Orchid conservation in China from 2000 to 2020: Achievements and perspectives

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ARTICLE INFO

Article history:
Received 5 April 2021
Received in revised form 3 June 2021
Accepted 11 June 2021
Available online 22 June 2021

Keywords:
Orchid diversity
In situ conservation
Ex situ conservation
Conservation biology
List of national key protected wild plants

ABSTRACT

We review achievements in the conservation of orchid diversity in China over the last 21 years. We provide updated information on orchid biodiversity and suggestions for orchid conservation in China. We outline national policies of biodiversity conservation, especially of orchid conservation, which provide general guidelines for orchid conservation in China. There are now approximately 1708 known species of Orchidaceae in 181 genera in China, including five new genera and 365 new species described over the last 21 years. The assessment of risk of extinction of all 1502 known native orchid species in China in 2013 indicated that 653 species were identified as threatened, 132 species were treated as data-deficient, and four species endemic to China were classified as extinct. Approximately 1100 species (ca. 65%) are protected in national nature reserves, and another ~66 species in provincial nature reserves. About 800 native orchid species have living collections in major botanical gardens. The pollination biology of 74 native orchid species and the genetic diversity and spatial genetic structure of 29 orchid species have been investigated at a local scale and/or across species distributions. The mycorrhizal fungal community composition has been investigated in many genera, such as Bletilla, Coelogyn, Cymbidium, Cypripedium, and Dendrobium. Approximately 292 species will be included in the list of national key protected wild plants this year. Two major tasks for near future include in situ conservation and monitoring population dynamics of endangered species.

Plant Diversity 43 (2021) 343–349

1. Introduction

The orchid family (Orchidaceae) is among the largest families of flowering plants, with approximately 750 genera and 28,000 species (Chase et al., 2015). Orchids are key species for conservation biology. Orchid seeds depend on mycorrhizal fungi for germination and some species even depend on mycorrhizal fungi for organic carbon for life (Liu et al., 2010; Xi et al., 2020; Zhang et al., 2020a). Most orchid species require pollinators for fruit set and some require specific pollinators (Maad and Nilsson, 2004; Reiter et al., 2019; Jiang et al., 2020; Liu et al., 2020c). And epiphytic orchid species need trees or stone to grow on. These intricate life histories pose challenges for orchid conservation. The over-collection of orchids, especially species with showy flowers and medicinal value, presents additional threats to wild plants (Gale et al., 2019; Liu et al., 2020b). All wild orchid species have been listed in Appendices of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES).

China is home to approximately 30,722 species of angiosperms (Wang et al., 2015; Qin et al., 2017a; Ren et al., 2019), of which 6% are orchids. The appreciation and cultivation of orchid plants have a long history in China (see Chen and Luo, 2003). The cultivation of Cymbidium Sw. began in the late Tang Dynasty, and orchid paintings appeared in the Northern Song Dynasty (see Chen and Luo, 2003). It has been estimated that Gastrodia elata Bl. (tianma) was first used as medicinal plants approximately 2000 years ago (see (Liu et al., 2010; Chen and Luo, 2003)). Recently, 1502 native orchid species in China have been assessed against Red List Criteria (IUCN, 2012); 653 (43%) are threatened with extinction, and four species are...
considered extinct (Qin et al., 2017b; Qin and Zhao, 2017). In the last six decades, China has established 474 national nature reserves (National Forestry and Grassland Administration of the People’s Republic of China, 2019); these provide strict protection for the in situ conservation of biodiversity, including orchid diversity. More than 20 academic botanical gardens aimed at plant conservation have been established. In this review, we describe recent achievements in the conservation of orchid diversity in China and provide suggestions for conservation in the near future.

2. Documentation of orchid biodiversity in China

Chen and Luo (2003) reviewed the history of Orchidology in China in detail, with a focus on progress in taxonomy and new discoveries from 1925 to 2002. Orchid sections in Flora Republicae Populares Sinicae (FRPS) were published in 1999 (Chen, 1999; Lang, 1999; Tsi, 1999), including 1247 species in 171 genera, prompting subsequent botanical surveys. Approximately 1388 species in 194 genera were included in the Flora of China (Chen et al., 2009). Five new genera, Cymbilabia D.K. Liu & Ming H. Li, Danxiaorchis J.W. Zhai, F.W. Xing & Z.J. Liu, Hsinhsua X.H. Jin, Schuit. & W.T. Jin, Thuniospis L.L. D.P. Ye & Shi J. Li, and Zhizhenia X.H. Jin, Lu Q. Huang, W.T. Jin & X.G. Xiang, have been proposed since 2009 (Zhai et al., 2013; Jin et al., 2014a, 2015; Li et al., 2015b; Liu et al., 2020a). Ten genera, Biermannia King & Pantl., Cleissocentron Brühl., Cleisostomopsis Seidenf., Cystorchis Blume, Gennaria Parl., Micropera Lindl., Plocoglottis Blume, Saccolabiopsis J.J. Sm., Thaia Seidenf., and Zeuxinella Aver., have been discovered as new records during botanical surveys across China in the last 21 years (Jin et al., 2003, 2015; Song et al., 2007; Huang et al., 2012; Lai and Jin, 2012; Xiang et al., 2012; Li et al., 2015a; Yang et al., 2013). Over the same time period, approximately 365 new orchid species have been proposed and 144 species have been documented as new records in China (see (Du et al., 2020) and https://www.ipni.org/). Of note, the classification of Orchidaceae has been updated (Chase et al., 2015), and approximately 30 genera have been reduced to synonyms (Chase et al., 2015; Jin et al., 2015, 2017; Raskoti et al., 2016; Schuiteman and Averyanov, 2017).

There are now approximately 1708 known species in 181 genera and five subfamilies of Orchidaceae in China (Tables S1 and S2). Most of these species belong to 17 tribes. The largest genera in China include Bulbophyllum Thouars s.l. (161 species), Calanthe R. Br. s.l. (60), Cymbidium (57), Cypræpidium L. (38), Dendrobium Sw. s.l. (116), Gastrochilus D. Don (41), Habenaria Wildl. s.l. (66), Hemninium L. s.l. (37), Liparis Rich. (80), Neottia Guett. s.l. (41), Oberonlia Lindl. (46), Ponerorchis Rchb.f. s.l. (39), and Platanthera Rich (56). Five genera (i.e., Danxiaorchis, Hancockia Rolfe, Haraeella Kudo, Ischnogynye Schltr., and Zhizhenia) are considered endemic to China.

3. Evaluating the conservation status of native orchid species

The China Biodiversity Red List—Higher Plants Project was initiated by the former Ministry of Environmental Protection (MEP) in 2008 with ambitious aims to assess the risk of extinction of all known species of higher plants in China against the IUCN Criterion (Version 3.1, Second edition). In September 2013, the Red List of China Higher Plants (RLCHP) was published jointly by MEP and the Chinese Academy of Sciences (CAS) (http://www.zhb.gov.cn/gkml/hhh/bgg/201309/20130912_280061.html). Experts from seven institutions or universities evaluated all 1502 known native orchid species in China. Approximately 653 species (43%) were identified as threatened, including species classified as critically endangered, endangered, and vulnerable. Approximately 132 species were treated as data-deficient in the Red list (Qin et al., 2017a, b). Four species endemic to China (i.e., Eulophia monantha W.W. Sm., Gastrochilus nanchuanensis Z.H. Ts., Liparis hensoaensis Kudô, and Tainia emeiensis K.Y. Lang) were evaluated as extinct, and Bulbophyllum yunnanense Rolfe was classified as regionally extinct (Qin et al., 2017a).

This orchid Red List generally agrees with expectations based on botanical surveys, market surveys, and herbarium information across China. For example, approximately 90% of 653 threatened orchid species have been affected by habitat loss, deterioration, and/or fragmentation. The results of orchid market surveys have suggested that the trade of wild-harvested orchids was very active in China (Song et al., 2017; Williams et al., 2018; Gale et al., 2019; Wong and Liu, 2019), and that the threat of wild harvesting has been significantly underestimated in Chinese Biodiversity Red List assessments (Liu et al., 2020b).

4. In situ conservation

The most effective approach to in situ conservation of orchid species takes into account the life history traits of the species and roles of mycorrhizal fungi and pollinators. More than 2750 nature reserves, including national and provincial reserves, were established across China by 2018 (Ministry of Ecology and the Environment, 2019). Many national nature reserves are well known for their rich orchid diversity. For example, there are about 100 species in the Bawangling National Nature Reserve (Hainan), 220 species in the Luchun Huanglianshan National Nature Reserve (Yunnan), 400 species in the Xishuangbanna National Nature Reserve (Yunnan), and 450 species in the Gaoligongshan National Nature Reserve (Yunnan). The Yachang Orchid National Nature Reserve was established in 2006 in Guangxi to protect native orchids in limestone regions (Cameron, 2010; Feng et al., 2012; Huang, 2017). Based on a biodiversity checklist, Qin et al. (2012) reported that 51.9% of 1334 orchid species are currently protected by nature reserves. Zhang et al. (2015) reported that approximately 90% of 1449 orchids species are covered by national nature reserves, and an additional 7% are covered by provincial nature reserves based on the literature and specimen information. In addition, Zhang et al. (2015) reported that 83 endemic species are not found in national nature reserves or provincial nature reserves (see Table S1 in Zhang et al., 2015). Based on a collaborative botanical survey across China, specimen information, and literature searches, Liu et al. (2020b) found that approximately 52.2% of 1582 orchid species have been discovered in at least one national nature reserve, and approximately 26% (412 species) have been found in three or more national nature reserves; these estimates are generally in agreement with those of Qin et al. (2012). Our analyses based on botanical surveys and specimen information indicated that approximately 1100 species (ca. 65%) (Table S3) are found in national nature reserves, and another approximately 66 species are found in provincial nature reserves.

5. Ex situ conservation of orchid diversity

In the last two decades, orchids have become a major focus of conservation efforts at 20 major public and academic botanic gardens. In particular, five botanical gardens in South China (i.e., South China Botanical Garden, CAS; Xishuangbanna Tropical Botanical Garden, CAS; Shanghai Chengshan Botanical Garden, CAS; Kunming Botanical Garden, CAS; and Wuhan Botanical Garden, CAS) are well known for their work on ex situ orchid conservation. The Shenzhen Orchid Center was established in Shenzhen (Guangdong Province) for ex situ conservation in 2005. Only one botanical garden in north China, the Beijing Botanical Garden, is known for ex situ orchid conservation. Huang (2014)
stated that there are living plants for approximately 585 species in 12 botanical gardens. Lin (2018) reported that approximately 790 native orchid species are in living collections at botanical gardens across China. Liu et al. (2020b) reported living collections for approximately 802 Chinese orchid species in at least one botanical garden or state-owned research institute. Based on checklists of Lin (2018) and Huang (2014), orchids from subtropical and tropical regions (southern and eastern China) are well protected in botanical gardens; however, there is a gap in the ex situ conservation of species in alpine and/or northern temperate regions. Among approximately 300 native orchid species in alpine regions and northern China, approximately 50 species are included in living collections in botanical gardens.

6. Orchid conservation biology

6.1. Pollination biology

Orchids are part of complex ecological systems. Most orchids depend on a functional group of pollinators for pollination success, and some require specific pollinators (Luo et al., 2020). Orchid diversity has been, in part, attributed to the coevolution of orchids and pollinators (Cozzolino and Widmer, 2005; Givnish et al., 2015). Understanding orchid pollination biology is very important for orchid conservation, especially in situ conservation and reintroduction efforts. Studies of the pollination biology of orchids have accelerated over the last two decades in China. The pollination biology of 74 orchid species has been investigated in the field, including 14 Cypripedium and nine Paphiopedilum Pfitzer species (Table S4). Specialized pollinators have been recorded for orchids, including wasps for Dendrobium sinense Tang & F.T. Wang (Brommann et al., 2009) and Coelogyne fimбриata Lindl. (Cheng et al., 2009); fruit flies for Cypripedium micranthum Franch. (Li et al., 2012) and Cypripedium budolphianum W.W. Sm. & Farrer (Zheng et al., 2010); hoverflies for Cypripedium subtropicum S.C. Chen & K.Y. Lang (Jiang et al., 2020), Epipactis veratrifolia Boiss. & Hohen. (Jin et al., 2014b), Paphiopedilum barbigurum Tang & F.T. Wang (Shi et al., 2009), and P. dianthum Tang & F.T. Wang (Shi et al., 2007); and dung flies for Cypripedium sichuanense Perner (Li et al., 2012). Habenaria malintana (Blanco) Merr. has been recorded as obligate agamospermous in southern China (Zhang and Gao, 2018). Asian honey bee (Apis cerana) is the main pollinator of ten species (e.g., Bulbophyllum ambrosia (Hance) Schlr. (Chen and Gao, 2011)). Pollinator attraction in 44 species relies on various deception mechanisms, including general food deception (such as Paphiopedilum micranthum T. Tang & F.T. Wang (Ma et al., 2016)), shelter imitation, Batesian mimicry, and brood-site imitation. Now pollination mechanisms have also been discovered, including rain pollination in Acampe rigida (Buch.-Ham. ex Sm.) P.F. Hunt (Fan et al., 2012), the rewarding mimicry system of Cypripedium subtrropicum (Jiang et al., 2020), the dual deceit strategy of C. tibeticum King ex Rolfe (Li et al., 2006), fungal imitation by Cypripedium fargesii Franch. (Ren et al., 2011), and the mimicry of honey bee alarm pheromones in Dendrobium sinense (Brommann et al., 2009).

6.2. Population genetics

Population genetic diversity is closely related to species fitness (Booy et al., 2000; Reed and Frankham, 2003). Populations and species with low genetic diversity may have reduced survival in changing environments (Markert et al., 2010). Population genetic structure across a species range may improve our understanding of evolutionary processes. Therefore, understanding genetic diversity of species is crucial and provides a basis for conservation strategies. The major aims of conservation programs are to maintain genetic diversity within populations of plant species. In the last two decades, the genetic diversity and spatial genetic structure of 29 orchid species (Table S5) have been investigated at a local scale and/or across species distributions. Most of these studies have focused on plants with medicinal or ornamental value, such as Paphiopedilum spp. (Li et al., 2002, 2014, 2016b, 2020; Huang et al., 2014; Wang et al., 2016a), Gastrodia elata (Wu et al., 2006; Chen et al., 2011, 2014; Li et al., 2011), Bletilla striata (Chung et al., 2013; Sun et al., 2016), Cypripedium (Guo et al., 2019), Dendrobium spp. (Ding et al., 2008, 2009; Cai et al., 2011; Li et al., 2008; Xu et al., 2011; Hou et al., 2012; Lu et al., 2013; Ye et al., 2017a, b), Cymbidium spp. (Wang et al., 2009; Liu et al., 2014; Zhao et al., 2017; Xie et al., 2020), and Changningia amaeno S.S. Chien (Li and Ge 2006). Recent results indicate that most orchid species have high genetic diversity and a high degree of genetic differentiation among populations, with an increase in genetic distance as geographic distance increases (Xie et al., 2020). Few self-pollination species, such as Bulbophyllum bicolor Lindl. (Hu et al., 2017), have extremely low levels of genetic diversity.

6.3. Mycorrhizal associations

Mycorrhizal fungi play a crucial role in orchid life cycle, distribution and abundance (Liu et al., 2010). Orchid seeds are tiny and devoid of endosperm, and are dependent on mycorrhizal fungi to supply the necessary nutrients for their germination. All orchids are mycoheterotrophic at early stages of development (Stoeckel et al., 2014), and maintain mycorrhizal symbiosis throughout their whole life cycle. Most terrestrial orchids depend fully or partially on mycorrhizal fungi for carbon and other resources in adult life as well, especially the partially (Roy et al., 2013) or fully mycoheterotrophic orchids (Smith and Read, 2008; Hynson et al., 2016). Mycorrhizal fungi have been increasingly recognized as an important factor in deciding whether an orchid occurs in a habitat or not (McCormick et al., 2018). In last two decades, the interactions between orchids and mycorrhizal fungi have been extensively studied in China. In addition, mycorrhizal fungal community composition has been investigated in some genera, such as Bletilla Rchb.f. (Tao et al., 2013; Li et al., 2018; Deng et al., 2019; Jiang et al., 2019; Xi et al., 2020), Coelogyne (Xing et al., 2015; Qin et al., 2020), Cymbidium (Li et al., 2016a; Liu et al., 2016; Sheng et al., 2012; Wu et al., 2010), Cypripedium (An, 2017; Fu et al., 2019; Miao et al., 2015; Quan et al., 2015), Dendrobium (Chen et al., 2012; Dan et al., 2012; Zi et al., 2014; Meng et al., 2019a; Shao et al., 2019, 2020b; Sarsaiya et al., 2020; Wu et al., 2020), Gymnadenia R.Br. (Gao et al., 2020; Xing et al., 2020a), Liparis (Ding et al., 2014, 2016; Gai et al., 2016), Paphiopedilum (Ding et al., 2014, 2016; Gai et al., 2016), and Pleione (Qin et al., 2019). The main taxa of mycorrhizal fungi that form symbiotic relationships with orchids are three groups within Basidiomycota (such as Tulasnellaceae, Ceratobasidiaceae and Sebacinales) (see details in Gao et al., 2019).

Mycorrhizal communities are influenced by geographic distance (Xing et al., 2020a), orchid species (Chen et al., 2019), host trees (Wang et al., 2017), orchid life forms (Xing et al., 2015, 2019), and phylogenetic constraints (Xing et al., 2017, 2020b). Studies indicate that numerous orchid species can be considered mycorrhizal generalists (Xing et al., 2020a) and mycorrhizal specificity in orchid species is phylogenetically conserved (Xing et al., 2017, 2020b). Additionally, many mycorrhizal fungal strains have been isolated and used for orchid seed symbiotic germination or orchid reintroduction (Wang et al., 2016b; Feng et al., 2019; Li et al., 2019; Meng et al., 2019b; Xu et al., 2019; Yang et al., 2019, 2020; Shao et al., 2020a, b; Xi et al., 2020; Zhang et al., 2020b).
7. National orchid conservation actions

7.1. Orchid diversity survey in China

To understand the biodiversity, distribution, population dynamics, and risk of extinction of orchid species, the Department of Wildlife Conservation of National Forestry and Grassland Administration (DWCFG) initiated the Orchid Diversity Survey in China in 2018. The project will span approximately five to six years from 2018 and utilizes new technologies and methods, such as an APP for survey information collection and the online identification of species. Approximately 393 experts and students from 31 institutions or universities have participated in fieldwork up to the end of 2020. More than 116,000 orchid records, approximately 30 new species, and 10 newly recorded species have been obtained during this survey.

7.2. Revision of the List of National Key Protected Wild Plants

The national key protected species are species that are protected by law across the country. In 1999, the former State Forestry Administration and the former Ministry of Agriculture issued the first version of the List of National Key Protected Wild Plants (LNKPWP) with permission from the State Council, representing a landmark plant conservation effort in China. The first version of the LNKPWP included 246 native species and eight categories (genera or families). However, orchid species were excluded due to technical issues. In 2018, the former State Forestry Administration and the former Ministry of Agriculture launched the revision of LNKPWP. A working team of 14 experts from 10 institutions or universities provided an orchid checklist to be included in a subsequent revision at the end of 2020. In total, 29 species and eight categories approximately 292 species will be included in the LNKPWP in 2021. Most or all species in the genera Anoectochilus Blume, Cymbidium, Cyripedium, Dendrobium, Paphiopedilum, and Pleione D. Don will be included. Most native members of these genera are classified as endangered due to over-collection and the trade of wild-sourced plants.

7.3. Important ecological programs

The Chinese government has launched several important and ambitious ecological programs since 1998, including the Natural Forest Protection Program, Conversion of Cropland to Forest Program, Program for Wildlife Conservation & Nature Reserve Development, Program for Integrated Management of Stony Desertification in Karst Areas, and Key Shelterbelt Development Programs in the Three-North Regions, the Yangtze River Basin and other River Basins. The habitats of orchids and other wildlife in China have been protected or rehabilitated, and some species have been recovered or rescued through in situ or ex situ conservation measures. The forest coverage in China increased from 8.6% in 1949 to 23.04% in 2020. The National Rescue and Conservation Plan on Plants with Extremely Small Populations (LNKPWP) with permission from the State Council, representing a milestone for nature conservation in China. This is a milestone for nature conservation in China. In early 2020, the NFGA initiated the integration and refining of all protected areas. This action is expected to be finished in 2021. All protected areas will be improved and strictly supervised.

For historical reasons, there are many types of protected areas in China managed by different governmental sectors, including national reserves, scenic and historic areas, forest parks, wetland parks, geological parks, and oceanic parks. More than 11,800 protected areas at the end of 2019 (see http://www.mnr.gov.cn/sjqttsj/202003/t20200311_2510199.html, http://www.mee.gov.cn/ywgz/zrstbh/zrbhdjg/201905/P020190514616282907461.pdf). Some of these protected areas are not effective owing to overlap, a lack of lawful and clear boundaries, a lack of formal management authority, insufficient financial support, or conflicts with local communities. Conservation gaps and fragmentation are also issues. To resolve these problems, the NFGA was established in 2018 during the reform of governmental institutions, with the responsibility of the conservation on terrestrial wildlife and management of all protected areas. The Guideline on establishing a system of natural protected areas with national parks as its main body was promulgated in June, 2019. The guideline proposed that, through top-level design, mechanism-based reforms, enhanced monitoring, and policy support, China would establish a system of protected areas with national parks as its main body, scientific categorization, reasonable space planning, strong conservation plans, and effective management. This is a milestone for nature conservation in China. In early 2020, the NFGA initiated the integration and refining of all protected areas. This action is expected to be finished in 2021. All protected areas will be improved and strictly supervised.

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Fourteen natural heritage and four mixed heritage areas nominated by the Convention Concerning the Protection of the World Cultural and Natural Heritage were also managed by the NFGA after the reform. Heritage sites that are important habitats of orchid species, such as Three Parallel Rivers of Yunnan Protected Areas, South China Karst, Wulingyuan Scenic and Historic Interest Area, and Mount Wuyi, will receive better protection through the updated protected area system (Zhang et al., 2015).

Before the end of 2020, the Chinese government had set up 10 pilot national parks in 12 provinces, occupying 220,000 km². Some are very important habitats for orchid species, such as the Giant Panda National Park, Wuyi Mountain National Park, Hainan Tropical Rainforest National Park, and Pudacuo National Park. The Chinese government will continuously provide abundant financial, technical, policy, and human resources to these national parks. The increase in national parks is expected to be beneficial for orchid species.

7.5. Other actions

The Department of Wildlife Conservation of National Forestry and Grassland Administration and the Shenzhen Orchid Research Center jointly organized the Workshop on Orchid Species Conservation in July 2018, inviting about 60 participants from the government, scientific institutes, and non-governmental organizations, as well as orchid hobbyists, to analyze achievements and gaps in orchid conservation. The Initiative on Protecting Wild Orchids and
Refusing Unregulated Trade was jointly published by 16 NGOs, including the China Wild Plants Conservation Association, China Flower Association, China Traditional Medicine Association, and TRAFFIC (http://env.people.com.cn/n1/2019/0202/c1010-30608826.html). These actions will improve orchid species conservation.

8. Perspectives on orchid conservation in China

Substantial achievements in orchid conservation have been made in China over the last 21 years. New conservation policies and projects have been proposed or implemented. The construction of an ecological civilization may be among the best strategies. Most orchids have strict habitat requirements and are likely to be affected by habitat fragmentation and destruction, over-collection, and climate change. Owing to gaps in laws during the past 21 years, it has been very difficult to end the trade of wild-sourced plants, which has posed a major risk to some groups of orchids.

The revision of LNKWP will improve this situation in the very near future. The high demand for orchids as medicinal plants and ornamental flowers will be limited mainly to artificial propagated specimens and will provide opportunities for conservation. To effectively conserve these nature heritages, we need to understand the biology of each species, including pollination biology, mycorrhizal fungal associations, life cycles, and population dynamics. Owing to the large number of species, strategies at the country level are urgently needed, including support for prior groups (such as Anoectochilus, Cymbidium, Cyripedium, Dendrobium, and Pleione) and regions for in situ or ex situ conservation with high species richness, long-term monitoring of wild populations, and cooperation between botanical gardens and protected areas for ex situ conservation and reintroduction. Two major tasks in the near future include in situ conservation and monitoring population dynamics of endangered species. To improve endangered species conservation and protected area management, several laws and regulations are urgently needed, including the Law on Protected Areas and Law on National Parks. The government plans to revise several regulations, such as the Regulation on Nature Reserves, Regulation on Scenic and Historic Areas, and Regulation on Wild Plant Conservation.

Author contributions
ZH.Z, RHS, YZ, XXK, XHJ wrote and revised the manuscript. All authors read and approved last manuscript.

Declaration of competing interest
The authors declare no conflict of interest.

Acknowledgement
We thank Dr. Zong-Xin Ren for comments on an early draft. This work was supported by Grants from National Forestry and Grassland Administration, China (No. 2019073018, 2019073019), National Natural Science Foundation of China (No. 31870195, 31670194).

Appendix A. Supplementary data
Supplementary data to this article can be found online at https://doi.org/10.1016/j.pld.2021.06.003.

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