How to conserve threatened Chinese plant species with extremely small populations?

Sergei Volis

Key Laboratory for Plant Diversity and Biogeography of East Asia, Kunming Institute of Botany, Chinese Academy of Sciences, Kunming, 650204, China

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ABSTRACT

The Chinese flora occupies a unique position in global plant diversity, but is severely threatened. Although biodiversity conservation in China has made significant progress over the past decades, many wild plant species have extremely small population sizes and therefore are in extreme danger of extinction. The concept of plant species with extremely small populations (PSESPs), recently adopted and widely accepted in China, lacks a detailed description of the methodology appropriate for conserving PSESPs. Strategies for seed sampling, reintroduction, protecting PSESP locations, managing interactions with the local human population, and other conservation aspects can substantially differ from those commonly applied to non-PSESPs. The present review is an attempt to provide a detailed conservation methodology with realistic and easy-to-follow guidelines for PSESPs in China.

1. Introduction

China is a globally recognized biodiversity center, harboring more than 30,000 higher plant species of which approximately 10,000 are endemics (Yang et al., 2005). Besides tremendous diversity and high endemism, the Chinese flora contains a large number of relic lineages of plant taxa. All these features give the Chinese flora a unique position in global plant diversity. Unfortunately, rapid economic development, population growth, intensive agriculture and the over-harvesting of timber and medicinal plants have led to serious destruction or alteration of the natural environment which has resulted in the extinction or decline of many species. At least 200 species have become extinct over the past 50 years (Chinese State Report on Biodiversity Editorial Committee, 1998) and c. 5000 species are currently threatened or on the verge of extinction, making China one of the highest priorities for global biodiversity conservation. Destruction and/or fragmentation of natural habitats in virtually all biomes of China are the most important causes of plant extinction. I will not go into the history of plant conservation in China as this subject is beyond the scope of this paper. Nor will I cover the current situation with protection of threatened species in China as this information can be found elsewhere (Liu et al., 2003; López-Pujol et al., 2006; Huang, 2011). Instead, my goal here is to present an analysis of current conservation practices in China, make a rough estimation of their effectiveness, and, after identifying the problems, to propose some possible solutions.

The major document regulating plant conservation in China is China’s Strategy for Plant Conservation (China’s Strategy for Plant Conservation Editorial Committee, 2008), which formulated the nation’s commitment to plant conservation and established targets to reduce the ongoing loss of plant diversity. Implementation of this plan is coordinated by the Chinese Academy of Sciences, State Forestry Administration and the Ministry of Environmental Protection. The strategy serves as a framework for Chinese plant conservation and includes 16 targets. The two targets most relevant for conservation of endangered plant species aim to protect ~90% of China’s national key protected plants through in situ efforts (Target 7), and to reintroduce 10% of China’s threatened plant species to...
their natural habitats and establish monitoring programs to track management success (Target 8). However, the progress of plant conservation in China is impeded by several factors. First, the criteria for prioritizing species to be protected are unclear. Second, detailed methodological conservation guidelines that can be efficiently applied to threatened species in China are absent.

In 1999, the State Council of China promulgated a list of National Key Protected Wild Plants (First Group) of 419 species to be legally managed and protected by the central government. In 2004, Wang and Xie (2004) published the China Species Red List (Vol. 1) based on IUCN classifications and academic experts recommendations, which substantially differed from the National Key Protected Wild Plants list. Unfortunately, only plant species listed in the latter list have been subject to conservation actions (Ma et al., 2013). The incongruence between the two lists has left many threatened species out of active conservation. In addition, the IUCN Red List approach has recognized limitations (Possingham et al., 2002; de Grammont and Cuarón, 2006; Miller et al., 2007; Mace et al., 2008; Harris et al., 2012) as will be discussed below.

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. The term “extremely small population” refers to a population having a narrow geographical distribution which has resulted from some negative external factors over a long time, and whose numbers are smaller than the minimum required to prevent extinction (State Forestry Administration of China, 2012). This was an important stage in Chinese plant conservation. Indeed, most endangered Chinese plant species are represented by very small populations (hereafter PSESPs), and must be the first priority for conservation. A survey conducted by the State Forestry Administration between 1997 and 2003 identified 189 national key protected wild plant species, most of which have fewer than 5000 individuals, with 11 having fewer than 10 individuals in natural populations. It should be noted that these numbers do not distinguish reproducing and non-reproducing adults, and may also include very young plants that will never reach adult stage.

Surprisingly, the newly formulated Chinese policy focus on PSESPs (Ren et al., 2012) has not been followed by amendments to the routinely applied plant conservation methodology. Although PSESPs have received much attention in the recent literature (Ren et al., 2012; Ma et al., 2013; Ma and Sun, 2013; Sun and Han, 2015; Yang et al., 2015b), no publications have provided a detailed description of the methodology appropriate for conserving PSESPs. The conservation methods appropriate for PSESPs are briefly presented in Ma et al. (2013). Undoubtedly, all the steps the authors propose are appropriate and important, but details on how they should be performed are not provided. Strategies for seed sampling, reintroduction, protecting PSEP locations, and interaction with the local population can substantially differ from those routinely applied to non-PSESPs. Ren et al. (2012) summarize the appropriate conservation strategies for PSESPs in China as involving: “(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”. Some of the listed measures can be easily understood and are unquestionably very important, e.g., “combining habitat protection and habitat restoration”. Others are equally important but require some explanation and more details. For example “improving the network of nature reserves and focusing on in situ conservation” is indeed an important task, but how should the network be improved: by an increase in number of reserves, changes in reserve management, closer coordination between the reserves or something else? Unfortunately, this is not explained. An urgent necessity for properly described conservation methodology for PSESPs motivated this study. The present review is an attempt to provide a detailed conservation methodology with realistic and easy-to-follow guidelines for PSESPs in China.

2. Identification of the species protection category

The IUCN Red List Categories and Criteria are intended to be an easily and widely understood system for classifying species at high risk of global extinction. However, although the general aim of the system is to provide an explicit, objective framework for the classification of the broadest range of species according to their extinction risk, the system criteria do not work well when applied to PSESPs. The IUCN Red List Criteria assume that the populations exhibit a normal demographic structure in which all the life cycle stages are present. This, however, is rather the exception than the rule with Chinese PSESPs. The fact that the species is represented by a very small population(s) is already an alarm that something is wrong with its demographic structure. Indeed, virtually all species with extremely small population sizes have abnormal population demographic structures. Some lack saplings, others lack seedlings or produce no seeds. Application of the IUCN rules related to decrease in area of occurrence/occupancy or population size has no meaning if most or all the individuals comprising a population cannot reproduce or the seeds produced do not germinate. This means that for many, if not most, of the PSESPs the current protection status is misleading and these species are actually at the very verge of extinction. For example, Davidia involucrata is not even included on the list of threatened Chinese plants, but all the natural populations of this species show no signs of regeneration. The majority of the plants in natural populations of this species are old (>50 years old) trees and no seedlings/saplings have been observed in these populations for the last few decades (Ma and Li, 2005; Zhang et al., 2008). The seeds produced are viable, but they do not germinate under natural conditions. On the other hand, thousands of D. involucrata trees have been produced artificially for landscaping in cities and many have been planted in Botanical Gardens and Arboreta. Has the artificial production and planting helped the species recover? There are no indications that it has. This example shows that neither reduction in the area occupied by a population or the population size itself can provide a reliable estimate of how endangered the species is. Similarly, Li et al. (2012) showed that lack of naturally regenerated seedlings in Metasequoia glyptostroboides calls into question the criteria used to define conservation program success, and suggested that the criteria for delisting species should not be based solely on the number of extant plants and their distribution ranges. Other examples of species for which no seedlings have been observed in natural populations include Magnolia sinica (Wang et al., 2015), Camellia changii (Ren et al., 2014), Acer yangbiense (Weibang Sun, personal communication), Quercus (Cyclobalanopsis) sichourensis, Pinus squamata, Nyssa yunnanensis, Annamocarya sinensis, Malania oleifera, Camellia fascicularis, Glyptostrobus pensilis, Diplonema yunnanensis, and Euryodendron excelsum (Sun, 2013). I propose that distorted population demographic structure must be adopted as
the most important indicator that the species is really endangered. Thus, we must first recognize the extreme danger of extinction for these species, make them the top priority for conservation, followed that with IMMEDIATE action; and second, we must concentrate our efforts on understanding why the seeds do not germinate under natural conditions or why the seedlings do not develop into saplings as opposed to producing artificially seedlings/saplings for landscaping, which has nothing to do with the real conservation of the species. The immediate actions must include fruit/seed collecting, mapping all the reproducing adults, and a preliminary survey of the population demographic structure. These first immediate actions must be followed by properly organized study of the species habitat, long-term observations on population demography and setting an Action Plan for the species recovery.

In general, conservation of every threatened species should start with proper mapping of its range, an inventory of its existing populations and a population demographic survey, but this is especially critical for PSESPs. This information is crucial for defining the species conservation status and its critical habitat, understanding factors determining species range, and for future decisions about species in situ conservation. Most PSESPs, although widespread in the past, currently fall into the category of rare species that have a very narrow ecological niche or occupy (micro)habitats that are rare by themselves (due to almost complete destruction of their natural habitats). This implies that the suitable habitat for such species is probably not randomly distributed, but uncommon (Maschinski et al., 2012). Unfortunately, in China, there are many more studies of genetic variation in threatened species than studies of their ecological niche or population demography. For most PSESPs we only have information about the populations’ locations and rough estimates of their sizes, but almost never their demographic structure, not to mention population viability analysis.

3. Identification of a threat

There is no doubt that human activity has been and continues to be the major threat to Chinese plant biodiversity. Loss of natural habitats due to agriculture and logging started in ancient times but rose dramatically after mass-scale forest clear-cutting in the 1950s—1960s. The destructive clear-cutting was followed by land conversion into forest plantations or agricultural fields. As a result, continuously distributed primeval forests became patches of secondary forests that survived within complex mosaics of land use. Some of these forest remnants are relatively large and less damaged than others due to their low accessibility and remoteness; these areas have preserved many species that disappeared elsewhere. However, alteration of the native forests by human activity has never stopped and is continuing as local logging, firewood cutting, charcoal production, agricultural development, overgrazing and uncontrolled harvesting of wild plants. Of the 8000 tree and shrub species in China, about 2000 are timber species (World Bank, 2001), uncontrolled harvesting of wild plants. Of the 8000 tree and shrub species, many have no clear boundaries, no management teams, and no staff (Liu et al., 2001). However, the rate of high-quality habitat loss after the reserve’s establishment was much higher than before its creation, and was even higher than in unprotected areas adjacent to the reserve (Liu et al., 2001). Besides these recognized problems with nature reserves, the situation with PSESPs is worsened by the fact that only some PSESPs are located within the reserves, while many other
populations are situated in unprotected environments. As a rule, these populations occupy very small territory and in many cases are surrounded by completely or partially altered environment that has no conservation value. In light of this, it is difficult to agree with the conclusion that “the current network of protected areas in north-western Yunnan is adequate to protect much of floral diversity in the region (Ma et al., 2007).” One solution for protecting PSESPs is the creation of small-scale reserves or Plant Micro-Reserves (PMR; Laguna, 2001; Laguna et al., 2004). Small reserves were long ago recognized as an efficient way to protect plant-rich flora in a fragmented landscape (Reznicek, 1987; Cowling and Bond, 1991; Falkner and Stohlgren, 1997; Götmark and Thorell, 2003), and became part of the designs of regional and national strategies for protected areas (Cowling et al., 2003; Draper et al., 2003; Kadis et al., 2013).

PMRs are small land plots (up to 20 ha) given legal protection status with the aim of long term monitoring and conservation of plant species and their habitat. Within PMRs, active management of plant populations is allowed, including seed collection and establishing living collections, population reinforcements and introductions, herbivore exclusion, scrub clearance, and restoration of suitable environmental conditions. Of course, the small reserves are not an alternative to large protected areas, but a complement to them, being the only option available to protect natural fragments surrounded by land unavailable for conservation purposes.

In China, small protected areas designated for a particular function, so called mini nature reserves (MNR) or “in situ conservation sites” (“bahu xiaqu” in Chinese), are sometimes established outside nature reserves. For example, two MNRs have been established to protect orchids (Liu et al., 2015).

5. Environmental education

Over-collecting is a very serious threat to many plant species in China, and addressing this threat should include but not be limited to a prohibition on the collection of seeds and other parts of endangered plants. Environmental education should also be improved, especially in local communities, where one of the main causes of ongoing species loss is the lack of true awareness or appreciation of the value these species possess beyond their practical use. Conservation policies have been proposed for ornamental and decorative species that encourage artificial breeding programs by state or private entities for commercial use. For medicinal plant species, where consumers prefer wild-gathered materials, policies by state or private entities for commercial use. For medicinal plant species, where consumers prefer wild-gathered materials, policies have been proposed that encourage a combination of artificial cultivation and cultiva in natural habitats (Ren et al., 2014; Liu et al., 2015). This is unlikely to work without a comprehensive educational campaign that starts from primary school, or even kindergarten, and which teaches children to enjoy nature without committing harmful acts, such as picking flowers or digging out plants. Such a campaign was launched in Israel during the 1960s and was a phenomenal success. Today in Israel, picking wild plants is no longer a threat to species with attractive flowers. In China, where many orchid species are severely threatened by collecting, such a campaign is urgently needed. The key factors explaining the tremendous success of the Israeli “Go Out to the Landscape, but Don’t Pick” campaign included targeting children in compulsory kindergartens, pre- and elementary schools, and the availability of an alternative, inexpensive flower supply (Tal, 2002).

Secondly, there is rapidly accumulating evidence that environmental education can inspire citizens to be involved in conservation actions (Brewer, 2006; Jordan et al., 2011; Chen et al., 2015). Thus educational campaigns in villages neighboring populations of threatened species can turn destroyers into conservation supporters and helpers.

6. ex situ: seed collections

At present in China, there are about 180 botanical gardens, having in their collections 22,000 higher plant species native to China, and three national germplasm banks. However, the efficiency of this impressive infrastructure for the conservation of threatened species seems to be low. For example, the China Germplasm Bank of Wild Species based at Kunming Institute of Botany, which has the largest seed bank collection, not only in China, but the whole Asia, stores in total 8855 species. However, only 47 (less than 0.6%) are species from critically endangered, endangered and vulnerable categories.

For ex situ collections to be useful in conservation of threatened species, they must be explicitly oriented towards conservation, i.e. the collections must not only adequately represent the species genetic diversity during storage but also ensure availability of stored germplasm for future in situ recovery efforts. For species with extremely small populations, all reproducing adults must be sampled, and sampling should be done repeatedly over several years because i) sampling large quantities of seeds is impossible when the population is small and seed production is limited, infrequent or varies among seasons; and ii) relatively small but more frequent sampling is less harmful for a population than larger samples taken more infrequently (Menges et al., 2004).

For rare and endangered species, and especially for PSESPs; collecting seeds from individual plants and keeping their seeds separately as maternal lines (families) is preferable to bulk collections. The reason is that seed banks of rare and endangered species must be useful for in situ actions, and for these actions genetic identity of the seeds can be very important. For example, specific genotypes may be needed to ensure sexual reproduction in a population, or genetic enrichment may be necessary to prevent the negative effects of genetic drift and inbreeding. Furthermore, only collections organized by family can be used for analyses of the species’ genetic structure, identification of evolutionarily significant units, assessments of gene flow and other important genetic information.

Even for relatively large populations the number of source plants and quantities of seeds per plant can be well below target levels. For PSESPs with infrequent and/or limited seed production, the quantities required for successful reintroduction cannot be collected in natural populations even after multiple visits and require an intermediate step of propagation. Thus, a good approach would be to distinguish short- and long-term seed collections (Volis, 2015). The goal of the long-term collection is to create a “strategic” source of germplasm that can be used for studying species biology, propagation and renewal, but not for in situ actions. The seeds stored in short-term collection, on the contrary, will be used exclusively for in situ actions either directly or after propagation.

7. ex situ: living collections

Living collections are an important element of modern conservation programs and botanical gardens are the major depositories of valuable living material for conservation. The Chinese Academy of Sciences has drafted and, in 2002, began implementation of a 15-year ex situ master plan to conserve the diversity of native Chinese plants in botanical gardens. Its main goals include increasing the number of native protected species to 21,000, enhancing garden collections of rare and endangered plants, as well as the creation of five new regional and nine specialized gardens (Huang et al., 2002).

There are several living collections strongly oriented towards endangered and rare species in China, such as Xishuangbanna Tropical Botanical Garden, South China Botanical Garden and
Kunming Botanical Garden. These and 13 smaller Chinese gardens provide shelter to the threatened species and participate in species-oriented conservation programs. For example, *A. yangbiense*, represented in nature by only five individuals, has been planted, hand-pollinated and the resulting seeds used to produce more than 1600 saplings now growing in the Kunming Botanical Garden (Yang et al., 2015). Similarly, 1300 saplings of *Q. sichourensis*, 400 saplings of *Magnolia ventii* and 100 saplings of *M. sinica* represented by eleven, 200 and 52 individuals in nature, respectively, were produced in the Kunming Botanical Garden and have been used in different conservation actions (Wang et al., 2015; Weibang Sun, personal communication). Another example is *Vatica guangxiensis*, an endangered species for which about 90 individuals from three remaining populations were successfully transplanted to Xishuangbanna Tropical Botanical Garden (Li et al., 2002).

However, utility and overall capacity of botanical gardens for maintaining living collections of threatened species should not be overestimated. One known problem is poor management, e.g. representation of species by only a few individuals, lack of information on accession sampling locality and mislabeling (Hurka, 1994). Another potential problem is the risk of spontaneous hybridization when related species, sub-species or ecotypes are grown in close physical proximity in the garden. The latter seriously undermines utilization of botanic garden ex situ collections for propagation because open-pollinated offspring may lack genetic integrity and harbor maladaptive gene combinations (Maunder et al., 2004). Finally, botanical gardens have obvious limitations in the number of individuals per species they can maintain. These issues strongly limit the utility of botanical garden living collections for conservation. Space limitations usually preclude achieving even the minimum recommended sample size of 15 individuals necessary to capture an acceptable level of genetic variation (Namoff et al., 2010).

**8. Integration of ex situ and in situ**

The utility of ex situ collections via storage and propagation of plant material that can later be used for in situ actions has been recognized, but the obvious space and logistical limitations of ex situ collections present well-known challenges (Hamilton, 1994; Schoen and Brown, 2001; Maunder et al., 2004; Volis and Blecher, 2010). This has motivated a search for an efficient integration of these two approaches by creating living collections of needed capacity under natural, semi-natural or artificial conditions. Two concepts of integrative conservation that suit PSESPs are “forest gene banks” (Uma Shaanker and Ganeshiah, 1997; Uma Shaanker et al., 2001; Uma Shaanker et al., 2002) and “quasi in situ” (Volis and Blecher, 2010; Volis, 2015). The former concept proposes use of a particular existing population as an in situ sink into which genetic material from several source sites is introduced and maintained. Thus the genetically diverse sink population serves as a repository of the species gene pool and, at the same time, allows for random interbreeding. Although this approach cannot be used in cases when introduction of non-locals may lead to outbreeding depression, in situations where plants originate from the same climatic zone and similar biotic environments it can 1) greatly improve the local population’s genetic variation and eliminate inbreeding depression; and 2) provide a large quantity of vigorous seedlings (due to heterosis) for creating new and reinforcing existing populations. The second concept proposes the creation of new, as opposed to existing populations, as depositories of genetically variable source material. The site for such living collections should contain individuals from populations sharing the same climatic zone and biotic/abiotic environment, have natural or semi-natural conditions and be protected.

Use of seeds for introduction is known to be ineffective compared with seedlings (Guerrant and Kaye, 2007; Godefroid et al., 2011). Raising large number of seedlings from seeds in botanical gardens or nurseries may not always be possible for logistic reasons. To obtain large quantities of seedlings required for in situ actions, two approaches can be used. “In situ seedling banks” (Pritchard et al., 2014) are created by sowing seeds and maintaining seedlings in the forest understory in a convenient, reduced space. This approach has certain advantages which make it easy to apply, including the wide range of forests that can be used, e.g., natural, degraded or planted forests, not excluding monoculture tree plantations. The critical points for this approach are high seed viability and germination rate, and low requirements for successful germination. The other limitations of this approach are that seedlings cannot withstand a long time in the shady understory and advance to saplings, and intense seedling herbivory (Benitez-Malvido et al., 2005). Another approach is to use wildlings. Although this method cannot be applied to those PSESPs that suffer from germination failure, it can be useful for other PSESP species. For example, intensive seed production of *Liriodendron chinense* trees planted in Gaowangjie Nature Reserve along a local road gave rise to dense stands of seedlings and saplings in proximity to the mother plants. These wildlings can be used for the creation of new populations of *L. chinense* in this area. Phoebe bournei, which is represented by many reproducing trees planted and maintained by farmers in a village of Baojing County, provides another example. The fruits produced are dispersed by birds into the surrounding village forest, where they readily germinate and grow to seedlings. However, due to apparent anthropogenic disturbance (grazing and cutting for firewood), which has altered the forest’s environmental conditions, the seedlings do not develop into saplings. Thus, *P. bournei* wildlings, which have no future in this environment, can be used for creation of new populations in a more suitable natural location.

Propagation of material for threatened species outside botanical gardens in China is currently done at the national field germplasm nurseries and plant introduction bases established by National Environmental Protection Agency specifically for this purpose (Division of Plant Conservation of the State Forestry Administration, 2005). Currently, there are 32 germplasm nurseries and 255 introduction bases. However, there is a very limited recognition of the importance of living collections in semi-natural and natural environments that serve both as depositories preserving species genetic variation and sites for seed propagation (but see Sun, 2013). The only such conservation project in China I am aware of is the reintroduction program on *M. ventii*. In this project, after propagation in the nursery, 300 saplings were planted in a semi-natural environment near natural population in Pingbian (Honghe prefecture, Yunnan province) (Weibang Sun, personal communication).

**9. in situ management**

The Convention on Biological Diversity (CBD, 1994) defines in situ conservation as “the maintenance and recovery of viable populations of species in their natural surroundings”. A naive and over simplistic view that once dominated among conservation biology practitioners was that if populations are legally protected their long-term survival is guaranteed. This, however, turned out to be far from true due to the fact that virtually all natural systems preserved in nature reserves represent some degree of human-induced changes that disrupted previously existing species interactions and ecological processes. Apart from this, fragmentation and environmental degradation reduced population sizes of many species below the viability threshold. Such populations are doomed to extinction even under the strictest protection in a reserve. Thus,
for in situ conservation to be effective it must be based on proper understanding of ecological processes within an ecosystem and population dynamics of threatened species. If necessary, actions must be implemented, including reestablishment of extinct or reinforcement of critically declined populations. But in many cases even this is not enough. When a population can no longer sustain its existence this indicates that the habitat has deteriorated and requires action, too. For example, analysis of regeneration in the only natural population of *M. glyptostroboides* revealed that in the last 41 years, habitat changes caused by detrimental activities of human residents (cultivation of profitable plants in the understory, selective cutting and harvesting of wood for fuel) have effectively ended recruitment of *M. glyptostroboides* (Tang et al., 2011). The latter means that neither strict protection nor reinforcement actions will rescue this population. Without restoring conditions that once were present in this habitat and under which natural germination was occurring normally (as evidenced by Chu and Cooper, 1950), the population has no chance of survival. Thus, in situ conservation of threatened species requires identifying the habitats in which they can maintain viable populations, and then protecting both the habitat and the species through carefully designed management. This especially applies to PSESPs. Modern conservation in situ includes not only protection of the population or group of populations within a protected area or habitat, but also involves, after identification of a threat, the preparation and implementation of management plans to eliminate the threat and recover the population(s).

For most of the threatened species with PSESPs, reinforcement (IUCN, 1998), i.e. supplementation of existing populations to enhance population viability (increase in population growth rate and decrease in probability of extinction) would be the optimal option, but only if the remaining populations are located in protected and non-degraded areas. If these locations are unprotected they are almost inevitably doomed to disappearance as a result of continuing anthropogenic disturbance. Supplementation must be aimed at restoring or improving reproduction and regeneration, for which necessary measures can be the introduction of plants of particular gender to correct the sex ratio in a population, and of adults needed to increase the pollinator visitation rates, or seedlings/saplings to rejuvenate the degraded populations. The material for reinforcement must originate either from the same location or from geographically closest population(s) within the same habitat and be genetically diverse.

Reintroduction, i.e., placement of plant material into an area where it occurred in the past, should be used for the species that went extinct in the wild, or for which natural populations are located in unprotected and rapidly deteriorating environments, while locations with suitable environments for these species exist in protected areas within the known species range. Translocation, i.e. movement of plant material to a seemingly suitable area with no documented past history of its existence, is the conservation action used to prevent species extinction when there is no remaining area left within a species’ historic range able to sustain viable population(s) (IUCN, 1998; Hoegh-Guldberg et al., 2008). Habitats suitable for the species may exist outside of the species’ recorded distribution but be unoccupied due to dispersal limitations or severe fragmentation of previously continuous habitat. In both reintroduction and translocation, creation of viable new populations requires prior knowledge of the species’ biology, including its reproduction, demography, environmental requirements and ecological interactions. In both actions the major criteria for evaluating the suitability of a site for reintroduction are ecological similarity with locations of extant populations and protection. For many PSESPs, however, the assumption that similarity to extant populations is the best criterion for successful establishment of a reintroduced population can be misleading, because their extant populations can be located in fragmented and degraded environments that do not support positive or stable population growth (Maschinski and Wright, 2006). In such cases, the reintroduction/translocation decisions must be based on detailed knowledge of historic species range, the ecological requirements of the species and habitat conditions at potential reintroduction sites. Valuable information for estimating suitability of a potential site for the endangered PSESPs can provide, on one hand, a comparison of ecological factors in locations still occupied by the species and locations where the species went extinct, and, on the other hand, a comparison of these factors in locations with PSESPs and in locations where the population size exceeds viability threshold (if the latter still exist). Identification of the habitats most suitable for the target species can utilize species distribution modeling, experimental introduction, or both. Distribution modeling is useful for broad categorizations of potential habitat, but for species with very limited distribution, where the importance of microhabitat conditions is apparent and there is a shortage of information on prior distribution (as the case with many PSESPs), only actual introduction can efficiently identify the species’ realized niche. Thus, for PSESPs we strongly recommend the experimental approach, i.e. experimental introduction across multiple (micro)sites within the current or documented historic species range (reintroduction), or within the presumed ecological niche of the species (translocation) (Fiedler and Laven, 1996; Falk et al., 1996; Maschinski et al., 2004; Maschinski and Wright, 2006; Guerrant and Kaye, 2007; Volis et al., 2010, 2011; Rünk et al., 2014).

For threatened PSESPs, source material for reintroduction or translocation should come from more than one population to prevent inbreeding depression, and these populations’ locations should have close environmental and ecological similarity with the recipient locations. A match of donor and recipient locations crucial for successful introduction can be difficult to recognize with certainty. For example, sites that appeared suitable based on expert opinion at the time of introduction turned out to differ in ecological similarity, and as a result success of the introduction varied (Noël et al., 2011).

Based on the latest theoretical developments in estimating safe number of introduced families and individuals, the effective population sizes should be at least 100 families and 1000 individuals, with a ratio for conversion of effective into census population size of 0.1—0.2 as the first approximation (Frankham et al., 2014). For many PSESPs this required number of families will be impossible to achieve due to the small number of reproducing adults in extant populations, but the required number of individuals (5000—10,000), derived from all available mother plants, can be achieved following proper propagation.

It must be noted that efficient conservation of a threatened species is impossible without preparing some kind of Action Plan specifying all the types of intervention needed for species recovery, such as population reinforcement, translocation or habitat restoration. The level of management intervention will depend on the nature and degree of the threats to which the populations/habitats are exposed, ranging from just monitoring to intensive recovery actions. These interventions can include weeding, eradication of exotic species, assisted pollination to increase seed set, removing risks to seedling recruitment, predator and pest control, augmenting dispersers, and reinforcement of populations by artificially or naturally propagated material (Heywood, 2015).

10. Information sharing

Good knowledge of the species distribution is a prerequisite for efficient conservation of threatened species. The Global
11. Conclusions and recommendations

1. Defining conservation status of PSESPs must not be based either on population decline or extant species range, because this information can be misleading. Instead, the decisions must be based on population sizes (number of reproducing individuals) and population demographic structure (whether it is viable or not).

2. Identification of a threat requires a preliminary demographic survey and assessment of anthropogenic disturbance followed by properly organized studies of population demography and the ecological requirements of the species.

3. Establishment of small-scale reserves or Plant Micro-Reserves must be recognized as the most appropriate approach for in situ conservation of PSESPs, although large nature reserves should be given priority whenever possible.

4. A strong environmental education campaign aimed at local communities (especially children) is needed to create awareness and appreciation of rare species’ value beyond their practical use.

5. ex situ collections must not only represent well the species genetic diversity during storage but also ensure availability of stored germplasm in future in situ recovery efforts. Collecting from individual plants and keeping their seeds separately as maternal lines (families or accessions) should be strongly encouraged over bulk collections.

6. Seed banks and botanical gardens must allocate more resources and space to PSESPs and more actively participate in PSESP conservation programs.

7. Usage of integrated ex situ — in situ approaches must be a norm in every conservation project. The living collections in natural or semi-natural environments must serve as depositories preserving species’ genetic variation, and as seed propagation sites.

8. in situ conservation must be based on proper understanding of ecological processes within an ecosystem and population dynamics of PSESPs. After identifying the habitats in which a species can maintain viable populations, an Action Plan must follow, specifying the carefully designed management needed for protecting both the habitat and the species. The latter can include population reinforcement, translocation or habitat restoration.

9. There must be a proper sharing of information on species occurrence, and active or completed programs for coordination of conservation efforts and for interactive learning. The latter requires the creation of a searchable database and repository for conservation related information, e.g. species management-related manuscripts, reports, and expert opinions.

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