Bulletin of Chinese Academy of Sciences

Volume 36 | Issue 4 Article 10

4-20-2021

Strengthen Ex Situ Conservation of Plants and Promote Protection and Utilization of Plant Resources

Ju ZHOU
Bureau of Science and Technology for Development, Chinese Academy of Sciences, Beijing 100864, China, zhouju@cashq.ac.cn

See next page for additional authors

Recommended Citation

ZHOU, Ju; YANG, Ming; WEN, Xiangying; LI, Nan; and REN, Hai (2021) "Strengthen Ex Situ Conservation of Plants and Promote Protection and Utilization of Plant Resources," *Bu*
Chinese Academy of Sciences (Chinese Version): Vol. 36 : Iss. 4 , Article 10.
DOI: https://doi.org/10.16418/j.issn.1000-3045.20210225101
Available at: https://bulletinofcas.researchcommons.org/journal/vol36/iss4/10

Strengthen Ex Situ Conservation of Plants and Promote Protection and Utilization of Plant Resources

Abstract

Plant resources are the basis of human survival and development. Due to human and natural disturbance, plant diversity is facing a serious threat. Ex situ conservation is an important way to remove the threat. Botanical garden and germplasm bank are the main institutions of ex situ conservation. A total of 105 634 species of plants have been ex situ protected in the global botanical gardens, accounting for about 30% of the global total, and more than 40% of the threatened species have been protected. More than 3 million crop germplasm resources have been collected in more than 500 germplasm banks around the world. China's botanical gardens ex situ protected more than 20 000 native plants, accounting for about 60% of the total species; the National Crop Germplasm Bank and resource nurseries preserved more than 500 000 germplasm resources. While strengthening plant conservation, ex situ plant protection institutions have carried out a lot of scientific research and resource utilization. In order to promote the ex situ conservation of plant diversity and green development, this study also reviewed the research progress of ex situ conservation of plants, and put forward some suggestions on strengthening ex situ conservation of plants in China.

Keywords

botanical garden; germplasm bank; biodiversity conservation; sustainable development

Authors

Ju ZHOU, Ming YANG, Xiangying WEN, Nan LI, and Hai REN

Citation: ZHOU Ju, YANG Ming, WEN Xiangying, LI Nan, REN Hai. Strengthen Ex Situ Conservation of Plants and Promote Protection and Utilization of Plant Resources [J]. Bulletin of Chinese Academy of Sciences, 2021 (4): 417–424.

Strengthen Ex Situ Conservation of Plants and Promote Protection and Utilization of Plant Resources

ZHOU Ju[1], YANG Ming[1], WEN Xiangying[2], LI Nan[2], REN Hai[2]

1. Bureau of Science and Technology for Development, Chinese Academy of Sciences, Beijing 100864, China;
2. Guangdong Provincial Key Laboratory of Applied Botany, South China Botanical Garden, Chinese Academy of Sciences, Guangzhou 510650, China

Abstract: Plant resources are the basis of human survival and development. Due to human and natural disturbance, plant diversity is facing a serious threat. Ex situ conservation is an important way to remove the threat. Botanical garden and germplasm bank are the main institutions of ex situ conservation. A total of 105,634 species of plants have been ex situ conserved in the global botanical gardens, accounting for about 30% of the global total, and more than 40% of the threatened species have been conserved. More than 3 million crop germplasm resources have been collected in more than 500 germplasm banks around the world. China's botanical gardens ex situ conserved more than 20,000 native plants, accounting for about 60% of the total species; the National Crop Germplasm Bank and resource nurseries preserved more than 500,000 germplasm resources. While strengthening plant conservation, ex situ plant protection institutions have carried out a lot of scientific research and resource utilization. To promote the ex situ conservation of plant diversity and green development, this study also reviewed the research progress of ex situ conservation of plants and put forward some suggestions for strengthening ex situ conservation of plants in China. **DOI:** 10.16418/j.issn.1000-3045.20210225101-en

Keywords: botanical garden; germplasm bank; biodiversity conservation; sustainable development

Since the industrial revolution, rapid population growth and urbanization have resulted in habitat destruction and fragmentation, overutilization of resources, species introduction without comprehensive consideration, invasion of alien species, environmental pollution, and climate change. In combination with low adaptability and breeding difficulty of plants, these problems have led to the shrinkage of wild plant distribution areas, habitat degradation, sharp decrease in resources, and worsened endangerment of some species. Currently, China and even the whole world have faced the challenges of plant diversity conservation, restoration, and sustainable utilization [1]. For this reason, the United Nations (UN) issues the "Convention on Biological Diversity," "Transforming Our World: The 2030 Sustainable Development Goals," and "UN Decade on Ecosystem Restoration (2021–2030)," all of which involve the ex situ conservation of plants.

Ex situ conservation refers to the relocation of plant seeds or live plants to a suitable environment created artificially for conservation, so as to protect the plants from natural disasters and human disturbance. As an effective means for species rescue, ex situ conservation is of great significance for the species whose original habitat is destructed and population survivability is threatened seriously. The institutions for ex situ conservation include botanical garden (arboretum) for cultivation of introduced species and germplasm (seed) bank for in vitro conservation by cryogenic technology. The priority of ex situ conservation is given to rare and endangered species, endemic species, wild relatives of cultivated plants, and species with scientific value and economic potential. Live (or dead) plants, seeds, isolated organs, tissue, pollen, and DNA materials are applicable for ex situ conservation [2].

In situ conservation and ex situ conservation are complementary to each other. They jointly contribute to plant biodiversity conservation and thereby enable the restoration and utilization of plant resources. The plant resources under ex situ conservation can provide a survival guarantee and ecosystem regulation services for mankind. Apart from this, they greatly influence the economic and social development in the fields of agriculture, medicine, industrial raw materials, environmental construction, etc. and support the research of life science. The exploration and utilization of the plant resources under ex situ conservation to boost economic development have been at the core of development strategies proposed by governments of various countries. This paper reviews the ex situ conservation of plants in the world and in China and put forward suggestions for ex situ conservation of plants in China. This research can provide reference for biodiversity conservation and sustainable utilization in China.

Received: 2021-04-03
Supported by: Special Fund for Biodiversity Research of Ministry of Ecology and Environment (No. 8-3-7-20-10)
Corresponding author: REN Hai, E-mail: renhai@scbg.ac.cn

1 Threat to plant diversity

1.1 Global plant diversity and its threats

In the world, 391,000 species of vascular plants have been named, of which about 21% are threatened with extinction. There are about 60,065 species of trees in the globe. Among them, 46% of the 34,204 evaluated species are subject to survival threat. Out of more than 70,000 existing species of medicinal plants, 15,000 species are under survival threat, and 723 species are facing the risk of extinction. At least 7,039 species of edible plants have been found, of which, however, only 417 species have been acclimatized as crops, while the others are facing the loss of genetic diversity ①.

1.2 Plant diversity in China and its threats

In China, 35,112 species of wild higher plants ② have been found by 2015, which belong to 3,818 genera and 454 families, including 3,045 species of bryophytes, 2,124 species of ferns, 227 species of gymnosperms, and 29,716 species of angiosperms. The bryophytes, ferns, gymnosperms, and angiosperms account for 18.8%, 17.7%, 22.2%, and 11.1% of the global total, respectively, in terms of species diversity. Regarding higher plants in China, there are 17,439 endemic species with a proportion of 47% [3].

The following results are obtained from the evaluation of 35,784 species of wild higher plants in China in 2017: extinct (21 species), extinct in the wild (9 species), regionally extinct (10 species); critically endangered (614 species), endangered (1,313 species), vulnerable (1,952 species), near threatened (2,818 species); least concern (24,243 species); data deficient (4,804 species). The proportion of species under threat is 15%–20% [4].

The field investigation on wild rice carried out by Chinese Academy of Agricultural Sciences for 18 consecutive years has discovered that the 3 species of wild rice distributed over 7 provinces were reduced to 636 populations from 2,696 populations due to human and livestock harm, inbreeding depression, genetic erosion, and competition with associated plants. The loss rate is up to 76.4%. In addition, 70% of the plants serving as medicinal materials in China rely on cultivation, and the species of the rest 30% face survival threat due to excessive harvesting.

2 History and current status of ex situ conservation of plants

2.1 History and current status of ex situ conservation of plants in the world

Botanical gardens were established in Europe in the mid-16th century. During the rise of the natural sciences and garden art in the late Renaissance, the early botanical gardens mainly functioned as places for cultivation of, research on, and experiments with medicinal plants. In the 18th century, botanical gardens were key to the introduction, domestication, and propagation of crops, which even influenced the ups and downs of some countries. In short, botanical gardens played a leading role in introduction, domestication, and propagation of plants over 500 years in modern times [5]. Botanical gardens have experienced the development stages of the medicinal botanical garden, tropical botanical garden, European classical botanical garden, municipal botanical garden, and special types of botanical garden (including the agricultural botanical garden, horticultural botanical garden, and germplasm resource gathering garden). In developed countries, botanical gardens are inclined to shoulder the responsibilities of the comprehensive biodiversity conservation and ecological environment education on the basis of strengthening research. In developing countries, the research capacity of botanical gardens remains to be strengthened. They intensify the utilization of economic plants while protecting rare and endangered plants and are also capable of science communication [6].

Botanic Gardens Conservation International (BGCI) has made statistics of 2,119 botanical gardens in which the information on live plants was available. These botanical gardens are growing 105,634 species, accounting for 30% of the global total, and more than 40% of the threatened species have been protected. Nevertheless, the botanical gardens are mainly distributed in the temperate zone, and thus 76% of the tropical plant species are not ex situ conserved. The initial species of Northern Hemisphere account for 93% of the plants under ex situ conservation. In addition, only 10% of the botanical gardens ex situ conserved rare and endangered plants [7]. At present, the Royal Botanical Gardens, Kew in the UK has collected more than 50,000 living plant species from all around the world, a world-class botanical garden with the most species [6].

More than 3 million crop germplasm resources have been collected in more than 500 germplasm banks around the world, including 1.2 million cereal samples, 350,000 beam samples, 80,000 rhizome samples, and 200,000 forage samples. Regarding storage, the top four countries are the USA (about 600,000 samples), China (about 430,000 samples), India (about 400,000 samples), and Russia (about 320,000 samples). In the world, 350 seed banks of the botanical gardens from 74 countriesare preserving 56,987 taxa, including more than 9,000 rare and endangered species [8]. Especially, about 60% of the cereal and crop germplasm resources held in the US National Plant Germplasm System (NPGS) are from other countries. Plenty of seeds from nearly 40,000 wild plant species are collected in “Millennium Seed Bank” in Kew, accounting for 10% of the global total [9].

① https://stateoftheworldsplants.org/2016/; https://stateoftheworldsplants.org/2017/.

② bryophytes + vascular plants, vascular plants = ferns + gymnosperms + angiosperms.

2.2 History and current status of ex situ conservation of plants in China

Overall, the preliminary system for ex situ conservation of plants has been established in China. Most of the Chinese native plants are in ex situ collection, and some economic plants have been introduced into China from biodiversity hotspot areas in the world. China has established more than 400 protection and breeding bases for wild plant germplasm resources, including nearly 200 botanical gardens and arboreta, preliminarily forming a network for ex situ conservation of plants. More than 1.05 million samples of germplasm resources have been preserved, and 60% of the plant species in China's flora have been under ex situ conservation [5,10].

Botanical gardens are the main institutions for ex situ conservation of living plants. The earliest botanical garden in China is the Hong Kong Zoological and Botanical Gardens established in 1871, but most botanical gardens were established after 1949. Botanical gardens in China cover the main climatic zones and vegetation regions, preliminarily forming a complete system for ex situ conservation of plants. China's system influences the development of botanical gardens. As the botanical gardens affiliated to different ministries have different functions and orientations, they contribute differently in the aspects of biodiversity conservation, scientific research, gardening and horticulture, as well as environmental education. Since the 1950s, the Chinese Academy of Sciences (CAS) has played an important role in the development of botanical gardens. Currently, the number of the botanical gardens developed and managed by enterprises tends to increase [5]. About 1,200 specialized gardens have been built in China, which preserves 23,340 species (or below species) belonging to 3,633 genera and 396 families. Among them, about 20,000 species are native plants, accounting for 60% of the total species of higher plants in China and 25% of the total species under nursing in the world [5]. About 1,500 threatened speciesare ex situ conserved in Chinese botanical gardens, which accounts for 39% of the native threatened species. Botanical gardens have been playing a positive role in biodiversity conservation of Chinese native plants [11].

Germplasm banks preserve the vast majority of crop varieties in China, including seed banks preserving seeds and germplasm nurseries for seedlings. The National Crop Germplasm Bank consists of 1 long-term germplasm bank and 10 middle-term germplasm banks, preserving 785 species amounting to 426,726 samples of seed resources. Three national germplasm nurseries preserve 64,493 samples of resources [1]. Four germplasm banks for medicinal plants and 82 medicinal botanical gardens have ex situ cultivated 8,249 species, and their germplasm banks preserve 6,507 species. The total number of species preserved is 10,785 after deduplication, including more than 200 rare and endangered species [12]. The Germplasm Bank of Wild Species in Southwest China preserves the seeds of 10,285 plant species. National forest germplasm banks and forest tree improved variety bases preserve more than 33,000 samples of germplasm resources (including those introduced). China National GeneBank preserves 30 million biological samples ③. These germplasm resources in germplasm banks can provide material support for follow-up utilization.

Since the collection, preservation, and ex situ conservation of plant resources started late in China, following problems still exist regarding ex situ conservation of plants: ① There is a lack of overall design and coordination at the national level. Some regions have not initiated ex situ conservation of plants on a large scale (for example, there is only one botanical garden in Qinghai-Tibet Plateau), and each germplasm bank does not have its distinctive features for conservation. ② The conservation capabilities of some germplasm banks remain to be improved, and there are no codes and standards regarding the construction and management of germplasm banks. ③ The talent team in each germplasm bank is not strong enough. ④ Exchange and communication are lacking between germplasm banks, and the information system needs further improvement. ⑤ The plant resources under ex situ conservation are not abundant enough, and genetic diversity conservation of economic plants is at a relatively weak level. ⑥ There is an urgent need to improve the theory and technology of ex situ conservation, and comprehensive benefits have not been made because of the loose linkage of ex situ conservation with in situ conservation, reintroduction, scientific research, development, application, and science communication. ⑦ International cooperation and influence in the field of ex situ conservation remain to be strengthened. It is necessary to strengthen cooperation in regard to the facilitation of introduction and benefit sharing.

3 Research progress on ex situ conservation of plants

3.1 Research based on botanical garden

The development history of botanical gardens over 500 years is full of the exploration of human beings for natural mysteries and peculiar plants and is also a history of human beings exploring, utilizing, and remaking nature and coexisting with nature at last [13]. The purpose for scientific research exists throughout the development process of botanical gardens. In the 16th–17th century, botanical

③ https://www.genomics.cn/gene.html.

gardens were mainly used for medicinal plants research and medicine discovery. The 18th century witnessed the important progress in plant taxonomy, such as herbarium preparation, the establishment of specimen room, the formation of binomial nomenclature, the emergence of Linnaean classification system and plant taxonomy, the compilation of flora, and the theories of speciation and evolution, which all came into being in botanical gardens. In the 18th–20th century, plant taxonomy was extended to all the subdisciplines of botany and further developed into the current plant molecular biology, genomics, metabonomics, etc., which are all related to botanical gardens. Since the 21th century, the functions of botanical gardens have been extended to plant diversity conservation, environmental protection, science communication, and public services such as leisure tourism [5].

The research on ex situ conservation in botanical gardens focuses on the ecological and biological characteristics of species (such as threat factors, survival potential, endangering mechanisms, and maintaining mechanisms), the influencing factors of plant colonization, genetic diversity and adaptability, the impact of global change on ex situ conservation, and the criteria for successful reintroduction (e.g., representative sampling, realization of reintroduction "from seed to seed" at the species level, and inter-species relation reconstruction at the ecosystem level) [6]. In recent years, significant improvement has been made in the high-efficiency conservation and reproduction technologies for the seedlings, seeds, branches, tissues, and DNAs of most rare and endangered plants, which enhances the proficiency for ex situ conservation.

The taxa to be collected with priority and the sampling strategy should be determined before ex situ conservation. New England Wild Flower Society developed a system for prioritizing the species to be collected [14]. Hoban [15] proposed that it is necessary to collect every population when the number of field population is less than 5, and at least 50 samples should be collected from each population. Hoban and Schlarbaum [16] proposed that the sizes and structures of populations and inter-population hereditary connection and pollination mode should be considered during sampling. In addition, they pointed out that the sampling strategies for the large-population and wind-pollinated plants should be different from those for the small-population and insect-pollinated plants.

The genetic information of plants to be ex situ conserved should be mastered. Wei and Jiang [17] analyzed 3,599 papers on ex situ conservation and found that the genetic diversity of populations under ex situ conservation is significantly lower than that of the corresponding wild populations. This low genetic coverage is caused by the imperfect sampling strategy and genetic erosion during ex situ conservation. Therefore, botanical gardens should attach importance to the genetic risk management related to genetic representativeness, genetic mixing, and genetic adaptation of the endangered plants during ex situ conservation [18,19]. Maxted et al. [20] proposed to enhance the genetic diversity coverage of sampling with the gap analysis method. Additionally, the endangerment and genetic representativeness of species and the collection cost to maintain the genetic representativeness should be taken into consideration during the collection of living plants [21].

The three aspects including species, biotic environment, and abiotic environment should be comprehensively taken into account during ex situ conservation. Currently, species and their biotic environments have been widely studied, such as the genetic structure of species and risk evaluation, the influence of pollinators on the breeding system, the disturbance of pests, and the construction of simulation communities. The research on abiotic environments mainly focuses on the climate (i.e., light, temperature, water, and humidity) similarity principle, and there are also a few studies focusing on the nutritional conditions of plants [22,23]. Ex situ conservation makes efforts to maintain the original genetic characteristics of species, while introduction and domestication alter the genetic characteristics of species so as to utilize them [24].

In the past few decades, the in situ/ex situ dichotomy affected the conservation movement and the development of associated organizations to a large extent. Braverman [25] believes that the division into in situ and ex situ for conservation is outdated, impractical, unsustainable, and incompatible with the natural culture, idea of multi-nature, and the nontraditional space concept. Therefore, Braverman recommended the integrated conservation approach for the future.

3.2 Research based on germplasm (seed) bank

Hawkes et al. [26] have established an integrated conservation approach for genetic resources of plants, which encompasses study, collection, various forms of ex situ and in situ conservation, evaluation, and utilization. The approach has become a guide to action for the construction of germplasm banks. In recent years, germplasm preservation technologies have made significant advances in the aspects of in situ, ex situ, and facility conservation (including low-temperature germplasm banks, tissue-cultured seedlings, somatic embryos, and cryopreservation of buds), and breeding methods (including seeds, spores, layering, ramet, cutting, and grafting), which further improve the technology system [27]. Regarding seed preservation technologies, the scientific issues should be focused on for seed banks including vigor, life, and cryopreservation of seeds [9]. For example, botanical gardens in Hawaii conduct ex situ conservation of plants and their cultivation for propagation by using co-constructed seed bank, miniature breeding laboratory, and greenhouse, which has effectively protected a number of threatened species in Hawaiian Islands from extinction. This method is also applicable to the ex situ conservation movement in other plant diversity hotspot areas [28].

3.3 Research progress in China

Since the 1980s, China has evaluated the conservation

status of plants according to the criteria of the International Union for Conservation of Nature (IUCN) and solved the problems related to the propagation and cultivation of more than 40 wild plants with extremely small populations [23]. Huang et al. [29] initiated the compilation of *Ex Situ Flora of China*, which provides basic information for ex situ conservation. Nanjing Botanical Garden Mem. Sun Yat-Sen has proposed the path of open field conservation of endangered plants, including the nursery cultivation under artificial management–transitionalplanting in the semi-natural habitat–naturalized planting by reintroducing of endangered plants to the natural habitat [23]. Wuhan Botanical Garden, CAS made a success in ex situ conservation of more than 30 species of rare and endangered plants in the Three Gorges Reservoir Area by ex situ building artificial community nurseries[23]. Xishuangbanna Tropical Botanical Garden, CAS has ex situ cultivated 45 species of national key protected plants in vegetation remnants in the tropical rainforest [23]. South China Botanical Garden, CAS has conducted the reintroduction of rare and endangered plants by integrating biotechnology, interspecific relationship reconstruction, and habitat restoration technology and explored the new pattern for commercialized production [30,31]. Liu et al. [5] reviewed the research progress on reintroduction of 206 rare and endangered species in China [32]. In addition, botanical gardens in China have cultivated 1,352 new plant varieties, applied for the certificates of new plant variety right for 494 plant varieties, and obtained 452 new varieties authorized by the country. In addition, they promoted 17,347 tree species for ornamental gardening/greening and 653 new fruit tree varieties, developed 748 varieties for medicine/drug, and developed 281 varieties to be processed as functional foods. The Chinese botanical gardens have contributed significantly to the exploration and utilization of plant resources.

4 Suggestions for ex situ conservation of plants in China

(1) It is recommended to establish a nationwide unified management mechanism for ex situ conservation of plants, strengthen the top-level design for the national botanical garden system, and improve and release relevant laws and regulations for ex situ conservation in China. There is a need to set and establish new botanical gardens in the frigid zone and cool temperate zone of Qinghai-Tibet Plateau to form a complete ex situ conservation network. In situ and ex situ conservation is expected to cover all the native species and effectively protect the wild plants in China.

(2) China should intensify the close cooperation of ex situ conservation of plants with scientific research, knowledge dissemination, ecological recreation, as well as the development and utilization of plant resources. Moreover, it should take full advantage of new technologies such as citizen science, the Internet, big data, and Artificial intelligence to benefit the public and serve the society. With the help of the above measures, the modernization of ex situ conservation can be promoted.

(3) More fund is needed to support and enhance the sustainable development ability of every garden/bank by category. During capacity building, the key points include the talent team construction, preparation of standards or regulations, construction of germplasm exchange and information sharing platform, backup banks, and safe preservation. In addition, it is also necessary to strengthen the integrated approach of ex situ conservation, in situ conservation, and reintroduction for promoting the effectiveness of plant conservation.

(4) China should establish the international cooperation and coordination mechanism for ex situ conservation of plants and resource sharing at the national level by fulfilling or participating in the international conventions or agreements such as the “Convention on Biological Diversity,” “Transforming Our World: The 2030 Agenda for Sustainable Development Goals,” and “UN Decade on Ecosystem Restoratiocn (2021–2030)” and intensifying international cooperation during the promotion of Belt and Road Initiative. For example, the alliance of botanical gardens based on the Belt and Road Initiative should be established under the framework of Alliance of International Science Organizations (ANSO), so as to improve the levels of the botanical gardens in ex situ conservation, capacity building, and environmental education in the countries along the Belt and Road.

References

1 Ren H, Qin H N, Ouyang Z Y, et al. Progress of implementation on the Global Strategy for Plant Conservation in (2011–2020) China. Biological Conservation, 2019, 230: 169–178.

2 Maxted N. In situ, ex situ conservation. Encyclopedia of Biodiversity (2nd Ed.). Amsterdam: Elsevier, 2013: 313–323.

3 Wang L S, Jia Y, Zhang X C, et al. Overview of higher plant diversity in China. Biodiversity Science, 2015, 23 (2): 217–224 (in Chinese).

4 Qin H N, Zhao L N. Evaluating the threat status of higher plants in China. Biodiversity Science, 2017, 25 (7): 689–695 (in Chinese).

5 Huang H W. “Science, art and responsibility”: The scientific and social function changes of a 500-year history of botanical gardens. II. Intension of sciences. Biodiversity Science, 2018, 26 (3): 304–314 (in Chinese).

6 Ren H, Duan Z Y. The Theory and Practice of Classical Botanical Garden Construction (second edition). Beijing: Science Press, 2017 (in Chinese).

7 Mounce R, Smith P, Brockington S. Ex situ conservation of plant diversity in the world’s botanic gardens. Nature Plants, 2017, 3: 795–802.

8 O’Donnell K, Sharrock S. The contribution of botanic gardens to ex situ conservation through seed banking. Plant Diversity, 2017, 39: 373–378.

9 Li D Z, Yang X Y, Pritchard H W. Problems and challenges in germplasm preservation. Bulletin of Chinese Academy of Sciences, 2010, 25 (5): 533–540 (in Chinese).

10 He S A, Zhang Z S, Gu Y, et al. Botanical Garden Science. Beijing: China Agriculture Press, 2005 (in Chinese).

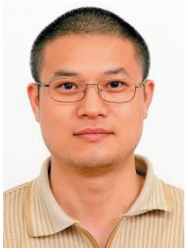
11 Jiao Y, Shao Y Y, Liao J P, et al. Status and future strategies of Chinese botanical gardens. Bulletin of Chinese Academy of Sciences, 2019, 34 (12): 1351–1358 (in Chinese).

12 Li B, Wei J H, Wang W Q, et al. Thought of propelling the construction on the system of national medicinal plant garden. Modern Chinese Medicine, 2013, 15 (9): 721–726 (in Chinese).

13 Huang H W. “Science, art and responsibility”: the scientific and social functional changes of a 500-year history of botanical gardens. I. Artistic appearance. Biodiversity Science, 2017, 25: 924–933 (in Chinese).

14 Farnsworth E J, Klionsky S, Brumback W E, et al. A set of simple decision matrices for prioritizing collection of rare plant species for ex situ conservation. Biological Conservation, 2006, 128 (1): 1–12.
15 Hoban S. New guidance for ex situ gene conservation: Sampling realistic population systems and accounting for collection attrition. Biological Conservation, 2019, 235: 199–208.
16 Hoban S, Schlarbaum S. Optimal sampling of seeds from plant populations for *ex-situ* conservation of genetic biodiversity, considering realistic population structure. Biological Conservation, 2014, 177: 90–99.
17 Wei X Z, Jiang M X. Meta-analysis of genetic representativeness of plant populations under ex situ conservation in contrast to wild source populations. Conservation Biology, 2021, 35 (1): 12–23.
18 Kang M, Ye Q G, Huang H W. Genetic risks in plant ex situ conservation. Hereditas (Beijing), 2005, 27 (1): 160–166 (in Chinese).
19 Lozada-Gobilard S, PánkovâH, Zhu J L, et al. Potential risk of interspecific hybridization in ex situ collections. Journal for Nature Conservation, 2020, 58: 125912.
20 Maxted N, Dulloo E, Ford-Lloyd B V, et al. Gap analysis: A tool for complementary genetic conservation assessment. Diversity and Distributions, 2008, 14 (6): 1018–1030.
21 Cibrian-Jaramillo A, Hird A, Oleas N, et al. What is the conservation value of a plant in a botanic garden? Using indicators to improve management of ex situ collections. The Botanical Review, 2013, 79 (4): 559–577.
22 Lawrence B A, Kaye T N. Reintroduction of *Castilleja levisecta*: Effects of ecological similarity, source population genetics, and habitat quality. Restoration Ecology, 2011, 19 (2): 166–176.
23 Xu Z F, Huang J Y, Hu H B, et al. A commentary on plant ex situ conservation and its researches in China nearly thirty years. Guihaia, 2008, 28 (6): 764–774 (in Chinese).
24 Heywood V H. The future of plant conservation and the role of botanic gardens. Plant Diversity, 2017, 39 (6): 309–313.
25 Braverman I. Conservation without nature: The trouble with in situ versus ex situ conservation. Geoforum, 2014, 51: 47–57.
26 Hawkes J G, Maxted N, Ford-Lloyd B V. The Ex Situ Conservation of Plant Genetic Resources. Dordrecht: Springer Science + Business Media, 2000
27 Pence V C, Ballesteros D, Walters C, et al. Cryobiotechnologies: Tools for expanding long-term ex situ conservation to all plant species. Biological Conservation, 2020, 250: 108736.
28 Werden L K, Sugii N C, Weisenberger L, et al. Ex situ conservation of threatened plant species in island biodiversity hotspots: A case study from Hawai'i. Biological Conservation, 2020, 243: 108435.
29 Huang H W, Liao J P, Zhang Z, et al. Ex situ flora of China. Plant Diversity, 2017, 39: 357–364.
30 Ren H, Jian S G, Liu H X, et al. Advances in the reintroduction of rare and endangered wild plant species. Science China Life Sciences, 2014, 57 (6): 603–609.
31 Ren H. Conservation and Reintroduction of Rare and Endangered Plants in China. Singapore: Springer Singapore,2020.
32 Liu H, Ren H, Liu Q, et al. Translocation of threatened plants as a conservation measure in China. Conservation Biology, 2015, 29 (6): 1537–1551.

(Translated by LI YY)



ZHOU Ju Associate Professor, Director of Division of Biotechnology, Bureau of Science and Technology for Development, Chinese Academy of Sciences (CAS), PhD of biochemistry. He is mainly engaged in biotechnology projects management and tech-transfer. E-mail: zhouju@cashq.ac.cn

REN Hai Director and Professor of South China Botanical Garden, CAS, Vice President of Ecological Society of China, President of Guangdong Botanical Society, Executive Director of International Association of Botanic Gardens, member of International Advisory Committee of Botanic Gardens Conservation International. He focuses on research and application of vegetation restoration and rare & endangered plants reintroduction. He has published more than 160 academic papers, 120 of which have been included in SCI. He has published three monographs, two of which are in English. He has been awarded three first prizes at provincial and ministerial levels. E-mail: renhai@scbg.ac.cn

