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Plant diversity and conservation in China: planning a strategic bioresource for a sustainable future

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China is one of the richest countries for plant diversity with approximately 33 000 vascular plant species, ranking second in the world. However, the plant diversity in China is increasingly threatened, with an estimated 4000–5000 plant species being threatened or on the verge of extinction, making China, proportionally, one of the highest priorities for global plant biodiversity conservation. Coming in the face of the current ecological crisis, it is timely that China has launched *China's Strategy for Plant Conservation* (CSPC). China has increasingly recognized the importance of plant diversity in efforts to conserve and sustainably use its plant diversity. More than 3000 nature reserves have been established, covering approximately 16% of the land surface of China. These natural reserves play important roles in plant conservation, covering more than 85% of types of terrestrial natural ecosystems, 40% of types of natural wetlands, 20% of native forests and 65% of natural communities of vascular plants. Meanwhile, the flora conserved in botanical gardens is also extensive. A recent survey shows that the 10 largest botanical gardens have living collections of 43 502 taxa, with a total of 24 667 species in *ex situ* conservation. These provide an important reserve of plant resources for sustainable economic and social development in China. Plant diversity is the basis for bioresources and sustainable utilization. The 21st century is predicted to be an era of bio-economy driven by advances of bioscience and biotechnology. Bio-economy may become the fourth economy form after agricultural, industrial, and information and information technology economies, having far-reaching impacts on sustainable development in agriculture, forestry, environmental protection, light industry, food supply and health care and other micro-economy aspects. Thus, a strategic and forward vision for conservation of plant diversity and sustainable use of plant resources in the 21st century is of far-reaching significance for sustainable development of Chinese economy and society.

ADDITIONAL KEYWORDS: bio-economy – *ex situ* conservation – garden flora – germplasm discovery – *in situ* conservation – nature reserves.

INTRODUCTION

China is one of the richest countries in terms of plant diversity, with a high percentage of the total number of plant species and high levels of endemism. China has approximate 33 000 vascular plants, ranking second in the world, of which more than half [50–60%; Mittermeier, Robles-Gil & Mittermeier, 1997; Liu *et al*., 2003; Ministry of Environmental Protection (MEP), 2003, 2008] are endemic to China. This tremendous plant diversity encompasses a huge number of species of pteridophytes (2322 species), gymnosperms (*c*. 250 species) and angiosperms (30 503 species), accounting for approximately 18, 26 and 10% of the world total, respectively (Table 1). The flora in China represents the living remnants of the early Miocene floras of the whole North Temperate regions and is the source of numerous crops and medicinal and horticultural plants. The ancient origin and complex composition of the flora of China has resulted in the presence of a large number of relic lineages of plant taxa, giving it a fundamental position in global plant diversity. Moreover, a long history of agricultural civilization and crop plant domestication in China has resulted in an enormous number of

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Table 1. The rich diversity of vascular plants in China according to plant groups*

	Family			Genus			Species		
Group	China	World	%	China	World	%	China	World	%
Pteridophytes	62	71	87	219	381	58	2322	13 025	18
Gymnosperms	12	15	80	42	79	53	250	980	26
Angiosperms	241	*c.* 400	60	3144	*c.* 10 000	31	30 503	*c.* 300 000	10

*Data were compiled based on several major sources for the *Flora of China* and on international databases of plant inventory and documentation.

cultivated germplasm resources of crops, vegetables, fruits and ornamentals. This reserve of natural treasure will be of crucial importance to humankind, serving as a primary bioresource for human living and sustainability of economic–social development and as an ultimate guarantee for the environment on which the survival of humankind depends [China's Strategy Plant Conservation Editorial Committee (CSPCEC), 2008].

However, rapid economic development and continuous population growth in China in the last 30 years have seriously damaged plant diversity and ecosystems, resulting in over-exploitation of plant resources and a dramatic increase in the number of endangered species. Plant diversity in China is increasingly threatened, with an estimate of *c*. 4000–5000 species being threatened or on the verge of extinction, proportionally making China one of the highest priorities for global biodiversity conservation.

The 21st century is predicted to be an era of bioeconomy driven by advances of bioscience and biotechnology. Bio-economy may become the fourth form of economy after agriculture, industry and information technology and is likely to have far-reaching impacts on sustainable development in agriculture, forestry, environmental protection, light industry, food supply, health care and other micro-economic aspects. Plant diversity is the origin and starting point of human knowledge and research and development relating to nature, access to bioresources and sustainable utilization. Bio-economy is different from the earlier forms of economy, which are less dependent on biological resources. whereas the bioeconomic era will involve the knowledge of nature, in-depth research and development, micro-creation (bio-industry), recycling, etc., and will represent the comprehensive integration of natural material resources, bio-functional resources, gene resources and bio-intelligent resources (bionic resource) at different levels, and it is hoped that the major expansion of integrated science and technology will provide renewable resources to support human economical and social sustainable development. Thus, a strategic and forward-looking vision for conservation of plant diversity and sustainable use of plant resources in the 21st century is of far-reaching significance for the sustainable development of the Chinese economy and society (Zhang & Huang, 2009).

GLOBAL SIGNIFICANCE OF PLANT DIVERSITY IN CHINA

The tremendous plant diversity in China of approximately 33 000 vascular plants (Table 1) should take a large proportional role in the *Global Strategy for Plant Conservation* (GSPC; Secretariat of the Convention on Biological Diversity, 2009).

Angiosperms

China has 241 families, 3144 genera and 30 503 species of angiosperms, representing approximately 60, 31 and 10% of the world total (Table 1). The four largest families (Orchidaceae, Asteraceae, Fabaceae and Poaceae) each have > 10 000 species, of which 7–10% occurs in China. In addition, China has 60 families with > 100 species. These 60 largest families represent basic components of the flora of China and encompass 19 700 species, approximately 80% of the China's total of angiosperms, which are widespread throughout the country. In addition, many genera with worldwide distributions have a large percentage of species occurring China; for example, *Saussurea* DC. has 320 species in China and 400 in the world, *Camellia* L. has 98 species in China and 119 in the world, *Primula* L. has 300 species in China and 500 in the world, *Gentiana* L. has 248 species in China and 360 in the world, *Ligularia* Cass. has 100 species in China and 150 in the world, *Corydalis* DC. has 300 species in China and 440 in the world, *Euonymus* L. has 125 species in China and 175 in the world and *Acer* L. has 150 species in China and 200 in the world (Flora of China, 2004).

Angiosperm diversity in China is well recognized by three significant characteristics, namely rich vegetation and forest types, palaeo-floristic origin and high endemism. These characteristics are underlined by geographical and climatic complexity creating tremendous diversity of habitats and ecosystems to nourish the plant diversity. Plants in different ecosystems are particularly diverse, ranging from alpine permafrost plants (e.g. *Phyllodoce caerulea* (L.) Bab.) to tropical rainforest plants (e.g. *Parashorea chinensis* H.Wang), from extreme xeric desert plants (e.g. *Reaumuria soongarica* (Pall.) Maxim.) to aquatic plants in marshes and wetlands (e.g. *Potamogeton* L.), from Himalayan cushion plants (e.g. *Androsace* L and *Pomatosace* Maxim.) to tropical mangroves (e.g. *Bruguiera gymnorhiza* (L.) Sav.) from the coast of southern China. This diversity reflects the continuous connection of tropical, subtropical, temperate and boreal forests, found only in China. Each climate zone harbours notable representative families and genera. For example, broadleaf deciduous forests dominated by Betulaceae, *Quercus* L. mixed with Salicaceae, Caprifoliaceae *s.l* and Berberidaceae are typical of the temperate zone, whereas evergreen forests dominated by Lauraceae, Magnoliaceae, Theaceae and Fagaceae mixed with Hamamelidaceae, Aquifoliaceae, Araliaceae and Nyssaceae and the monotypic families Cercidiphyllaceae and Tetracentraceae (= Trochodendraceae *sensu* APG III, 2009) are typical of the subtropical zone. Similarly, tropical forests in South China are well represented by many families of Dipterocarpaceae, Annonaceae, Burseraceae, Sapotaceae, Meliaceae, Clusiaceae, Combretaceae, Samydaceae (= Salicaceae *sensu* APG III, 2009), Euphorbiaceae and Datiscaceae.

The richness of the palaeo-floristic or primitive components in Chinese flora has been well recognized by the botanic community. These components include many relictual groups that are only found in China, notably in Magnoliaceae, Ranunculaceae, Trochodendraceae, Cercidiphyllaceae, Saururaceae, Chloranthaceae, Hamamelidaceae, Lardizabalaceae, etc.

The high level of endemism is one of the most significant features of the angiosperm flora. There are estimated to be approximately 250 genera and 15 000–18 000 species endemic to China, including many well known, such as *Bretschneidera sinensis* Hemsl., *Cercidiphyllum japonicum* Siebold & Zucc., *Euptelea pleiosperma* Hook.f. & Thomson, *Trochodendron aralioides* Siebold & Zucc., *Tetracentron sinense* Oliv., *Helianthemum soongaricum* Schrenk, *Tetraena mongolica* Maxim., *Liriodendron chinense* (Hemsl.) Sarg. *and Davidia involucrata* Baill., etc. This combination of a huge diversity of plants and associated unique features is of great significant and plays a fundamental role for global conservation for plant diversity.

GYMNOSPERMS

Although gymnosperms account for only *c*. 0.8% of all seed-bearing plants, they have a wide distribution and are major components of boreal and alpine forests in the Northern Hemisphere. The gymnosperm flora of China is one of the richest in the world, including 12 families, 42 genera and 250 species, and conifer forests account for 52% of the total forest area in China. The warm climate from the Mesozoic to the Cenozoic and the lower impact of Quaternary glaciations resulted in China being a favourable refugium, retaining a large number of ancient lineages and relictual and endemic taxa that disappeared in other parts of the world, for example the monotypic family *Ginkgoaceae* and the monotypic genera *Metasequoia* Hu & W.C.Cheng, *Cathaya* Chun & Kuang, *Pseudolarix* Gordon, *Pseudotaxus* W.C.Cheng and many relictual species of *Cycas* L.

PTERIDOPHYTES

The pteridophyte flora of China is probably most impressive in terms of number of families and genera, with a total of 62 families and 219 genera recorded in China accounting for 87% of all families and 58% of genera (Table 1). A total of *c*. 2322 species (out of 13 025 worldwide) are known, giving China the richest diversity in the world, 18% of the total. In addition, six endemic genera and 500–600 endemic species have been identified in China (MEP, 1998). South-western China is a recognized geographical distribution centre of Asia pteridophyte flora and it is one of the floristic diversity centres for pteridophytes. As many as 2000 pteridophyte species have been recorded in four provinces (Sichuan, Guizhou, Yunnan and Guangxi) in south-western China. In Yunnan province alone, there are approximately 1500 pteridophytes. Apparently, this region probably serves a centre of radiation, with reducing numbers of species in all directions: 700 species occur in the Indo-China peninsula (Vietnam, Laos and Cambodia), < 640 in Thailand, 550 in Malaysia, 1000 in Philippines, 639 in Japan, 600 in India, 430 in Australia and 420 in North America (Lu, 2004).

CROP PLANTS

During > 7000 years of agriculture, China has accumulated a rich genetic diversity of cultivated plants. China is one of the eight original centres of crop plants (Vavilov, 1951). Of approximately 1500 crop plants cultivated in the world, 300 crop plants originated or were domesticated and/or underwent differentiation in China. Notable examples include rice (*Oryza* L.) with 50 000 cultivars and landraces domesticated from three wild species (*O. rufipogon* Griff., *O.*

officinalis Wall. ex Watt and *O. meyeriana* (Zoll. & Moritzi) Baill.); wheat (*Triticum* L.) with 30 000 varieties or landraces, millet (*Setaria italica* (L.) P.Beauv.) with 25 000 varieties or landraces and soybean (*Glycine max* (L.) Merr.) with 20 000 varieties or landraces.

China also has a wealthy genetic pool of vegetables, with 14 000 documented varieties or landraces belonging to 229 species and 56 families, of which 135 species originated in China. Notable examples include the 50 most widely used vegetables, such as heading Chinese cabbage (*Brassica campestris* L. ssp. *chinensis* (L.) Makino var. *communis* Tsen & Lee), wuta cabbage (*B. campestris* L. ssp. *chinensis* (L.) Makino var. *rosularis* Tsen & Lee), purpurea cabbage (*B. campestris* L. ssp. *chinensis* (L.) Makino var. *purpurea* Hort.), Gongdong cabbage (*B. campestris* L. ssp. *chinensis* (L.) Makino var. *utilis* Tsen & Lee), taicai (*B. campestris* L. ssp. *chinensis* (L.) Makino var. tai-tsai Hort.), leaf mustard (*B. campestris* L. ssp. *chinensis* (L.) Makino var. *foliosa* Bailey), stem mustard (*B. juncea* var. *tsatsai* Mao), fat melon (*Benincasa hispida* Thunb. Cogn.), Chinese leek (*Allium tuberosum* Rottler ex Spreng.), Chinese green onion (*A. fistulosum* L.), chufa (*Eleocharis tuberosa* Schult.), etc. (MEP, 1998). In addition, there are about 200 wild vegetable species that could be further explored for the vegetable industry.

Equally impressive is that China is the country with the largest number of fruit and nut plants, more than 300 fruit crops belonging to 50 families and 81 genera, of which more than 50 originated or were domesticated in China; these include peach (*Prunus persica* L.), huangpi (*Clausena lansium* (Lour.) Skeels) and many other fruits (Li, 1998; Zhu, 2004). Moreover, the naturally occurring wild fruit and nut plants (a documented 1076 species belonging to 73 families and 173 genera) in China have tremendous potential for domestication and commercial cultivation. The largest genera of fruit and nut plants are *Rubus* L. including 196 species, *Ribes* L. 56 species, *Actinidia* Lindl. 52 species, *Rosa* L. 40 species, *Elaeagnus* L. 25 species, *Vitis* L. 23 species, *Cerasus* Mill. 22 species (= *Prunus* L.), *Quercus* L. 21 species, *Malus* Mill. 21 species, *Diospyros* L. 19 species, *Vaccinium* L. 18 species, *Castanopsis* (D.Don) Spach 16 species, *Viburnum* L. 14 species, *Crataegus* L. 13 species, *Ziziphus* Miller 13 species and *Pyrus* L. 12 species. These 17 largest genera encompass a total of 628 species, accounting for 60% of the wild fruit and nut plants native to China (Li, 1998).

Ornamental and gardening plants

China is well recognized as the 'mother of gardening'. There are more than 7500 ornamental and garden plants native to China. Many popular flowers and ornamentals over the world are from China or have centres of distribution in China. For example, *Camellia* L. has > 199 species in China, *Rhododendron* L. 600 species, *Syringa* L. 25 species, *Michelia* L. 35 species, *Magnolia* L. 30 species, *Deutzia* Thunb. 40 species, *Rosa* L. 80 species, *Paeonia* L. 11 species, *Dendranthema* (DC.) Des Moul. 35 species, *Cymbidium* Swartz 34 species, *Primula* L. 180 species, *Delphinium* L. 110 species, *Viburnum* 110 species and *Lilium* L. 30 species (Zhu, 2004). In addition, many well-known landscape plants are widely grown worldwide, including *Davidia involucrata*, *Ginkgo biloba* L., *Metasequoia glyptostroboides* Hu & W.C.Cheng, *Cathaya argyrophylla* Chun & Kuang, *Pseudotaxus chinensis* W.C.Cheng, *Emmenopterys henryi* Oliv., *Tsoonngidendron odorum* Chun, *Tapiscia sinensis* Oliv., etc.

Medicinal plants

China has a long history of using medicinal plants, dating back to the Palaeolithic period, and boasts more than 8000 medicinal plants (Encyclopedia of Chinese Agriculture Editorial Committee, 1990; Hamilton, 2004). At least 6000 species have been documented in the literature, including approximately 100 gymnosperm and 4300 angiosperm species. Within gymnosperms, different species in each family of almost all gymnosperms in China have been used as herbal medicines in one way or another; notable example includes ginkgo, *Cephalotaxus fortunei* Hook., *C. sinensis* Rehder & E.H.Wilson, *Taxus* L and *Ephedra sinica* Stapf. In the angiosperms, many families and genera have been investigated for medicinal uses. Notable examples include: Ranunculaceae, of which 39 genera and *c*. 700 species are medicinally used in China; Berberidaceae, of which 11 genera and 260 species native to China are medicinal plants; Papaveraceae, of which the majority of the 300 species belonging to 19 genera have been used as medicinal plants; Verbenaceae, with 21 genera and 180 species native to China, of which 80 species in 14 genera are used in herbal medicine; Campanulaceae, with > 150 species belonging to 17 genera in China, of which 50 species in 11 genera are documented in herbal recipes; Lamiaceae, with 800 species in 99 genera in China, of which 250 species in 50 genera are used medicinally; Apiaceae, with 500 species in 90 genera native to China, of which 150 species of 45 genera have been used medicinally; Zingiberaceae, with > 100 species in 19 genera native to China, of which 80 species in 12 genera are medicinal plants; Liliaceae *s.l.*, with *c*. 560 species in 60 genera in China, the majority of which are medicinal plants. Furthermore, plants in some small families such as

Aristolochiaceae are all used medicinally. There are many special well-known authentic Chinese herbal medicines, including *Panax ginseng* C.A.Mey., *Angelica sinensis* (Oliver) Diels, *Astragalus membranaceus* (Fisch.) Bunge, *Schisandra chinensis* K.Koch, *Glycyrrhiza uralensis* Fisch., *Ephedra equisetina* Bunge, *Coptis chinensis* Franch., *Fritillaria cirrhosa* D.Don, *Panax pseudoginseng* Wall., *Eucommia ulmoides* Oliv., *Rheum officinale* Baill., etc., and discovery of medicinal uses of more plant species continues (Zhu, 2004).

EXTINCTION CRISIS

Despite the great richness, the flora of China is coming under increasing threat from the country's explosive economic growth. Rapid industrialization, mammoth development schemes, intensive agriculture and the over-harvesting of timber and medicinal plants have taken an alarming toll on wild plants and the integrity of the ecosystem. The cumulative effect of these factors has been an unnerving tenfold leap in the number of threatened plant species since 1992, with up to > 15% of native plants in China now threatened or on the verge of extinction. Destruction and/or fragmentation of natural habitats are the most important causes of plant extinction. Habitats in all the different biomes of China have been subjected to modification and loss.

Destruction and fragmentation of natural habitats

Human disturbance and the resultant ecosystem degradation and habitat loss have severely threatened natural populations of many pteridophyte species as a result of rapid industrialization and urbanization in China over the past 30 years. Some species are in critical danger or in brink of extinction; for example, *Cystoathyrium chinense* Ching, *Cyrtomium hemionitis* H.Christ, *Trichoneuron microlepioides* Ching and *Isoetes sinensis* Palmer have either been considered as extinct in the wild or are even extinct.

Over-logging in the past 50 years has severely decreased the conifer forests in China and many gymnosperms are currently threatened and endangered. The majority of gymnosperm plants are a timber resource. The largest natural conifer forests in the Daxinganling, Xiaoxinganling and Changbai Mountains in north-east China have been over-logged, greatly reducing the natural reserves since the 1950s. Similarly, natural conifer forests in the Hengduan Mountains in south-west China were over-harvested since the1960s, with only patches of forests remaining on inaccessible mountain cliffs. The situation in central, east and south China is even worse because of high levels of economic development and the dense population, resulting in almost all natural conifer forests being logged and replaced by artificial planting of mason pine, Chinese fir and cypress. Deforestation and damage to natural habitats of conifer forests have changed the forest ecosystem and habitat environments, accelerating the rate of disappearance of many understory gymnosperms. Approximately 63 species (28% of the total) are threatened or endangered, including *Thuja sutchuenensis* Franch. and *Cycas taiwaniana* Carruthers, which are extinct in the wild, and many others that are close to extinction (notably the critically endangered *Cycas multipinnata* C.J.Chen & S.Y.Yang, *Keteleeria pubescens* W.C.Cheng & L.K.Fu, *K. oblonga* W.C.Cheng & L.K.Fu, *K. hainanensis* Chun & Tsiang, *Abies beshanzuensis* M.H.Wu, *A. yuanbaoshanensis* Y.J.Lu & L.K.Fu, *Picea montigena* (Mast.) Cheng ex Chen, *Pinus squamata* X.W.Li, *Cephalotaxus lanceolata* K.M.Feng, *Amentotaxus formosana* H.L.Li and *A. yunnanensis* H.L. Li, MEP, 1998).

The large Chinese population and a long history of exploitation of plant resources have imposed severe pressure on the diversity of angiosperm plants, because many angiosperm species are the targeted products of high-quality timbers, valuable medicinal herbs and economic crops. Angiosperm plants have suffered irremediable damage in the past. Many species have depleted to the brink of extinction by over-harvesting in the wild because of high-value products for herbal medicines, ornamentals and timbers, including many species of Orchidaceae, *Cinnamomum* spp., *Phoebe* spp., *Paeonia* spp., *Coptis* spp., *Ferula* spp., *Fritillaria* spp., *Juglans mandshurica* Maxim., *Phellodendron amurense* Rupr., *Fraxinus mandshurica* Rupr., *Erythrophleum fordii* Oliv., *Dalbergia odorifera* T.C.Chen, *Zelkova schneideriana* Hand.-Mazz., *Alseodaphne hainanensis* Merrill, *Hydnocarpa hainanensis* (Merrill) Sleumer, *Garcinia paucinenvis* Chun & F.C.How, *Panax ginseng* C.A.Meyer, *Dracaena cochinchinensis* (Loureiro) S.C.Chen, *Cistanche deserticola* Y.C.Ma, *Morinda officinalis* F.C.How, *Oplopanax elatus* Nakai, *Rhodiola sachalinensis* Borissova, etc.

Rare and threatened plants

Currently, 4408 vascular plant species are of urgent conservation concern and are included in the China Species Red List. These plants are widely distributed in 169 families and 1025 genera (Wang & Xie, 2004). Notably, Orchidaceae alone include > 1200 red-listed species. Many other plants are of great significance and of global conservation concerns. For example, Magnoliaceae has its centre of diversity in southern China (Cicuzza, Newton & Oldfield, 2007). Southern

China is the world centre of diversity and distribution of Magnoliaceae with over 40% of the species occurring there. A significant number are considered globally threatened because of habitat decline and over-exploitation. Of 42 Chinese *Magnolia* spp. recorded as being threatened (Cicuzza, Newton & Oldfield, 2007), 32 are endemic to China. China is also an important centre of diversity for oak species, with > 100 taxa. Oaks (*Quercus* spp.) are important components of the broadleaved evergreen forest in China. Fifteen species of Chinese oaks are recorded as threatened, with a further 11 species recorded as data deficient (Oldfield & Eastwood, 2007). South-west China is the global centre of diversity for maples (*Acer* spp.), with 115 of the taxa evaluated in compiling the Red List of maples out of total of 191 being Chinese. In addition, the closely related *Dipteronia dyeriana* Henry is considered to be threatened (Gibbs & Chen, 2009).

Over-exploitation of wild plant resources

In addition to habitat loss and modification, direct exploitation of plant resource is a serious threat to many Chinese plants. Groups of species that have been subjected to particularly intense exploitation pressures include trees which yield valuable timber, species harvested for gums, resins and fibres, ornamental species such as cycads and orchids, and plants harvested for their medicinal products.

Exploitation of timber resources in China has contributed both to the loss of forest habitats and pressure on the targeted species themselves. A notable example is *Picea neoveitchii* Mast., which was extensively logged from the 1850s to 1990s for its straight trunks of quality wood, resulting in its endangered status and destruction of associated vegetation. Dipterocarpaceae are another group of plants that have been depleted. Various species are important as a source of timber and also for the production of balsam. *Dipterocarpus retusus* Blume is now rare in Yunnan. The wood is heavy and is used for building houses. The tree is a source of a balsam used for caulking boats. Of the four species of *Hopea* Roxb. in China, two are considered under threat. The endemic *Hopea hainensis* Merr. & Chun is considered to be an endangered species of scattered occurrence. The durable wood is used for making boats and building bridges and houses. Other dipterocarp species threatened by a combination of habitat loss and felling for timber include *Vatica guangxiensis* S.L.Mo, a species occurring in Guangxi and Yunnan and in Vietnam, the wood of which is used for making boats, house construction and furniture, and *Vatica mangachapoi* Blanco, with wood used for similar purposes (MEP, 1998).

For ornamental plants, with the long tradition of gardening and appreciation of ornamental plants in China, harvesting from the wild has contributed to the decline of many species. This process was accelerated with the opening up of China to external horticultural exploration in the 19th century, and again with the rapid urbanization and increasing wealth in the late 20th century. Orchids, for example, have been heavily exploited worldwide by collectors. China has 1388 orchid species in 194 genera, with 11 genera and 491 species endemic to China. China has a long tradition spanning 2000 years of the use of orchid species in herbal medicine and a 1000-year tradition of orchid cultivation for ornamental horticulture. Ornamental orchids that have been subject to intense collecting pressures include the classic example of the genus *Cymbidium* Swartz (Du Puy & Cribb, 2007). Species commonly collected for sale include widespread species such as *C. goeringii* (Rchb.f.) Rchb.f, *C. sinense* (Jackson ex Andrews) Willd., *C. ensifolium* (L.) Sw. and *C. faberi* Rolfe, which are reaching the point of conservation concern in parts of their range. It has been estimated that approximately 60% of China's native cycads have been lost over the past 100 years, mainly as a result of collection for horticulture, particularly in the 1980s, and clearance of land for agriculture (Chen & Liu, 2004). Species that are close to extinction include *Cycas revoluta* Thunb. and *Cycas szechuanensis* W.C.Cheng in Fujian and *Cycas hongheensis* S.Y.Yang & S.L.Yang in Yunnan. A small population of *Cycas micholitzii* Dyer in Xinlong, Hainan province, has probably disappeared. In the past 3 years, *C. multipinnata* C.J.Chen & S.Y.Yang, *C. diannanensis* C.J.Chen and *C. debaoensis* Y.C.Zhong & C.J.Chen individuals have been significantly reduced in number (by *c*. 20–30%).

Exploitation of medicinal plants is even more intensive. Of the 600 plant species that are regularly used, only approximately one third are established in cultivation, which helps to prevent unsustainable harvesting from the wild (Ai, 2004). Wild harvesting of medicinal plants for local consumption and international trade continues to be a major threat to wild plant diversity in China. China is a major and growing manufacturing centre for medicinal plant extracts and finished products. These increasingly rely on cultivated material, but were initially based on the exploitation of plants from the wild. One typical example is *Fritillaria cirrhosa*. The bulbs of *F. cirrhosa*, called 'bei mu', are one of the most popular herbal medicines in China and are collected in the wild throughout the country. There is a huge annual demand for manufactured products of Chuan bei mu (authentic source from Sichuan province) produced mainly from *F. cirrhosa*; this has been estimated to be worth *c*. $US400m annually (figure from 2002–2003). The bulbs are dried, powdered and used as an infusion or made into pills to treat coughs and asthma. Several species are cultivated for traditional Chinese medicine in different parts of China (Leon, Fay & Rix, 2009). As commercial cultivation of this species has not yet proved successful, a major reintroduction programme of *F. cirrhosa* bulbs has been underway for the last 15–20 years in an attempt to repopulate the natural low-growing alpine scrub habitat of the species in the Ganzi district of Sichuan. Using bulbs grown in the nearby nursery from wild-collected seed, some 10 000 hectares of this habitat have been set aside for this natural fostering work and the potential to establish a sustainable harvesting programme in the future is considered to be promising (Leon, Fay & Rix, 2009).

Invasive species

China has a long history of introduction of non-native species, attributable to their potential economic value or other type of benefits (medicinal, ornamental, soil improvement, erosion control, landscaping, etc.). Fifty per cent of invasive alien plants were intentionally introduced for reasons of this nature. For comparison, 25% of alien animals were intentionally introduced. In a survey carried out from 2001–2003, 188 alien plants were recorded (Xu *et al*., 2004). Rapid growth in trade and transportation systems in China is increasing the introduction and spread of invasive species, leading to transformation in the structure of ecosystems (Ding *et al*., 2008).

One example of an invasive plant is *Tithonia diversifolia* A.Gray*,* an alien ornamental plant introduced from Central America, which has become widely naturalized in Yunnan, currently distributed in at least 64 counties, representing *c*. 60% of the province. *Tithonia diversifolia* probably first escaped and became naturalized in the 1930s (Wang *et al*., 2008). The naturalized populations of *T. diversifolia* in Yunnan are shrubs, most of which flower between October and February and fruit from late December. Mature plants can produce a large number of light-winged fertile seeds that can be readily dispersed by air, water, vehicles, human activity or on livestock. Human introduction for green manure, ornamentals and the intensive transportations all play an important role in the spread of alien invasive species, which are increasingly causing enormous environmental damage.

CHINA'S NATIONAL STRATEGY FOR PLANT CONSERVATION

Coming in the face of the looming ecological crisis, it was timely for China to launch its national Strategy for Plant Conservation (CSPC). This aims to tackle the plant conservation issues, demonstrating the firm commitment of China to the environment and to its international obligations as a signatory to the Convention on Biological Diversity (CBD). In developing the national strategy, the Chinese government has increasingly recognized the importance of plant diversity to the efforts of the country to conserve and sustainably use plant diversity and identified key areas of action for plant conservation. The Chinese national strategy and implementation has significantly enhanced CBD's efforts in the context of the strategy and the CBD 2010 Biodiversity Target.

The strategy is modelled on the GSPC targets, covers 16 targets focusing on four key themes. These themes span: (1) understanding and documenting existing plant diversity; (2) conservation of plant diversity; (3) sustainable use of wild plant resources; and (4) generating public awareness and education of plant diversity (CSPCEC, 2008).

Theme 1. Understanding and documenting existing plant diversity

In order to efficiently conserve the Chinese flora, it is vital to gain a thorough understanding of the current state of wild populations, present botanical collections and conservation efforts.

Current status

- China's vast flora has been documented in the *Flora Republicae Popularis Sinica*, with 31 142 species entries spanning 80 volumes and 126 published books, and the 12-volume *Flora of China*, available in English. Additionally, most Chinese provinces and municipalities have also published local floras, such as the 21-volume '*Flora of Yunnan*'.
- A 'virtual herbarium', an online resource containing scanned images of pressed plants and associated information, is under development.
- The first Red Data Book, a catalogue that lists rare species and those in danger of extinction, for Chinese plants was published in 1992. In 2004, the first volume of the *China Species Red List* was published.
- A number of models for the conservation and sustainable use of plant resources have been developed, tailored specifically to the local situation in China.

Actions planned include

- launching a new national survey of plant species and habitats, starting with key areas and groups of plants. This will include ensuring that recently discovered species are added to the flora and old records are verified. Significantly, this will incorpo-

rate a conservation assessment, focusing initially on known threatened plants, plants of economic importance and endemic species;
- accelerating the construction of China's National Herbarium and the development of a national network of herbaria;
- completing the development of the virtual herbarium and making digitized specimens available via the Internet;
- conducting a survey of the conservation status of plants both *in situ* and *ex situ* conservation programmes;
- completing the updating of the Plant Red List (a list of native threatened and endangered plants species);
- developing and scaling up models for the further conservation and sustainable use of plant resources in China.

Theme 2. Conservation of plant diversity

The strategy provides details of a comprehensive plan for conserving native plants, both *in situ* (in their native habitat) and *ex situ* (in managed collections). This dual method is considered the most robust approach to wildlife conservation, providing an important 'backup' against uncertainty.

Current status

- Since 1956, China has established > 3000 nature reserves, covering *c*. 16% of the land area. In addition, the large number of forest parks and small reserves provide a basis for the development of a network of *in situ* conservation areas for wild plants.
- Sixty-five per cent of higher plant communities in China, including most species under national key protection, are currently conserved in these nature reserves.
- To date, 160 botanical gardens and arboreta have been established in China, cultivating c. 70% of the native plants.
- A national Chinese seed bank of crop plants and a network of regional seed banks ensure the long-term genetic conservation of important crops such as rice and soya beans.
- A national medicinal plant genetic resource bank is currently being established.

Actions planned include:

- reviewing the current network of nature reserves to ensure that all of the major ecological zones are represented, with particular emphasis on desert, grassland and wetland ecosystems;
- launching assessments into the impact of proposed development projects on plant diversity;
- banning development projects in areas where pollution is deemed to be likely to have an impact on key biodiversity areas;
- establishing a wild plant monitoring system, the remit of which will include monitoring 90% of key conserved wild plants;
- establishing a national network of *ex situ* conservation centres, based in the 160 botanical gardens in China;
- ensuring the conservation of 70% of the genetic diversity of the major economic plants of China in seed banks.

Theme 3. Sustainable use of wild plant resources

Ensuring the sustainable use of wild plant resources is of key importance to conservation as unsustainable wild harvesting is often a key driver in the extinction of economically valuable species.

Current status

- China is a signatory to the Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES) and has enacted laws to prevent the illegal trade in endangered plants. Inspection stations have been established at all major ports to enforce these laws.
- Of the 600 plant species that are regularly used, sustainable cultivation systems have been developed for 200 species, thereby limiting their unsustainable harvesting from the wild.
- The first organic and 'green' product certification schemes in China have been introduced and are being actively promoted. These currently include > 12 868 Chinese products which have been certified as 'green'.
- Forest certification schemes that officially verify the 'green' credentials of sustainably sourced timber are under development.
- Several volumes of the China ethno-medicine encyclopaedia have been published. This publication officially catalogues the uses and preparation methods of a wide range of medicinal plants (Xiao, 2002; Ai, 2004).

Actions planned include:

- active state promotion of a wide range of sustainable agricultural practices, including organic growing;
- building ecological criteria into new development projects, including the construction of 10 000 new 'eco-villages';
- commissioning a study into the scale of the international trade in wild Chinese plants;

- initiating an aggressive crackdown on illegal logging and over-exploitation of medicinal plants and timber;
- strengthening support for the nascent development of forest certification schemes;
- actively promoting the cultivation of useful wild plant species, to relieve the pressure of harvesting on wild plant populations, including close monitoring of the populations of plant resources in the wild;
- systematically collecting and documenting traditional knowledge, particularly that of minority ethnic groups, as part of a broader effort to preserve traditional cultures.

Theme 4. Generating public awareness and education of plant diversity

Support at grass roots level is vital to the success of any major conservation project. Generating public awareness for plant conservation is particularly important in the Chinese context, as popular knowledge and support for environmental issues remain at a low level.

Current status

- Plant diversity conservation, as part of broader environmental education, has been incorporated into the Chinese primary and secondary school curricula.
- China runs a number of large-scale public environmental awareness campaigns each year. Tied to specific themes such as 'Tree Planting Day', 'Earth Day' and 'World Biodiversity Day', etc., these campaigns typically include the hosting of news conferences, international conventions and painting exhibitions.
- Forest parks, botanical gardens and nature reserves are overwhelmingly popular attractions in China and play a significant role in plant diversity conservation and education. In 2005, these facilities combined attracted > 440 million visitors.

Actions planned include:

- equipping every administrative level of the Chinese government with a wild plant conservation campaign branch;
- establishing a specialized plant diversity campaign team in each regional/local nature conservation institution;
- designating a national 'Wild Plant Conservation Day' as part of the existing calendar of large-scale state public environmental awareness campaigns;
- investing heavily in improving environmental campaigns and education websites and visual and audio databases, in order to modernize education and training approaches;
- establishing an environmental education system, such as 'green nursery schools', 'green schools' and 'green universities', and ensuring that environmental courses and lectures are incorporated into non-environmental fields.
- opening up Chinese botanical gardens to the outside world in order to exchange scientific knowledge and expertise with partners around the globe.

IN SITU CONSERVATION AND NATURE RESERVES

The philosophical ideology of nature conservation has a long history in China, and the conceptual ideology behind nature and wildlife protection could be dated back as early as the Zhou dynasty (1046–256 BC). The tradition of protecting holy places around Buddhist and Taoist temples and worshipped mountains still continues. The historical relationships between nature conservation and minority cultures evolved into a deeply rooted cultural diversity for nature protection, ranging from the exemplary conservation of holy land, holy mountains and holy trees to various styles of worshiping nature by many ethnic minorities in China (Yang *et al*., 2004). For example, in Xishuangbanna (Yunnan Province) some 400 'spirit mountains' with a total area of nearly 500 km^2 have historically been protected by Dai minority people (Walters & Hu, 2003). To cope with the urgent needs for mitigating increasing loss of plant diversity, a modern nature reserve network has been developing rapidly to ensure effective *in situ* conservation of Chinese native plants (López-Pujol & Zhao, 2004).

However, a nature reserve system based on modern concepts has only been developed in China since a little more than 50 years ago, with the symbolic flagship of Dinghushan Nature reserve being established by the South China Botanical Garden of the Chinese Academy of Sciences in 1956. Tremendous progress has been made in the last 30 years and, by 2007, there were 2531 natural reserves established, covering a total of 151.88 million hectares, accounting for 15.2% of mainland Chinese territory (Fig. 1). These natural reserves play important roles in plant conservation, covering 85% of the types of terrestrial natural ecosystems, 40% of the types of natural wetlands, 20% of native forests and 65% of natural communities of vascular plants. The numbers of natural reserves and area coverage already exceeds the world average and this achievement has been well received by the international conservation community. In addition, more than 50 wetland parks, 2151 forest parks, 187 national parks and approximately 480 provincial scenic spots and historical sites across the country have been established (MEP 2008).

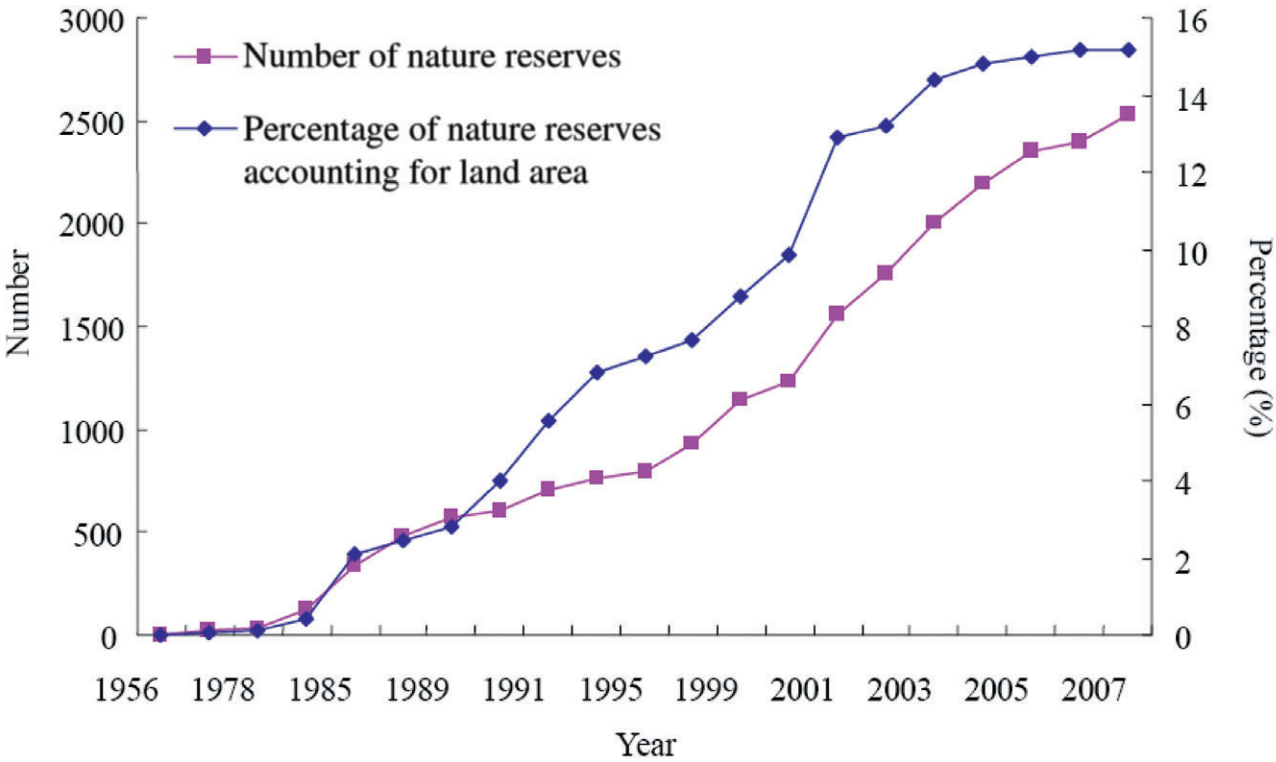

Figure 1. Increase in the number of nature reserves in China (MEP, 2008).

To date, > 3000 nature reserves have been established, covering *c.* 16% of the land surface of China. Of these, > 60% of nature reserves are designated for natural ecosystem protection, approximately 30% for wildlife and 1% for natural relics. Thus, high priority has been given to protection of various ecosystems, natural habitats and wildlife species in China. Chinese nature reserves are subdivided into nine categories, including forest ecosystems, grassland and meadow ecosystems, desert ecosystems, wetland and river–lake ecosystems, marine and coastal ecosystems, wild animals, wild plants, geological relics and palaeontological relics. Each category varies in different numbers and acreages. For example, forest ecosystems account for > 1000 nature reserves and > 20% of the land area covered by Chinese nature reserves, wetland and river ecosystems for > 200 nature reserves and > 10% land area and wild plants for approximately 140 nature reserves and > 6% area coverage.

With regard to *in situ* plant conservation, the nature reserves in the natural ecosystems and wild plants categories harbour a large number of plant species and a high percentage of the Chinese flora, with these nature reserves each hosting several hundred to > 3000 plant species. However, the exact number of plant species conserved *in situ* in the nature reserves is unknown because of the rapid increase in the number of nature reserves and the lack of complete inventories. It is difficult to assess how much overlap there is for plants conserved *in situ* in Chinese nature reserves, but, in general, the checklist for each nature reserve is available for data analysis and monitoring purposes. For example, the flagship Dinghushan Nature Reserve established in 1956, with a total area of only 1133 hectares, harbours *c.* 1900 plant species, of which 100 are rare and threatened. Many plants are keystone species with great value for scientific research and are conservation priorities for regional evergreen broadleaf forests.

One of the most impressive results for *in situ* conservation of plant species in Chinese nature reserves is the effective conservation of critically endangered plants, according to surveys conducted by the State Forest Administration (SFA) during 1997–2003, and recent statistics by the National Botanical Garden Working Committee of the Chinese Academy of Sciences. These surveys generated useful baseline data that provide valuable information for the status of 200 critically endangered plants with minimal population sizes. These species were of national or provincial top priority for protection and were evaluated using four criteria: (1) very few individuals in the wild, critically endangered and high risk of extinction in the wild; (2) niche habitats and extremely narrow distribution; (3) potential genetic value is unknown, but wild extinction will result in loss of gene flow and reduction of local diversity; and (4) potential ecological and social–economical values. More than 182 plant species with minimal population sizes are at high risk of wild extinction, including *Sinojackia xylocarpa* Hu, *Bhesa sinensis* (H.T.Chang & S.Y.Liang) H.T.Chang & S.Y.Lia, *Carpinus putoensis* W.C.Cheng, *Diploknema yunnanensis* D.D.Tao, Z.H.Yang & Q.T.Zhang, *Gleditsia japonica* Miq. var. *velutina* L.C.Li and *Abies beshanzuensis* M.H.Wu. Of the species assessed, 12 have minimal population sizes of < 10 individuals in the wild, 45 have 10–100 individuals, 68 species have 100–1000 individuals and 57 species have 1000–5000 individuals. Most of the species with minimal population sizes have one to three distribution sites, usually with very narrow distributions and niche habitats, and are highly vulnerable to any anthropogenic and environmental disturbance. Approximately 70% of these critically endangered and highly prioritized plants have been protected at different levels in Chinese nature reserves and categorized as national, provincial, city and county designated nature reserves. The remaining 30% of endangered plants are probably protected in either Chinese natural forest parks or small designated protection spots. However, an inventory and monitoring system for *in situ* conservation is not well developed and is urgently needed.

To further strengthen Chinese national needs for *in situ* conservation of plants, priorities have been set to: (1) improve the national system of nature reserves; (2) carry out pilot projects of establishing national nature reserves to enhance *in situ*-based management; and (3) improve *in situ* conservation outside nature reserves and establish a series of mini-nature reserves and conservation sites (MEP, 2008).

EX SITU CONSERVATION AND SUSTAINABLE USE OF PLANT RESOURCES

Ex situ conservation plays a key role in securing the conservation of plant diversity, not only as an insurance policy for the future, but also as a basis for restoration and reintroduction of threatened and endangered plants back to natural habitats. The most effective *ex situ* conservation measures are the conservation of living plants in botanical gardens (and arboreta) and field germplasm repositories and seed banks (Hawkins, Sharrock & Havens, 2008).

Historically, botanical gardens had major roles in plant introduction and conservation, botanical research and sustainable utilization of plant resources. Ancient Chinese gardens can, in all probability, be dated back to the Xia dynasty (2100–1600 BC) when unimproved wild species were used for ornaments, and even possibly before then to *c.* 2800 BC when the legendary Shennong established a medicinal garden, currently regarded as the earliest botanical garden in the world (Xu, 1997; López-Pujol, Zhang & Ge, 2006).

However, Western-concept botanical gardens designated for plant introduction, conservation and botanical research were first established during the 1920s–1930s. The first modern botanical gardens were established in Jiangsu Province (Nanjing Botanical Garden, 1929) and Guangdong Province (South China Botanical Garden, formerly South China Institute of Botany, 1929), but, before then, several botanical gardens had been established by westerners or colonial gardeners, such as the Hong Kong Zoological and Botanical Garden in 1861, the Hengchun Tropical Botanical Garden (Taiwan) in 1901, the Xiongyue Arboretum (Liaoning Province) in 1915 and the Taipei Botanical Garden (Taiwan) in 1921 (Xu, 1997; López-Pujol, Zhang & Ge, 2006). In general, botanical gardens in China have developed in four phases: 1950–1965 was the initiation phase, with 43 botanical gardens being established by 1965; 1966–75 was a slow development phase, when only approximately nine botanical gardens were developed as a result of the 10 years of the 'Cultural Revolution' period of social and economical instability in China; 1976–1990 was a booming development phase, when the number of botanical gardens increased rapidly to 123 by 1990; and 1991–present was a period of continuously rapid growth, up to a total of 160 botanical gardens (He, 2002) (Fig. 2). Most botanical gardens are located in the temperate region (42%) and subtropical regions (48%) of China, accounting for nearly 90% or 142 of the total of 160 gardens. In the past 10 years, more efforts have been put into establishing botanical gardens in southern and south-western China, where more centres of plant diversity and high plant endemism occur.

The Chinese Academy of Sciences (CAS), as the leading national academic organization in natural science, manages a total of 16 botanical gardens (arboreta) dedicated to the exploration, utilization and conservation of strategic plant resources. These 16 botanical gardens are distributed over 10 provinces or autonomous regions in China, occupying a total area of 14 000 hectares. The CAS botanical gardens are the largest group of botanical gardens devoted to *ex situ* conservation and implementation of the National Strategy for Plant Conservation and to botanical research, public education and tourist services. The ten main botanical gardens maintain living collections of 43 502 taxa (including varieties), with a total of 24 667 species in *ex situ* conservation when

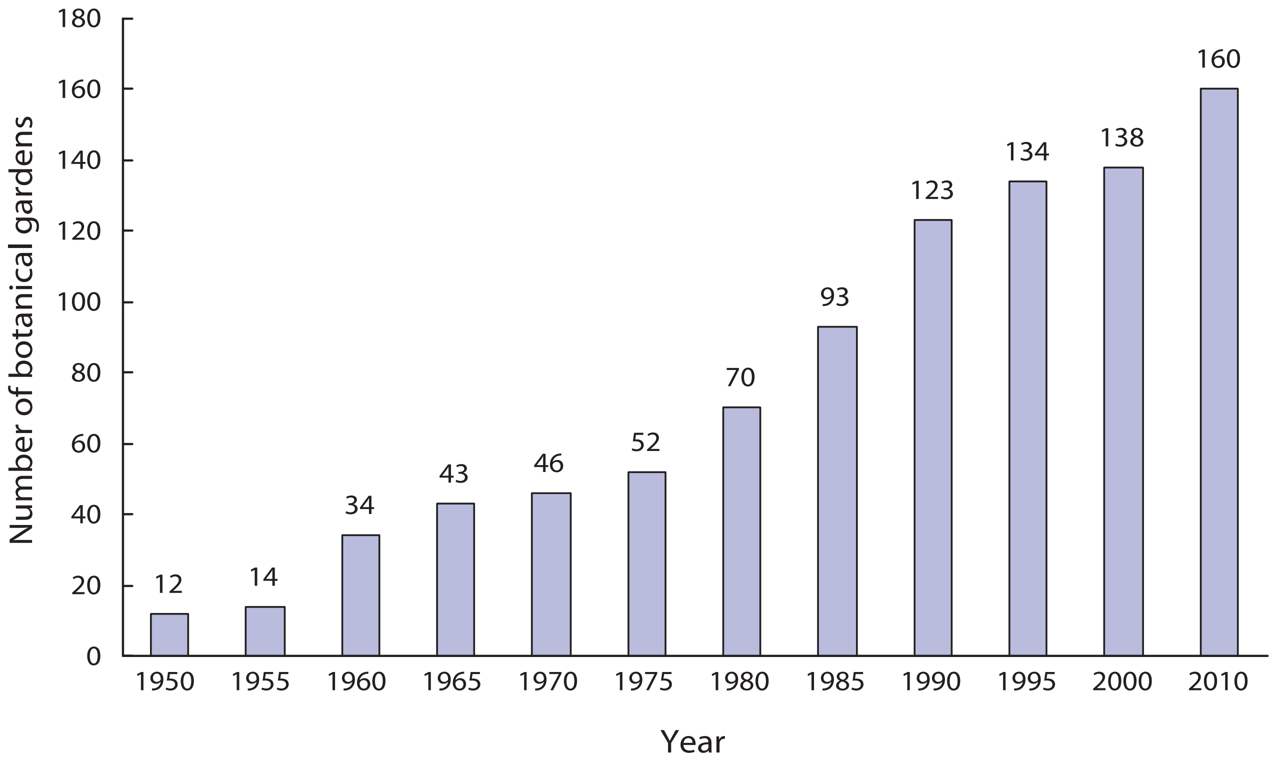

Figure 2. Increase in the number of Chinese botanical gardens in the past 60 years, updated from He (2002).

overlaps of taxa across these gardens are eliminated (Table 2). This accounts for approximately 95% of total *ex situ* conserved species of living collections in all Chinese botanical gardens. Apparently, with the enhancement of infrastructure and capacity in the past 10 years, the CAS botanical gardens have been well developed as national centres for *ex situ* conservation and sustainable utilization of plant resources. Of 24 667 plant species in *ex situ* living collections, an estimate of native Chinese plants is probably approximately 80%, the other 20% being introduced from outside of China. This provides an important reserve of plant resource for sustainable economic and social development in China.

Ex situ conservation has been highly emphasized in botanical gardens. In 1998, with the re-evaluation of the global view of China's role in plant conservation and sustainable use of plant diversity, the CAS developed a new strategy for botanical garden research and formulated a long-term master plan, moving the CAS botanical garden development forward into the 21st century. Subsequently, the CAS reorganized its botanical gardens and designated three National Core Botanical Gardens and also promoted the concept of Scientific Botanical Gardens. The CAS encapsulates its efforts for enhancement of its botanical gardens as a 'Supporting Platform for Innovation Research of Life Science' and initiated a 'Knowledge Innovation Programme' at the three core gardens, namely the South China Botanical Garden (SCBG), the Xishuangbanna Tropical Botanical garden (XTBG) and the Wuhan Botanical Garden (WBG). This marked the idea of establishing a National Scientific Botanical Garden in China. As the projects continue successfully, the capacity in science and technology innovation has shown great improvement in these core botanical gardens. In terms of *ex situ* conservation, the core botanical gardens have reinforced their efforts, and collection and conservation of resource-plant species have been extensively enhanced (Table 2). In the meantime, a large number of specialized collections have been renovated and enhanced for botanical research and germplasm discovery. The most well-known examples include SCBG holding the world's largest collection of Magnoliaceae with > 130 species, Zingiberaceae with > 120 species, Arecaceae with 382 species and the largest Chinese collection of bamboos (Poaceae) with > 200 species and WBG holding the world's largest collections of *Actinidia* with > 52 species and aquatic plants with > 800 taxa.

All these core botanical gardens have become important centres in China to conserve strategic plant resources important to the bio-industry. With their species conservation standard pegged to the demands of the nation for new source plants for development of agriculture, forestry, environmental

Table 2. Contribution of the ten main Chinese botanical gardens to the *ex situ* living collections for plant conservation in China (2009)

Botanical garden	Number of verified taxa*	Number of verified Red List plant taxa
South China Botanical Garden (SCBG)	7898	710
Xishuangbanna Tropical Botanical garden (XTBG)	7420	571
Wuhan Botanical Garden (WBG)	5023	652
Beijing Botanical Garden-CAS (BBG)	3463	177
Lushan Botanical Garden (LBG)	4378	229
Nanjing Botanical Garden (NBG)	2701	263
Turpan Botanical Garden (TBG)	490	26
Guilin Botanical Garden (GBG)	3843	445
Kunming Botanical Garden (KBG)	3330	423
Fairy Lake Botanical Garden (FLBG)	4956	441
Total number of verified taxa in *ex situ* collections	43 502	3973
	Number of verified species	Number of verified Chinese Red List species†
Total number of *ex situ* conserved in China	24 667	1633
Total number of *ex situ* conserved native plants in China	*c*. 19 334	1633
Total number of plant species recorded in China	33 000	388 (1992 Red List,); 4408 (updated in 2004)
Ex situ conserved % of the total number of species in China	59.8%	*c*. 100% of the 1992 Red List; 37% of 2004 Red List
% unduplicated across gardens	66.7%	46.48%
% duplicated across gardens	33.3%	53.52%

*Includes varieties.
†Plants on the Chinese Red List are currently considered as national conservation concerns, but most have not yet been evaluated under the IUCN Red List categories.

remediation and the newly emerging bio-industry, these core botanical gardens are also an important resource platform to serve social and economic sustainable development in China.

The flora conserved in botanical gardens is quite extensive and different regional native floras are represented across China, as most botanical gardens have emphasized the collection and conservation of the local or regional flora. Duplication of *ex situ* conserved plants across different gardens has been shown to be an insurance policy to safeguard unpredictable losses. Of 24 467 plants *ex situ* cultivated in the ten botanical gardens, 8215 species accounting for 33.3% have been duplicated in at least one other garden (Table 2). However, when considering duplication of numbers of taxa (including taxonomic entities below the species level) *ex situ* conserved in different regions, the percentage of duplicated number of taxa ranges from 51.4 to 71.6%, with an average value of 59.1% (Table 3) duplication. This is revealed as a highly focused conservation strategy on local flora where the botanical garden is located. Moreover, a high percentage of duplication within each region indicates regional duplication should be more important than duplication across China, because similarity of climates and environments within each region, rather than across different regions in China, should provide favourable conditions for *ex situ* conservation of living collections.

Conservation of rare and threatened plants has been prioritized in botanical gardens because *in situ* conservation cannot save all species, and *ex situ* conservation offers an effective supplementary conservation activity to *in situ* efforts (Hawkins, Sharrock & Havens, 2008). Major progress has been made by botanical gardens towards rescuing threatened and rare plants and it is estimated that all 388 species categorized as requiring national protection (eight species in the first grade, 159 species in the second grade and 211 in the third grade) (Fu, 1992) are included in *ex situ* living collections. However, species on a recently published red list of 4408 rare or endangered species (Wang & Xie, 2004) have not been extensively collected because this red list is not widely accepted and not finalized by Chinese government conservation agencies. Each of the ten main

Table 3. Number of plant taxa (including introduced taxa) and per cent duplication of *ex situ* living collections in Chinese botanical gardens located in different geographic regions*

Regions	Number of taxa (regional total)	Duplication	Red List taxa (regional total)	Duplication
South China	12 074	68.8%	996	85.0%
South-west China	9779	56.5%	839	72.7%
Central China	7740	64.6%	740	80.3%
North China	3463	41.7%	177	84.2%
East China	2701	71.6%	263	95.1%
North-west China	490	51.4%	26	57.7%
Average		59.1%		79.2%

*Includes varieties.

botanical gardens currently holds 26–710 rare and threatened plants (Table 2), accounting for an average 8.7% of total *ex situ* living collections. Some 1633 rare and endangered plants are maintained in the living collections of these gardens, accounting for 37% of the total 4408 plants recently updated. Obviously, gap analysis and re-evaluation of the *ex situ* conservation strategy is still urgently needed to ensure that they can act as a real safety net for rare and endangered species. A significant feature of *ex situ* conservation of rare or threatened taxa is much higher duplication in different regions, with average value of 79.2% (Table 3), which provides a safeguard against unpredictable losses. When each individual species is considered, 874 rare or threatened taxa have been backed up in at least one other botanical garden, accounting for 53.3% of the total rare or threatened plants conserved *ex situ* (Table 2). However, an assessment in depth for all plant species presently known to be threatened at the national level should be an urgent priority. Gap analyses should be also critical for selected groups of plant in *ex situ* collections as a basis for strengthening these and planning for restoration of key species [Botanic Gardens Conservation International, (BGCI), 2007].

While prioritization of *ex situ* living collections continues to be important, wide-scale seed-banking efforts have been taken rapidly, particularly in great concern over the changing climate where virtually all species are at risk. One of the progresses complementing the *ex situ* living collections is the construction of national seed banks. For example, the China Southwest Wildlife Germplam Genebank project, operated by the Kunming Institute of Botany, Chinese Academy of Sciences, by the end of 2009, included 31 199 accessions from 4781 plant species belonging to 1337 genera and 166 families. The goal of the gene bank is targeted for seed banking a total of 100 000 accessions and 10 000 plant species by 2020. In relation to crop diversity, the need for *ex situ* conservation of diverse crop material has been recognized as increasingly urgent – with a particular need to focus on crop wild relatives and local varieties of crops as a rich source of diversity and adaptive traits for extreme climatic conditions. The Ministry of Agriculture has established cold storage seed banks to safely conserve crop genetic resources. These seed banks include long-term, medium-term and duplicate cold-storage facilities of crop seeds, which have included 390 000 accessions of seeds of crop germplasm belonging to 450 species, 160 genera and 28 families. The seed banking efforts were initiated in China in the 1980s, when the No. 1 National Seed Bank was established in Beijing in 1983, with a capacity of 230 000 accessions of seeds. Then, a few years later, the No. 2 Seed Bank was established in 1988, with a capacity of > 450 000 accessions, and with what was a commitment to global germplasm conservation of *Brassica campestris* L., *B. campestris* ssp. p*ekinensis* L., *Raphanus sativus* L and *Triticum aestivum* L. [Ministry of Agriculture (MOA), 1995; Gu, 1998]. These efforts and construction have formed a basic national network of seed banking of crop seeds for the long term, including approximately 208 000 accessions of grain crops, 61 000 of rice, > 1000 for apples, pears and peaches, 25 000 of vegetables and 3000 of grass and green manure crops (MOA, 1995). In addition, 32 national field germplasm repositories designated for perennial and vegetatively propagated crops, mostly for fruit and nut crops and their wild relatives, have collected more than 1300 species of rare and endangered plants (MEP 2008). These efforts and measures have greatly enhanced the *ex situ* conservation capacity of crop diversity for food security.

In relation to the evaluation and sustainable use of plant resources, along with *ex situ* conservation, the CAS-affiliated botanical gardens also established 90 specialized gardens, which created a solid foundation for botanical garden research, conservation and utilization of plant resources. These efforts also greatly contributed to global conservation of genetic germplasm. Plant resources collected and evaluated by botanical gardens have made a significant contribution to developing new industries, fostering new economic growth and enhancing economic development. Historically, plant introduction and new cultivar development and research conducted in the CAS botanical gardens had made many significant innovations and in transferring technology to agricultural and industrial developments in China. Many new cultivars of plant resources in current agricultural industries are derived from the knowledge and technical support of early research conducted by the CAS botanical gardens. For example, the research and development achievement of the Chengdu Diao company, a CAS-founded enterprise, in developing a new cardiovascular drug, and the subsequent formation of the Chengdu Diao medicine cooperation, was originally initiated from a survey, collecting and evaluating peltate yam (*Dioscorea zingiberensis* C.H.Wright) resources in China by the CAS botanical gardens during the 7th and 8th 5-Year National Economic Plan periods (late 1980s–early 1990s). The project on the 'rubber–-tea intercropping system' run by the XTBG resulted in a total plantation area of approximately 133 000 hectares, contributing significant benefits to economic, ecological and social aspects. The new resource of dragon-blood plants (*Dracaena cochinchinensis* (Lourt) S.C.Chen) discovered by the XTBG ended the history of the importation of such herb medicines for China, with a dozen Chinese pharmaceutical factories manufacturing this Chinese traditional medicine regarded as 'King drug for blood circulation'. WBG bred and selected a series of new kiwifruit (*Actinidia*) and lotus (*Nelumbo nucifera* Gaertn.) root varieties, which have become the major varieties widely grown for fruit and vegetable production in China. A recently developed new yellow-flesh kiwifruit variety of Jintao has been patented in Europe and South America and the propagation right was licensed for 28 years worldwide. The cultivar has now been promoted in European kiwifruit production and marketing, which is regarded as a good model of China's intellectual property of new cultivars transferred to the international market. Subsequently, a 3R model 'Resource, Research, and Resolution' for the sustainable use of plant resources has been formulated for botanical gardens conservation and research.

In recent years, these three core botanical gardens have also filed more than 100 patents and developed or released more than 40 new cultivars for the agriculture, forestry and horticulture industries, contributing to new growth in these industries. The initiation of the *Knowledge Innovation Program* at the CAS core botanical gardens has not only stimulated science and technology innovation within CAS botanical gardens, but also provided guidance to other Chinese botanical gardens and has played a leading role for healthy development in botanical gardens all over China. Accordingly, these core botanical gardens have increasingly played an important role in the international botanical garden community and a leading position in Asian botanical gardens.

PROSPECTS AND PLANTS AS A STRATEGIC BIORESOURCE IN PLANNING A SUSTAINABLE FUTURE

Plants are the core component of biodiversity on earth, the primary source of material for human living and sustainable economic productivity and the ultimate guarantee of the environment upon which human survival depends. They are the fundamental sources for provision of human necessities, including food, timber, oil and medicine, and a source of spiritual needs. So far, we have only explored and utilized a small proportion of all plant species, and the potential of the vast majority of wild plants has yet to be understood and is still beyond human knowledge, despite their great economic and social values. Although we depend on plants for our livelihood and socio-economic development, the damage to plants by human activities has reached an unprecedented level, gravely threatening human survival. The impact of human destructive activities is taking its toll on nature and the current extinction rate of plant species is 2000 times faster than would normally occur in nature (Brooks *et al*., 2006).

One of the major challenges facing humanity in the 21st century is how to resolve the paradox of the increasing demand on plant resources (food, timber, natural medicines, energy, oil, fruit and vegetables, flowers, etc.) vs. our sustainability in the future. The convergence of our knowledge with the intention of solving this paradox is hopefully managed by developing the revolutionary bio-industry and bio-economy. 'An important species can affect a country's economy and a special gene can affect a country's prosperity' (Zhang & Huang, 2009). Botanic research, knowledge and technology innovation and sustainable utilization of plants in a country can be a reflection of its overall development and strength. In the 21st century, biological resources may be one of the most crucial resources for the globalized economical and societal sustainability. Whoever possesses rich plant resources, innovative knowledge and new technologies for plant conservation and sustainable utilization will have a distinct advantage.

CHINA'S NATIONAL CENTURIAL SURVEY OF PLANT DIVERSITY AND RESOURCES

With inadequacy and inaccuracy of information on the current status of plant diversity and resources in China, the current information is largely out of date for practical use, consistent with the rapid economical and social development. The initiation of the National Centurial Survey of Plant Diversity and Resources is one of the urgent tasks for biodiversity conservation and botanical research in China. The centurial survey will result in the completion of the country's report on the current status of Chinese plant resources that should provide a solid scientific basis for the formulation of the social and economic development strategies of China.

China's strategy for plant conservation beyond 2010

The richness of future plant diversity depends on how we act and what we conserve today (Hawkins *et al*., 2008). Although China has developed its national Strategy for plant conservation along the lines of GSPC (CSPCEC, 2008), the Strategy should be updated and reformulated for a broader scope and more achievable framework in an ongoing strategic plan beyond 2010, taking into consideration the increasing pressures on plant diversity and the underlying causes of plant diversity loss. To meet the future of economical and social sustainability in 21st century China, the updating and implementation of the new strategy beyond 2010 should ensure that: (1) China will be able to continue to rely upon plants for ecosystem goods and services, including food, medicines, clean water, climate amelioration, rich, productive landscapes, energy sources and a healthy atmosphere; (2) China secures the ability to fully utilize the potential of plants to mitigate and adapt to climate change, recognizing the role of plant diversity in maintaining the resilience of ecosystems; (3) the risk of plant extinctions caused by human activities will be greatly diminished and the genetic diversity of plants safeguarded; (4) the rich evolutionary legacy of plant diversity will be used sustainably and derived benefits will be enhanced to solve pressing problems, support livelihoods and improve social–economical development (Gran Canaria group, 2006; Hawkins *et al*., 2008). Conservation strategies should be prioritized.

Protected areas and in situ conservation

Defining priority areas is a crucial approach to formulate a sound national *in situ* conservation plan, because habitat protection is of great important to save plant diversity and individual plant species, particularly for plants in niche habitats. Based on extensive research and information available, a further *in situ* conservation plan and its implementation should emphasize the hotspots, ecoregions and centres of plant diversity by taking into consideration the sound scientific bases of the ecosystem, phylogeographical and/or refugium and biological corridor approaches.

Ex situ conservation and the Chinese garden flora

Ex situ conservation plays a key role in securing plant diversity, not only as an insurance policy for the future, but also as a basis for restoration and reintroduction of endangered plants into the wild. The increasing awareness of the impact of climate change on plant distribution *in situ* has made *ex situ* conservation more crucial. Moreover, endemic, rare and threatened species are especially vulnerable to extinction, as they are narrowly distributed in limited regions and/or with limited numbers of populations and small population sizes, which make them particularly vulnerable to changes in their habitats. While *ex situ* conservation priorities have continuously focused on threatened and endangered plants, the species that are more vulnerable to environmental and habitat changes in the overall background of climate changes deserve more conservation attention. Although 160 botanical gardens have been established in China and hold *ex situ* living collections of 24 667 plant species in total, they are still inadequate measures in percentage terms for representing Chinese native flora, genetic integrity and population diversity, assessment of genetic risks designated for recovery and restoration, low coverage of threatened and/or potentially threatened plants, etc. Priority in the national *ex situ* conservation strategy in future needs to be given to enhancement of *ex situ* living collections, including increasing coverage of Chinese native flora, replication backup, increasing the percentage of taxa directly collected from the wild and species integrity of the garden *ex situ* living collections. Immediate measures should be taken to collect the taxa more vulnerable to climate change in security of future losses. A nationwide inventory and documentation of garden living flora is urgently needed.

Research and sustainable utilization of plants

Although the birth of the 'garden' could date back to the Yin-Zhou dynasty in China, more than 3000 years ago, the modern concept of a botanical garden originated in Europe, nearly 500 years ago (the Padova Botanical Garden in Italy was established in 1545). In general, modern scientific botanical gardens in a sense started from the collection, evaluation and display of medicinal plants. The expansion started when the West began its colonization of the rest of the world, where plants were collected, introduced, domesticated, utilized and studied on an unprecedented large scale. Approximately a century ago, botanical gardens gradually emerged as integrated scientific institutions to conduct botanical research. In the 19th century, for example, the botanical research conducted by scientific botanical gardens, such as comparative morphology and comparative anatomy, made important contributions to the foundation of modern plant science. In the 19th century and the early 20th century, the Engler plant classification system was developed (Raven, 1981). Also, to a certain extent, most of the original research on agricultural or forestry species, medicinal plants and plant breeding resources stem from plant collection, evaluation and research in the early history of botanical gardens. However, modern life science has entered the era of molecular biology. Scientific researches in traditional botanical gardens now face a great opportunity and a serious challenge, particularly in the aspect of micro-botanical research.

- Strengthen capacity and scientific research. Botanical institutions and botanical gardens should take into account the current status of natural resources in China and the nationwide needs in shaping their position. While they should focus on the safety of plant resources and the sustainable utilization of plant resources in China, they should also support the sustainable development of the national economy and the establishment of a harmonious society in China. Botanical institutions and botanical gardens should reinforce the construction of specialized gardens of endemic and native plant resources (especially plants with economic and environmental potential). Focus should be placed on the selection, evaluation and sustainable utilization of and research into critical plant resources that are required by various bio-industries in China.

Enhancement of specialized gardens and related scientific research

To keep pace with social and economic development in China, botanical institutions and botanical gardens should further reinforce the construction of practical specialized gardens on the basis of current plant collections and enhance plant germplasm evaluation and discovery of useful plant genetic resources to meet social and economic development needs in China. These specialized gardens could include:

- Medicinal plant gardens. Considering the growing demand for health care by the Chinese population and, on the basis of the geographical distribution of medicinal plants and the traditional status of Chinese medicines, medicinal plant gardens and the discovery and research on medicinal plant resources should be reinforced. Botanical gardens should focus on research on medicinal plant resources that can serve as a health supplement, tonic or special regulatory medicines and provide such information and products to the industry and society.
- Industrial bio-energy plant gardens. Considering the demand of energy sources in China, the construction of gardens for industrial bio-energy sources and research on biodiesel plants should be enhanced. Botanical institutions and botanical gardens should focus on the research of biodiesel plant resources that are rich in carbon–hydrogen content. Research on biodiesel plant screening, evaluation and cultivation and applications for industrial uses should be encouraged.
- Landscaping and ornamental plant gardens. Considering the demand of urban landscape development and environmental improvement in China, and with the history of abundant endemic ornamental plant resources in China, the construction of gardens for landscaping and ornamental plants should be reinforced. Botanical gardens should conduct research on new cultivars of flowers, landscaping plants and turf that will be suitable for the different climate zones in China and for commercial production.
- Special fruit and vegetable gardens. Considering the demand for food quality and diversity from the national development of an affluent society in China, botanical gardens should discover more native plant resources to reinforce the construction of fruit and vegetable gardens, to develop and release new fruits and vegetables (such as special aquatic vegetables and healthy, medicine-functional fruit and vegetables).
- Specialized gardens of plant collections for degraded habitat restoration and environmental amelioration. Considering the demand for massive construction in China, resulting in damage to the environment, especially by mining, large-scale construction projects and urbanization, with the background in the selection and genetic improvements of pioneer native plants in China, botanical institutions and botanical gardens should set up specialized gardens to conduct research on useful tree and shrub species and improved cultivars.

A research and development platform of molecular biology that supports research in life sciences and modern comparative biology should be enhanced

For > 400 years of the development of modern biology, scientific botanical gardens have made significant contributions to comparative biology research, for example traditional comparative morphology, comparative anatomy and comparative physiology, etc. Modern life science and biotechnology researches have now entered into an era of molecular-level research. The substantial resource materials held by botanical gardens will provide valuable material and common-garden or intra-region research venues for the modern frontier of life sciences, such as comparative functional genomics, comparative phytochemistry and comparative proteonomics. Also, research on model genes and model plant species discovery should be considered in botanical gardens, taking account of enriched plant resources in *ex situ* collections. Intellectual property rights for new genes and new model species will be obtained so that the botanical gardens will become a fundamental research platform that will support modern life science and biotechnology in China.

Digitizing botanical gardens

A germplasm collection management system and an information-sharing system for a National Botanical Garden System of China should be set up in order to enhance the resource management within the botanical garden network, improve the efficiency on application, research and development and information exchange, and raise the level of popular science education of the public media.

- Develop a National Botanical Gardens information management protocol (policies and technical standard).
- Establish a digitized platform (geographical information system) on information management covering all Chinese botanical gardens.
- Develop an integrated national botanical gardens public science education website for public awareness and biodiversity and environmental education.

Botanical institutions and botanical gardens are undertaking to secure the safety of China's plant resources and ensure the sustainable use of these resources. They are vital in achieving these two missions. Meanwhile, through further refining the research scope in botanical institutions and botanical gardens, and strengthening both the networking and research facilities for botanical gardens in China, the safety of plant germplasm resources – especially endemic plants, critically endangered plants, species with high economic or scientific research value and keystone species in major ecosystems in China, and also the research and sustainable utilization of Chinese plant germplasm resources – can be realized, and can provide a solid foundation for the sustainable utilization of plant resources.

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