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SYNOPSIS

Wild Plant Species with Extremely Small Populations Require Conservation and Reintroduction in China

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China is exceptionally rich in biodiversity, with more than 30 000 vascular plant species that include many endemic genera, species of ancient origin, and cultivated plants (Yang et al. 2005). Because of rapid economic development, population growth, pollution, and continuing resource exploitation, China's plant diversity faces severe threats. According to the Chinese National Report on Biodiversity, 15–20 % of the animal and plant species in China are now threatened. In the past 50 years in China, about 200 species have become extinct, and about 4000–5000 vascular plants are currently endangered. China has 156 of the 640 species on the list of the "Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES)." The first volume of the "China Plant Red Book" identified 388 rare and endangered species, including 121 endangered species, 110 rare species, and 157 vulnerable species. In 1999, the "National Key Protected Wild Plants" identified about 1700 rare and endangered plant species (Chinese State Report on Biodiversity Editorial Committee 1998).

In 2008, the Chinese government launched "China's Strategy for Plant Conservation," which proposed 16 goals or targets and implemented in situ conservation (e.g., nature reserves) and *ex situ* conservation (e.g., botanical gardens) of wild plants in China. Target 6 aimed to provide in situ protection for about 60 % of the threatened species. Target 8 aimed to provide *ex situ* protection for about 60 % of the threatened plant species, of which 10 % would be included in reintroduction programs (China's Strategy for Plant Conservation Editorial Committee 2008). In 2012, the State Forestry Administration of China formulated the "Conservation Program for Wild Plants with Extremely Small Population in China" as their 2012–2015 operational plan.

Conservation and reintroduction of rare and endangered plants with extremely small populations has been very difficult, especially because there are few successful examples to follow (Godefroid et al. 2011; Polak and Saltz 2011). Conservation and reintroduction of plants with extremely small population requires a systematic approach. Because conservation and reintroduction of plants with extremely small population is considered essential for ecological, economic, and human health, research on this topic has been a major focus in the fields of international conservation biology and restoration ecology (Albrecht et al. 2011). In this paper, we review the research concerning the conservation and reintroduction of rare and endangered plants in China and elsewhere, and we propose a direction for future development of this field.

THE STATUS AND PROBLEMS WITH CONSERVATION OF WILD PLANTS WITH EXTREMELY SMALL POPULATION IN CHINA

The term "extremely small population" refers to a population with a narrow geographical distribution that has been disturbed and stressed by external factors over a long time and the numbers of which are smaller than the minimum required to prevent extinction (State Forestry Administration of China 2012). For most extremely small populations in China, the main factors causing their vulnerability to

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extinction are habitat destruction, over-exploitation, and environmental pollution. At present, these populations are also under stresses associated with global climate change. Only a small fraction of species have become rare and endangered because of inherent vulnerability. Based on a survey conducted by the State Forestry Administration during 1997–2003, of the 189 national key protected wild plant species, 11 have wild populations with fewer than 10 individuals. Most of these 189 species have fewer than 5000 individuals in their wild populations (fewer than 10 000 for herbaceous species), which is below the internationally recognized minimum size of a viable population (Division of Plant Conservation of the State Forestry Administration 2005). The loss of these populations will affect or even destroy the structure and function of their mother ecosystems. Among the 120 wild plant species with extremely small populations closely monitored by the State Forestry Administration, nine have fewer than 10 individuals among all distribution sites in the wild; three of these species (*Carpinus putoensis*, *Abies beshanzuensi*, and *Ostrya rehderiana*) are under "first-grade state protection" and six are under "second-grade state protection" (the intensity of protection, from highest to lowest, is first-grade, second-grade, and provincial). Twenty nine species have populations ranging from 10 to 99 individuals, including seven first-grade state protection plants nine second-grade state protection species, and 13 provincial key protected plants. A total of 46 species have wild populations containing from 100 to 999 individuals. Among these, four species are under the first-grade state protection, three are under second-grade state protection, and 39 are under provincial key protection. Among the 33 species with 1000–9999 wild individuals, 19 are under first-grade state protection, eight are under second-grade state protection, and six are under provincial protection. Wild populations of *Taxus cuspidate*, *Taxus fuana*, and *Hopea hainanensis* exceed 10 000 and all are under the first-grade state protection.

The distribution of plants with extremely small populations is often very narrow (see Fig. 1, Electronic Supplementary Material). Among the 120 species with extremely small populations in China, 54 species have only one distribution area/point, 22 have two distribution areas, 23 have 3–4 distribution areas, 14 have 5–9 distribution areas, and seven have more than 10 distribution areas. Among those plant species with one, two, or 3–4 distribution areas, 35, 26, and 59 are under first-grade state protection, second-grade state protection, and provincial key protection, respectively.

To protect wild plants, China began establishing nature reserves in 1956. To date, there are a total of 2349 nature reserves including 265 national nature reserves (132 are wild plant nature reserves) in China, covering an area of 2 260 000 ha. In addition, 180 botanical gardens in China have introduced and preserved about 22 000 higher plant species; these botanical gardens have preserved about 70 % of the plant species in the Chinese flora (China's Strategy for Plant Conservation Editorial Committee 2008). China has also launched national and provincial plant resource surveys, completed the China Plant Red Book, and established a suite of new techniques for the introduction and cultivation of rare and endangered plants, for the conservation of seeds, and for the in vitro conservation of plant organs and tissues. In addition, the National Environmental Protection Agency has established about 250 bases for the protection and propagation of special taxa. Most of the rare and endangered plant species initially released by the state have been conserved *ex situ* at these bases (Division of Natural Conservation of the State Environmental Protection 1991). Germplasm gene pools and databases of nationwide rare and endangered plant species have been established, and intensive research is being conducted on the introduction, breeding, ecological characteristics, morphology, anatomy, and phylogeny of dozens of rare and endangered plant species. Those works have already reduced the threat of extinction for several species (Wu et al. 2004).

Unfortunately, most wild plant species with extremely small populations are not legally included in the state protection program because of gaps in related laws and regulations regarding wild plant conservation. Research on such species is lacking, especially with regard to developmental biology, population genetics, reproductive biology, population ecology, and community ecology. Because these species are not included in specific state conservation strategy, most wild plant species with extremely small populations remain in danger of extinction. It follows that the overall prospects are not good for preserving wild plant species with extremely small populations in China. Correcting this problem will require modification of conservation laws and regulations.

THE REINTRODUCTION OF WILD PLANTS WITH EXTREMELY SMALL POPULATION IN CHINA

For reintroduction of rare and endangered plants, plants protected and propagated via *ex situ* conservation are returned to their original natural and semi-natural ecosystems or to suitable wild habitats. The goal is to establish a population with sufficient numbers and genetic resources to enable it to adapt to change and to be self-sustaining and self-renewing (Griffith et al. 1989; IUCN 1998). International organizations have also published guidelines for the reintroduction of wild species, and at least 249 reintroduction trials involving 172 taxa have been conducted worldwide (Godefroid et al. 2011). More than 890 papers

related to reintroduction have been published (Polak and Saltz 2011). To date, there have been 62 successful reintroduction cases in the world (Albrecht et al. 2011).

Based on *ex situ* conservation and research on threatened plants, China has performed several reintroduction experiments. Until now, 38 plant species have been successfully reintroduced. Reintroduced herbs include *Primulina tabacum*, *Paphiopedilum wardii*, *Paphiopedilum armeniacum*, *Paraisometrum mileense*, *Tigridiopalma magnifica*, *Metabriggsia ovalifolia*, *Paphiopedilum malipoense*, and *Doritis pulcherrima*. Reintroduced shrubs include *Myricaria laxiflora* (Chen et al. 2005), *Loropetalum subcordatum*, and *Cycas debaoensis* (Ren et al. 2008). Reintroduced trees include *Disanthus cercidifolius subdp longipes*, *Nageia nagi*, *Manglietia longipedunculata*, *Bretschneidara sinensis*, *Parakmeria lotungensis*, *Davidia involucrate*, *Dipteronia sinensis*, *Lirianthe odoratissima*, *Manglietia aromatica*, *Euryodendron excelsum*, *Formanodendron doichangensis*, *Pachylarnax sinica*, *Cyclobalanopsis sichourensis*, *Nyssa yunnanensis*, and *Diploknema yunnanensis* (Sun et al. 2006; Zheng and Sun 2009). The lower plant *Adiantum reniforme. var. sinense* has also been successfully reintroduced (Ren 2012).

The reintroduction of plant species with extremely small populations in China involves a number of main features and problems. Botanical gardens play an important role in the early stage of wild plant reintroduction because such gardens research introduction techniques are related to *ex situ* conservation. The government is important because it promotes interactions with international organizations and it develops and implements the relevant laws and regulations. For example, the State Forestry Administration approved the "Implementation Plan for Saving Wild Plants of Extremely Small Populations" in 2012; Botanical Garden Conservation International launched a "10 species program" in China aiming at insuring species survival and population recovery. Those works are conducted mainly in relatively developed areas, such as Guangdong and Zhejiang provinces, or biodiversity-rich regions (such as Yunnan province), and over a short period of time, but few related papers have been published. The plant species that have been systematically studied include *Primulina tabacum*, *Tigridiopalma magnifica*, *Bretschneidara sinensis*, *Pachylarnax sinica*, and *Cyclobalanopsis sichourensis*. The species that have been reintroduced are confined to those in single-species families and genera, and relic species or rare and endangered species.

With respect to the reintroduction of wild plants, researchers in China have studied the ecological characteristics, population genetics, and breeding biology of 28 species. The research has confirmed that these species have narrow distribution areas and shrinking population sizes related to anthropogenic disturbance and climate change. *Primulina tabacum*, *Tigridiopalma magnifica*, and *Cycas changjiangensis* have had 3, 1, and 2 wild distribution points (populations), respectively, that became extinct in the past decade (Ren et al. 2010, 2012). The genetic diversity of these plants is generally low. These plants have varying degrees of natural reproduction barriers (Jian et al. 2010).

To increase the successful reintroduction of rare and endangered species, researchers have combined methods of biotechnology and ecological restoration. Our investigations showed that reintroduction of *Primulina tabacum* often required the use of bryophytes as nurse plants (Ren et al. 2010). Successful reintroduction of *Tigridiopalma magnifica* indicated that rare and endangered species can be transplanted and established with anthropogenic assistance under the conditions of global climate change, which clarified current academic debate (Ren et al. 2012). We have also successfully reintroduced some trees (including species of Magnoliaceae) and produced substantial numbers of plants from seeds. Some of these seedlings have been used for urban landscaping. Most importantly, we have established the following protocol for the reintroduction of rare and endangered plants: first, select the appropriate target plant species; second, conduct basic research on their breeding and other aspects of their biology and ecology; and then, reintroduce them to the wild while also developing their market-oriented production. By consulting with regional and national agencies concerned with ecological planning, we have promoted this protocol for the reintroduction of rare and endangered plants throughout China.

TRENDS AND PROSPECTS

Most early attempts at reintroduction of rare and endangered plants have failed. This is mainly because of the lack of basic scientific information about target species life history, morphology, reproductive biology, horticulture, and ecology. Currently, the reintroduction of wild plants focuses on the following issues: the causes of extinction or population decline; the current ecological characteristics; the selection of areas and boundaries for reintroduction; and the establishment of an effective strategy or actions to rescue the declining or near extinct population. Given climate change, researchers currently disagree whether introduction of individuals into existing populations or translocation can help rare and endangered plant species survive.

The conservation strategies for extremely small populations in China and other developing countries involve: (1) initiating the national key protected wild plants resources survey and established resource information systems; (2) improving the network of nature reserves and

focusing on in situ conservation; (3) establishing networks for national botanical gardens and strengthening near-in situ conservation and *ex situ* conservation; (4) increasing the construction of breeding centers and combining in situ and *ex situ* conservation; (5) combining habitat protection and habitat restoration; (6) improving and expanding the species' living space; (7) rationally combining conservation, germplasm preservation, and sustainable utilization; and (8) conservation may also include overall planning; government guidance, participation and cooperation by scientists, government, and the public in creating realistic policies and regulations, and emphasis on international cooperation and public education.

Saving wild plants with extremely small populations is critical for sustainable development and ultimately for human well-being. With the timely implementation of the conservation actions described here, wild plants with extremely small populations could have a bright future.

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