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Plant biodiversity in China: richly varied, endangered, and in need of conservation

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Abstract. China is among the world's richest countries in terms of plant biodiversity. Besides the abundant flora, containing some 33,000 vascular plants (30,000 angiosperms, 250 gymnosperms, and 2600 pteridophytes), there is extraordinary ecosystem diversity, as well as a large pool of both wild and cultivated germplasms. China is also considered one of the main centers of origin and diversification for seed plants on Earth, and is especially profuse in phylogenetically primitive taxa and/or paleoendemics due to the refuge role glaciation played during the Quaternary period. The collision with the Indian subcontinent significantly enriched Chinese flora and led to the formation of many neoendemisms. However, flora distribution remains uneven, and some local floristic hotspots are found across China, such as Yunnan, Sichuan and Taiwan. Unfortunately, this biodiversity faces enormous threats, which have increased substantially over the last 50 years. The combined effects of habitat destruction and/or fragmentation, environmental contamination, over-exploitation of natural resources, and to a lesser extent, introduction of exotic species, have caused irreparable damage to China's plant biodiversity. Burgeoning economic and population growth have also contributed to this deterioration. It is believed that up to 5000 flora species are currently endangered in China, with some taxa having already become extinct. Although in recent years government authorities have made some efforts to preserve biodiversity, much work remains to be done. While China has established an extensive network of nature reserves and protected areas, encompassing more than 16% of the total land area, insufficient budgetary and staffing commitments are common limitations in their management structures. *Ex-situ* conservation is also deficient, primarily because the botanical gardens are not representative of several local floras, nor are they often of adequate size or representative of endangered species. The lack of effective and efficient environmental legislation and education are also problems that continue to accelerate the loss of plant biodiversity in China.

Introduction: the significance of plant biodiversity in China

Biodiversity is the general term referring to the total sum of life's variety in a region, or indeed across the whole Earth. According to the Convention on Biological Diversity, three levels of biodiversity, all strongly inter-correlated, exist: ecosystem diversity, species diversity, and genetic diversity (Glowka et al. 1994). Even discarding ethical and aesthetic considerations, the loss of plant biodiversity poses enormous direct and indirect economic consequences, as plants are essential sources of food and medicines, among other uses. The over-exploitation of plant resources, in tandem with increasing habitat destruction and/or fragmentation, pollution, and introduction of exotic species, have led numerous plant species to the inevitable brink of extinction. Today, it is widely recognized that the rate of plant extinction has reached one species per day due to human activities, a rate some 1000–10,000 times faster than would naturally occur otherwise (Hilton-Taylor 2000), and a trend which may result in the disappearance of between 60,000 and 100,000 plant species during the next 50 years (Akeroyd 2002; Bramwell 2002). The latest investigations on the scope of the world's threatened flora suggest that as many as half of the world's plant species may be qualified as threatened by extinction under the IUCN criteria (Pitman and Jørgensen 2002).

China is one of the richest countries in plant biodiversity, ranking third in the world (after Brazil and Colombia) in the number of species (Anonymous 1996a; Liu et al. 2003), and one of the world's 17 'mega-diversity' countries (Mittermeier et al. 1997). The estimated number of vascular plant species is nearly 33,000, with 30,000 angiosperms, 250 gymnosperms, and 2600 pteridophytes (Table 1). Furthermore, approximately 2200 bryophytes can be found in China. There are more than 3000 different genera and ca. 334 families of angiosperms, about 42 genera and 11 families of gymnosperms, 231 genera belonging to 63 families of pteridophytes, and nearly 500 genera and 106 families of bryophytes (Lu 2004; Wang 2004; Wu et al. 2004a, b; Table 2). Nevertheless, these figures do not include data from either Taiwan or Hong Kong (see Table 3), which we discuss separately from mainland China due to their own idiosyncrasies. Taiwan, renowned as a 'Natural Botanic Garden' (Gu 1998), harbors more than 4000 vascular plants, with more than 3400 angiosperms, about 30 gymnosperms, more than 600

Table 1. Richness of Chinese flora (data are only for mainland China).

Taxa	Species in China (SC)	Species in the world (SW)	SC/SW (%)
Lichen	2000[c]	10,000[f]	20.0
Fungi	8000[b,d]	70,000[e]	11.4
Algae	8979[d]–12,500[a]	40,000[e]	22.4–31.2
Bryophyta	2200[a,b,c,d]	15,000[f]	14.7
Pteridophyta	2300[a]–2600[b, c, d, g]	13,025[f]	17.6–20.0
Gymnospermae	192[a]–270[d,i]	980[f]	19.6–27.5
Angiospermae	25,000[b]–30,000[c,d,h]	258,650[f]	9.7–11.6

[a]Li (2003).
[b]NEPA (1994).
[c]Xue (1997).
[d]SEPA (1998).
[e]Groombridge (1992).
[f]IUCN (2004).
[g]Lu (2004).
[h]Li (1996).
[i]Wang (2004).

Table 2. Endemicity of the Chinese flora (data are only for mainland China).

Taxa	Endemic species in China (ESC)	Known species in China (KSC)	ESC/KSC (%)	Endemic genera in China (EGC)	Known genera in China (KGC)	EGC/KGC (%)
Bryophyta	225[d]	2200[a,b,c]	10.2	8[b]–13[a]	494[b]–495[a]	1.6[b]–2.6[a]
Pteridophyta	–	2300[a]–2600[b,c,g]	–	5[b]–6[a]	224[a,b]–231[g]	2.2[b]–2.6[a]
Gymnospermae	79[f]	232[f] (192[a]–270[c])	34.0[f]	5[a,f]–8[b,h]	42[i] (34[b]–35[a,f])	14.3[a,f]–23.5[b]
Angiospermae	> 9000	27,403[f] (25,000[b]–30,000[c])	> 33.0	243[h] (232[b]–246[a])	3116[b]–3128[a]	7.4[b]–7.8[a]
Total	10,000[e]–18,000[c]	33,000	30.3–54.5	253[b]–270[a]	3868[b]–3882[a]	6.5[b]–6.9[a]

[a]Li (2003).
[b]NEPA (1994).
[c]SEPA (1998).
[d]MFC (2004).
[e]Fu (1992).
[f]Values calculated from data contained in FOC (2004).
[g]Lu (2004).
[h]Ying and Zhang (1994).
[i]Wang (2004).

Table 3. The Chinese 'hotspots'.

Hotspot	Area (in km^2)[1]	Vascular plants[2]	No. of vascular plants per 100 km^2	Angiosperms[2]	Gymnosperms[2]	Pteridophytes[2]	Bryophytes[2]
Yunnan Province	394,000 (4.1%)	16,600[a]/–	4.21	15,000[a]/–	100[a]/21[a]	1500[a]/–	1500[a]/–
Sichuan Province	488,000 (5.1%)	9500[b]/1467[b]	1.94	8711[b]/–	89[b]/14[c]	708[c]/–	–/–
Qinghai-Xizang Plateau	2,000,000 (20.8%)	12,000[d]/3500[d]	0.60	–/–	–/–	–/100[d]	641[e]/–
'South-Central China' hotspot	500,000 (5.2%)	12,000[f]/3500[f]	2.40	–/–	–/20[g]	–/100[g]	–/50[g]
NW Yunnan	70,000 (0.73%)	7000[h]/910[i]	10.00	–/–	–/–	–/–	–/–
Xishuangbanna	19,200 (0.20%)	5000[j]/–	26.04	–/150[a]	–/–	–/–	–/–
Three Gorges Area	53,200 (0.55%)	2859[k]–6388[l]/286[m]	5.37–12.01	2708[k]/–	41[k]/–	110[k]/–	–/–
Hainan	15,500 (0.16%)	4200[n]/630[n]	27.10	–/–	–/–	–/–	412[o]/–
Taiwan	36,000 (0.37%)	4077[p]/1067[p]	11.32	3420[p]/977[p]	28[p]/18[p]	629[p]/72[p]	900[q]–1404[o]/–
Hong Kong	1100 (0.01%)	2135[r]/25[s]	194.09	1911[r]/–	9[r]/–	215[r]/–	360[o]/–

[a]Yang et al. (2004).
[b]Li and Zhang (2002).
[c]SUU (1994).
[d]Miller (2003).
[e]Donoghue et al. (1997).
[f]Kelley (2001).
[g]CI (2004).
[h]Xu and Wilkes (2004a).
[i]Xu and Wilkes (2004b).
[j]Zhang and Cao (1995).
[k]YWRP (2004).
[l]Wu et al. (2003a, b).
[m]Xu et al. (2000).
[n]Carpenter (2001).
[o]Zhang and Corlett (2003).
[p]Hsieh (2003).
[q]Hallingbäck and Hodgetts (2000).
[r]Corlett et al. (2000).
[s]Groombridge (1994).
[1]In parentheses, percentage of the hotpots' area with respect total China's land.
[2]First value is the total number of species in the hotspot, second value is the number of endemic species to the hotspot.

pteridophytes and about 900 bryophytes (Hsu and Agoramoorthy 1997; Hsieh 2003). An area measuring only about 1100 km^2 and one of the most densely populated areas on Earth, the Hong Kong Special Administrative Region (HKSAR) retains a very rich plant biodiversity, with more than 2100 higher plants. Of these, ca. 1900 are angiosperm species and more than 200 are pteridophytes (Xing et al. 1999; Corlett et al. 2000). Moreover, about 360 bryophytes (Zhang and Corlett 2003) and 260 lichens (Wu 2002) have been reported in the HKSAR.

China encompasses enormous variations in geographical, climatological and topographical features, in addition to a complex and ancient geological history (with most of its lands formed as early as the end of the Mesozoic period). This country spans five climatic zones (cold-temperate, temperate, warm-temperate, subtropical, and tropical), and is home to the highest mountain ranges on Earth (the Himalayas), vast plateaus such as Qinghai-Xizang ('Tibetan'), deserts (e.g. Taklamakan), and at least in part, Asia's greatest rivers, including the Mekong, Brahmaputra, Yangtze, and Yellow rivers. All of these features contribute to the enormous diversity of habitats and ecosystems found in China, as well as to the vast species diversity described above. This ecosystem richness includes several types of forests (coniferous, broad-leaved, and mixed), grasslands, shrubs, meadows, deserts (covering up to 20% of the Chinese landmass), marshes, savannas, tundras, and alpine and snow ecosystems. Moreover, the vegetation of China remains unique in maintaining an unbroken connection between tropical, subtropical, temperate, and boreal forests (Qian 2002; Qian et al. 2003; FOC 2004).

China also contains a large pool of wild germplasms, including many primitive members in different plant groups (about 1200 primitive, relict, or monotypic genera currently found in China are already extinct in parts of the Northern Hemisphere; Fu 1992). Moreover, genetic diversity in cultivated plants is equally rich. China is one of the eight original centers of crop plants in the world (Vavilov 1951), with more than 200 originated and differentiated extant types (Gu 1998), resulting from more than 7000 years of agricultural activities (Chapman and Wang 2002; Hancock 2004). Notable examples include rice (*Oryza sativa*), which consists of some 50,000 strains and three wild relatives (*O. granulata*, *O. officinalis*, and *O. rufipogon*), soybeans (*Glycine max*), embracing about 20,000 strains in China, and wheat (*Triticum* sp.), with ca. 30,000 cultivars (SEPA 1998). Nearly 10,000 cultivars and crops breeds are cultivated in China. Of the nearly 300 fruit tree species belonging to the 81 genera and to the more than 50 families currently found in China, 50 species were domesticated in China (Zhu 2004). In addition, China boasts at least 400–500 wild species of vegetables, 379 wild species of oil plants, more than 200 wild species of starch plants and sugar plants, and about 200 wild species of aromatic plants (MOA 1995; Zhu 2004). It is estimated that as many as 2200 ornamental species belonging to 30 different genera originated in China (SEPA 1998), and nearly 11,000 species of medicinal plants have been in use since the Paleolithic period (Hamilton 2004).

Endemic and/or threatened species: current status

The flora in China is extremely rich and diversified, which has been attributed to the highly complex and extended geological and evolutionary history inherent to the Asian continent (Qian and Ricklefs 1999, and references therein). Determining the reasons for this exceptionally rich flora garnered widespread attention by botanists during the last decades of the 20th Century (Raven and Axelrod 1974; Latham and Ricklefs 1993; Axelrod et al. 1996; Guo et al. 1998; Guo 1999; Qian and Ricklefs 1999; Qian 2001; Tiffney and Manchester 2001; Qian 2002; Qian et al. 2003), briefly explained below.

One of the main features of Chinese vascular flora is its ancient origin. While the discovery of some primitive angiosperm fossil records dating from the early Cretaceous period in Liaoning, such as those of *Archaefructus liaoningensis*, as well as in the Heilongjiang provinces (Sun et al. 1998; Chapman and Wang 2002), lends credence to the belief that China was one of the areas of angiosperm origin, the lack of a continuous fossil record prevents the formation of any definitive conclusions. Regardless, what is clear is that China was a center of angiosperm diversification and evolutionary radiation (Takhtajan 1969; Wu 1989; Latham and Ricklefs 1993; Qian and Ricklefs 1999), due to its close connection to the centers of origin of flowering plants, most likely located in tropical regions of SE Asia (Morley 2000; Qian 2001). The link to southern tropical areas dates back at least 200 million years (Hallam 1994), and undoubtedly played a major role in enriching not only angiosperm, but also gymnosperm and pteridophytic Chinese flora (Guo et al. 1998).

Plate tectonics have greatly influenced the topographic and climatic modeling of China, thereby exerting tremendous influence over the country's floristics. China's landmass was formed from several tectonic plates originating from Laurasia and Gondwana. The initial collision of the Gondwanan terranes with what is now northern China in the Triassic-early Jurassic period, and the further impact of the Indian subcontinent during the Eocene period (Morley 2000; Qian 2001), are responsible for China having inherited elements of both Laurasian and Gondwanaland floras. Although China (and East Asia) were separated from western Eurasia by the Tethys Sea (the Turgai barrier), a land bridge linking eastern and western Eurasia ensured their connection more than ca. 35 million years ago (Hallam 1994), permitting a floristic exchange with Central Asia (and subsequently with the Mediterranean basin and even North Africa; Wu 1980; Qian and Ricklefs 1999). Moreover, the connection with North America via the Bering Sea land bridge allowed the migration of numerous species from these areas (Guo 1999; Qian et al. 2003).

Perhaps the most important force shaping the contemporary floristic richness of China is the climatic change that occurred during the Neogene period. The limited ice coverage in East Asia during the Quaternary glaciations (significantly milder than in Europe and North America, and limited only to northern areas north of 60′ N; Qian and Ricklefs 1999) enabled the Chinese paleocontinent to serve as a refuge for many ancient species, ensuring their survival to the present day. This fact, coupled to the close relationship that China shared with the evolutionary centers of vascular plants in tropical Asia (which served as a source for the introduction of new lineages), is responsible for the exceptional richness of several phylogenetically primitive vascular plant groups in China; e.g., pteridophytes, gymnosperms, Magnoliidae, and Ranunculidae (Qian and Ricklefs 1999; Qian 2001). Noteworthy is the presence of very old gymnosperm lineages comprising paleoendemics, most having become extinct long ago in other regions of the Northern Hemisphere. Many gymnosperms are monotypic or oligotypic, denoting an antiquity most likely stemming from relics or remnants of wider groups from the Tertiary period or even earlier (Qian 2001). Some examples of antique lineages include the pre-Jurassic Cycads; the Cretaceous Cercidiphyllaceae, Celastraceae, Magnoliaceae, Rhamnaceae, Tetracentraceae, Trochodendraceae, *Cephalotaxus*, *Picea*, and *Torreya*; and the Tertiary Bretschneideraceae, Calycanthaceae, Eucommiaceae, Myricaceae, Nyssaceae, Saururaceae, Simaroubaceae, Theaceae, *Cryptomeria*, *Cunninghamia*, *Ephedra*, *Keteleeria*, *Podocarpus*, and *Tsuga*.

Some of these paleoendemics (dating from the Cretaceous and Tertiary periods) have remained superficially unchanged for millions of years, thus earning the name 'living fossils' (Qian 2001). Examples include *Cathaya argyrophylla*, *Cycas panzhihuaensis*, *Ginkgo biloba*, *Glyptostrobus pensilis*, and *Metasequoia glyptostroboides*, all of which illustrate the ancient origin and persistence of endemic Chinese flora. Other 'living fossils', although not strictly endemic, include: *Amentotaxus yunnanensis*, *Cunninghamia lanceolata*, *Fokienia hodginsii*, *Keteleeria davidiana*, *Platycladus orientalis*, and *Taiwania cryptomerioides*.

The southwestern part of China is also the cradle of numerous neoendemisms, in addition to paleoendemisms. The collision of the Indian subcontinent with Asia has been postulated to explain the tremendous floristic richness of that area, with over 17,000 species of seed plants (Qian 2002). This collision, which took place during the Eocene period, resulted in the formation of the Himalayas and the surrounding mountain ranges, in addition to the Qinghai-Xizang Plateau. Moreover, it proved the genesis of the monsoon climate, of great importance for the further floristic development of the entire SE Asia region (Chapman and Wang 2002). One of these surrounding mountain ranges, the Hengduan Mountains, as well as the large watersheds of the Mekong and Salween rivers, became natural barriers preventing species from spreading, thereby favoring both variance and intense allopatric speciation processes (Wu and Wu 1996; Qian 2002). The vast array of new habitats created by the uplift of the Himalayas and surrounding mountains across a wide altitudinal range made this region not only a survival centre for relict species, but also in terms of speciation and evolution (Chapman and Wang 2002; Qian 2002). Some examples of this 'paradox' are the genera *Primula* and *Rhododendron*, present in the region before the Himalayan uplift and which became highly diversified through allopatry with the creation of numerous new habitats (Chapman and Wang 2002). Most species generated there penetrated further into the tropical and warm-temperate regions of eastern China, as well as the temperate and boreal regions of northern China (Qian 2002).

It is widely accepted that more than 10,000 higher plant species are currently endemic to China (Fu 1992; Pitman and Jørgensen 2002), with some estimates putting this number at 18,000 (Groombridge 1994; SEPA 1998). In fact, the Sino-Himalayan region is regarded as among the leading centers of endemism in the world, in addition to California, the European Alps, the Mediterranean region, the alpine regions of central Africa, New Caledonia, Hawaii, and the Cape region of South Africa (Kruckeberg and Rabinowitz 1985). There are many extremely narrow endemics, taxa with typically a few individuals restricted to only one locality, such as *Craigia kwangsiensis*, *Cycas szechuanensis*, *Magnolia zenii*, *Pinus squamata*, *Rhododendron liboense*, and *Ulmus gaussenii*. A few species have only one or two individuals; e.g., *Gleditsia vestita*, a taxon reduced to two individuals in Hengshan Mountain, Hunan Province (He 1998); *Carpinus putoensis*, with a sole plant located in Putuo island (Zhoushan archipelago, Zhejiang Province), discovered in 1930 and not subsequently found in any other locale (He 1998); and *Betula halophila*, with only one remaining tree in Balibagai (northern Xinjiang; IUCN 2004).

About 243 genera are endemic to China (Ying and Zhang 1994; see Table 2), as well as 4 families, the relict and monotypic Ginkgoaceae, Eucommiaceae, Davidiaceae, and Acanthochlamydaceae, although the latter two remain taxonomically controversial and some authors have moved them to lower ranks. In addition, nearly endemic families include the monotypic Bretschneideraceae, Rhoipteleaceae, Cercidiphyllaceae, Circaeasteraceae, Eupteleaceae, Tetracentraceae, and Trochodendraceae. Of the well-known endemic genera in China, most are monotypic or oligotypic, such as *Ajaniopsis*, *Cathaya*, *Changium*, *Craigia*, *Chuanminshen*, *Dysosma*, *Echinocodon*, *Glyptostrobus*, *Kingdonia*, *Metanemone*, *Metasequoia*, *Ombrocharis*, *Phaeostigma*, *Pseudolarix*, *Pseudotaxus*, *Schnabelia*, *Semiliquidambar*, *Sinojackia*, *Sinoleontopodium*, and *Tetrapanax*.

Perhaps the most well known example of endemism is the family Ginkgoaceae. Once widespread in the Northern Hemisphere, at present the family has only one living species: the dioecious *Ginkgo biloba*, a 'living fossil' due to its ancient origins (dating to the lower Jurassic period, about 190 million years ago) and high resemblance to fossil species from the Early Cretaceous *Ginkgo adiantoides* (Del Tredici et al. 1992). Taxonomically located within its own division (Ginkgophyta), *Ginkgo biloba* is cultivated worldwide for its horticultural value, timber, and medicinal properties. The only presumed wild population, although some doubt persists regarding its true 'wildness', is located in Tianmushan (Zhejiang Province), and contained only 167 individuals in the 1989 census (Del Tredici et al. 1992). Nevertheless, three additional populations have recently been proposed as wild: Wuchuanshan (Guizhou Province), Dahong (Hubei Province) and Longchou (Guangxi Province; Zheng et al. 2004). The endemic and monotypic genus *Cathaya*, also considered a 'living fossil' and occasionally referred to as the 'Panda' of the plant kingdom (He 1998), has a sole species, *C. argyrophylla*, discovered in 1958 in Huaping (Guangxi). Another example of a 'living fossil' is the endemic genus *Pseudolarix*, with one unique species (*P. kaempferi*).

Although not endemic to China, there are still many genera whose predominant species have been recorded there (Wu et al. 2003a, b). For example, nearly 650 *Rhododendron* species of the approximately 1025 distributed worldwide have been recorded in China, representing the country's largest plant genus (Ng and Corlett 2000). Other genera featuring a high species' richness are *Saussurea* (320 species found in China, 400 worldwide), *Pedicularis* (352 C, 600 W), *Camellia* (98 C, 119 W), *Primula* (300 C, 500 W), *Gentiana* (248 C, 360 W), *Aconitum* (211 C, 400 W), *Ligularia* (100 C, 150 W), *Delphinium* (173 C, 350 W), and *Corydalis* (300 C, 440 W) (FOC 2004). Moreover, China boasts the world's most highly diverse Bambusoideae subfamily (the 'bamboos'), with the principal centers located in southern China (Bystriakova et al. 2003). In fact, of the nearly 1500 species of bamboos known in the world, almost half (626 species) are found in China (Ohrnberger 1999).

A second issue concerning Chinese flora is its high level of endangerment. More than 3000 species are endangered at present (Fu 1992; Gu 1998), although some estimates place this figure at 4000–5000 (Wang 1992; NEPA 1994; Xu 1997). Unfortunately, some plant species (ca. 200 since the 1950s; Zhang et al. 2000) had already become extinct in China during the past decades and can actually only be found in the literature; e.g., *Adiantum lianxianense*, *Dalbergia sacerdotum*, *Ormosia howii*, and *Otophora unilocularis*, which are EX ('extinct') following the IUCN criteria (IUCN 2004). *Firmiana major*, a tree species that survives only as a few individual plants situated around temples and villages in Yunnan Province, is regarded as EW ('extinct in the wild'); its wild populations probably once existed in central and western Yunnan (IUCN 2004). *Rhododendron kanehirae*, which is native to Taiwan, is also considered EW. Nevertheless, many species remain on the brink of extinction, including *Abies beshanzuensis*, *Acer yangbiense*, *Archangiopteris itoi*, *Cycas hongheensis*, *Cycas debaoensis*, *Cystoathyrium chinense*, *Myristica yunnanensis*, *Nyssa yunnanensis*, *Parakmeria omeiensis*, and *Sonneratia hainanensis*.

Despite the fact that many species have been severely threatened by extinction for some time in China, it was not until 1984 that a national list of rare and endangered plant species was first published (Fu 1992), encompassing 388 species [8 listed as 'first grade' nationally protected (NPC-1), 159 species as 'second grade', and 221 species as 'third grade']. In 1992, the first volume of the *China Plant Red Data Book* was published, including all 388 of the endangered taxa warranting protection. Of these, 121 were listed as 'endangered', 110 as 'rare', and 157 as 'vulnerable'. The second volume of the *Red Book* is currently in preparation and will contain 640 additional species, with the third volume to follow soon after. Meanwhile, China promulgated, based on the request of the Statute of Protection of Wild Plants in China (implemented in 1997), the first compilation of the List of National Key Wild

Flora Under Protection in 1999, which included 419 species and 13 groups (3 families, 9 genera and 1 section), distributed into two protection categories. Category I (maximum protection) includes 7 species and 4 groups, while category II lists 352 species and 9 groups. However, only 675 taxa (species and subspecies) from mainland China have been evaluated in the *2004 IUCN Red List of Threatened Species*, with 474 classified into one of the threat IUCN categories (CR, EN or VU), and 4 already extinct (IUCN 2004). In the Taiwan and Hong Kong regions, 85 and 6 taxa are listed as threatened, respectively. These values far fall below the estimates noted above (up to 5000), suggesting a limited scope to the conservation studies of Chinese flora undertaken in recent years. Moreover, the plants that appear in the 2004 IUCN *Red List* are globally threatened; a regional assessment for all 675 evaluated taxa in China needs to be conducted.

Most areas of small range species co-occurrence (centers of endemism) are severely threatened by human activities and have suffered significant habitat loss; i.e., the 'biodiversity hotspots' (Myers et al. 2000; Brooks et al. 2002). Three of the 34 listed world hotspots in 2005 (Mittermeier et al. 2005) are located almost completely ('South-Central China') or partially ('Indo-Burma' and 'Himalaya') within China's borders. The South-Central China hotspot is mainly comprised of the Hengduan Mountains region, which comprises portions of southeastern Xizang (Tibet), western Sichuan and northern Yunnan. Although this area represents only 5% of China's total land mass, it harbors nearly half the total number (12,000) of all Chinese flowering plants, of which 3500 are endemic to this area (Kelley 2001) (Table 3). In addition, more than 200 genera are endemic to the Hengduan Mountains, including *Acanthochlamys*, *Anemoclema*, *Dipoma*, *Formania*, *Isometrum*, *Metanemone*, *Salweenia*, *Sinadoxa*, and *Skapanthus* (Chapman and Wang 2002). Nevertheless, it is home to only about 8% of the primary vegetation (Myers et al. 2000). This hotspot is most likely the botanically richest region – of comparable size – in the world's temperate zone (Kelley 2001). The Hengduan Mountains are recognized as an important Tertiary center of species diversification, as well as a refugium for certain Laurasian angiosperm groups (*Circaeaster*, *Kingdonia*, *Primula*, *Rhodiola*, *Rhododendron*, and *Saussurea*). The South-Central China hotspot is also very rich in medicinal plants, harboring more than 2000 species, mainly used in Tibetan medicinal drugs (Xu and Wilkes 2004a). Some of these are endemic; e.g., *Corydalis benecincta*, *Incarvillea forrestii*, *Lilium lophophorum*, and *Meconopsis speciosa*.

Due to its highly diverse geographical features and climate conditions (subtropical and tropical), Yunnan Province is home to more than half of the vascular plants in China, comprising nearly 17,000 species, whereas it only accounts for 4% of the total area. Of these, 15,000 are angiosperms, 100 gymnosperms, 1500 pteridophytes, and 1500 bryophytes (Yang et al. 2004) (see Table 3). Moreover, Yunnan flora is similarly characterized by a high degree of endemicity. Thirty angiosperm genera occur only in Yunnan (e.g., *Chaerophylopsis*, *Cyphoteca*, *Ferrocalamus*, *Manglietiastrum*, *Musella*, and *Siliquamomum*, among others; Guo and Long 1998). In addition to the northern section of the province, which belongs to the South-Central China world hotspot, the Xishuangbanna region, located in southern Yunnan and bordering Laos and Myanmar, belongs to the 'Indo-Burma' hotspot. It harbors approximately 5000 species of higher plants (Zhang and Cao 1995; Liu et al. 2002), with more than 150 endemic to Xishuangbanna (Table 3). This region also contains 94 species of bamboos (Chapman and Wang 2002). Due mainly to extensive deforestation, approximately 340 plant species are now recognized as threatened in Xishuangbanna (Zhang and Cao 1995), while about 600 have most likely been lost there (Liu et al. 2002). Hainan Island is also part of the larger Indo-Burma biodiversity hotspot, featuring high plant diversity with about 4200 species, 630 of which are endemic to the island (Carpenter 2001) (Table 3), and 50 of which are endangered.

Sichuan is the second-ranking Chinese province (including the Chongqing Municipality) in terms of plant biodiversity after Yunnan, containing about 9500 species of vascular plants from over 1600 genera distributed in 230 families. Of these, 8711 are angiosperms, 89 are gymnosperms (Li and Zhang 2002), and 708 are pteridophytes (SUU 1994; see Table 3). Sichuanese flora also contains numerous relict and/or endemic species; among the vascular plants, 1467 species are endemics (Li and Zhang 2002). Xizang, with lands crossing two world biodiversity hotspots (South-Central China and Himalaya), represents yet another biodiverse plant-rich area, harboring 9600 species of vascular plants. Nevertheless, the biogeographical area to which belongs, the Qinghai-Xizang Plateau, contains over 12,000 species distributed in 1500 genera of vascular plants. Of these, about 3500 species and at least 29 genera are endemic to the Plateau, including ca. 100 pteridophytes (Miller 2003) (Table 3), although at least 40 species are seriously endangered.

The Taiwan and Hong Kong regions can also be regarded as 'local hotspots'. Taiwan, mainly due to its insularity, has a rich flora of endemic taxa (about one-quarter of the total flora; i.e., 1000–1100 taxa; Gu 1998; Hsieh 2003) (see Table 3), including *Abies kawakamii*, *Amentotaxus formosana*, *Calocedrus formosana*, *Camellia hengchunensis*, *Chamaecyparis formosensis*, *Cycas taitungensis*, *Keteleeria davidiana* var. *formosana*, and *Lilium formosanum*. The *Red Book* of Taiwan lists 502 species, of which 3 are already extinct, 14 are endangered, 62 are vulnerable, and 423 are listed as rare (TESRI 2004). In only the last twenty years, 11 species have been added to the Taiwanese *Red Book*. Approximately 400 species (57 pteridophytes, 4 gymnosperms, and 339 angiosperms) of vascular plants are considered very rare in the Hong Kong SAR (Corlett et al. 2000), with some severely threatened, including *Aristolochia westlandii* and *Diospyros vaccinioides* (both are CR based on the IUCN criteria; IUCN 2004). Hong Kong also contains examples of endemic flora; e.g., the recently described species *Asarum hongkongensis* and *Balanophora hongkongensis* (HKISD 2004), as well as the rarities *Bulbophyllum tsaenum*, *Macromitrium brevituberculatum*, *Osmunda mildei*, and *Syrrhopodon hongkongensis* (Chau et al. 2000; Zhang and Corlett 2003).

Threats to Chinese plant biodiversity

Natural processes, such as demographic, genetic, and environmental stochasticity, may threaten or directly cause the extinction of plant species. Catastrophes (e.g., floods and storms) are relatively frequent in some areas of China and can easily cause local extinction of plant populations. Nevertheless, these processes are often enhanced by the impact of anthropogenic activities, resulting in negative synergic effects on biodiversity. The main human threats to the Chinese plant biodiversity, both directly and indirectly, are described below.

Habitat destruction

Destruction and/or fragmentation of natural habitats are the principal causes of species extinction. China has experienced in the past, particularly from 1950s onward, a tremendous loss of natural habitats, mainly due to the over-logging of forests (for timber, fuel wood and paper), as well as from the conversion of both forests and grasslands into croplands. Forests are among the most severely affected ecosystems, with an estimated deforestation rate of 0.6% per year throughout the 1990s (Dinerstein and Wikramanayake 1993). Some areas have suffered a dramatic reduction in forest coverage; e.g., the rainforest on Hainan Island covered 25.7% of the total area in the early 1950s; 30 years later, this coverage had decreased to 10.6% (Chen and Chen 1998). The forest cover of Xishuangbanna has also diminished, from more than 60% to less than 30% (Zhang and Cao 1995). Indeed, approximately 70% of the natural forests from the three largest coniferous areas in China (Da Hinggan Ling, Changbai Mountains and southwestern Hengduan Mountains) have been cleared (SEPA 1998). Throughout China, however, forest cover has progressively increased over the last 40 years due to afforestation and/or reforestation campaigns. In 1962, forest cover measured around 9.0% of the total land, while in 1981 it had increased to 12.0%, and then to 16.5% by the end of 2002 (World Bank 2001; SEPA 2003). Nevertheless, nearly all of these new plantations, which replaced logged natural forests, have been mono-specific, often consisting of exotic species, and greatly diminishing the biodiversity value of the original forestlands (World Bank 2001; Xu and Wilkes 2004a). The progressing expansion of the desert in the northeastern provinces (Xinjiang, Inner Mongolia, Gansu, Xizang, and Qinghai) is a direct consequence of the massive conversion of grasslands into crop fields, especially during the 1960s and 1970s. At present, China exhibits the highest ratio of actual to potential desertified land in the world (2,620,000 km^2 are suffering desertification of a total 3,320,000 km^2 susceptible to desertification; Gu 1998; World Bank 2001). About 67,000 km^2 of grasslands from the 1950s to 1970s were converted into farmlands as part of the national food self-sufficiency policy, and it is estimated that about 34% of grasslands are moderately to severely degraded, with ca. 90% degraded to some degree (World Bank 2001). Grasslands destruction has palpable consequences even in urban areas; e.g., the increasing incidence of dust storms in Beijing. Moreover, the loss of vegetation cover and the subsequent erosion of soil and water (the estimated area subjected to erosion is approaching 3.67 million km^2 – 38% of the country's land – and increases 10,000 km^2 annually; Zhang et al. 2000; CBD 2004) may contribute to the incidence of such natural disasters as floods and landslides, which have significantly increased in the past 40 years. For instance, the devastating floods in the middle reaches of the Yangtze River and in northeastern China in 1998 are believed to have been caused, at least in part, by the deforestation of river catchments in those areas (Zhang et al. 2000; World Bank 2001).

Environmental contamination

Environmental contamination is responsible for severe habitat degradation, potentially compromising species survival. The most problematic issue is the air pollution stemming from the extensive use of coal as the main energy resource in China, accounting for 70.7% of the total energy consumption in 2002 (World Bank 2003). Most SO_2 and suspended particulate emissions originate from this source. SO_2 emissions increased from 19 Mt in 1989 to 26.2 Mt in 1996. However, their levels decreased to 20.8 Mt in 2000, a reduction of about 21% (Streets et al. 2001), due to the combined effects of declining coal consumption and improving pollution controls. The effects of acid deposition, primarily associated with SO_2 emissions, have proven severe in the most industrialized areas (south, central, and east China), where the yearly average values of acid rain pH are less than 5.0 (with peaks as low as 2–3). In fact, they have brought about the disappearance of some lichen species from cities and forests near the pollution sources (SEPA 1998). CO_2 emissions, mainly originating from coal use, may contribute to the widely supposed global climate change now ongoing, due to their 'greenhouse' effect. While the growth in CO_2 emissions has proven significantly less than was previously projected, it still remains significant (22% increase during the period 1990–1996; Streets et al. 2001). Indeed, a simulation with doubled CO_2 concentrations in a climate change model would result in dramatic alterations to the current ecosystem distribution, as well as the migration of numerous species northward (Chen et al. 2003). Nevertheless, a slight reduction (about 7.3%) was detected during the years 1996–2000; a trend also exhibited by black carbon (2.2% reduction from 1997 to 2000), and CH_4 emissions (a decrease of 32% from 1995 to 2000) (Streets et al. 2001), which may ameliorate this conjectural scenario.

Over-exploitation of species for human use

The over-exploitation of species of economic interest may seriously threaten their survival. For example, though protected by law, certain plants used in

Traditional Chinese Medicine (TCM) are still over-collected. More than 5000 plant species are often used in TCM (Liu 2001); in 1990, traditional Chinese doctors prescribed ca. 700,000 tons of plant material (Xiao 1991). Furthermore, other kinds of traditional medicine also make extensive use of plants, such as Tibetan medicine (up to 3600 plant species). Overall, it is estimated that more than 11,000 species are used in China for their medicinal properties (Hamilton 2004). Among the 426 herbal, unprepared, or stir-baked drugs listed in the 1995 edition of the *Pharmacopoeia of the People's Republic of China*, 28 are included in the *China Plant Red Data Book* because of their threatened status. However, 49 additional plants listed in the *Red Book* are also extensively used in TCM (Peng and Xu 1997). Other valuable medicinal plants similarly protected by law, such as *Dendrobium candidum*, *Gastrodia elata*, *Cistanche deserticola*, *Panax ginseng*, *Boschniakia rossica*, and *Oplopanax elatus*, are dwindling in wild habitats due to over-collecting. Moreover, despite widespread cultivation in China there are some species whose wild populations remain severely depleted, both in number and size (e.g., *Ginkgo biloba* and *Juglans regia*). In addition to medicinal plants, non-timber forest products have been subjected to over-collection as well, including edible mushrooms (e.g., *Tricholoma matsutake*) and some orchids (e.g., *Paphiopedilum*) for their horticultural value.

Other human activities, such as fuel wood collection and timber procurement, have severely affected some forest species. Of the 8000 tree and shrub taxa in China, about 2000 are timber species (World Bank 2001). Fuel wood still serves as the main source of heating in rural mountain areas, constituting nearly 70% of their total energy consumption. About 1300 km^2 of forest in NW Yunnan disappear annually due to fuel wood collection (Xu and Wilkes 2004b); in Diqing Prefecture (NW Yunnan) alone, a total of 600,000 m^3 of fuel wood are collected each year (Xu and Wilkes 2004a). Some of the most threatened species include *Haloxylon ammodendron*, *Cistanche deserticola*, *Dalbergia odorifera*, *Tetraena mongolica*, and *Sophora moorcroftiana*. Until the logging ban of 1998 (around 300 million m^3/year) – implemented as consequence of the Yangtze River floods – China's forests resources had less than 10 years of remaining life (World Bank 2001). Nonetheless, illegal commercial logging still occurs on a small scale, and it is estimated that about 80 million m^3 are illicitly logged nationwide every year (CEPF 2002). This is particularly egregious in Yunnan Province, where the actual cutting volume (including timber and fuel wood) is over 40 million m^3, despite reductions in the state's logging limit to 3 million m^3 in 1998 and to 0.83 million m^3 in 2000 (Yang et al. 2004).

Introduction of exotic species

China has a long history of introducing non-native species for their potential economic value or other supposed benefit (medicinal, ornamental, soil improvement, erosion control, landscaping, etc). The first species introductions took place more than 2000 years ago and comprised *Carthamus tinctorius*, *Medicago sativa*, *Punica granatum*, *Tamarindus indica* and *Vitis vinifera*, among others (Xie et al. 2001). China is a country particularly vulnerable to invasive species as its wide range of suitable habitats and environmental conditions affords the establishment and spread of new species (Xie et al. 2001). The first batch of invasive alien species in China was recently (2002) approved by the government and contains 16 taxa (SEPA 2003). However, in a preliminary review of alien invasive species made by Xie et al. (2001), approximately 380 species of vascular plants that have become invasive in China were identified. Some alien species have been introduced to restore the natural vegetation without any previous assessment of their potential damage to local ecosystems. For example, *Sonneratia apetala*, native to Bangladesh, has been used to reforest mangroves in the Dongzhaigang Nature Reserve in Hainan Province (Xie and Li 2004). Some of the invasive species most hazardous to native flora are *Eichhornia crassipes*, *Alternanthera philoxeroides*, *Eupatorium adenophorum*, *Spartina anglica*, *Lantana camara*, and *Mikania micrantha*. *Alternanthera philoxeroides* is one of the world's worst tropical aquatic weeds, spreading artificially in China as pig fodder beginning in the 1950s, although it escaped from cultivation since the 1980s. At present, it can be found in 20 provinces, forming dense mats that float on the surface of ponds and lakes, shading the indigenous aquatic vegetation from sunlight (Ye et al. 2003). *Eupatorium adenophorum* is a perennial shrub that has invaded large areas in southern China, displacing the native flora. Its incidence is especially severe in Yunnan, where it covers an area of 247,000 km^2 (Xie et al. 2001). In addition to plants, mammals, birds, mollusks, insects and microorganisms have also caused damage to native plant biodiversity. Examples include nutria (*Myocastor coypus*), the sulphur-crested cockatoo (*Cacatua sulphurea*), rainbow lorikeet (*Trichoglossus haematodus*), the giant African snail (*Achatina fulica*), the pine scale (*Hemiberlesia pitysophila*), the fall webworm (*Hyphantria cunea*), the vegetable leaf miner (*Liriomyza sativae*), and the North American pinewood nematode (*Bursaphelenchus xylophilus*), among others.

Lack of effective environmental legal protection

The Chinese government bears a major responsibility for the tremendous losses in plant biodiversity in the past but still at present. Development policies have historically been focused on the exploitation of natural resources. These include the 'Great Leap Forward' (1959–1960), a period in which communities were encouraged to be self-sufficient in steel, with entire forests cut down for fuel wood. During the Cultural Revolution (1966–1976), campaigns for local self-sufficiency in grain, in tandem with the lack of logging controls, permitted the clearing of most forests. Another cause of deforestation is the repeated changes in forestland ownership. After the land nationalization and communization of the 1950s, a household responsibility system was introduced in 1978 that continues to the present day. These changes have brought uncertainty to land ownership policies; indeed it is sometimes difficult to know into which of the main ownership categories – i.e., state, collective or household – a forestland falls, all of which has abetted illegal logging. In fact, sudden changes in ownership policy have historically been linked to significant increases in exploitation of forest resources (Xu and Wilkes 2004a).

Following the adoption of the country's 'open-door' policies in 1978, the government began to legislate environmental protection and biodiversity conservation. While some laws and regulations have been incorporated into the legal system, they do not ensure adequate protection of plant biodiversity. The intended scope of this legislation is to manage the use of natural resources, and not their conservation while also coping with the growing problem of enforcement (Li 1998). For instance, the environmental impact assessment, introduced into legislation 20 years ago, still lacks effective implementation, and is typically only applied to large construction projects.

Economic and population growth

China's economic growth over the last two decades has reached the highest rates of GDP (gross domestic product) in the world (an average of 9.4% during the period 1979–2002; World Bank 2003), leading to strongly increased demands on the country's natural resources. In fact, their exploitation has proven ecologically unsustainable, particularly in the last five decades. One of the best examples is the construction of Three Gorges Dam, which will flood over 600 km of the Yangtze main channel, an inundation area totaling of 28,000 km^2 when finally filled in 2009 (Park et al. 2003). It will affect about 550 species, forcing the disappearance of entire plant populations including such botanically interesting species as *Buddleia lindleyana*, *Buxus harlandii*, *Dimocarpus longan*, *Distylium chinense*, *Eriobotrya japonica*, *Hibiscus syriacus*, *Litchi chinensis*, and *Trachycarpus fortunei* (Anonymous 1996b; YWRP 2004). Three taxa will sustain major damage: *Adiantum reniforme* var. *sinense*, *Chuanminshen violaceum*, and *Myricaria laxiflora*, as all are endemic to the Three Gorges area. Fortunately, a series of conservation measures has been planned for these taxa, including the establishment of species-specific reserves (for the three former taxa) and the maintenance of germplasm banks (YWRP 2004) Translocation of individual *Myricaria laxiflora* from populations that will be flooded to new locations is currently underway, while that of *Adiantum reniforme* var. *sinense* has already been planned (Huang 2005).

Economic development has involved the construction of numerous industries and the growth of new road networks (about 25,000 km of new motorways have been built in the last decade). The unprecedented rise in the per capita income and living conditions experienced by Chinese people (e.g., the poverty incidence has declined from 49% in 1981 to 7.8% in 1999; World Bank 2003) has generated a new industry, domestic tourism, with the subsequent construction of new hotels and holiday resorts, often located close to areas of natural and scenic interest or even inside nature reserves (J. López-Pujol, pers. obs.). Improving accesses to these natural areas – via the construction of new roads and cable cars – has contributed to habitat degradation, since it has created an enormous influx of visitors. For example, the construction of a new motorway linking Zhongdian with Kunming (Yunnan) will greatly facilitate tourist access to the Three Parallel Rivers area (J. López-Pujol, pers. obs.), probably one of the world's least disturbed temperate ecological areas. The number of visitors in Huangshan Mountain has increased from 280,000 in 1979 to more than 1 million in 2001 (Eagles et al. 2001). As a consequence of tourism's impact in these areas, some species are now threatened, including the lichen *Phizoplaca huashanensis*, an endemic species of Huashan Mountain (Shaanxi Province), or the moss species *Actinothuidium hookeri* and *Hylocomium splendens* in Emei Mountain (Sichuan Province; SEPA 1998).

Population growth, which has slowed since the implementation of the one-child policy, still remains significant. At present, the estimated total Chinese population is ca. 1300 million, and is predicted to rise to 1480 million by 2025 (World Bank 2001). Moreover, given the expected economic growth (China may become the world's largest economy by 2041 in terms of GDP; Wilson and Purushothaman 2003), the demands on natural resources per capita will increase exponentially. Numerous species, particularly those of economic value (agricultural, medicinal, timber), will suffer from increasing direct (over-exploitation) and indirect (land conversion by farming, industrialization, or urbanization) effects, placing them on the verge of extinction.

Past and current conservation measures

China has a long history of nature conservation; the first rules concerning wildlife protection may well predate the Zhou period (1122–221 BC; Edmonds 1994). Historical conservation of the lands surrounding Buddhist and Taoist temples, as well as their 'sacred mountains', by monks has preserved these areas intact until the present day. Moreover, there is a clear link between biodiversity conservation and minority cultures in China; indeed, the conservation of Holy Places, Holy Mountains, and Holy Trees by several ethnic minorities is well known (Yang et al. 2004). There are, for example, 400 'spirit mountains' in the Xishuangbanna region (Yunnan Province), an area totaling nearly 500 km^2, which have historically been protected by local communities of Dai nationality (Zhu 2001; Walters and Hu 2003). However, modern nature conservation began late in China, and can be divided into *in-situ* and *ex-situ* measures, as described below.

In-situ *conservation*

The development of modern protected areas in China can be divided into four main stages: 1956–1965, the initiation; 1966–1974, stagnation and devastation; 1975–1978, restoration; and 1979-present, a period of rapid growth (Lü et al. 2003). China's first nature reserve was founded in 1956 at Dinghu Mountain in Guangdong Province (Gu 1998). In 1957, the Wanmu Nature Reserve was established in Fujian Province, and in 1958, the Xishuangbanna Nature Reserve in Yunnan. Seven years later, up to 19 nature reserves had been established, encompassing an area of about 0.7% of the total Chinese land surface (Gu 1998). By the end of 2003, there were a total of 1999 nature reserves, covering a total area of 1,439,800 km^2; i.e., more than 14% of the nation's surface (SEPA 2003). Most have been established in the last two decades (see Table 4), comprising the principal governmental measure for protecting China's biodiversity.

All nature reserves in China are placed into one of three categories based on their function; i.e., natural ecosystems, wildlife, and natural relicts. Besides nature reserves, there are two types of protection also recognized by Chinese law: natural parks and scenic spots. A natural park in China differs from a nature reserve in that conservation of the ecosystem and biodiversity ranks equally with public enjoyment as the primary purpose (Gu 1998). The first

Table 4. Evolution of nature reserves in mainland China.

Year	Number	Area (km^2)	Percentage of Chinese territory	Number of national nature reserves
1956	1	11	–	–
1965	19	6488	0.07	–
1978	34	12,650	0.13	–
1982	119	40,819	0.43	–
1985	333	193,300	1.99	–
1987	481	237,495	2.47	–
1989	573	270,630	2.83	–
1990	606	400,000	4.00	–
1991	708	560,660	5.85	77
1993	763	661,840	6.80	–
1995	799	718,500	7.19	99
1997	926	769,790	7.64	124
1999	1146	845,090	8.80	155
2000	1227	982,100	9.85	155
2001	1551	1,298,900	12.9	171
2002	1757	1,329,500	13.2	188
2003	1999	1,439,800	14.4	226
2010[a]	1800	1,550,000	16	220
2050[b]	2500	1,728,000	18	–

Sources: Gu (1998) and SEPA (2003).
[a,b] are expected values (SFA 2004).

natural park, Zhangjiajie National Forest Park (Hunan Province), was established in 1982 (Gu 1998). By the end of 2002, there were 1078 forest (including grasslands and wetlands) parks, totaling more than 98,000 km^2. Scenic spots, selected for their visual value, can also serve to protect plant diversity, and in 2002, about 690 scenic areas had been established in China, covering some 96,000 km^2 (Anonymous 2003). In addition, there are more than 50,000 small-protected areas, covering an area of nearly 14,000 km^2 (Zhu 2001). Thus, taking into account all the protected areas described above, the total protected land amount rises to ca. 1,650,000 km^2, which represents about 16.4% of the Chinese national territory. Nevertheless, many protected areas include villages, farms, grazing lands, and plantations, wherein the effectively protected land is substantially lower. Seventeen Ecological Function Protection Areas have recently been proposed, encompassing 7% of the total land area, although they would overlap many other protected areas (Xie 2003a).

Nature reserves, natural parks, and scenic spots fall under four administrative management categories: national, provincial, municipal (or prefectural), and county-level. National nature reserves (226 of the 1999) are those with a significant international influence and/or special value for scientific research. Some protected areas have received international recognition: 26 have been designated as Biosphere Reserves under UNESCO's Man and the Biosphere Program; 8 are Natural World Heritage Sites; and 30 have been designated globally significant wetlands under the RAMSAR Convention (see Table 5 and Figure 1). One of China's 'flagship' protected areas is the Xishuangbanna Nature Reserve, established in 1958. With a total area of 2070 km^2, it covers more than 10% of Xishuangbanna Prefecture (Yunnan Province), and despite having lost about 40% of its forest cover (CNCMAB 2004), harbors about 3500 species of higher plants, of which 300 are considered rare. In addition, these small areas are home to 200 species of food plants, 100 species of oil plants, 50 bamboo species, 300 plant species of medicinal interest, and 30 'living fossil' species (Nepal 2000).

Established in 1960, the Tianmushan Nature Reserve (Zhejiang Province) is one of the most famous protected areas in China due to its remarkable number of large trees. Also known as the 'kingdom of big trees', with an area of only 42.84 km^2, this reserve is believed to contain one of the wild populations of *Ginkgo biloba* (Del Tredici et al. 1992). In addition, there are exceptionally large trees of *Cryptomeria japonica* var. *sinensis*, *Cyclocarya paliurus*, *Emmenopterys henryi*, *Liquidambar formosana*, *Litsea auriculata*, *Nyssa sinensis*, *Pseudolarix kaempferi*, and *Torreya grandis*. The reserve is also very rich in plant biodiversity, containing about 2160 species of higher plants (Tang and Hegde 2001), with 29 taxa included in the *China Plant Red Data Book* (Del Tredici et al. 1992). The existence of Buddhist temples in the area since antiquity has probably preserved this 'holy mountain' to the present time.

In the last 20 years, Taiwan has developed a complex network of protected areas geared towards conserving its plant and animal biodiversity, which accounts for 19.5% of the total land area. To date, 6 national parks, 19 nature

Table 5. Internationally recognized protected areas in China.

Name	Location (province)	Area (km^2)	Date of inscription	Type of protected area under Chinese laws	Number in the map[a]
Natural World Heritage Sites					
Huanglong	Sichuan	700.00	1992	Nature Reserve/ Scenic Spot	1
Jiuzhaigou Valley	Sichuan	720.00	1992	Nature Reserve	2
Mount Emei and Leshan Giant Buddha	Sichuan	154.00	1996	Scenic Spot	3
Mount Huangshan	Anhui	154.00	1990	Scenic Spot	4
Mount Taishan	Shandong	250.00	1987	Scenic Spot	5
Mount Wuyi	Fujian	999.75	1999	Nature Reserve	6
Three Parallel Rivers of Yunnan Protected Areas	Yunnan	16,984.00	2003	Nature Reserve/ Scenic Spot	7
Wulingyuan	Hunan	264.00	1992	Scenic Spot	8
Biosphere Reserves					
Baishuijiang	Gansu	2137.50	2000	Nature Reserve	9
Baotianman	Henan	909.50	2001	–	10
Bogeda	Xinjiang	1286.90	1990	–	11
Changbai Mountain	Jilin	1964.65	1979	Nature Reserve	12
Dalai Lake	Inner Mongolia	7400.00	2002	Nature Reserve	13
Dinghu Mountain	Guangdong	11.33	1979	Nature Reserve	14
Fanjing Mountain	Guizhou	383.00	1986	Nature Reserve	15
Fenglin	Heilongjiang	283.53	1997	Nature Reserve	16
Foping	Shaanxi	350.00	2004	Nature Reserve	17
Gaoligong Mountain	Yunnan	2935.64	2000	Nature Reserve	18
Huanglong	Sichuan	1380.00	2000	Nature Reserve/ Scenic Spot	19
Jiuzhaigou Valley	Sichuan	1060.90	1997	Nature Reserve	20
Maolan	Guizhou	213.30	1996	Nature Reserve	21
Nanji Islands	Zhejiang	206.29	1998	Nature Reserve	22
Qomolangma Mountain (Everest)	Xizang	33,800	2004	Nature Reserve	23
Saihan Wula	Inner Mongolia	1005.06	2001	–	24
Shankou Mangrove	Guangxi	80.00	2000	Nature Reserve	25
Shennongjia	Hubei	704.67	1990	Nature Reserve	26
Tianmushan	Zhejiang	42.84	1996	Nature Reserve	27
Wolong	Sichuan	2000.00	1979	Nature Reserve	28
Wudalianchi	Heilonjiang	–	2003	–	29
Wuyi Mountain	Fujian	565.27	1987	Nature Reserve	30
Xilin Gol	Inner Mongolia	10,774.50	1987	Nature Reserve	31
Xishuangbanna	Yunnan	2417.00	1993	Nature Reserve	32
Yading	Sichuan	–	2003	–	33
Yancheng	Jiangsu	2800.00	1992	Nature Reserve	34
Ramsar Sites					
Bitahai Wetland	Yunnan	19.85	2004	Nature Reserve	35
Chongming Dongtan	Shanghai	326.00	2002	Nature Reserve	36
Dafeng (*Elaphurus davidianus*) Reserve	Jiangsu	780.00	2002	Nature Reserve	37
Dalai Lake	Inner Mongolia	7400.00	2002	Nature Reserve	38

Table 5. Continued.

Name	Location (province)	Area (km^2)	Date of inscription	Type of protected area under Chinese laws	Number in the map[a]
Dalian Spotted Seal (*Phoca vitulina*) Reserve	Liaoning	117.00	2002	Nature Reserve	39
Dashanbao	Yunnan	59.58	2004	Nature Reserve	40
Dongdongtinghu	Hunan	1900.00	1992	Nature Reserve	41
Dongzhaigang	Hainan	54.00	1992	Nature Reserve	42
Eerduosi	Inner Mongolia	76.80	2002	Nature Reserve	43
Eling Lake	Qinghai	659.07	2004	Nature Reserve	44
Honghe	Heilonjiang	218.36	2002	Nature Reserve	45
Huidong Harbor Sea Turtle Reserve	Guangdong	4.00	2002	Nature Reserve	46
Lashihai Wetland	Yunnan	35.60	2004	Nature Reserve	47
Maidika	Xizang	434.96	2004	Nature Reserve	48
Mai Po Marshes & Inner Deep Bay	Hong Kong	15.13	1995	SSSI	49
Mapangyong Cuo	Xizang	737.82	2004	Natural Park	50
Nan Dongting Wetland and Waterfowl Reserve	Hunan	1680.00	2002	Nature Reserve	51
Napahai Wetland	Yunnan	20.83	2004	Nature Reserve	52
Niaodao ('Bird Island')	Qinghai	536.00	1992	Nature Reserve	53
Poyanghu	Jiangxi	224.00	1992	Nature Reserve	54
San Jiang	Heilongjiang	1644.00	2002	Nature Reserve	55
Shankou Mangrove	Guangxi	40.00	2002	Nature Reserve	56
Shuangtai Estuary	Liaoning	1280	2004	Nature Reserve	57
Xi Dongting Lake (Mupinghu)	Hunan	350.00		Nature Reserve	58
Xianghai	Jilin	1054.67	1992	Nature Reserve	59
Xingkai Lake	Heilongjiang	2224.88	2002	Nature Reserve	60
Yancheng	Jiangsu	4530.00	2002	Nature Reserve	61
Zhaling Lake	Qinghai	649.20	2004	Nature Reserve	62
Zhalong	Heilongjiang	2100.00	1992	Nature Reserve	63
Zhanjiang Mangrove	Guangdong	202.79	2002	Nature Reserve	64

Sources: Hayes and Egli (2002), UNEP-WCMC (2004), WH (2004), WI (2004) and WNBR (2004).[a]The numbers correspond with their location in Figure 1.

reserves, 13 wildlife protection areas, 24 nature protected areas, 29 major wildlife habitat areas, and 9 national forest nature protected areas have been established (Yang and Su 2004). Kenting, the first national park in Taiwan (established in 1984), contains rich subtropical and tropical flora, with about 2200 plant species (Hsu and Agoramoorthy 2004). Of these, more than 1000 are vascular plants (constituting 25% of the total species on the island) and 41 are classified as rare, including five endemics (Gu 1998). The impact of tourism (the park receives about 3 million tourists annually) and the severe erosion detected in some areas are the main conservation challenges facing the park (Hsu and Agoramoorthy 2004).

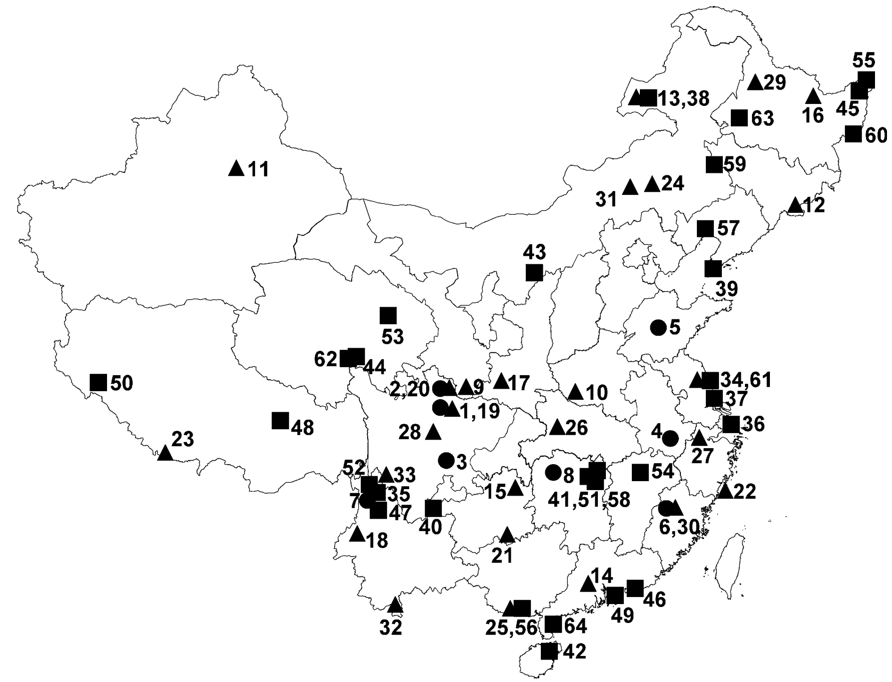

Figure 1. Location of the internationally recognized protected areas in China. The numbers correspond with their location in Table 5. Circles represent the Natural World Heritage Sites, triangles the Biosphere Reserves, and squares the RAMSAR Sites.

About 40% of the land area in Hong Kong is protected, the highest percentage in the Asia Pacific region. Nevertheless, these protected areas do not adequately cover some habitat types, such as freshwater wetlands and *feng shui* forests near urban areas (Yip et al. 2004). Two main kinds of protected areas have been established in Hong Kong: country parks (at present there are 23) and special areas (15). In addition, 64 sites of special scientific interest ('SSSIs'; Wu 2002) have been designated, mostly due to their floristic importance. The most emblematic protected area in HKSAR is the Mai Po Marshes & Inner Deep Bay, which was designated as a Wetland of International Importance (RAMSAR Convention) in 1995.

Ex-situ *conservation*

Although it is widely assumed that the most effective conservation measures are those involving *in-situ* strategies, *ex-situ* facilities are important in providing scientific background and source material for future re-enforcements and/or re-introductions. In fact, the most widely recognized *ex-situ* conservation strategy is the preservation of living plants in botanical gardens (and arboreta). Although the first modern botanical gardens were not established in China until the beginning of the Twentieth Century, we can date their origin to ca. 2800 BC (Medicinal Botanic Garden of Shennong), the earliest known botanical garden in the world (Xu 1997). Sima Guang (1086–1019 AD) built his 'Enjoying-Myself Garden', with designed plots and name cards in the plants (Gu 1998). Temple gardens have played a significant role in the *ex-situ* conservation of Chinese flora; e.g., more than 100 plant species have been cultivated in the temple gardens of Xishuangbanna (Liu et al. 2002). The first modern botanical garden, Hengchun Tropical Botanical Garden (Taiwan), was established in 1901, followed by Xiongyue Arboretum (Liaoning Province) in 1915, Taipei Botanical Garden (Taiwan) in 1921, and Nanjing Botanical Garden Mem. Sun Yatsen (Jiangsu Province) in 1929 (Xu 1997). Nevertheless, Hong Kong's Zoological and Botanic Garden precedes these, established in 1861 (Chapman and Wang 2002). At present, about 140 botanical gardens have been set up in China (Zhu 2001; He 2002; Huang et al. 2002), encompassing an area of ca. 2500 km^2 and cultivating about 23,000 species of vascular plants, of which 18,000 are species found in China (Xu 1997, 1997); i.e., 55% of Chinese flora. Of these, 4 are located in Hong Kong, 1 in Macao, and 4 in Taiwan.

At present, the largest botanical gardens in China are Beijing Botanical Garden (South), Xishuangbanna Tropical Botanical Garden, Kunming Botanical Garden, Nanjing Botanical Garden Mem. Sun Yatsen, and South China Botanical Garden (see Table 6). Xishuangbanna Tropical Botanical Garden (XTBG) contains a collection of about 8000 taxa (Walters and Hu 2003), as well as several special collections (palms, orchids, bamboos, tropical fruits, economic trees, shade-plants, medicinal plants, and tropical conifers). It also harbors a collection of 30 species endemic to Xishuangbanna (BGCI 2004) and an *ex-situ* conservation area for rare and endangered plants of southern Yunnan, preserving ca. 1300 species (Xu 1997). Among the highlights of Kunming Botanical Garden's (Kunming, Yunnan) special collections are *Camellia*, *Rhododendron*, and Magnoliaceae (He 2002). It also contains a medicinal plant garden with ca. 1000 species used in Traditional Chinese Medicine (KIB 2003). The Nanning Medicinal Plant Garden has about 2500 species of medicinal plants, with 134 endemic to Guangxi Province (He 2002).

Perennial and vegetatively propagated crops are preserved in 32 national field germplasm nurseries (Zhu 2001), with over 37,000 germplasm accessions belonging to 1026 species or subspecies (Gao et al. 2000). Furthermore, about 255 plant introduction bases had been established by the end of the 1990s, thereby assuring the conservation of more than 80% of the nation's protected rare and endangered species. For example, these nurseries have successfully propagated such rarities as *Abies beshanzuensis*, *Alsophila spinulosa*, *Camellia petelotii*, *Carpinus putoensis*, *Cathaya argyrophylla*, *Davidia involucrata*, *Ormosia hosiei*, and *Ostrya rehderiana* (Xu et al. 1999; Zhu 2001).

Seed storage in germplasm banks began in China during the 1980s with the establishment of the No. 1 National Gene Bank (1983), with a capacity of

Table 6. Some botanical gardens in China[a].

Name	Location	Area (km^2)	Number of taxa[b]	Data of establishment
Beijing Botanical Garden (South)	Beijing	0.56	5000	1955
Beijing Botanical Garden (Northern)	Beijing	4.00	2700	1956
South China Botanical Garden	Guangzhou (Guangdong)	3.00	5000	1959
Nanjing Botanical Garden Mem. Sun Yatsen	Nanjing (Jiangsu)	1.87	3000	1929
Kunming Botanical Garden	Kunming (Yunnan)	0.44	4000	1938
Shanghai Botanical Garden	Shanghai	0.81	5000	1974
Xishuangbanna Tropical Botanical Garden	Menglun (Xishuangbanna, Yunnan)	9.00	8000	1959
Shenzen Fairy Lake Botanical Garden	Shenzen (Guangdong)	5.90	3000	1982
Wuhan Botanical Garden	Wuhan (Hubei)	0.70	4000	1956
Xiamen Botanical Garden	Xiamen (Fujian)	2.27	3000	1960
Qinling Botanical Garden	Zhouzhi County, Xi'an (Shaanxi)	458.00	6100 (2005); 30,000 (2010)	2005 (first phase); 2010 (second phase)
Hong Kong Zoological and Botanic Garden	Hong Kong SAR	0.054	1200	1861
Taipei Botanical Garden	Taiwan	0.08	1500	1921

[a]Data extracted from Xu (1997), Gu (1998), and BGCI (2004).
[b]'Taxa' include species, subspecies, and varieties.

230,000 seed accessions, and the No. 2 National Gene Bank (1988), the latter accommodating more than 450,000 accessions. Both are located in Beijing, No. 2 being responsible for the global germplasm conservation of *Brassica campestris*, *B. campestris* subsp. *pekinensis*, *Raphanus sativus*, and *Triticum aestivum* (MOA 1995; Gu 1998). Moreover, a National Duplication Gene Bank was set up in Xining (Qinghai Province) in 1995, which has a total capacity for 400,000 accessions. Currently, about 318,000 accessions have been deposited in these long-term storage facilities, representing 30 families, 174 genera, and 600 crop species (Gao et al. 2000). Twenty-seven mid- and short-term seed storage facilities have also been built by local agricultural science academies in various provinces and municipalities (Zhu 2001). China also established a seed bank in 1994 specifically for medicinal plants in Zhejiang Province, with a capacity for 50,000 accessions (Xue 1997; Gu 1998). In addition, the Chinese Academy of

Medical Sciences set up a medicinal plant germplasm bank with a collection of 900 species (Xu et al. 1999). Taiwan has also made great efforts to conserve its germplasm resources; the genebank of the Taiwan Institute of Agriculture can store 240,000 long-term accessions (Gu 1998). Nevertheless, in China *in vitro* plantlets conservation has only been applied to potatoes and sweet potatoes. By the end of the 1990s, there were four *in vitro* storage facilities, two for potatoes (Beijing and Keshan, Heilongjiang Province) and two for sweet potatoes (Beijing and Xuzhou, Jiangsu Province; MOA 1995; Gu 1998).

Environmental legislation and government planning

In addition to *in-situ* and *ex-situ* measures, environmental legislation and government planning are also essential to ensure adequate conservation of biodiversity. Although China has passed a series of laws (nearly 20) addressing biodiversity conservation since the early 1980s (see Table 7), legislation is still limited. The most relevant laws governing plant biodiversity include the Environmental Protection Law (issued in 1979, revised in 1989), the Forest Law (issued 1984, revised 1998), the Grassland Law (issued 1985), and more recently, the Seeds Law (2000). China has also issued a significant number of administrative regulations (Table 7): the Regulation about Nature Reserves (1994), the Regulation on Wild Plants Protection (1996), and the Regulation about Protection and Administration of Wild Medicinal Material Resources (1987) (Xu et al. 1999; Wang et al. 2000).

Nevertheless, there is some governmental oversight actively supporting biodiversity conservation in China in addition to these other laws and regulations, the most relevant being the Environmental Impact Assessment (EIA) system, which was legally implemented in 1981 and amended several times thereafter (1986, 1989, 1998, and 2002). Others mechanisms include: licensing systems (such as forest logging and land use licenses), geared towards administering paid use of natural resources and their sustainable utilization (Xu et al. 1999); economic incentives, based on the establishment of financial subsidies, tax-deductions, and compensation fees to enhance sustainable exploitation of natural resources (e.g., the Forest Ecological Compensation Fee, implemented in 2001, for restructuring the timber industry in favor of sustainable forestry; CEPF 2002; CBD 2004); and the quarantine system, established in the early 1980s.

China has joined a number of internationally recognized conventions and programs, such as the UNESCO's Man and Biosphere Program (MAB), the CITES Convention, the Convention Concerning the Protection of the World Cultural and Natural Heritage (WHC), the RAMSAR Convention, the Convention on Biological Diversity (CBD), and the United Nations Convention to Combat Desertification. In addition, China joined IUCN as a country member in 1996 and became a member of the International Convention on New Plant Variety Conservation in 1999 (Zhu 2001). China signed the Kyoto Protocol in

Table 7. Legislation concerning biodiversity conservation issued in China.

Legal instrument	Date of issue (and revision)	Lead agency
Laws		
Environmental Protection Law	1979 (1989)	State Environmental Protection Agency (SEPA)
Constitution	1982	National People's Congress
Marine Environmental Protection Law	1982 (1999)	State Marine Administration (SMA)
Forest Law	1984 (1998)	State Forestry Administration (SFA)
Grassland Law	1985	Ministry of Agriculture (MOA)
Water and Soil Conservation Law	1991	State Environmental Protection Agency (SEPA)
Import and Export Animal and Plant Quarantine Law	1991	Ministry of Agriculture (MOA)
Seeds Law	2000	Ministry of Agriculture (MOA)
Law on Desert Prevention and Transformation	2001	State Environmental Protection Agency (SEPA)
Law on the Environmental Impact Assessment	2002	State Environmental Protection Agency (SEPA)
Law on Biosafety	Under redaction	State Environmental Protection Agency (SEPA)
Administrative regulations		
Plant Quarantine Regulation	1983	Ministry of Agriculture (MOA)
Temporary Regulation on Management of Scenic Spots	1985	Ministry of Construction (MOC)
Regulation for the Implementation of the Forest Law	1986	State Forestry Administration (SFA)
Regulation about Protection and Administration of Wild Medicinal Material Resources	1987	State Administration of Traditional Chinese Medicine (SATCM)
Regulation about Control of Forest Fires	1988	State Forestry Administration (SFA)
Regulation about Control of Forest Pests	1989	State Forestry Administration (SFA)
Regulation about Seed Management	1989	Ministry of Agriculture (MOA)
Regulation on Afforestation in Urban Areas	1992	State Forestry Administration (SFA)
Regulation about Nature Reserves	1994	State Environmental Protection Agency (SEPA)
Regulation on Wild Plants Protection	1996	State Forestry Administration (SFA)
Regulation on the Safety Management of Agricultural Biological Genetic Engineering	1996	State Environmental Protection Agency (SEPA)
Regulation on New Plant Varieties Conservation	1997	Ministry of Agriculture (MOA)
Environmental Management Regulation of Construction Projects	1998	State Environmental Protection Agency (SEPA)
Regulation for Implementation of Forest Law	2000	State Forestry Administration (SFA)
Regulation of Biosafety Management in China	2001	State Environmental Protection Agency (SEPA)

2002, which was recently ratified (November 2004). State-level planning related to biodiversity conservation began in earnest during the early 1990s. To implement Article 6 of the CBD, the China Biodiversity Conservation Action Plan was launched in 1994 (see NEPA 1994). The First National Report on Implementation of the CBD was submitted in 1997, the second following in 2001. In 1994, *China's Agenda 21* was issued as a guide for drawing up medium and long-term plans on sustainable economic and social development. A third national plan was launched at the end of 1997, *China's Biodiversity: A Country Study*, which analyzed the country's overall biodiversity, its economic value and benefits, the cost of implementing the CBD, and long-term objectives for biodiversity conservation and sustainable use of biological resources (SEPA 1998). The Tenth Five-Year (2001–2005) Plan of National Economic and Social Development, as well as the 2015 Plan, place more emphasis on sustainable development strategy as one of the state's central policy goals (Zhu 2001).

The most relevant inter-departmental programs include: the China Environmental Protection Action Plan (1996–2000), implemented to ensure the conservation and sustainable utilization of forests, grasslands, the marine environment, wetlands, nature reserves and species (Xue 1997; Xu et al. 1999); the Development Plan for Nature Reserves in China, consisting of two phases (1996–2000 and 2001–2010); and the National Tenth Five-Year (2001–2005) Plan for Environmental Protection, which establishes several goals, such as a 10% reduction in the discharge of major pollutants, and an expansion of the nation's nature reserves to encompass 13% of the total land area (SEPA 2002). The Chinese government has also sought to implement several departmental plans, detailed herein. The State Environmental Protection Agency (SEPA, formerly NEPA) launched the China Trans-Century Green Engineering Plan (issued in 1996), as well as China's Agenda 21 for Environmental Protection (issued in 1994). The State Forestry Administration (SFA, formerly Ministry of Forestry) initiated the National Plan for Forest Ecological Construction in 1998, with three objectives: short (1996–2000), moderate (2001–2010), and long-term (2011–2050). It has also issued China's Forestry Biodiversity Conservation Action Plan (1992), the Forestry Action Plan for Agenda 21 (1995), the Action Plan for Implementing the UN Convention to Combat Desertification (1998), and the Conservation and Sustainable Use of Wetland Biodiversity in China (2000–2004). In addition, all of the agencies and ministries have launched their own sectorial Tenth Five-Year (2001–2005) and 2015 long-term plans.

The future of plant biodiversity in China: problems, prospects, and recommendations

Habitat destruction

The huge habitat destruction suffered in China, particularly since the 1950s, began to receive attention by the government authorities only in recent years, due at least in part, to the occurrence of natural disasters and the fall in crop productivity associated with soil erosion and land desertification. To redress this situation, the state implemented a series of forestation and shrub or grass-planting projects. Although the first plans were ratified in the late 1970s (Jiang 2002), they consisted exclusively of mono-culture forest plantations involving exotic species, lacking any scientific basis and failing to account for local floristic features. For example, state plans implemented in the Northern Loess Plateau resulted in substantial changes in local vegetation (Jiang et al. 2003), as well as the construction of the shelter forest system – such as those found in the Triple-North region and the middle and lower reaches of the Yangtze River – often consisting of mono-cultures. New afforestation initiatives should follow some basic scientific guidelines to avoid certain pitfalls; e.g., ban the introduction of exotic species, prevent massive invasions and severe pest outbreaks, and guarantee the availability of habitats and resources to indigenous species. One of the principal objectives of the 'Great Western Development Plan', a global program to bridge the gap between the prosperous coastal areas and the under-developed interior provinces, one still currently under way (endorsed in 2000), is to ensure sustainable natural resources management through forestation and grass planting (CEPF 2002; Jiang et al. 2003). Two large-scale programs focusing on the Upper Yangtze and Yellow Rivers, the Natural Forest Conservation Program (1998–2010) and 'Grain to Green' (or Land Conversion Program, 1999–2010), have been launched to reduce the erosion of sloping lands caused by deforestation and cultivation. (Zhang et al. 2000; CEPF 2002). Between 1996 and 2050, the National Plan for Forest Ecological Construction intends to increase forest coverage to 17.5% of the total land area by 2010 and by 25% in 2050 (Xue 1997; Xu et al. 1999), an ambitious initiative that should incorporate the scientific criteria mentioned above. Although these programs arguably represent one of the best opportunities for biodiversity conservation, additional efforts should be made by authorities to achieve an integrated strategy of sustainable forest exploitation and long-term ecological protection, instead of merely relying on tree plantation.

Protected areas

China's National Endangered Plant and Wildlife Protection and Nature Reserves Construction Program, aimed at protecting biodiversity over the next 50 years, stipulates that the number of nature reserves must reach 1800 by 2010 (with 220 of those at the national level), occupying an area about 1,550,000 km^2 and accounting for 16% of the Chinese territory. By 2050 the number of nature reserves should reach 2500, encompassing an area of 1,730,000 km^2 and accounting for 18% of the total land surface (SFA 2004). In fact, the goal for 2010 has been already attained due to the impressive rate of nature reserves establishment, particularly during the last 20 years (see Table 4). For instance, in Tibet alone, nature reserves cover about 400,000 km^2; i.e., one-third of the province's total land area (Miller 2003). Unfortunately, provisions for staffing and financing to manage and protect these reserves have not increased at the same rate. For example, by 1997 only 67% of all nature reserves had staffs and budget; i.e., about one-third were protected only 'on paper' (Jim and Xu 2004). Moreover, by 1997 only 20.8% of the staff was professionally trained (to include higher education) (World Bank 2001). The problem is due, at least in part, to the fact that only a minority of the reserves (about 10.7% at the end of 2002) are financed at the state-level, with adequate resources (staff and budget) for their management and protection. Consequently, many reserves are forced to be self-sufficient through resource exploitation, a policy inconsistent with their intended purpose. Construction of tourist facilities (resorts, new access routes) and over-exploitation of wildlife resources (e.g., medicinal and edible plants) should evolve towards sustainability, instead of seeking short-term benefits, and should be planned and managed to combine biodiversity protection with assurances of adequate economic benefits to local communities. Their growing prosperity, in tandem with increasing demands on natural resources, would best harmonize in the commercial cultivation of economically viable species, such as medicinals, which would also serve to reduce their endangered status. Involving local communities in the management and administration of reserves is a key step for the long-term sustainability of nature reserves, since it is the best way to ease the pressures brought on reserves by local residents (Eagles et al. 2001).

Nevertheless, nature reserves are afflicted with other serious problems besides insufficient budgets. Overlapping management – in some cases involving up to seven administrations (World Bank 2001) – can cause confusion, inefficiency, uncertain boundaries, and multiple designations of the same reserve. To date, many reserves are too small, too damaged, or too remote from biologically significant areas to determine their success in biodiversity protection (World Bank 2001; Jim and Xu 2004). The design of nature reserves has not been entirely rational in the past, nor have criteria addressing biogeographical and/or ecosystem representativeness been followed. Furthermore, lands managed by the army are still excluded from the protected areas network, while in other countries the military is granted secondary stewardship (Liu et al. 2003). Establishing a centralized management by a new Nature Reserves Service at the state-level, and with adequate funding, may be the best way to solve these problems, as has been suggested by several authors (World Bank 2001; Liu et al. 2003).

Evaluating the effectiveness of nature reserves is generally a neglected issue in China, as they are not routinely monitored (Lü et al. 2003). For instance, of those reserves located in the South-Central China hotspot, 25% have no patrols, 75% have no monitoring programs in place, and 70% lack comprehensive resource inventories (CEPF 2002). Another example is the Wolong Giant Panda Reserve, which after its establishment in 1975, remains unexpectedly fragmented, with rates of habitat loss inside the reserve similar or even higher than those outside the reserve (Liu et al. 2001). One general trend is that nature reserves often do not provide adequate protection of their flora. This is true even of international-level reserves, an all too common occurrence exemplified by *Ophiopogon xylorrhizus*, a narrow endemic species confined to an area 30×20 km within the Xishuangbanna Biosphere Reserve (Yunnan). Of the extant populations of this species, one has recently become extinct, while population sizes have significantly decreased in the other localities (Ge et al. 1997).

The traditional cost-benefit approach is seldom appropriate for managing protected areas or the natural environment in general, since there are numerous ecological values improperly weighed or undervalued, such as the inherent ethical and aesthetic values (Yang and Xu 2003). Nevertheless, Chinese managers often look only for short-term economic gain, without considering the long-term ecological benefits provided by environmental protection, such as the prevention of soil and water erosion and the reduction of floods and droughts (Athanas et al. 2001). For example, the economic value of the environmental services provided by the Changbai Mountain Biosphere Reserve is estimated to be 16 times higher than that garnered from the conventional timber production co-located there (Athanas et al. 2001).

Ex-situ *conservation measures*

Although the number of botanical gardens has significantly increased during the last decades, they remain relatively few in number and are often not of adequate size (about 40% of the botanical gardens are smaller than 0.5 km^2) nor plentiful in species (ca. 60% of them have fewer than 1000 taxa) (NEPA 1994). Yet another deficiency is that they are not representative of the local floras across China; some regions boasting a rich plant diversity have too few botanical gardens, such as the Himalayas, the Qinghai-Xizang Plateau, and the dry-hot valleys of southwestern China, a trend also apparent in the three primary distribution centers for endemic plants in China (SW Sichuan-N Yunnan, E Sichuan-W Hubei, and S Yunnan-SW Guangxi) (Xu 1997; Ying 2001; He 2002). Moreover, conservation of the protected rare and endangered species has still not been attained; currently, about 350 of the 388 species included in Volume I of *China Plant Red Data Book* (i.e. 90%) are cultivated, while only about 200 of the 640 species listed in the forthcoming Volume II of the *Red Book* (i.e. 31%) are preserved in China's botanical gardens (Xu 1997). Xu (1997) also warns of the risks in cultivating one species in less than 5 different botanical gardens, which is a common occurrence among the protected rare and endangered species. From the first batch of the *Red Book*, only 48.5% of the species are preserved in ≥ 5 botanical gardens, a percentage that dropped to 0.5% in the second batch. Furthermore, population sizes are generally not sufficient for maintaining adequate levels of genetic diversity. Only a few cultivated species included in the first or second batch of the *Red Book* (less than 40%) have more than 10–20 individuals in any given botanical garden, the threshold for preserving genetic diversity suggested by Xu (1997). Some of these deficiencies should be remedied by the Qinling Botanical Garden (Xi'an, Shaanxi Province), which after its completion in 2010 will be the largest botanical garden in the world, with an extension encompassing 458 km^2. A total of 6100 rare and endangered species will be specifically cultivated, 3200 of them belonging to the Qinling area, 900 from temperate areas, and 2000 from tropical and subtropical zones (Anonymous 2002). Meanwhile, the Chinese Academy of Sciences has drafted a 15-year *ex-situ* master plan to conserve the diversity of native Chinese plants in botanical gardens, which is now being implemented. Its main goals are to increase the number of native protected species to 21,000, to enhance the garden collections of rare and endangered plants, and to create 5 new regional gardens (Huang et al. 2002).

The establishment of a new germplasm bank in Kunming (Yunnan) has been planned to secure the preservation of the germplasm resources of SW China. The ambitious goal of collecting the seeds of 24,000 plant species native to Yunnan, Guizhou, Sichuan, Guangxi, and Tibet should be reached in 2010 (Cyranoski 2003). *In-situ* and *ex-situ* conservation approaches have been successfully combined in the conservation of the endangered species *Vatica guangxiensis* at Xishuangbanna Tropical Botanical Garden. The only three remaining populations of this species (located in Yunnan and Guangxi) have been included in the Nature Reserves network, with about 90 individuals successfully transplanted to this garden (Li et al. 2002).

Environmental legislation

Legislation addressing biodiversity has significantly expanded in the last two decades. Nevertheless, two major problems remain: an insufficient and inefficient legal system and a lack of enforcement (Li 1998; Xu et al. 1999). The main purpose of these laws and regulations has been to manage the use of natural resources and not their conservation. Moreover, they are often oriented to only one type of natural resource, lacking specific regulations to preserve entire ecosystems (Li 1998). There is no comprehensive law governing nature conservation, since the Environmental Protection Law is mainly focused on pollution control (Xu et al. 1999). Another inconsistency inherent to China's environmental legislation is the lack of rules regarding civil and criminal responsibilities compared with those delineating administrative responsibility. In addition, administrative punishments only mandate damage compensation rather than removal and/or rehabilitation (Xu et al. 1999).

Historically, law enforcement has been one of the major problems in the establishment of a sound legal system in China. Violations of environmental legislation are all too common and even tolerated. For example, there is a generalized lack of effective *in-situ* legal protection for nationally listed rare and endangered plant species; this is the case for approximately 1/3 of those species found in the Yangtze Valley (Xie 2003b). According to Li (1998), there are three main causes explaining this poor enforcement: a lack of capability on the part of administration (staff is not sufficient to ensure legislation enforcement), lack of coordination among the different administrative levels (several agencies are sometimes responsible for the same protected area), and widespread corruption among government officials.

Implementation of the environmental impact assessment (EIA) has experienced enormous difficulties in the past. Prior to passage of the Law on the Environmental Impact Assessment in September 2003, Chinese environmental legislation only focused on individual construction projects that might pollute the environment, rather than addressing all activities affecting natural resources. Moreover, EIA only targeted individual construction projects, was not binding on government-proposed projects, and did not fully review all the construction projects. At the end of the 1990s, the rate of inspection had reached about 90% (Xu et al. 1999; Zhu 2001) despite the fact that it had been deemed mandatory for all construction projects. The recent implementation of the EIA Law is a very positive step, as it expands the scope of independent oversight, reviewing all governmental land use and regional construction and development programs, which have usually generated larger environmental problems than did individual construction projects.

Scientific research

Large-scale national surveys of vegetation, natural ecosystems, flora and fauna began in the late 1950s, and include *Vegetation of China* (1980), *Cryptogams of China* (4 volumes), *Flora of China* (*Flora Reipublicae Popularis Sinicae*) (60 volumes of the 80 projected in 1950), and *Economic Flora of China* (Xu et al. 1999). Currently, the Missouri Botanical Garden (MBG) and the Chinese Academy of Sciences (CAS) are working together on the 'Flora of China' project, an international effort to produce a 25 volume English-language revision of the *Flora Reipublicae Popularis Sinicae*. At present, 11 volumes have already been published and they can also be browsed online (see FOC 2004). These same institutions (MBG and CAS) have also promoted the 'Moss Flora of China' project, which aims to provide an online version of the 8 printed volumes of the *Moss Flora of China*, to include Hong Kong and Taiwan (MFC 2004). Regarding conservation biology, some surveys and studies have been published since the early 1990s, including *Chinese Biodiversity – Status and Conservation Strategy* (Chen et al. 1993), *A Biodiversity Review of China* (McKinnon et al. 1996), *Conserving China's Biodiversity* (Schei and Wang 1997), *China's Biodiversity: A Country Study* (SEPA 1998), and *The Plant Life of China* (Chapman and Wang 2002). The first volume of the *China Plant Red Data Book* was finally published in 1992 after 10 years of work (Fu 1992), and the second volume is currently in preparation. Furthermore, provinces such as Guizhou, Henan, and Shaanxi have published their own plant red books.

Other biodiversity surveys include the national survey on traditional Chinese medicinal resources, conducted between 1984 and 1994, and identifying 12,807 species (11,146 plants and 1581 animals; Xu et al. 1999). SFA has performed five-year surveys (including censuses) of forest resources since 1973, recently completing their 6th forest survey. Moreover, some 36 ecological field stations have been established, organized into the Chinese Ecosystem Research Network. China also has more than 150 biodiversity databases (Xu et al. 1999; SEPA 2004). Taiwan has also made considerable efforts to study the island's biodiversity, with the publication of *Flora of Taiwan* (6 volumes, two already available online; FOT 2004) and the *Red Data Book of Taiwan Region: Criteria and Measure for Rare and Threatened Plant Species* (Lai 1991). In the Hong Kong SAR, the first surveys on flora were conducted as early as 1861, with the *Flora Hongkongensis* of G. Bentham. The most recent works on plant biodiversity are the *Hong Kong Vascular Plants: Distribution and Status* (Corlett et al. 2000), and the *Check List of Hong Kong Plants*, 2001 version (Wu 2002).

Despite the significant strides made by these various administrations, universities, and research institutes, there are still significant gaps in the knowledge of biological diversity. The lack of information on China's threatened plant species is particularly worrisome; of the nearly 5000 endangered taxa, only 675 from mainland China are evaluated in the *2004 IUCN Red List of Threatened Species* (IUCN 2004). Two additional volumes of the Plant *Red Book* are need, since the first volume appeared as long ago as 1992. Moreover, the evaluation criteria for the threatened species in the Chinese *Red Book* (e.g., a plant species must number 10 or fewer populations to be considered threatened), as well as the threat categories (i.e. 'endangered', 'rare', and 'vulnerable'), which are strongly influenced by the academic interest of species (Xie 2003b), should be replaced with the standard international criteria (i.e., IUCN criteria).

Economic policies, financial resources, and environmental education

Government policies have promoted rapid growth since the end of the 1970s, when the 'open-door' policy was first adopted. These policies, which encourage short-term economic benefits, have also been implemented in protected areas. Some nature reserves are currently both exploiting natural resources and promoting tourism in unsustainable fashion. Natural parks, due to their dual roles of preserving nature and providing public enjoyment, have policies generally geared toward commercial and economic development. Tourism and natural resource in protected areas should be planned and managed in such a way as to ensure their long-term sustainability.

One of the main reasons for the over-exploitation of natural resources and the lack of biodiversity protection is that the importance of biodiversity is not fully understood. Moreover, its economic value is often underestimated, as potential long-term benefits are seldom contemplated (McNeely et al. 1990; Green et al. 2005). For example, the 1998 flooding in the Yangtze area caused a total loss of 167 billion yuan (about 20 billion USD; Zhang et al. 2000). The annual economic loss caused by environmental pollution and overall damage to biodiversity during the 1990s may well have surpassed 600 billion yuan (about 72 billion USD; SEPA 1998). In contrast, the total value of China's ecosystem services may total approximately 8000 billion yuan per year (about 960 billion USD), according to calculations made by Chen and Zhang (2000), a figure very close to the Chinese GDP in 1999.

Using the environmental Kuznets curve (EKC) hypothesis, low-income societies can be characterized by low environmental degradation (including resource depletion), which increases with economic growth until a certain level, after which further increases in income result in environmental improvements (Panayotou 1995; Yandle et al. 2004). This fact seems clearly linked to the changing value of biological resources during the evolution of economic development: high in 'traditional societies' (being highly dependent on the direct use of natural resources but at a highly sustainable rate). This trend greatly diminishes in transition economies (which base their economic growth primarily on such over-exploitation, and subsequent trade, of natural resources). Subsequently, the curve tends upwards again in developed societies, which demand services (rather than goods) derived from environmental conservation (e.g., 'ecotourism' and the return to 'traditional' or 'folk' medicine and foods; Thampapillai et al. 2004). The Chinese population's recent but unprecedented access to wider industrially-based goods, as well as the burgeoning employment opportunities (mainly cheap labor) stemming from skyrocketing industrial activities unfortunately involves the continuous and still long-term decimation of natural resources, especially given their under-valued nature and increasing demand.

Another major culprit in the current loss of biodiversity is the lack of financial resources. The current investment levels of the Chinese government remain inadequate, although they have increased significantly in recent years. The total environmental investment for the Ninth Five-Year Plan (1996–2000) was less than 1% of GDP (i.e. 450 billion yuan), and is about 1.3% of GDP (i.e. 700 billion yuan) in the Tenth Five-Year Plan (2001–2005) (World Bank 2001). Expenditure should increase at least 3.5% GDP per annum, based on the estimated environmental costs forecast by the World Bank (2001). In addition to increasing such funding, the government should encourage the active participation of all sectors of Chinese society, the private sector in particular (e.g., foundations associated with private companies given fiscal exemptions), as well as non-governmental organizations (NGOs).

The lack of available information on both ecological and biodiversity data and environmental governmental policies, coupled to a lack of education, renders civil society insensitive towards the current loss of biodiversity. Environmental awareness should be enhanced, both through both public media and education systems (including high schools and universities). Environmental awareness should be particularly geared towards the indigenous and local communities, as they usually have more direct contact with the natural resources in both protected and unprotected areas. Government efforts should also be made to offer high-level conservation education programs, as suggested by Wu et al. (2004a, b); e.g., establishing a national centre for ecological and evolutionary studies and enhancing cutting-edge research in the already extant institutes and universities.

Conclusions

(1) China boasts an extremely rich plant biodiversity on the three basic levels: species diversity, ecosystem diversity, and genetic diversity, due to the wide variations in geographical, geological, climatological, and topographical features spanning its territory. At the species level, there are more than 33,000 taxa of vascular plants (ca. 30,000 of these are angiosperms) in mainland China alone. The Taiwan and Hong Kong regions are also home to numerous species (more than 4000 and 2000 higher plants, respectively).

(2) The primitive groups of vascular plants (i.e., pteridophytes, gymnosperms, Magnoliidae, and Ranunculidae) are abundant in China. Ancient gymnosperm lineages, most being monotypic or oligotypic and probably remnants of larger groups from the Tertiary period or earlier, are still thriving in China, when they have long ago been rendered extinct in other regions of the Northern Hemisphere. In addition, China is considered one of the main centers of diversification for seed plants on Earth, containing fossil remains of primitive angiosperms dating from the early Cretaceous period.

(3) Many species (more than 10,000), as well as some genera (nearly 250) and a few families (Ginkgoaceae, Eucommiaceae, Davidiaceae and Acanthochlamydaceae) are endemic to China. While most are paleoendemisms, significant percentages are neoendemisms formed via allopatric speciation.

(4) Several paleo-geological and paleo-climatic events have been hypothesized to explain such high rates of taxonomic richness: the initial collision of the Gondwanan terranes, as well as the subsequent impact of the Indian subcontinent (resulting in the formation of the Himalayas). Also believed to have played a part are long established land interconnections with surrounding areas, and the climatic change that occurred during the Neogene period.

(5) Approximately 3000–5000 species are considered endangered, with nearly 200 species rendered extinct since the 1950s. Moreover, many species are currently on the brink of extinction.

(6) Several local 'biodiversity hotspots' have been identified in China, in addition to 3 of the world's 34 hotspots ('South-Central China', 'Indo-Burma' and 'Himalaya'), including northern Yunnan, Xishuangbanna,

Sichuan, the Tibetan Plateau, the Three Gorges area, and Hainan and Taiwan Islands.

(7) The combined effects of habitat destruction and/or fragmentation, environmental contamination, over-exploitation of natural resources, and to a lesser extent, the introduction of exotic species, have caused irreparable damage to plant biodiversity. Economic and population growth have also contributed to this deterioration. Habitat destruction (primarily resulting from over-logging and cropland expansion) is the leading cause of species extinction, particularly since the 1950s. The over-exploitation of species of economic interest seriously threatens their survival, as have alien invasive species, with some 380 species of vascular plants infesting areas in China. In addition, previous policies focusing on the exploitation of natural resources must be amended and/or replaced by ones promoting scientific conservation and sustainable utilization of plant diversity.

(8) Legal *in-situ* protection strategies in China – nature reserves, natural parks, and scenic spots – have been significantly expanded since their establishment in the late 1950s. Taking into account all the known protection statistics, the total protected land areas in China measure ca. 1,650,000 km^2, representing approximately 16.4% of the country's national territory. Lack of staffing and investment are all too common problems afflicting protected areas, with most forced into self-sufficiency by exploiting their own resources. Other deficiencies include overlapping management structures, inadequate design, and a lack of monitoring and/or evaluation. Yet another weakness is the utter disregard or under-evaluation of the ecological benefits provided by protected areas in pursuit of short-term economic gains; i.e., mortgaging future economic welfare to satisfy immediate needs.

(9) At present, about 140 botanical gardens have been established, cultivating ca. 23,000 species of vascular plants, of which 18,000 are native to China. Nevertheless, there are still too few botanical gardens, with none adequate in size or in the number of representative species, poorly approximating China's richest floristic areas and lacking the majority of the country's rare and endangered species. It is to be noted, however, that 32 national field germplasm nurseries, 255 plant introduction bases, and 3 national gene banks have been established in China.

(10) While significant advances have been made in scientific research on China's mainland flora, additional efforts are needed. Some international large-scale projects, such as 'Flora of China' and 'Moss Flora of China', are currently underway, and are remedying this situation. However, many gaps still remain, especially in the knowledge of rare and threatened species. Taiwan and Hong Kong have also made considerable strides in studying their respective biodiversity.

(11) Legislation addressing biodiversity conservation was first initiated in the early 1980s, but remains relatively limited and is afflicted by two major failings: (1) the lack of a sufficiently broad conservationist scope – the main purpose of legislation is to manage the use of natural resources and

not their conservation, and there are no specific regulations to preserve entire ecosystems; (2) the lack of any effective enforcement.

(12) Some state-level plans concerning biodiversity conservation have been applied since the early 1990s. Minor plans have also been implemented since the late 1970s, including those on forest plantations, but more often than not these have consisted of mono-cultures involving exotic species. New afforestation projects must prevent the introduction of exotic species and pursue an integrated strategy of sustainable forest exploitation and long-term ecological protection.

(13) One of the main causes for the current loss of biodiversity is the lack of any true awareness or appreciation of its value. Another reason is the lack of financial resources; current investment levels by the Chinese government remain inadequate. In addition to increasing such funding, the government should encourage the active participation of all sectors of society in biodiversity conservation, particularly the private sector and non-governmental organizations. Environmental education should also be strengthened and specifically geared towards indigenous and local communities.

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