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Seed Plant Species Diversity and Conservation in the Northern Gaoligong Mountains in Western Yunnan, China

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Plant species diversity was surveyed in the northern Gaoligong Mountains of western Yunnan, China, from 1990 to 2006. During the floristic surveys of seed plants, 2514 native species and 302 varieties (or subspecies) belonging to 778 genera in 171 families were recorded. We also found that 12 families are endemic to eastern Asia, 14 genera and 1232 taxa are endemic to China, and 132 taxa are endemic to the northern Gaoligong Mountains. According to the International Union for Conservation of Nature (IUCN) Red List Categories and Criteria, 25 threatened taxa identified in the survey are endemic to this region. The flora is rich because of the role the northern Gaoligong Mountains played as a center of species diversification during the uplift of the eastern rim of the Tibetan Plateau in the Quaternary and as a refuge during the last glacial maximum. Unfortunately, this biodiversity faces massive threats because of the combined effect of habitat destruction or fragmentation and overexploitation of natural resources. Taking into consideration that human population growth will further increase pressure on this biodiversity in the near future, we suggest that conservation priority be given to the endemic plants, as well as to the habitats of primarily evergreen broad-leaved forest, coniferous broad-leaved mixed forest, and alpine shrub and meadows.

Keywords: *Seed plant species diversity; endemic species; habitat conservation; northern Gaoligong Mountains; China.*

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Introduction

Rising between the great Nujiang (Salween) and Irrawaddy rivers, the Gaoligong Mountains lie in the border area between southwestern China and northern Myanmar (Burma) between 24°40′N and 28°30′N. From north to south, the Gaoligong Mountains are divided into 3 large regions (northern, middle, and southern) in accordance with unique geological history and special ecological environments (Guo 2000).

The northern Gaoligong Mountains are a relatively independent physiographic unit in the subtropical zone of southwestern China. The region is exceptionally interesting to biologists because of its diverse biota and complex biogeographic features. Two of Asia's greatest rivers, the Nujiang and the Irrawaddy, flow in parallel through the area within 100 km of each other (Geatz 1999). The region lies within the Hengduan Mountains in Yunnan and part of the Eastern Himalayas and is one of the most biologically diverse temperate ecosystems on Earth (Mittermeier et al 1998). It is situated on the boundary between the temperate and tropical regions of Southeast Asia and is characterized by spectacular mountains and river gorges. The combination of complex climatic and physical conditions, extreme topographic relief, and a broad gradient of biomes provides diverse habitats in which different animals and plants with different evolutionary backgrounds developed, consequently making the northern Gaoligong Mountains a globally significant region for its rich biodiversity, rare ecosystems, and high concentration of endemic taxa (Ying and Zhang 1984; Wang 1985, 1989; Li XW 1994; Wang and Zhang 1994; Ying and Zhang 1994; Ying 1996, 2001; Hao 1997; Geatz 2002). All global biodiversity analyses have identified the mountains of south–central China, Indo-Burma, and the Himalayas as conservation priorities for plant diversity (Barthlott et al 1996; Olson and Dinerstein 1998; Myers et al 2000), and the northern Gaoligong Mountains are included within the mountains of south–central China near the other two hotspots. The region is recognized as an important Quaternary center of species diversification, as well as a refugium for certain Laurasian angiosperm groups (*Primula* spp, *Rhododendron* spp, and *Syncalathium* spp) (Wang et al 2008; Milne et al 2010; Zhang et al 2011). The area is also rich in medicinal plants, used mainly as drugs by Tibetan and Nu people (Dao et al 2003; Xu and Wilkes 2004).

Previous studies conducted in the northern Gaoligong Mountains have focused on forest physiognomy and

forest species composition gradients (Wang et al 2004; Li et al 2007, 2008; Ou et al 2008; Xu et al 2008). Few studies have dealt with seed plant species diversity and conservation, with the notable exception of Li H (1993, 1994), who published a list of vascular plant species recorded in the Dulongjiang Valley during an extensive survey. To date, the northern Gaoligong Mountains remain incompletely explored, though they are expected to be the part of the mountain range that is richest in biodiversity with the highest endemism because of highly diverse geographic features and climatic conditions (Yang 1991; Zhang et al 1992).

In recent history, biodiversity in this region has suffered from heavy human disturbance. The local people are poor and have so far relied heavily on natural resources to meet their basic needs, for example, by collecting non-timber forest products to provide housing, food, medicine, cash income, and fuelwood (Xu and Wilkes 2004). In addition, habitats have undergone severe fragmentation because of the increasing construction of infrastructure for commercial tourism, roads, and hydropower development. Therefore, there is an urgent need for measures to reconcile the conflicts between biodiversity conservation and local economic interests, as well as a need for sound data to inform policy- and decision-making in this respect.

The research for the present paper aimed to inventory seed plant species and measure endemic richness in the northern Gaoligong Mountains. We present overall results and assess the conservation priority of endemic species.

Study area

The northern Gaoligong Mountains lie in northwestern Yunnan Province, adjacent to Chayu County of Xizang (Tibet) to the north. The eastern side is defined by the Nujiang. On the southern and western sides, it reaches the Dandanglika Shan ridge and adjacent Myanmar (Figure 1). The northern Gaoligong Mountains (27°30′–28°22.4′N, 98°11.2′–98°47.5′E) range from 1160 to 5128 m (Guo 2000).

The characteristics of vegetation in the northern Gaoligong Mountains (Guo 2000) are as follows: (1) Evergreen broad-leaved forest is well developed (below 2800 m), including several types such as *Cyclobalanopsis* spp forest, *Lithocarpus hancei* forest, *Pinus bhutanica* forest, and *Taiwania cryptomerioides* forest. (2) Coniferous broad-leaved mixed forest, dominated by *Tsuga dumosa,* has a zonal distribution (between 2600–3100 m), and *Picea* forest is rare in the region. (3) Alpine shrub vegetation is well developed, but alpine meadows are not (above 3700 m). (4) Based on the different landforms and substrates, the nonzonal vegetation types are restricted to certain areas; the *Trachycarpus princeps* community, for example, is restricted to marble cliffs (between 1400–1600 m).

Methods

Intensive field surveys were conducted in this region, and plant specimens were collected to depict the flora of the area and make an inventory of plants over a 17-year period (July 1990–September 2006). In addition, the collectors continuously observed land use and land cover change and reviewed literature on these phenomena. At each locality, individual specimens were recorded and habitat, habit, characteristics of flowers and fruits, altitude, and abundance were noted. Voucher specimens are deposited in the herbariums of the Kunming Institute of Botany, Chinese Academy of Sciences, California Academy of Sciences (CAS), and Royal Botanic Garden Edinburgh. All specimens were identified according to the published volumes of the *Flora of China, Flora Reipublicae Popularis Sinicae,* and *Flora Yunnanica.* The numbers of families, genera, and species and the growth form spectrum of taxa were then analyzed using Microsoft Excel. Species nomenclature can be obtained from the checklist of vascular plants for Gaoligong Shan, Yunnan Province, China (CAS 2011).

The present conservation status of endemic flora of the northern Gaoligong Mountains is illustrated here as determined by application of International Union for Conservation of Nature (IUCN) conservation categories and criteria (IUCN 2001).

Results

Seed plant species diversity

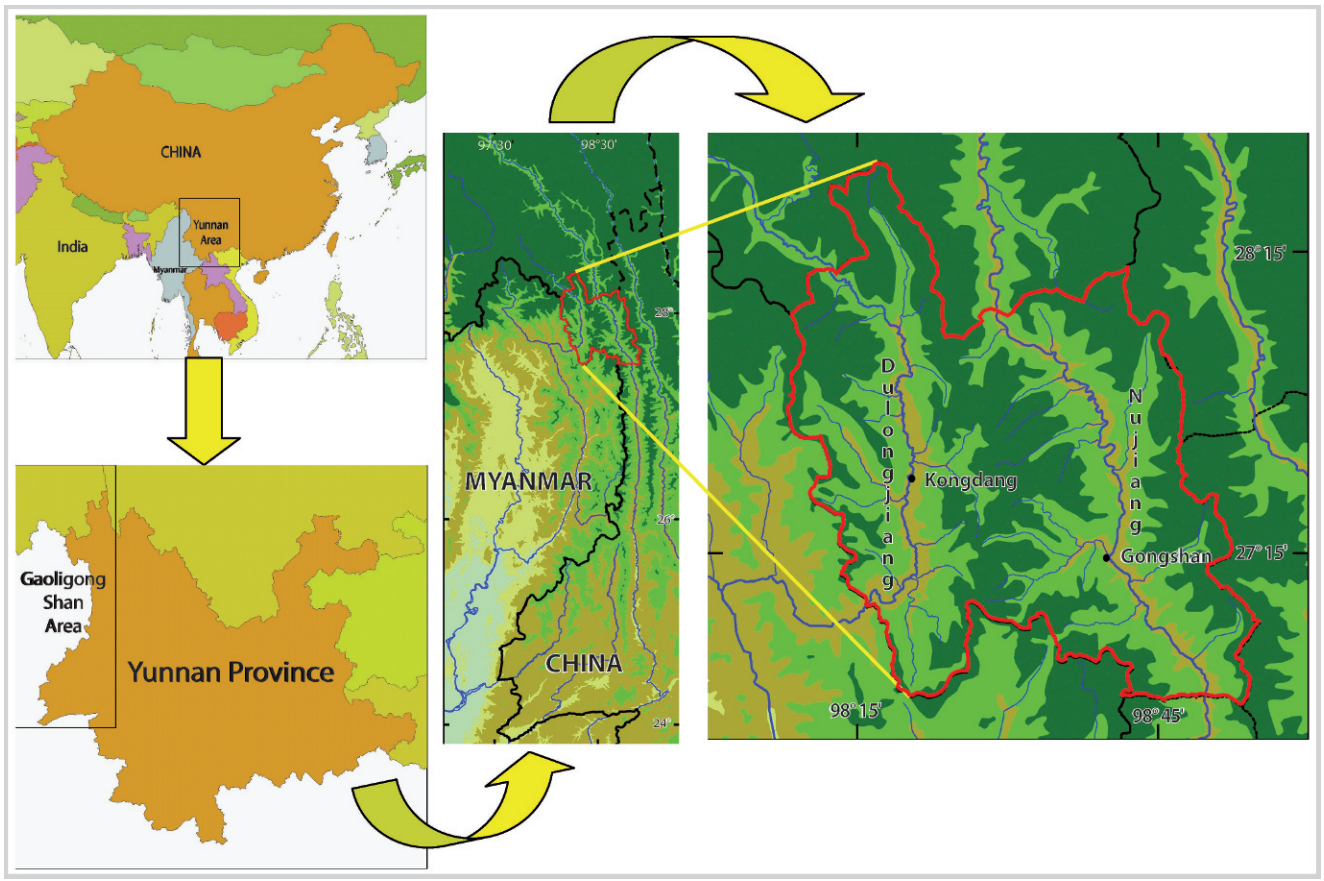
Counting all seed plant collections undertaken during our surveys and historical herbarium specimens, 2514 native species and 302 varieties (or subspecies) belonging to 778 genera in 171 families were recorded in this region (Table 1). This table shows that, compared with the Yalu Tsangpo Big Bend Gorge in the Medog region of southeastern Xizang in the eastern Himalayas—which has almost the same area as the northern Gaoligong Mountains—the northern Gaoligong region is much richer in species.

The basic growth form spectrum is represented in this region as follows: herbs 52.5% (1477 taxa), shrubs 27.8% (783 taxa), trees 11.2% (316 taxa), vines 5.4% (152 taxa), and epiphytes 2.9% (83 taxa), as well as 5 saprophytic orchids (*Galeola faberi, Galeola lindleyana, Gastrodia elata, Neottia acuminata,* and *Neottia listeroides*).

Endemism

In the northern Gaoligong Mountains, 12 families are endemic to eastern Asia: Cephalotaxaceae, Tetracentraceae, Eupteleaceae, Circaeasteraceae, Actinidiaceae, Stachyuraceae, Dipentodontaceae, Podoaceae, Aucubaceae, Helwingiaceae, Carlemanniaceae, and Triplostegiaceae.

FIGURE 1 Location of the northern Gaoligong Mountains. (Map by the authors)



At the generic level, 14 genera in 12 families are endemic to China: *Paragutzlaffia, Metapanax, Notoseris, Syncalathium, Heteropolygonatum, Davidia, Berneuxia, Whytochia, Gaoligongshania, Smithorchis, Eurycorymbus, Pterygiella, Dickinsia,* and *Sinolimprichtia,* of which 4 genera are woody and 10 are herbaceous. The genus *Gaoligongshania,* a bamboo, is endemic to the Gaoligong Mountains.

At the species level, 1232 taxa are endemic to China, of which 132 are endemic to the northern Gaoligong Mountains. Among these northern Gaoligong Mountain endemic taxa, 21 occur on both the east and the west sides of the region, 25 occur only on the east side, and 86 occur only on the west side. The most important habitats for these endemic taxa are undisturbed primarily

TABLE 1 Comparison of the diversity of seed plants in the northern Gaoligong Mountains, Yunnan, and China.

Area	Gymnosperm			Angiosperm		
	Families	Genera	Species	Families	Genera	Species
NGLGM[a)]	5	11	11	166	767	2503
YLTPBBG[b)]	6	9	10	174	717	1633
Yunnan[c)]	10	32	92	230	1953	14,000
China[d)]	11	42	232	334	3128	27,403

[a)]This study.
[b)]Sun and Zhou (2002).
[c)]Zhou and Chen (2006).
[d)]López-Pujol et al (2006).
NGLGM, northern Gaoligong Mountains; YLTPBBG, Yalu Tsangpo Big Bend Gorge.

evergreen broad-leaved forest, coniferous broad-leaved mixed forest, alpine shrub, and meadow at altitudes above 1240 m, which are more extensive on the west side.

Conservation value of endemic taxa

All endemic taxa in the northern Gaoligong Mountains were evaluated according to IUCN risk categories and criteria (IUCN 2001). The threat level summary indicates that 10 taxa are critically endangered, 5 are endangered, 10 are considered vulnerable to extinction, and 107 are still data deficient (*Supplemental data,* Table S1; http://dx.doi.org/10.1659/MRD-JOURNAL-D-10-00056.S1).

Threats to plant biodiversity in the northern Gaoligong Mountains

Natural disasters (eg landslides) are relatively frequent in some areas of the northern Gaoligong Mountains and can easily cause local extinction of plant populations. These processes are often exacerbated by the impact of human activities. The main human threats to plant biodiversity in this region, both directly and indirectly, are described here.

Destruction and fragmentation of natural habitats are the principal causes of species extinction. The northern Gaoligong Mountains have experienced massive loss of natural habitats in the past, mainly because of excessive logging of forests (for timber and fuelwood) but also because of conversion of forests into croplands. Swidden cultivation has been the main agricultural technique for centuries among many of the area's ethnic groups (Shen et al 2010), resulting in the fragmentation of forests at lower altitudes. In most regions, expansion of the area of cultivated fields because of the increasing population has meant the permanent replacement of forest, particularly in forest areas close to villages (Xu and Wilkes 2004).

The overexploitation of species of economic interest may seriously threaten plant survival. Some valuable medicinal plants are dwindling in wild habitats because of overcollecting, such as *Dendrobium candidum, Gastrodia elata, Paris* spp, *Panax* spp, and *Taxus* spp. Moreover, despite widespread cultivation of some species in the area, wild populations of these species remain severely depleted, both in number and in size (eg *Coptis teeta*). In addition to medicinal plants, non-timber forest products, including edible vegetation, have been subjected to overcollection (eg *Maianthemum* spp; see Meng et al 2006)—as have some orchids (eg *Cymbidium* spp) for their horticultural value. Charcoal production is a direct threat to the dominant trees in the evergreen broad-leaved forests because this activity is focused mainly on the Fagaceae family (particularly *Lithocarpus* and *Cyclobalanopsis*).

In addition, a rapidly warming climate appears to be threatening plant biodiversity in this region, as discussed by Baker and Moseley (2007).

Discussion

Geological background of floristic richness

The northern Gaoligong Mountains are at the margins of several tectonic plates—the Eurasian Plate, the Indochina Block, and the Indian Plate (Chaplin 2005). The collision of the Indian subcontinent with Asia in the early Tertiary resulted in the uplift of the eastern rim of the Tibetan Plateau during the Quaternary, which created many new habitats across a wide altitudinal range in this region (An et al 2001). These new habitats favored diversification and speciation of plants in the northern Gaoligong Mountains (eg *Primula* spp, *Rhododendron* spp, and *Syncalathium* spp) (Wang et al 2008; Milne et al 2010; Zhang et al 2011). The wide altitudinal gradients in the region would have provided suitable habitats for many species to survive because of the rugged, dissected topography (Chaplin 2005). During the last glacial maximum, the region had extensive ice caps (Shi 2002) and the precipitation level was close to that of the present day or even greater (Yu et al 2003; Zheng et al 2004), which enabled the northern Gaoligong Mountains to serve as a refuge for many ancient species because of humid conditions (eg *Taiwania cryptomerioides;* see Lepage 2009).

In addition, the west side is more complex in microclimate structure, topography, and ecological features and has less human disturbance than the east side, which probably accounts for the higher recorded endemism on the west side (Chaplin 2005).

Conservation priority of plant biodiversity in the northern Gaoligong Mountains

Conservation projects often focus on protecting and maintaining endemic species because they are seen as a hallmark of local biodiversity (Kessler 2000). Moreover, endemism is commonly regarded as an important criterion for the conservation priority of a particular area, one considered more useful than species richness (Myers et al 2000; Kier and Barthlott 2001). Although not all 132 endemic taxa in the Gaoligong Mountains are immediately threatened by extinction, some are known so far only from the type specimen or from a few collections made in the type's locality (eg *Ternstroemia longipedicellata* and *Rubus gongshanensis*). Furthermore, habitat fragmentation may convert a previously more continuous population structure to a metapopulation structure, with local populations becoming so small that they may face a substantial threat of extinction (eg *Salvia heterochroa* and *Elatostema lihengianum*; see Hawksworth and Kalin-Arroyo 1995). Others, such as *Paris dulongensis* and *Cymbidium gongshanense,* face a potential risk of extinction because of overcollecting for their medicinal or horticultural value. According to the *Catalogue of National Protected Key Wild Plants* (SC 1999), not all local endemic taxa have been included in the list of protected plants despite relatively scarce populations. They should therefore be considered threatened plants when establishing future conservation priorities because of their extremely restricted distribution.

Considering that strict and narrow endemic species are restricted to small areas and that they are therefore highly vulnerable to human disturbance and other forms of environmental change (Myers 1988; Williams 1993; Tchouto et al 2006), it is important to study their habitats (community type) for any conservation initiatives. Our study in the northern Gaoligong Mountains revealed that primarily evergreen broad-leaved forest, coniferous broad-leaved mixed forest, alpine shrub, and meadows are richer in strict and narrow endemics compared to the other forest types. Most of these types were at altitudes above 1240 m, and they were virtually undisturbed or less disturbed by human activities. Therefore, these community types should be considered a conservation priority because of their critical importance in conserving plant diversity in this region.

Conclusions

This study has revealed that the northern Gaoligong Mountains are characterized by a rich flora with 2514 native species and 302 varieties (or subspecies) of seed plants, of which 132 are found only in this area. The study provides important information about the conservation value of endemic taxa, as well as the habitats (community types) in this area, the endemic plants, and the habitats of primarily evergreen broad-leaved forest, coniferous broad-leaved mixed forest, alpine shrub, and meadows, to which conservation priority should be given. This information is essential for decision-making processes concerned with biodiversity conservation and sustainable natural resource management in this area.

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Supplemental data

TABLE S1 Endemic taxa in the northern Gaoligong Mountains and their conservation value according to IUCN risk categories and criteria (IUCN 2001).

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