Conservation Biology

Special Section: Balancing Conservation and Development to Preserve China's Biodiversity

Orchid conservation in the biodiversity hotspot of southwestern China

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Abstract: *Xishuangbanna is on the northern margins of tropical Asia in southwestern China and has the largest area of tropical forest remaining in the country. It is in the Indo-Burma hotspot and contains 16% of China's vascular flora in <0.2% of the country's total area (19,690 km^2). Rapid expansion of monoculture crops in the last 20 years, particularly rubber, threatens this region's exceptional biodiversity. To understand the effects of land-use change and collection on orchid species diversity and determine protection priorities, we conducted systematic field surveys, observed markets, interviewed orchid collectors, and then determined the conservation status of all orchids. We identified 426 orchid species in 115 genera in Xishuangbanna: 31% of all orchid species that occur in China. Species richness was highest at 1000–1200 m elevation. Three orchid species were assessed as possibly extinct in the wild, 15 as critically endangered, 82 as endangered, 124 as vulnerable, 186 as least concern, and 16 as data deficient. Declines over 20 years in harvested species suggested over-collection was the major threat, and utility value (i.e., medicinal or ornamental value) was significantly related to endangerment. Expansion of rubber tree plantations was less of a threat to orchids than to other taxa because only 75 orchid species (17.6%) occurred below the 1000-m-elevation ceiling for rubber cultivation, and most of these (46) occurred in nature reserves. However, climate change is projected to lift this ceiling to around 1300 m by 2050, and the limited area at higher elevations reduces the potential for upslope range expansion. The Xishuangbanna Tropical Botanical Garden is committed to achieving zero plant extinctions in Xishuangbanna, and orchids are a high priority. Appropriate in and ex situ conservation strategies, including new protected areas and seed banking, have been developed for every threatened orchid species and are being implemented.*

Keywords: conservation status, ex situ conservation, Orchidaceae, species diversity, Xishuangbanna, Yunnan

La Conservación de Orquídeas en el Hotspot de Biodiversidad del Suroeste de China

Resumen: *Xishuangbanna está en los límites del norte del Asia tropical en el suroeste de China y tiene superficie más grande del remanente de bosque tropical en el país. Se encuentra dentro del hotspot Indo-Burma y contiene el 16% de la flora vascular de China en un área <0.02% del total del país (19, 690 km2). La rápida expansión de los monocultivos en los últimos 20 años, particularmente el hule, amenaza a la biodiversidad excepcional de esta región. Realizamos censos sistemáticos de campo, observamos mercados, entrevistamos a los recolectores de orquídeas y determinamos el estado de conservación de todas ellas para entender los efectos del cambio de uso de suelo y la recolección sobre la diversidad de especies de orquídeas y para determinar las prioridades de protección. Identificamos 426 especies de orquídeas de 115 géneros en Xishuangbanna, 31% de todas las especies de orquídeas que se encuentran en China. La riqueza de especies fue mayor en las elevaciones de 1000-1200m. Tres especies de orquídeas fueron reconocidas como posiblemente extintas en vida silvestre, 15 como en peligro crítico, 82 como en peligro, 124 como vulnerables, 186 como de poca preocupación y 16 como deficientes de información. La declinación de las especies cosechadas a lo*

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Paper submitted August 26, 2014; revised manuscript accepted February 26, 2015.

Conservation Biology, Volume 00, No. 0, 1–10

DOI: 10.1111/cobi.12584

largo de 20 años sugiere que la sobre-colecta fue la principal amenaza, y que el valor de utilidad (es decir, el valor medicinal u ornamental) estuvo significativamente relacionado con la amenaza. La expansión de las plantaciones de árboles de hule fue una amenaza menor para las orquídeas que para otros taxones ya que sólo 75 especies de orquídeas (17.6%) aparecen debajo del techo de 1000m de elevación para el cultivo de hule, y la mayoría de estas especies (46) se encuentran en reservas naturales. Sin embargo, se proyecta que el cambio climático eleve este techo a aproximadamente 1300m para el año 2050 y el área limitada en elevaciones más altas reduce el potencial para la expansión de extensiones cuesta-arriba. El Jardín Botánico Tropical de Xishuangbanna está comprometido con la obtención de cero extinciones en Xishuangbanna, y las orquídeas son una alta prioridad. Se han desarrollado y se están implementando estrategias apropiadas de conservación in situ y ex situ, que incluyen nuevas áreas protegidas y bancos de semillas para cada especie amenazada de orquídeas.

Palabras Clave: conservación ex situ, diversidad de especies, estado de conservación, Orchidaceae, Yunnan, Xishuangbanna

Introduction

With 880 genera and more than 25,000 species, the orchid family is one of the most species-rich families of flowering plants (Cribb et al. 2003). Orchids are widely distributed and occur in almost every habitat, apart from glaciers and deserts, but most species are found in the tropics and subtropics (Cribb et al. 2003; Chen et al. 2009). Two-thirds of species are epiphytes and lithophytes, which are mainly distributed in the tropics (Swarts & Dixon 2009). Many orchids are rare and narrowly distributed in specific habitats (Koopowitz et al. 1993; Cozzolino & Widmer 2005; Jacquemyn et al. 2005; Crain & Tremblay 2014), possibly because of their mycorrhizal specificity, pollinator specialization, and germination limitation (Gravendeel et al. 2004; McCormick & Jacquemyn 2014). Orchids are among the most threatened of all flowering plants, and many species are threatened with extinction in the wild due to habitat loss and over-collection (Hágsater & Dumont 1996; Pillon & Chase 2007; Swarts & Dixon 2009). Orchids are considered flagship species for plant conservation globally (Baillie et al. 2004).

Only 3.2% of the land area of China is tropical, but this area hosts almost half of China's native flora. Tropical China is on the northern margins of tropical Asia and includes the extreme southeastern part of Tibet, southern Yunnan, southwestern Guangxi, southern Taiwan, and Hainan (Hou 2003). Xishuangbanna is a prefecture (administrative division of a province) bordering Laos and Myanmar in southern Yunnan (21°09'N-22°36'N, 99°58'E-101°50'E) and supports the largest area of tropical forest remaining in China (Cao et al. 2006). It is part of the Indo-Burma Global Biodiversity Hotspot (Myers 1998) and supports 16% of China's vascular flora (4152 species in 188 families) in <0.2% of the country's land area (19,690 km^2).

China is an orchid-rich country with 1388 species recorded, mainly in the tropical and subtropical regions in the south and southwest (Chen et al. 2009). Xishuangbanna is one of the most orchid-rich areas in China according to systematic field surveys conducted in 1988 and 1992 (Tsi & Chen 1995). As with much of tropical Asia, land use has changed greatly in Xishuangbanna in the past 20 years. In particular, monoculture rubber plantations now occupy 22% of the total land area, including most available land below 900 m (Xu et al. 2014). However, 3 major nature reserves protect 15.5% of Xishuangbanna, and orchids also occur in the forested holy hills of the Dai ethnic group and in traditionally managed tea gardens. Concerns about the impact of these changes on floristic diversity have led the Xishuangbanna Tropical Botanical Garden (XTBG) of the Chinese Academy of Sciences to develop a conservation plan, entitled Integrative Conservation for Zero Extinction in Xishuangbanna, that entails the use of in and ex situ conservation, reintroduction, ecological restoration, and education to ensure that no additional native plant species become extinct in Xishuangbanna (J. Chen, personal communication).

Orchids are extremely susceptible to habitat disturbance, at least in part because of pollinator specialization and mycorrhizal specificity (Jacquemyn et al. 2007). Moreover, around 350 species (25%) are used in traditional Chinese medicine, and many populations of these species have been exploited to the point of extirpation (Luo et al. 2003; Liu et al. 2014). As a result, the Orchidaceae has a higher proportion of threatened genera and species than other families (Pillon & Chase 2007), and this situation is particularly serious in Xishuangbanna, making this family a major challenge for the Zero Extinction plan.

Although the general threats to orchids are known, effective conservation requires the identification of priority species, sites, and threats. Therefore, based on data from a 3-year field survey, we assessed the current status of all orchid species in Xishuangbanna, analyzed the distribution of orchid species richness relative to habitat and elevation, and identified the major threats to orchids in the region. We then developed a conservation strategy for each threatened species to achieve an ultimate goal of zero extinctions in this family. We addressed 3 major questions: how has orchid species diversity in Xishuangbanna changed in the 20 years since the surveys by Tsi and Chen (1995); how many orchid species are threatened and what are the major threats; and how can orchids be protected from extinction in Xishuangbanna?

Methods

Study Area

Xishuangbanna is mountainous and elevation ranges from 480 m in the south to 2400 m in the north. Limestone is extensive in the southeast at 600–1600 m (Cao et al. 2006). Xishuangbanna has a monsoon climate with hot, wet summers and cool, dry winters. The monthly mean temperature ranges from 15.7°C to 25.8°C at 558 m asl. Annual precipitation ranges from 1200 to 1556 mm, >80% of which occurs between May and the end of October. Morning fog reduces water stress between November and February.

Assessment of Orchid Diversity

Tsi and Chen (1995) recorded 335 orchid species in 96 genera in systematic field surveys conducted in 1988 and 1992. An additional 32 species in 22 genera were subsequently found during ad hoc field studies, of which 6 species were new records for China and 26 were new to Xishuangbanna (Gao et al. 2014). We studied all available publications, records, and data related to orchids of Xishuangbanna and examined all specimens in Chinese herbaria (Gao et al. 2014) (Supporting Information). Information about their distributions, flowering times, and habitats were used to plan field surveys. We conducted these surveys on 8 separate occasions during different seasons from April 2011 to December 2013 and surveyed most sites investigated by Tsi and Chen (1995) (Fig. 1). Each survey lasted 9–17 days, for a total of 108 days in the field. For each species we recorded geographic information, number of mature individuals, growth and fruiting status, seedling presence, host tree species, and habitat. We checked the nomenclature of all species in the recently published Flora of China (Chen et al. 2009). Synonyms, misidentifications, and cultivated plants were excluded from the list of native species in Xishuangbanna (Supporting Information).

A nonparametric randomization test was used to identify differences in orchid species richness by elevation. Elevation was divided into 10 categories: <600 m, 600–800 m, 800–1000 m, 1000–1200 m, 1200–1400 m, 1400–1600 m, 1600–1800 m, 1800–2000 m, 2000–2200 m, and >2200 m. Similarity in species composition was estimated for each pair of elevation ranges with the Sørensen similarity index $S = 1 - 2\ w/(a + b)$, where a and b are the numbers of species in each elevation category and w is the number of species in common.

Assessment of Conservation Status and Analysis of Threat Factors

The conservation status of all native plant species in Xishuangbanna was assessed in 2012–2014 to set conservation priorities. Assessments for each species were based on the number of mature individuals and the number of known localities in which the species occurred. Threat categories were based on a simplified version of the International Union for Conservation of Nature (IUCN) Red List categories and criteria. We used IUCN Red List terminology because it is widely understood in China, but the urgency of the situation in Xishuangbanna made it necessary to do the initial assessment without the comprehensive documentation that the IUCN process normally uses. The IUCN (2014) makes clear that the absence of high-quality data should not deter attempts to apply their criteria. Our use of the IUCN categories is thus within the spirit of their guidelines, although it is not a formal red-list assessment at this stage.

The categories were PEW (possibly extinct in the wild), not seen in last 20 years or only known locations destroyed; CR (critically endangered), <50 mature individuals or only known locations threatened with destruction; EN (endangered), <250 mature individuals; VU (vulnerable), <5000 mature individuals and only 1–5 locations; and LC (least concern), >5000 individuals and many locations. An additional category, DD (data deficient), was used as sparingly as possible. We did not use the category NT (near threatened) because our data were insufficient to distinguish such species consistently from those assessed as VU and LC. The assessment process started with an examination of the entire angiosperm flora (ca. 4000 spp.) by experts with field experience in Xishuangbanna that spanned 50 years. This was followed by extensive field surveys and reviews of herbarium collections. Orchids were thereafter assessed separately from other angiosperms because more recent and more detailed information was available and over-collection is much more important for orchids than other taxa (Huang 2011). The impact of over-collection was assessed based on 20 years of field observations, surveys of local markets, interviews with orchid collectors, and the literature (Gao et al. 2014).

Experience suggests that life form, vegetation type, elevation range, and utility value (i.e., medicinal or ornamental value) are likely to influence orchid endangerment in Xishuangbanna. Multinomial logistic regression was used to analyze the relationships between these 4 factors and orchid endangerment (i.e., categories PEW, CR, EN, and VU). We used 3 life form categories (epiphytic, terrestrial, and mycoheterotrophic), 5 vegetation types (tropical seasonal rain forest, tropical montane rain forest, tropical seasonal moist forest, tropical montane evergreen broad-leaved forest, and tropical monsoon

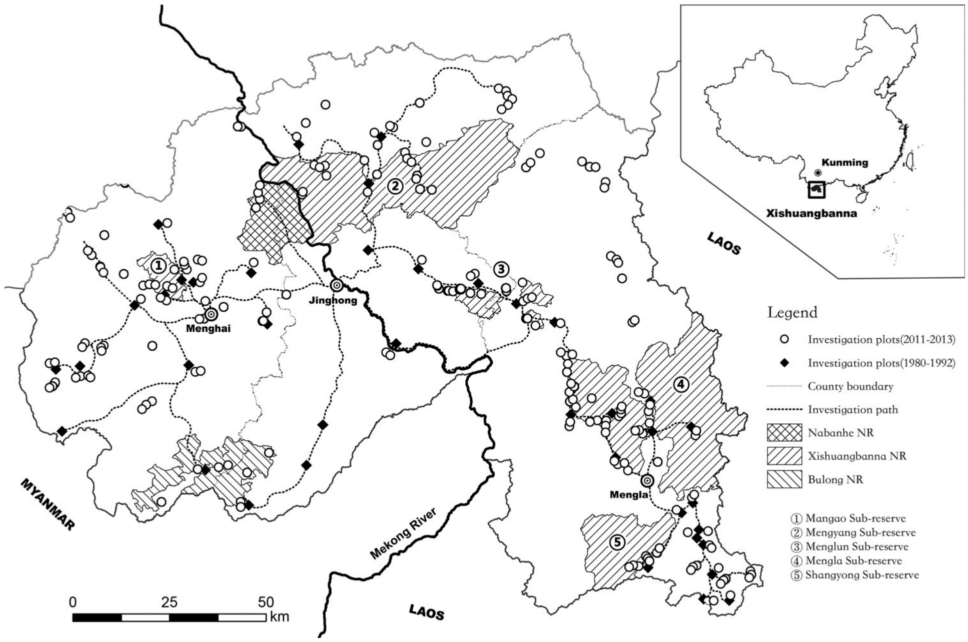

Figure 1. The location of Xishuangbanna, the 3 nature reserves (NR), and the sites investigated during the orchid surveys conducted in 1980–1992 and 2011–2013.

Table 1. Locations, environments, and orchid diversities of 3 traditional tea gardens and a nearby natural forest.

Study sites (location)[a]	Range of elevation(m)	Annual precipitation (mm)	Annual mean temperature (°C)	Species diversity index: No. of species	Margalef index	Shannon-Wiener index	Pielou index
NNM-TTG (21°57′31″ N; 100°36′14″ E)	1350-1613	1650	18.2	25	3.51	1.95	0.61
JNM-TTG (21°59′05″ N; 101°05′07″ E)	1130-1380	1400	18.9	32	4.05	2.28	0.66
JMM-TTG (22°12′13″ N; 100°01′71″ E)	1250-1450	1690	18.4	43	5.85	3.20	0.80
NF-JMM (22°09′37″ N; 100°00′57″ E)	1492-1550	1690	18.4	40	5.64	2.89	0.78

[a]*Abbreviations: NNM, NanNuo Mountain; TTG, traditional tea garden; JNM, JiNuo Mountain; JMM, JingMai Mountain; NF, natural forest.*

forest), two elevation ranges (below and above 1000 m, the maximum elevation for rubber cultivation), and three utility values (ornamental, medicinal, and no-value [Zhu & Yan 2012]). Lithophytes were included with epiphytes because many species grow on both trees and rocks. Statistical analyses were performed using SPSS version 13.0 for Windows.

In Situ Conservation Status

The major nature reserves (NR), Xishuangbanna National Nature Reserve, Naban River Watershed National Nature Reserve, and Xishuangbanna Bulong Nature Reserve, contain examples of all major vegetation types (Fig. 1). We used plant species checklists for these 3 NRs and other available data to assess the in situ conservation status of all orchids as I, effectively protected, >10 populations in NRs; II, well protected, 5–10 populations in NRs; III, poorly protected, 1–5 populations in NRs. For the holy hill forests of the Dai ethnic group, which lack formal protection, we relied on previous surveys (Gao et al. 2014).

Tea gardens are a major land use type at higher altitudes and have a much longer history than rubber plantations. Although most are now low-growing monocultures, traditional tea gardens with native shade trees are still widespread. Because of their small size and high diversity, we used plot sampling to investigate orchid species diversity and abundance. Three traditional tea gardens, in JiNuo Mountain (JNM), NanNuo Mountain (NNM), and JingMai Mountain (JMM), were selected for investigation during 2013 and 2014. Nine 20×20 m^2 plots were randomly established at each site, and at JMM the survey was repeated in the nearby natural forest to compare orchid richness between the ecosystems (Table 1). The species richness and diversity were determined using the Margalef index ($d_{Ma} = (S-1)/\ln N$), Shannon-Wiener index ($H' = -\sum^{P_i} \ln P_i$), and Pielou index ($J_{SW} = -\sum^{P_i} \ln P_i / \ln S$), where S is the species numbers, N is the total number of individuals, and P_i is the relative frequency of species i.

Results

Orchid Species Diversity in Xishuangbanna

During our 3 years of field surveys, 253 orchid species in 76 genera were recorded, including 65 species in 36

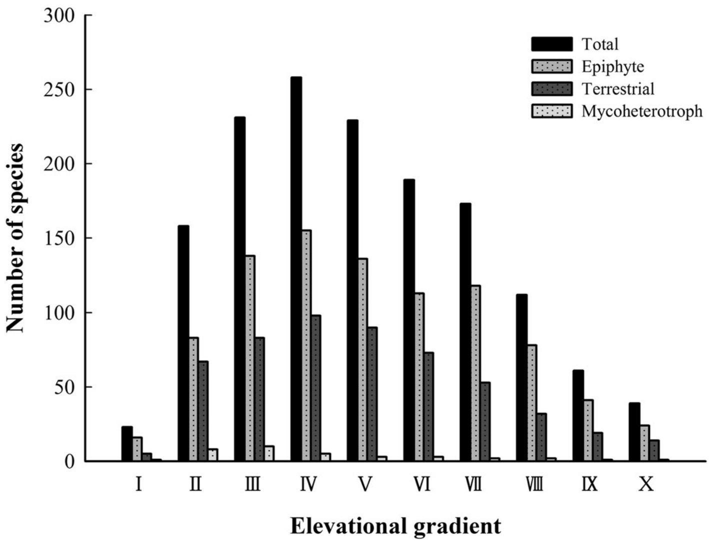

Figure 2. Orchid species richness relative to elevation in Xishuangbanna (elevational belts: I, <600 m; II, 600–800 m; III, 800–1000 m; IV, 1000–1200 m; V, 1200–1400 m; VI, 1400–1600 m; VII, 1600–1800 m; VIII, 1800–2000 m; IX, 2000–2200 m; X, >2200 m).

genera new to Xishuangbanna, 2 genera new to China (*Thaia* and *Lesliea*), 4 species new to science, and 14 new records for China. In total, 426 orchid species in 115 genera have now been recorded in Xishuangbanna, almost one-third (31%) of all Chinese orchids, and 12 species are endemic to this area. Of these, 68% (289 species) are epiphytic, 29% (124) are terrestrial, and 3% (13) are mycoheterotrophic (Supporting Information).

Total orchid species richness varied significantly among elevation belts ($\chi^2 = 383.84$, $n = 9$, $p < 0.001$) and was highest at 1000–1200 m (273 species) and lowest above 2200 m (51 species) (Fig. 2). Epiphytic orchids showed the same pattern as other orchids, but terrestrial and mycoheterotrophic orchids were found mostly at lower elevations (Fig. 2). The dendrogram obtained from a hierarchical classification based on the Sørensen similarity index showed a clear distinction between a floristically homogeneous high elevation group and a more varied low elevation group (Fig. 3).

Conservation Status and Threats to Orchids

Out of the 426 orchid species recorded in Xishuangbanna, 3 were classified as PEW, 15 as CR, 82 as EN, 124 as VU, and 186 as LC. The remaining 16 were DD (Supporting Information). The 3 PEW species were represented by specimens from Xishuangbanna in the herbaria of the Institute of Botany in Beijing (PE) or XTBG (HITBC), but they have not been recorded subsequently. *Dendrobium pseudotenellum* was collected in Shanyong Mengla in 1984 (Y.Z.Ma, 133; PE), *Epipactis helleborine* in Ganlanba Jinghong in 1988 (G.D.Tao, 44157; HITBC), and *Eria yanshanensis* in Menghai in 1983 (X.Q.Chen & Z.H.Tsi, 0023; PE). For the 15 CR species, *Acampe joiceyana Aerides falcata Bulbophyllum gymnopus Disperis neilgherrensis*, and *Pectelis sagarikii,* were very narrowly distributed; only single populations of each species with <50 mature individuals were found in Xishuangbanna. The other 10 CR species, *Cymbidium mastersii, Dendrobium parciflorum*, *D. wattii*, *Paphiopedilum parishii*, *Papilionanthe biswasiana Pecteilis henryi Phaius flavus P. tancarvilleae P. wallichii*, and *Phalaenopsis mannii*, were also narrowly distributed (1-3 collection sites known) and have high ornamental value. Fewer than 50 mature individuals of each of these 10 species were found during field surveys after over-collection in the past 20 years (J. Y. G and Q. L., personal observations; Gao et al. 2014). The 16 DD species were recorded by Tsi and Chen (1995), but we could not find records of the specimens supposedly deposited in PE, and we did not find them in the field surveys.

Among the 4 factors investigated, only utility value was significantly related to endangerment of orchids as a whole ($\chi^2 = 34.98$, $p < 0.001$) (Table 2). Whether an orchid was PEW was not related to any factor; CR was significantly related to ornamental value (Wald = 15.98, $P < 0.001$) and to occurrence in tropical montane rain forest (Wald = 699.44, $p < 0.001$) and tropical seasonal moist forest (Wald = 182.15, $P < 0.001$); EN was significantly related to ornamental value and medicinal value (Wald = 5.56, $p < 0.05$; Wald = 3.58, $P < 0.05$, respectively); and VU was significantly related to ornamental value (Wald = 12.67, $P < 0.01$).

In Situ Conservation Status

Overall, 284 of 426 orchid species (66.7%) were present in the 3 NRs; 73 species were evaluated as effectively protected, 80 species as well protected, and 131 species as poorly protected. The remaining 142 species were not recorded in the NRs (Supporting Information). The 73 effectively protected species included 2 EN species, 16 VU species, and 55 LC species. The 80 well protected species included 7 EN species, 29 VU species, and 44

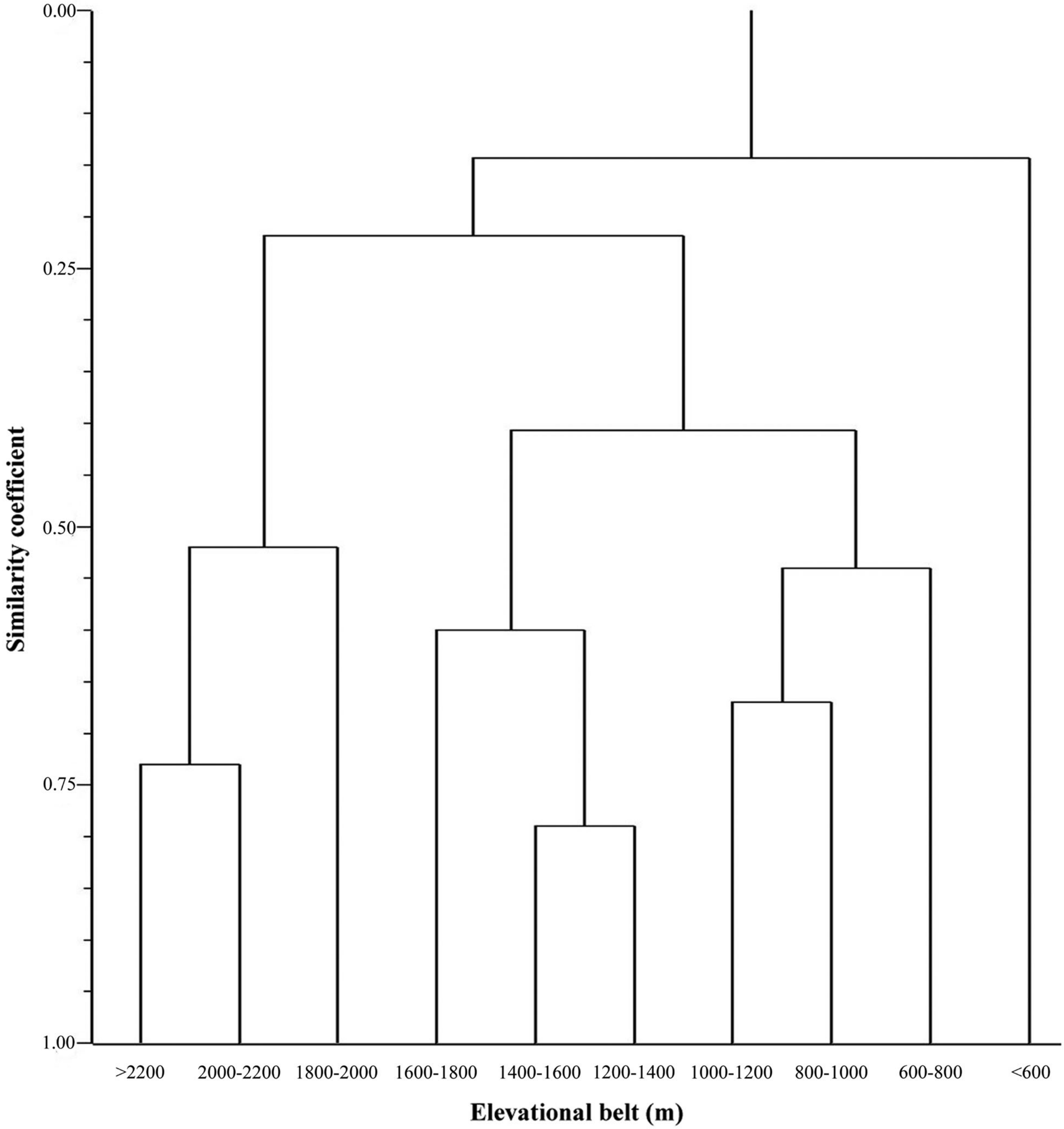

Figure 3. Dendrogram constructed from a hierarchical classification based on the Sørensen similarity index showing 2 distinct groups of orchid species relative to elevation.

LC species, whereas the 131 poorly protected species included 5 CR species, 33 EN species, 42 VU species, and 51 LC species. The 142 species recorded only outside NRs included all 3 PEW species, 10 CR species, 40 EN species, 37 VU species, 36 LC species, and 16 DD species (Fig. 4).

Sixty-five species were recorded in the 3 traditional tea gardens. Some occurred in all three tea gardens, such as *Mycaranthes pannea*, *Luisia magniflora*, and *Vanda brunnea*. The JMM garden had the highest orchid richness (43 species) (Margalef index, $D_{JMM} = 5.85$; Shannon-Wiener index, $H_{JMM} = 3.20$), and the indices of richness and diversity at this site were higher than in the nearby forest (Table 1).

Discussion

Status Assessments

We found 65 species in 36 genera new to Xishuangbanna, including two genera and four species new to China. The number of species recorded in Xishuangbanna

Table 2. The results of a multinomial logistic regression between potential predictors and level of orchid endangerment.

Effect factors	*-2 log likelihood*	χ^2	*p*
Life form	296.77	9.82	0.127
Vegetation type	309.46	22.52	0.278
Elevation range	293.48	6.53	0.163
Utility value	321.93	34.98	<0.001

increased from 335 species in 96 genera to 426 species in 115 genera since Tsi and Chen (1995), despite massive deforestation in the last 20 years. This shows that orchid species diversity in the area was previously greatly underestimated. Narrow distributions and short flowering times make it easy to overlook orchids in the field, and many collectors lack the necessary taxonomic expertise to separate similar species. Xishuangbanna has <0.2% of China's total land area but supports 31% of China's orchid species, confirming it as China's orchid hotspot. China's other major tropical forest area, Hainan Island, is larger than Xishuangbanna (34,420 km^2) but has less remaining forest and supports far fewer orchid species (214 in 78 genera) (Yu et al. 2007). Despite the high diversity, only 12 species are known to be endemic to Xishuangbanna; most others are shared with neighboring countries, including Laos, Myanmar, and northern Thailand. However, rapid land-use change and over-collection pose similar threats in these countries, so these cross-border distributions do not necessarily increase species security. Moreover, peripheral populations of widespread species have potential ecological and evolutionary importance (Abbitt et al. 2000; Leppig & White 2006).

The conservation statuses we assigned to orchids in Xishuangbanna were in some cases very different from those assigned in the China Species Red List (CSRL) (Wang & Xie 2004) because our assignments reflect more recent and complete information and because of the large difference in the spatial scale of the assessments. For example, *Papilionanthe teres* has CR status on the CSRL because only a single location was known in China, but we evaluated it as VU because it is common in karst regions in Xishuangbanna. In contrast, *P. biswasiana* is EN on the CSRL and is more widely distributed in China, but we classified it as CR because only one population with <50 mature individuals is known in Xishuangbanna (Supporting Information). Although a case can be made for using different criteria and nomenclature for local assessments (Crain & White 2011), the familiarity of conservation officials with the Chinese translations of the IUCN categories greatly facilitates the communication needed for effective conservation action.

Threats

The recent, dramatic expansion of rubber monocultures has been considered the major threat to biodiversity in Xishuangbanna (Li et al. 2007; Ziegler et al. 2009). Rubber plantations are a very poor habitat for orchids, and only 3 terrestrial species, *Zeuxine nervosa*, *Liparis barbata*, and *Crepidium purpureum*, were occasionally found in them. However, rubber is less of a threat to orchids than other plants; only 75 orchid species (17.6%) occur below 1000 m, the current ceiling for growth of rubber, and most of these (46) occur in NRs. However, all three PEW species had past distributions that largely overlapped with the current rubber-dominated area, and seven of 15 CR species are threatened by rubber expansion. Moreover, many species now persist only in highly fragmented forests surrounded by rubber plantations, and the long-term viability of these populations is unknown. Populations in small fragments may be affected by changes in microclimate, and changes in pollinators and mycorrhizal fungi may affect population dynamics (Batty et al. 2002; Chen & Gao 2011).

Utility value had the strongest relationship with endangerment; 15 CR, 16 EN, and 36 VU species were over-collected because of their ornamental value. Twenty-six EN species were collected for medicinal purposes. China has a very long history of using orchids in traditional Chinese medicine. Many species of *Dendrobium* (known as ShiHu in Chinese) are used as medicine and health food (Liu et al. 2014), including 22 of 48 species in Xishuangbanna (Wang et al. 1995). Most of these were widely distributed in Xishuangbanna but massively collected during the 1990s. We classified 1 species of *Dendrobium* as EW, 2 as CR, 17 as EN, 15 as VU, and 13 as LC (Supporting Information). Even when the species was not endangered, many populations had been extirpated, as has occurred elsewhere in China (Luo et al. 2003).

Climate change is likely to become an increasing threat to orchids in southwestern China over the next few decades. A downscaled ensemble of 19 Earth System Models from the Coupled Model Intercomparison Project Phase 5 (CIMP5) with 4 different representative greenhouse gas concentration pathways (RCPs) projected a 1.6-2.4°C increase in mean annual temperature by 2050 and little change in rainfall (Zomer et al. 2014). To survive, orchids would need to move approximately 300 m upward in elevation, which is probably within the dispersal capacities of most orchids if habitat is available. However, warming will also lift the current 1000-m ceiling on rubber cultivation, threatening the orchid-rich 1000–1200 m belt, and the ability of orchids and their habitats to shift to higher elevations will be limited by the decline in land area. Northward migration is a theoretical alternative, but habitats are fragmented and the rates of movement required for latitudinal escape are a thousand times greater than for upward migration (Liu et al. 2010). Large uncertainties in rainfall projections make predictions for water stress unreliable, but conditions may become drier (Zomer et al. 2014), increasing the threats to orchid persistence.

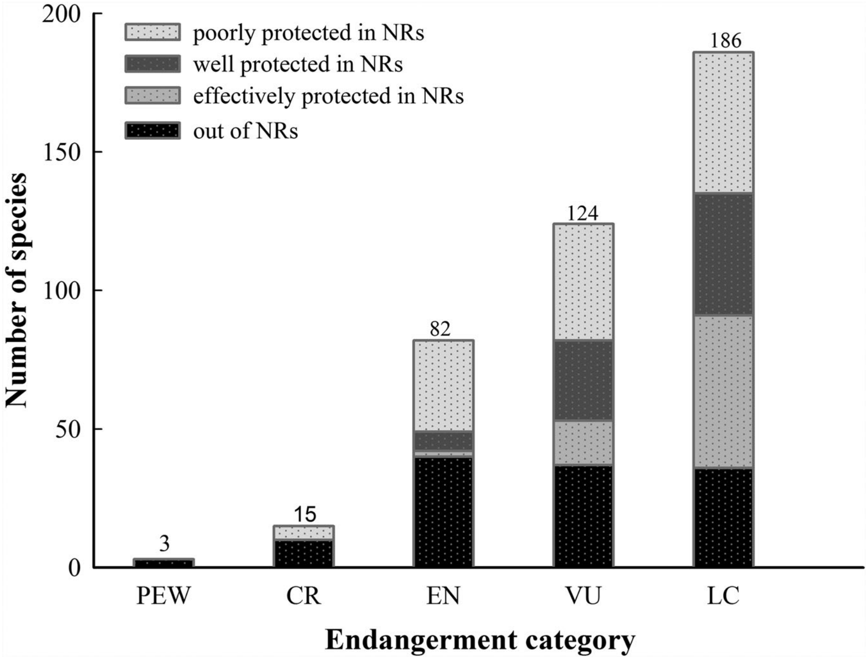

Figure 4. The in situ conservation status of orchid species in different endangerment categories (NR, nature reserve; PEW, possibly extinct in the wild; CR, critically endangered; EN, endangered; VU, vulnerable; LC, least concern).

Conservation Action

The leading role of in situ conservation of orchids in Xishuangbanna is played by the NRs, which protect at least part of the range of two-thirds of the orchid flora. These NRs are relatively large by Chinese standards (Zhao et al. 2013) and cover 15.5% of the land area, but leave one-third of all orchid species unprotected. More NRs are clearly needed in Xishuangbanna, but it is unlikely that the reserve system can be extended enough to secure the future of all species. Dai holy hills can also act as orchid refuges, especially in lowland areas. A survey of 180 Dai villages during 2011–2012 showed that 328 remnant pieces of holy hills covered 25.3 ha and held 114 orchid species, including many that are over-collected elsewhere, such as *Acampe ochracea*, *Aerides rosea*, *Ascocentrum ampullaceum*, *Dendrobium nobile*, *D. sulcatum*, *D. thyrsiflorum*, *D. wardianum*, *Vanda coerulea*, and *V. coerulescens* (Gao et al. 2014). Many holy hill forests have been cleared, degraded, or drastically reduced in area in recent years, so incentives for the continuation of this traditional conservation practice are needed.

The major commercial crops are not significant habitats for orchids in Xishuangbanna, but traditional tea gardens, where tea is grown under a canopy of native trees, support a high diversity of orchids, consistent with a previous study that found 51 orchid species (Qi et al. 2005). Although many traditional gardens have been converted to modern tea monocultures, the premium paid for the tea they produce in a traditional manner has ensured that 5494 ha persist in Xishuangbanna at altitudes of 1200–1800 m (Luo et al. 2013). These gardens are important for other native species (Qi et al. 2005), so their continued protection and traditional management is important.

To address the threat from habitat destruction outside NRs, we divided species into three in situ conservation action categories depending on their status in the reserves: no action for the 153 species effectively or well protected in NRs; population augmentation or reintroduction for the 131 species poorly protected in NRs; and mini nature reserves (MNR) for the 142 species occurring only outside NRs. The MNRs are small protected areas designated for a particular function, in this case protecting orchids. Two have been established so far and are managed under the Xishuangbanna National Nature Reserve: Qingshizhai MNR (21°47′N, 101°22′E; elevation 1110–1132 m) is 9 ha and supports 44 orchid species; Yinchang MNR 21°59′N, 101°14′E; elevation 1402–1472 m) is 588 ha and supports 42 orchid species.

According to our observations, over-collection is a very serious threat to many orchid species in the area. To address this threat, we recommend action to deter collection. For ornamental orchids, in our experience, local consumers value unique colors and forms, so we recommend conservation policies that encourage artificial breeding programs by state or private entities for commercial use. For medicinal orchids, where consumers favor wild-gathered materials, we recommend policies that encourage a combination of artificial cultivation and cultivation in natural habitats.

Given the threats to orchid habitats described above, ex situ conservation is needed to provide additional security for threatened species. Orchids are well suited to this because they have numerous seeds per fruit that can survive long-term storage at subzero temperatures (-5 °C or -20 °C) after being dried to low moisture contents, and the seeds are relatively easy to grow (Seaton & Pritchard 2003; Seaton & Ramsay 2005). Seeds of 133 species from different populations have already been stored in the XTBG seed bank (Supporting Information). Because some orchids depend on specific fungi for germination and establishment, an orchid-fungus bank has been established at XTBG, and the fungi for some species have been isolated from protocorms with a seed baiting technique (Zi et al. 2014) or directly from the mycorrhizae. Seedlings of more than 60 species have been obtained through in vitro germination of stored seeds. Seedlings of 5 threatened species have been used to practice reintroduction since 2012, and the results have been encouraging (Gao et al. 2014). The same techniques will be useful for assisted migration of orchid populations to new locations at higher elevations or latitudes if this becomes necessary (Liu et al. 2010). In the meantime, long-term monitoring of orchid populations is needed to assess the impacts of climate change and to detect early warning signs of potential problems.

Public support within Xishuangbanna will be essential for the success of the Zero Extinction project. Educational activities focused on orchid conservation include lectures to middle school and college students, training courses and discussion meetings with NR staff and local people, an orchid photography competition, and an orchid show in XTBG. A book entitled *Orchids of Xishuangbanna: Diversity and Conservation* has also been published (Gao et al. 2014) that highlights the beauty and diversity of the local orchid flora and promotes their conservation.

Key features of our assessment approach include its speed, comprehensiveness, and the use of new and existing data from multiple sources, including literature records, herbarium specimens, field surveys, and expert knowledge. Our aim was to produce a useable assessment that could be applied immediately in setting priorities for *in* and *ex situ* conservation. However, Xishuangbanna is only 0.2% of China's total area, and a major on-going focus of the Zero Extinction project at XTBG is an attempt to extend this process to other botanical gardens in China (through the Chinese Union of Botanical Gardens) in order to assess and protect China's entire native flora. The same approach is likely to be effective in other parts of the tropics and subtropics, where high biodiversity and rapid development make traditional, species-by-species approaches to conservation assessment too slow.

Acknowledgments

This work was supported by the National Natural Science Foundation of China (grant number 31170358 and 31470450) to J.Y.G. and Direction 3 of the 1-3-5 plan of XTBG. We are grateful to H. Liu from Florida International University for her valuable comments on earlier drafts, and three anonymous reviewers for their insightful and extremely useful comments. We also thank X.H. Jin, H. Lin, Z.B. Yang, Y.H. Tang, J.W. Li, W.L. Zhang, X. Zhou, L.L. Chen, X.J. Wang, and S.C. Shao for their contributions to field surveys.

Supporting Information

A checklist of orchids in Xishuangbanna with information on species distribution, elevational range, flowering time, in and ex situ conservation status, and endangerment status (our assessment and status assigned in the China Species Red List) (Appendix S1) and a checklist of orchids in Xishuangbanna with information on herbarium records used in the current study and references (Appendix S2) are available online. The authors are solely responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

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