro culture, micropropagation, mycorrhization, genetic transformation, plant part substitution, etc.) it is possible to preserve pollen, embryos, embryonic axes, shoot apexes, cell suspensions, adventitious buds, DNA, etc. in cryopreservation at −196 °C (Kasagana and Karumuri 2011). Artificial seeds or alginate encapsulated microshoots produced in the laboratory are being used for reintroduction of wild-extinct or endangered species (Srivastava et al. 2009). Botanical Survey of India, CIMAP (Central Institute of Medicinal and Aromatic Plants; 2762 accessions of 418 MPs in seed gene bank, 1774 accessions of 244 MPs in field gene bank, 264 accessions of 44 MPs in in vitro gene bank, and 1389 accessions of 53 MPs in DNA bank), TBGRI (30,000 plants, 1000 angiosperms, and 100 rare species), and National Bureau of Plant Genetic Resources (NBPGR) are maintaining herbal gardens, seed banks, and in vitro banks dedicated to MPs. China has national MPs gardens in several provinces and a national MPs seed bank in Beijing (Liu et al. 2011). Croatia (900 accessions of 180 MAP), Czech republic (973 accessions of 78 MAP), Poland (159 accessions of 13 MPs), and Slovenia (650 MAP accessions) have preserved their MPs in seed/gene banks. Israeli gene bank contains 197 in situ, 584 ex situ, and 576 seed accessions of 15 MAP and 50 seeds each of 74 MAP. 8. To seek public support and cooperation through sensitizing and educating them on the importance of conserving MPs with the help of medicinal plant gardens in hospitals, parks, colleges; guided tours to such gardens; organizing lectures and campaigns; introducing courses in student curricula, etc. Sensitizing communities that reside inside forests and forest fringe areas is especially important in conserving MPs diversity as traditional knowledge on their ethnomedical uses is fast disappearing. This is also important since forests are exploited for food, fruit, flower, foliage, fodder, fuel, fiber, wood/timber, and other economic purposes and MPs form a negligible part (FAO 2010), hence ignored. WHO, IUCN, WWF, and TRAFFIC revised these guidelines taking into account information and research, policy and legislation, conservation strategies, sustainable production, healthcare, responsible business practices, equity and awareness, training and capacity building (Kathe 2006). Biodiversity informatics that links taxonomy and distribution with environmental variables to assist MAP conservation is an evolving new science (Paton 2009).

11.10 Cultivation for Protecting Genetic Diversity

The dilemma on the choice of wild or cultivated MPs for use in medicines has been raging for a long time. Scientists opine that preference for wild species is based on local perceptions (Robbins 1998) which are based on the presumption that the percentages of pharmacologically active secondary metabolites are higher in wild-gathered MPs, e.g., roots of wild American ginseng (*P. quinquefolius*) are considered more potent than those of cultivated plants (Sanders and Hamrick 2004). Some researchers feel that traditional perceptions are not completely unfounded as wild plants grow under specific ecological conditions (that influence accumulation of phytochemicals) which are difficult to replicate in cultivated regions (Schippmann et al. 2006). Scientific investigations however, confirmed that phytochemical concentrations can be regulated in cultivated MPs (Palevitch 1991). Product quality of domesticated Chinese MPs cultivated near the regions of their wild growth was found to be better than wild populations due to better cultivation practices (Guo et al. 2009). Many international traders and companies accept cultivated MPs (Laird and Pierce 2002). MPs that are presently available in copious quantities, species with restricted habitats or that can be easily multiplied in their native environments or trees/shrubs with long gestation periods and those for which cultivation may not confer socioeconomic, environmental, or other benefits need not be cultivated (Schippmann et al. 2006). For some MPs cultivation in forests or fringe areas is advocated. In India, in joint forest management program *vana samrakshana samithies* (forest protection councils) are formed with indigenous people who are permitted to cultivate small pockets of denuded forest areas. In China, semi-wild cultivation through natural nurseries of MPs or domestic cultivation by poor families is being practiced (Guo et al. 2009; Liu et al. 2011). Ex situ cultivation of MPs that are used in home herbal remedies or locally traded in small amounts through home herbal gardens in villages and towns, roof herbal gardens and growing them in pots in cities are becoming popular (Schippmann et al. 2006; Rao and Rajeswara Rao 2006; Guo et al. 2009). Avenue plantations with trees/shrubs and national parks dedicated to MPs are also becoming common (Liu et al. 2011). MPs which have been overexploited, whose habitats have been destroyed or degraded, that are regularly traded in large quantities with insufficient wild supplies, which are expensive, which have been extinct in the wild, that are listed in IUCN or country red lists or CITES appendixes and are banned for exports and whose genetic diversity has been eroded are ideal for cultivation. Cultivation's main thrusts are to discourage over- or destructive harvesting of wild populations thereby preserving genetic diversity in situ, preventing genetic erosion and to serve as economically viable renewable resource for quality MPs (Canter et al. 2005; Lubbe and Verpoorte 2011). Both collection and cultivation are market driven. Shi et al. (2008) demonstrated that cultivation of *Coptis chinensis* has not resulted in loss of genetic diversity. A similar finding was reported in goldenseal (*Hydrastis canadensis*) where cultivated and wild plants did not display differences in genetic diversity (Kerry 2009). Wild and cultivated *Allanblackia* trees had similar genetic diversity (Atangana 2010). Domestic cultivation of several MPs through seeds collected from wild population maintained 90 % genetic diversity. Even after 40 years of domestic cultivation, cultivated populations of *Codonopsis pilosa* retained high genetic diversity. Similar observations were recorded in *P. quinquefolius*, *P. ginseng*, *P. notoginseng,* and *Paeonia lactiflora* (Guo et al. 2009). Cultivated populations of *Primula veris* were more polymorphic than their wild relatives (Morozowska and Krzakowa 2003). Hybridization of cultivated varieties with wild populations was suggested to preserve genetic diversity. MPs can be cultivated as standalone crops (pure stands), can be integrated with agricultural, forest, or horticultural crops in intercropping, alley cropping, multistoried cropping systems, or in crop sequences (Rao and Rajeswara Rao 2006; Rajeswara Rao et al. 2012). Contract (Heywood 1999: contract cultivation of MAP by US pharmaceutical and cosmetics firms in developing countries; Lubbe and Verpoorte 2011: contract cultivation of *P. somniferum* in Tasmania and other MPs in India, Poland, South Korea by European companies) and corporate cultivation are catching up.

Cultivation requires varieties bred by traditional or modern biotechnological methods (marker assisted selection, transgenic plants) or carefully selected from wild populations to yield more biomass containing greater percentages of secondary metabolites and modern cultivation practices for these varieties under different agroclimatic conditions. Knowledge about the existing genetic diversity greatly helps in selecting plants having maximum gene pools either for cultivation or for improvement. Table 11.5 lists some of the varieties developed in India. Systematic cultivation of MPs is becoming a profitable farming enterprise. About 900 MPs are cultivated (Schippmann et al. 2006) and more species are needed to be cultivated. In China about 250 MPs were cultivated in 330,000–460,000 ha and 700–1300 MPs are grown in botanic gardens (Akerele et al. 1991; Heywood 1999). About 400 MPs are now cultivated in China in 10 million hectares (Ran 2008; Guo et al. 2009). In Europe 130–150 MAP (>100,000 ha; Lubbe and Verpoorte 2011), in Bulgaria 20–25 % of MPs in trade, in Croatia >3000 ha, in Finland 30 herbs (<5000 ha), in Poland 60 (20,000 ha with 20,000 tons production), in Hungary 40 MAP, in Romania 52 (4000 ha), in Italy over 100 MAP (3350 ha), in Spain 14 (6000 ha grown, 100,000 ha wild-collected), in Latvia 20 MPs (300 ha), in Serbia 30 MAP (<5000 ha), in UK culinary herbs (4200 ha), and in India <50 MPs (Ved and Goraya 2008) are cultivated in >95,000 ha (Chaddha and Gupta 1995). Small-scale cultivation of many more MPs is practiced in home gardens and by herbalists. Cultivation of MPs is prevalent in both developing and developed countries (Lubbe and Verpoorte 2011). The benefits and drawbacks of wild collection *versus* cultivation are enumerated in Table 11.6. Taking cognizance of importance of cultivation, WHO (2003) has issued guidelines on Good Agricultural Practices (GAP) laying emphasis on selection of MPs, their botanical identity, site selection (avoid polluted areas), ecological, environmental, and social impact, climate, soil, use of organic and inorganic nutrients with limited use of chemicals, irrigation and drainage, plant maintenance and protection, harvesting, personnel and strict quality control measures for producing biomass free of biotic and abiotic contaminants. With preference for organically produced and labeled MPs, guidelines given by World Fair Trade Organization (http://www.wfto.com/), International Federation of Organic Agricultural Movements (http://www.ifoam.org/), Fairtrade Labeling Organizations International (http://www.fairtrade.net/), Organic Trade Association (www.ota.com/pics/documents/short%20overview%20MMS.pdf) are to be followed for easy market acceptance and higher profits from organically cultivated MPs.

In addition to simple cultivation (including organic agricultural) practices under rainfed and irrigated conditions for enhancing quality and biomass yield per unit area per unit time; micropropagation protocols (Sharma et al. 2010) for rapid multiplication, for producing disease-free plantlets, for selecting somaclonal variants in vegetatively propagated species, for enhancing secondary metabolites in shoot or root (hairy root) cultures (shake flask and bioreactor technologies, e.g., *C. roseus*); biotechnological methods to identify genes and engineer biosynthetic pathways either for better accumulation of phytochemicals or elimination of undesirable phytochemicals; plants with different ploidy levels through induced mutations, soil less culture techniques, e.g., hydroponics and cultivation under controlled conditions (polyhouses, greenhouses), etc. have yielded fruitful results (Rajeswara Rao 1999; Rajeswara Rao and Rajput 2005; Canter et al. 2005; Reddy and Rajeswara Rao 2006; Rajeswara Rao et al. 2007; Lubbe and Verpoorte 2011).

Table 11.5 Cultivated varieties of medicinal plants developed in India

Common name	Botanical name	Variety
Aloe	*Aloe vera*	Sheetal
Carry me seed	*Phyllanthus amarus*	Jeevan, Navyakrit, Kayakirti
Chamomile	*Matricaria chamomilla/recutita*	Vallari, Prashant, Sammohak, Del
Coleus	*Plectranthus/Coleus forskohlii*	Bhagya
Egyptian henbane	*Hyocyamus muticus*	NP-41, HMT-1C
Gotu kola	*Centella asiatica*	Majja Poshak, Subhodak, RK1, RK2
Guggul	*Commiphora mukul/wightii*	Marusudha
Henbane	*Hyocyamus niger*	Aela, Aekla, IC-66
Indian gooseberry	*Emblica officinalis*	Banarsi, Krishna, Balwant, Francis, Kanchan, Neelam, Mehrun, Dongri, Agra bold, Modibagh, Banarsired, Amrit, Chakaiya, Faizabad, BSR-I, BGK-1, GA-1, Anand-1,2,3
Indian snakeroot	*Rauvolfia serpentina*	RS-1
Itching/velvet bean	*Mucuna pruriens*	Ajar
Kangaroo apple	*Solanum laciniatum*	EC-113465
King of bitters	*Andrographis paniculata*	Megha
Liquorice	*Glycyrrhiza glabra*	Mishree
Long pepper	*Piper longum*	Pipali, Viswam
Medicinal yam	*Dioscorea floribunda*	FB(C)-1, Arka-upkar
Milk thistle	*Silybum marianum*	Liv, Sil-9
Opium poppy	*Papaver somniferum*	Ajay, Shweta, Shyama, Shubhra, Vivek, Sanchita, Sujata, Rakshit, Sampada, Trishna, Kirtiman, JA-16, UO-285, NRBI-3
Periwinkle	*Catharanthus roseus*	Nirmal, Dhawal, Prabal
Psyllium	*Plantago psyllium/ovata*	Mayuri, Niharika, GI-1, GI-2
Sacred basil	*Ocimum sanctum/tenuiflorum*	Ayu, Kanchan, Angana
Safed musli	*Chlorophytum borivilianum*	Oj
Satavari	*Asparagus racemosus*	Shakti
Senna	*Cassia senna/angustifolia*	Sona, ALFT-2
Sweet flag	*Acorus calamus*	Balya
Sweetleaf	*Stevia rebaudiana*	Meethi, Madhu
Sweet wormwood	*Artemisia annua*	Arogya, Suraksha, Jeevan Raksha, Asha
Tropical soda apple	*Solanum viarum*	Glaxo, IIHR 2n-11
Waterhyssop	*Baccopa monnieri*	Jagriti, Pragyashakti
Wild gooseberry	*Emblica fischeri*	Champakkad large, Krishna
Wintercherry	*Withania somnifera*	Poshita, Rakshita, NMITLI-118, Chetak, Pratap, Jawahar-20, WSR, Nagori

Table 11.6 Benefits and drawbacks of wild collection *versus* cultivation of medicinal plants (Sanders and Hamrick 2004; Schippmann et al. 2006; Lange 2006b; Qing et al. 2010; Lubbe and Verpoorte 2011; Rajeswara Rao et al. 2012)

Wild collection	Cultivation
Reduction in population sizes and densities. Pollen, seed, and gene exchanges are restricted due to habitat degradation. Faulty harvesting at wrong phonological stages limits regeneration capacity of species. Genetic diversity depletion and genetic erosion. Extinction of species and ecotypes. Slow-growing and endemic species with specific habitat requirement and limited distribution are susceptible to overcollection. Exploitation of ethnic communities by unscrupulous agents	Conservation of species by discouraging wild collections. Relieves pressure on threatened, slow-growing species. Crop improvement through research and organic certification. Possibility of domestication of exotic species. High yields of biomass and secondary metabolites through cultivation of high yielding varieties. Contract and corporate farming are feasible
Irregular/diminishing availability and supplies. Knowledge about the resource is inadequate. Over- or destructive harvesting due to common access, illegal activities, lack of management plans, low prices, community needs, etc. Wastage due to overexploitation	Sustainable availability of raw material. Organic methods of cultivation and minimum use of chemicals. Amenability for inclusion in different cropping systems and crop rotations
Collection of wrong species due to confusing common names. Possibility of admixture with related species, sometimes with poisonous species	Botanical identity and purity of the species are guaranteed
Variable quality. Possibility of contamination with biotic (insect pests or diseases) or chemical contaminants. Quality control is difficult	Uniform quality. Quality improvement and quality control are practiced. Cultivation close to polluted areas is prohibited
Difficulties in harvesting, handling, drying, storage, and transportation	Harvesting, handling, storage, transportation are regulated avoiding contamination at all stages
Pest control difficult	Pest management is easy
Seasonal employment for local communities and indigenous people	Year round employment is possible by integrating different species with existing cropping patterns of agricultural, horticultural, and forest crops
Health/accident risks to collectors	Protection to workers is ensured
Adds income to local communities with no investment. Takes care of primary healthcare needs of indigenous people. Provides incentives to protect genetic diversity and wild populations. Product is organically produced and is cheaper. For habitat-specific species or species with small market or with narrow ecological range or whose plant parts require large cultivation space or where cultivation practices are nonexistent, wild collection is preferred	Product is expensive due to investments in domestication, cultivation, and research. Land for MPs is limited. Not a beneficial production system for all MPs. Heavy dependence on cultivated MPs may rob income of local communities involved in wild collections and limit incentives to protect wild populations. Narrows genetic diversity, may lead to genetic erosion. Populations become homozygous over time. Low-yielding wild relatives are ignored.

(continued)

Table 11.6 (continued)

Wild collection	Cultivation
	Continuous cultivation of varieties on contiguous areas renders them susceptible to pests and diseases. Dependent on human care and profits. Seed exchange among farmers and movement of seeds to other environments may pose the risk of maladaptation. Gene flow between maladapted plants and native populations may alter their genetic structure
Ambiguous land rights give rise to ownership conflicts. Resource utilization, benefit sharing, and IPR issues need to be resolved. Unfair/illegal trade practices. Difficulties in traceability and labeling on source and time of collection of each batch	Cultivation is carried out on private lands or public institutions with clear land records. IPR issues may still arise when imported material is used for research and patenting. Traceability and labeling of each batch are possible. Trade practices are reasonably fair

IPR Intellectual property rights

11.11 Conclusion and Prospects

MPs have been used for their curative property since ancient times. They provide revenue and health security to ethnic indigenous communities. Information on MPs is scattered in botany, chemistry, medicine, agriculture, horticulture, forestry, religion, etc., their centers of origin and biology are largely unknown. Unlike food, fruit, flower, foliage, fodder, fiber, fuel, timber crops, MPs are wild-gathered or cultivated for phytochemicals. Plants in general (<5 % of world flora have been comprehensively assessed by IUCN) and MPs in particular received less attention relative to animals and birds. Since revenue from exports constitute a small proportion, nations tend to focus on other high-priority sectors placing less importance on MPs. Forests are the primary habitats and the lives of forest-dwelling ethnic people (illiterate, poor, unemployed with few livelihood options) are intertwined with preservation and utilization of MPs through their cultural heritage and traditional knowledge a closely guarded secret passed on by word of mouth through generations. Exploding human population, rapid urbanization, and city-dwelling modern man's foray (roads, railways, airports) into the forests with exploitation/profit motive (hydel projects, mining, industries, logging, ranching, tourism) triggered today's crisis of genetic erosion and biodiversity loss. Human interference inflicted habitat loss, habitat and population fragmentation, commercial overexploitation of wild flora (MPs are collected as part of nonwood/timber forest products), overgrazing, invasive species, pollution, climate change, and escalating national and international business have severely disturbed evolutionary processes, gene flows, adaptive and regenerative capacities and increased geographical distances leading to irreplaceable loss of genetic/species/ecosystem diversity that took thousands of years to develop, wealth of gene pools and accelerated extinction of MPs. The concomitant loss of cultural diversity and traditional knowledge is largely ignored. It is feared that much of the traditional knowledge has been lost. Wild-gathered MPs suffered severe losses of population sizes, densities, and gene pools over the past decades. Substitution of threatened MPs with alternate species with identical curative properties or phytochemicals can relieve pressure on threatened MPs. Although recovery, conservation (in situ and ex situ), and cultivation programs have yielded some gains, they need to be further strengthened by governments and stakeholders through collaborative multi-stakeholder approach to preserve existing genetic diversity and prevent further genetic erosion, since not all MPs can be brought under cultivation immediately. This is particularly important for MPs as all reforestation programs concentrate on timber or commercial species in spite of the fact that minor-forest products' collection is more remunerative and less damaging to the ecosystem. Only a small fraction of all known MPs have been investigated for their genetic diversity and genetic erosion employing morphoagronomic, biochemical and molecular markers and enzymes. There is an urgent need to gather data on other MPs before it is too late. Conservation schemes should shun profit perspective and should include ecosystem and indigenous people's needs for their preservation and sustainability. Documentation (authenticity, traceability, accountability, legal authorization), certification (organic cultivation, quality control, social accountability; good collection, agricultural, manufacturing and business practices) labeling, and brand development are becoming increasingly important for wild-collected and cultivated MPs. Cultivation should be made profitable with easy market access. The initiatives undertaken by countries may lead to revision of number of MPs and their threat perceptions from time to time. Modern research may also place new species into MPs domain demanding regular supplies initially through wild collections. Use of modern technologies such as biotechnology, remote sensing, geographic information system, biodiversity informatics, computer simulation programs and databases will greatly help in devising recovery, conservation, and cultivation schemes. Existence of large number of species (>70,000) with inadequate research funds, loss of forests, ever increasing national and global demands, hype and hoax claims, genetic resource utilization with benefit sharing and patent conflicts are the challenges that need to be resolved for checking genetic erosion, preserving genetic diversity, cultural diversity, traditional knowledge, and genetic resources for posterity.

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