Postprint of Plant Introduction and Ex Situ Conservation at South China National Botanical Garden

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Abstract

Based on the plant introduction and survival records of the South China National Botanical Garden, we analyzed its plant introduction, survival, and species conservation status in specialized gardens. The results are as follows: (1) Since 1956, a total of 19,154 species, 99 subspecies, and 136 varieties of vascular plants (80,597 accession numbers) belonging to 325 families and 3,952 genera have been introduced, with 11,581 species, 52 subspecies, and 80 varieties (24,352 accession numbers) currently surviving, belonging to 290 families and 2,777 genera; the introduction records involve 565 species of nationally key protected wild plants (421 species currently surviving), covering 95% of national first-class key protected wild plant species in South China (36/38, with 29 species surviving), 76.4% of national second-class key protected wild plant species (269/352, with 229 species surviving), and 54.3% of threatened plant species (547/1,008, with 414 species surviving); (2) In terms of geographical sources, the most plants were introduced from Guangdong Province (7,193 accession numbers, 2,523 species), followed by Hainan (3,658 accession numbers, 1,593 species), Guangxi (4,744 accession numbers, 1,559 species), and other neighboring provinces; additionally, through introduction and exchange with 61 countries worldwide, some precious plant resources from the same latitude regions were acquired; (3) Fourteen specialized gardens, such as the Magnolia Garden, which conduct ex situ conservation by plant groups, generally maintain high levels in both introduction quantity and survival rate; (4) The correlation between species survival number and introduction frequency is extremely significant ($r = 0.85^{***}$); (5) The introduction survival rate of naturally distributed species in South China is higher than that of species from other regions. In the future, the South China National Botanical Garden should pay attention to the following aspects in plant ex situ conservation work: (1) Based on investigation, cataloging, assessment, and research, strengthen the introduction and collection of rare and endangered plants, native plants,

and economic plants in tropical and subtropical regions to further improve the quantity and quality of ex situ conservation; (2) Establish an ex situ conservation network system for plants in South China to effectively protect regional plant diversity; (3) Further improve the infrastructure construction and information management level of ex situ conservation to enhance ex situ conservation efficiency; (4) Strengthen international scientific research cooperation and species exchange.

Full Text

Preamble

Plant Introduction and Ex-situ Conservation in South China National Botanical Garden

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Abstract

Based on plant introduction and survival records from the South China National Botanical Garden (SCNBG), this paper analyzes the status of plant introduction, survival, and ex-situ conservation in specialized gardens. The results show that: (1) Since 1956, a total of 19,154 species, 99 subspecies, and 136 varieties (80,597 accession numbers) of vascular plants belonging to 325 families and 3,952 genera have been introduced, of which 11,581 species, 52 subspecies, and 80 varieties (24,352 accession numbers) belonging to 290 families and 2,777 genera are currently surviving. The introduction records involve 565 species of National Key Protected Wild Plants (421 species surviving), covering 95% (36/38) of the first-class National Key Protected Wild Plants in South China (29 species survived), 76.4% (269/352) of the second-class National Key Protected Wild Plants (229 species survived), and 54.3% (547/1,008) of threatened plant species (414 species survived). (2) In terms of geographical sources, the most plants were introduced from Guangdong Province (7,193 accession numbers, 2,523 species), followed by Hainan (3,658 accession numbers, 1,593 species), Guangxi (4,744 accession numbers, 1,559 species), and other surrounding provinces. Through exchange with 61 countries worldwide, SCNBG has also obtained valuable plant resources from regions at similar latitudes. (3) Fourteen specialized gardens for ex-situ conservation organized by plant taxonomic groups, such as the Magnolia Garden, demonstrate high performance in both introduction quantity and survival rate. (4) The correlation between species survival numbers and introduction frequency is extremely significant ($r = 0.85^{***}$). (5) The survival rate of species naturally distributed in South China is higher than that of species from other regions. Future ex-situ conservation efforts at SCNBG should focus on: (1) strengthening the introduction and collection of rare and endangered

plants, native plants, and economically important plants in tropical and subtropical regions based on investigation, cataloging, evaluation, and research to further improve the quantity and quality of ex-situ conservation; (2) establishing a plant ex-situ conservation network system in South China to effectively protect regional plant diversity; (3) further improving infrastructure and information management systems for ex-situ conservation to enhance efficiency; and (4) strengthening international scientific cooperation and species exchange.

Keywords: botanical garden, ex-situ conservation, vascular plants, plant introduction, survival

Introduction

Plant resources constitute a core component of global biodiversity and the material foundation for sustainable socio-economic development. Plants are essential for life on Earth, providing not only food, medicine, fiber, and energy necessary for human survival, but also participating in ecological processes such as climate regulation, soil fertility improvement, and air and water purification (Ren, 2017; Mounce et al., 2017; Ren et al., 2019). However, due to habitat degradation, species invasion, overexploitation, and climate change, plants are being lost at a rate 500 times higher than natural extinction, with approximately 40% of global plant species threatened (Humphreys et al., 2019; Antonelli et al., 2020; Zhao et al., 2022). In China, 15-20% of species face extinction risk (Ren et al., 2019). Currently, numerous threatened species remain insufficiently protected, and global plant diversity conservation remains a serious concern (Balding & Williams, 2016; Roberson et al., 2020).

Ex-situ conservation of plants is a crucial approach to biodiversity conservation that complements in-situ conservation. It not only compensates for the limitations of in-situ protection but also provides essential backup in case of species extinction in the wild (Oldfield & Newton, 2012; Cavender et al., 2015; Wen & Chen, 2022). Botanical gardens and arboreta serve as important institutions for plant ex-situ conservation, playing a significant role and making substantial contributions to global plant diversity protection (Heywood, 2017; Breman et al., 2021). Currently, 1,193 botanical gardens worldwide have completed ex-situ collections of one-third of global higher plants (living plants and seeds) (Wen & Chen, 2022). China's 160 botanical gardens have ex-situ conserved 23,340 species of vascular plants (including infraspecific taxa), with nearly 20,000 being native species (Huang & Zhang, 2012). To further strengthen plant diversity conservation, President Xi Jinping announced at the 15th Conference of the Parties to the UN Convention on Biological Diversity: "Based on the principle of combining in-situ and ex-situ conservation, we will launch the construction of national botanical garden systems in Beijing, Guangzhou, and other locations," opening a new chapter in China's plant diversity conservation.

Living plant collections are the core and "soul" of botanical gardens (Huang et al., 2015). Improving the efficiency of plant ex-situ conservation is a key

issue for botanical gardens. Internationally renowned botanical gardens such as Kew, Edinburgh, and Arnold Arboretum, as well as Chinese Academy of Sciences-affiliated gardens (including South China Botanical Garden, Wuhan Botanical Garden, and Xishuangbanna Tropical Botanical Garden), all emphasize living plant collection and have developed collection plans and scientific strategies for plant diversity conservation (Ren & Duan, 2017; Huang, 2018). To clarify the status of ex-situ conservation in Chinese botanical gardens and standardize plant introduction and management, researchers have developed the Plant Information Management System (PIMS) for Chinese botanical gardens, established living plant management databases, compiled and published the "Standard System of Botanical Gardens in China" (Huang et al., 2019), and written standardized procedures for introduction and living plant management. Since different climatic conditions create different floras, ex-situ conservation must consider not only plant genetic diversity but also climatic and soil condition similarities. China is currently deploying a national botanical garden system across different geographical regions and climate zones to construct a plant ex-situ conservation network and improve conservation efficiency. However, Chinese botanical gardens still face issues such as unclear conservation inventories and missing introduction archive data, and systematic research on introduction and conservation efficiency remains lacking.

The South China National Botanical Garden (SCNBG) is located in the northeastern suburbs of Guangzhou at 23°10 N, 113°21 E, within a south subtropical monsoon climate zone characterized by hot, rainy summers with high humidity and warm, dry winters with lower humidity. The annual average temperature is 21.8°C, with extreme highs of 38.0°C and extreme lows of 0°C, and annual rainfall of 1,600-1,800 mm. The region represents the core distribution area of China's most representative evergreen broad-leaved forests, with unique geographical advantages, excellent hydrothermal conditions, and rich plant diversity. Based in South China, SCNBG has long been dedicated to the introduction, collection, and ex-situ conservation of global tropical and subtropical plants. After more than 60 years of introduction and cultivation, SCNBG has accumulated relatively complete introduction and conservation archive data. This study organizes plant introduction and survival data accumulated since 1956 to analyze plant introduction, survival, and specialized garden conservation status, aiming to clarify current ex-situ conservation status and deficiencies, and provide references for SCNBG and other botanical gardens to develop plant introduction and ex-situ conservation strategies to improve conservation quality and efficiency.

1 Data and Methods

The data used in this study primarily include SCNBG's historical introduction records (1959-2022) and species survival records (comprehensive surveys conducted in 2014-2015 with subsequent updates), integrated with plant information (including natural distribution) from the Plant Photo Bank of China

(PPBC, http://ppbc.iplant.cn/). The collected data were processed as follows: (1) Deleted forma, cultivar, and hybrid records (which were not included in subsequent analysis); (2) Consulted Plants of the World Online (POWO, https://powo.science.kew.org/) to standardize and unify nomenclature; (3) For cases where both species and infraspecific taxa existed, deleted subspecies and variety records to avoid duplicate statistics; (4) Categorized introduction sources into field collection, botanical garden exchange, gift, and purchase, with purchase and gift categories excluded from subsequent analysis; (5) Supplemented and standardized introduction location information, with foreign introductions recorded at the country level in English, domestic introductions recorded at the province level in Chinese, and all institutions recorded with full names; (6) Supplemented species protection levels and threatened status according to the "List of National Key Protected Wild Plants" (Lu et al., 2021) and "Threatened Species List of China's Higher Plants" (Qin et al., 2017). After processing, 80,597 introduction records (accession numbers) and 24,352 species survival records (accession numbers) were obtained. Based on these records, we analyzed plant introduction, survival, and specialized garden conservation at SCNBG.

2.1 Plant Introduction Status

Analysis of 80,597 introduction records at SCNBG revealed that introductions identified to species and infraspecific levels accounted for 74.3% (59,905 records), including 59,512 at species level, 169 at subspecies level, and 224 at variety level. Additionally, 13.4% (10,771) of records were identified to genus level and 7.3% (5,881) to family level, while 5% (4,040) remained unidentified. Among insufficiently identified records, 2,055 lacked detailed introduction information and 4,209 were introduced from abroad. Material categories were dominated by seedlings (9,748 records, 69.7%) and seeds/spores (2,781 records, 19.9%), with other categories comprising only 10.4% (1,450 records). Identified introduction records involved 325 families, 3,952 genera, 19,154 species, 99 subspecies, and 136 varieties, including 36 families, 133 genera, 795 species, 4 subspecies, and 2 varieties of pteridophytes; 11 families, 65 genera, 333 species, and 3 varieties of gymnosperms; and 278 families, 3,754 genera, 18,026 species, 95 subspecies, and 131 varieties of angiosperms (Table 1). Among identified families, Orchidaceae had the most introduced species (1,086), followed by Fabaceae (1,015) and Cactaceae (835) (Table 2). At the genus level, the top three were *Hoya* (237 species), *Dendrobium* (162 species), and *Eucalyptus* (161 species) (Table 3).

Introduction records included 565 species from the "List of National Key Protected Wild Plants," comprising 73 first-class and 492 second-class protected species. These records covered 94.7% (36/38) of first-class National Key Protected Wild Plants distributed in South China (Guangdong, Guangxi, Hainan, Hong Kong, Macau) and 76.4% (269/352) of second-class species. Additionally, they encompassed 54.3% (547/1,008) of threatened plants in South China,

including 67 Critically Endangered (CR), 182 Endangered (EN), and 298 Vulnerable (VU) species.

Based on 59,505 introduction records (19,389 species including subspecies and varieties) identified to species level, we analyzed introduction frequency (one accession number counted as one introduction). We found that 86.9% (16,853 species) of vascular plants were introduced fewer than 5 times, with 52.5% (10,170 species) introduced only once and 16.7% (3,241 species) introduced twice. Thirty-five species had more than 50 introductions, with 14 species exceeding 100 introductions (Figure 1 [Figure 1: see original paper]). The most frequently introduced species was *Roystonea regia* (230 introductions), followed by *Mangifera indica* (207) and *Dracontomelon duperreanum* (173) (Table 4).

2.2 Ex-situ Conservation Status

SCNBG currently cultivates and conserves 290 families, 2,777 genera, 11,581 species, 52 subspecies, and 80 varieties (21,746 accession numbers) of vascular plants ex-situ, including 35 families, 104 genera, 519 species, 1 subspecies, and 1 variety of pteridophytes; 10 families, 50 genera, and 157 species of gymnosperms; and 245 families, 2,623 genera, 10,905 species, 51 subspecies, and 79 varieties of angiosperms (Table 1). The family with the most surviving species is Cactaceae (752 species), followed by Orchidaceae (639) and Apocynaceae (467) (Table 2). Two hundred eight families have introduction survival rates above 50%, with 37 families achieving 100% survival, such as Didiereaceae (8 species introduced, all survived) and Menyanthaceae (7 species introduced, all survived). One hundred seventeen families have survival rates below 50%, and 35 families failed completely, including Winteraceae (13 introductions, 9 species, none survived), Loasaceae (7 introductions, 4 species), and Dipteridaceae (10 introductions, 4 species). The top three genera in terms of surviving species are *Hoya* (212 species), *Magnolia* (147), and *Euphorbia* (120) (Table 3). Two thousand three hundred ninety-four genera have survival rates above 50%, with 1,374 achieving 100% survival. One thousand one hundred seventy-five genera failed completely, including *Allocasuarina* (Casuarinaceae, 16 species introduced), *Hesperocyparis* (Cupressaceae, 13 species), and *Hydriastele* (Arecaceae, 10 species). Species survival numbers correlate extremely significantly with introduction frequency ($r = 0.85$, $p < 0.001$, Figure 2 [Figure 2: see original paper]). The species with the most surviving accession numbers is *Roystonea regia* (219), consistent with its highest introduction frequency, followed by *Dracontomelon duperreanum* (171) and *Mangifera persiciforma* (142). SCNBG has successfully conserved 421 National Key Protected Wild Plants ex-situ, including 58 first-class species (29 distributed in South China) and 363 second-class species (229 distributed in South China). It has also successfully conserved 414 threatened plants from South China, accounting for 41.1% of threatened plants in the region, including 49 CR, 135 EN, and 230 VU species.

2.3 Historical Introduction and Specialized Garden Development

Established in 1956, SCNBG has undergone five planning adjustments across four developmental periods: exploration and establishment (1956-1966, 10 specialized gardens constructed), recovery and expansion (1973-1987, 10 gardens), stable maintenance (1988-2002, 6 gardens), and leapfrog development (2003-2021, 12 gardens), totaling 38 specialized gardens. Since 2022, SCNBG has entered the national botanical garden construction phase, with 4 additional gardens planned. Throughout its history, systematic introductions have been conducted through field collection, botanical garden exchange, institutional/personal gifts, and purchases. Analysis of 61,664 records with detailed introduction dates revealed sporadic introductions during early exploration (1957-1962), rapid development in the later period (1963-1966) peaking in 1964 (1,555 introductions, 4,788 total), a brief stagnation period (1967-1972), soaring introduction numbers during recovery and expansion with annual introductions fluctuating around 1,000 (except 1986-1987, 13,397 total), slow growth during stable maintenance with most years below 100 introductions (peaking at 1,708 in 2001, 7,158 total), and since 2003, annual introductions mostly exceeding 1,500 with six years surpassing 2,500, ranking 2004 (3,480), 2011 (3,411), and 2010 (3,026) as the top three years (34,414 total) (Figure 3 [Figure 3: see original paper]).

Among the existing 38 and planned 4 specialized gardens, 14 are organized by plant taxonomic groups for ex-situ conservation: Palm Garden, Bamboo Garden, Magnolia Garden, Orchid Garden, Cycad Garden, Gymnosperm Garden, Ginger Garden, Camellia Garden, Rhododendron Garden, Pandanus Garden, Lauraceae Garden, Fagaceae Garden, Ardisia Garden, and planned Fabaceae Garden. Statistics for these gardens (Table 5) show that except for Arecaceae (43%), Fabaceae (45.8%), and gymnosperms (46.7%), all other groups have survival rates above 50%, with Magnoliaceae achieving the highest rate at 98.1%, followed by Lauraceae and Bambusoideae (both 75.3%). Orchidaceae has the most introduced/surviving species (1,166/720 introductions/species), followed by Fabaceae (1,015/465), reflecting their high ornamental value and species richness. Pandanaceae has the fewest introduced/surviving species, while large families such as Theaceae, Ericaceae, Lauraceae, and Fagaceae show significant gaps compared to species numbers recorded in *Flora Reipublicae Popularis Sinicae* and *Flora of China*. The four gardens targeted for international excellence (excluding the Medicinal Garden) involve Magnoliaceae, Zingiberaceae, and Bambusoideae, all showing high introduction/survival numbers, survival rates, and coverage of domestically distributed species.

2.4 Introduction Source Analysis

Domestic provinces with high introduction frequency (field collection category) are all located in southern China, involving 28,691 accession numbers and 7,173

species. Guangdong Province ranks first in both accession numbers (7,193) and species count (2,523), followed by Yunnan (5,838/2,068). Guangxi ranks third in accession numbers (4,744) but fourth in species count (1,559), while Hainan shows the opposite pattern with fewer accession numbers (3,658) but slightly more species (1,593) than Guangxi (Table 6). The top three domestic exchange institutions are Xishuangbanna Tropical Botanical Garden, Chinese Academy of Sciences (1,262/571 accession numbers/species), Kunming Institute of Botany, Chinese Academy of Sciences (635/409), and Institute of Botany, Chinese Academy of Sciences (551/388) (Table 7).

Foreign introductions involve 61 countries, with 5,428 records covering 1,802 species. Twelve countries have over 100 introductions (6 Southeast Asian, 2 South American, 2 North American, 1 African, and 1 Southern Hemisphere). Vietnam has the most introductions (1,061), followed by Peru (807) and Indonesia (683). Indonesia has the most introduced species (430), followed by the United States (296) and Thailand (178) (Table 6). The top foreign exchange institutions by accession numbers are Adelaide Botanic Garden, Australia (202), Fairchild Tropical Botanic Garden, USA (187), and Royal Botanic Gardens, Kew, UK (157), while the top by species count are Fairchild Tropical Botanic Garden (160), Adelaide Botanic Garden (157), and Kew (126) (Table 7).

2.5 Introduction Survival Rate Analysis

Using natural distribution data from *Flora Reipublicae Popularis Sinicae* (Flora Reipublicae Popularis Sinicae Editorial Committee, 1959–2004), *Flora of China* (Wu et al., 1989–2013), *Species Catalogue of China: Volume 1 Plants* (Biodiversity Committee, Chinese Academy of Sciences, 2013–2018), and Plants of the World Online (POWO, https://powo.science.kew.org/), we analyzed the relationship between survival rate and natural distribution for 19,389 introduced vascular plant species (Figure 4 [Figure 4: see original paper]). Results show that foreign species have approximately 51% survival rate, while domestic species exceed 65.8%, with survival rates gradually increasing and stabilizing around 75% as the number of naturally distributed provinces increases. Analysis of narrow-range species (naturally distributed in only one Chinese province) revealed that Guangdong has the highest survival rate at 79.1% (125/158), followed by Guangxi (77.6%, 187/241) and Hainan (73.1%, 261/357), while Xinjiang has the lowest at 22.3% (21/94) (Table 8). Overall, species naturally distributed in South China show significantly higher survival rates than those from other regions, with survival rates decreasing as natural distribution distance increases.

Furthermore, using 6,108 well-documented, clearly sourced, and accurately identified records, we analyzed the relationship between survival rate and introduction source province. Hubei ranked first with 71.7% survival (137/191), followed by Guizhou (69.7%, 46/66) and Fujian (59.4%, 126/212). In contrast, Guangdong, Hainan, and Guangxi in South China ranked 6th (41.7%, 1,040/2,484), 8th (33.7%, 265/786), and 10th (31.7%, 155/489) respectively (Table 9). Anal-

ysis of annual survival and mortality from these provinces (Figure 5 [Figure 5: see original paper]) shows that high survival rates in Hubei, Guizhou, and Fujian result from most introductions occurring in the past decade, likely due to improved conservation conditions and management. Conversely, lower survival rates in South China's three provinces reflect longer introduction histories, larger introduction bases, and management-related mortality of some long-introduced species.

Discussion and Conclusion

A botanical garden's mission and planning significantly influence periodic plant introduction. SCNBG's exploration and stable maintenance periods focused on wild plant resource development and domestication, with relatively low annual introduction numbers. The recovery and expansion and leapfrog development periods emphasized specialized garden construction, plant introduction, and rare/endangered plant propagation, maintaining high annual introduction levels. Geographically, SCNBG adheres to its mission of "based in South China, dedicated to global tropical and subtropical plant conservation, research, and education." Domestic introductions center on Guangdong, radiating to surrounding provinces like Hainan, Guangxi, Hunan, and Jiangxi, focusing on species collection and ex-situ conservation in southern subtropical and tropical regions. International exchange covers six continents (excluding Antarctica), acquiring valuable resources from similar-latitude regions like Mexico, Myanmar, and India, and maintaining close species exchange with Southeast Asian countries. SCNBG plays an important role in ex-situ conservation of rare and endangered plants, successfully conserving 421 National Key Protected Wild Plants (58 first-class, including 29 distributed in South China; 363 second-class, including 229 in South China) and 414 threatened South China plants (41.1% of the regional total), including 49 CR, 135 EN, and 230 VU species. The focus has been on ornamental groups, while surviving groups are mainly widespread, highly adaptable species. Most species have been introduced too few times, while a few are over-introduced, primarily landscape or street trees. Different plant groups generally show high survival rates, and specialized gardens have considerable conservation numbers.

Despite conserving over 10,000 species, SCNBG still faces challenges. Numerous unidentified accession numbers exist, related to introduction materials being mostly seeds and seedlings lacking diagnostic characteristics. Plant identification is fundamental to conservation and utilization and requires urgent attention. Previous introduction priorities focused on ornamental groups, with insufficient attention to "3E" plants: Endemic, Economic, and Endangered species, which should be priority collection and research targets (Ren et al., 2022; Wen & Chen, 2022). Existing and planned specialized gardens show significant gaps in Pandanus, Camellia, Rhododendron, Lauraceae, and Fagaceae collections, requiring enhanced future collection efforts. Groups poorly adapted to Lingnan climate (Ericaceae, conifers) and low-survival groups need improved cultivation

techniques, facilities, and natural condition simulation. Over-introduced species (e.g., *Roystonea regia*, *Mangifera indica*, *Dracontomelon duperreanum*) should be avoided in future introductions. Exchange with similar-latitude countries and Southeast Asian neighbors should be strengthened to increase introduction diversity. Additionally, greater emphasis is needed on introduction, ex-situ conservation, and reintroduction of National Key Protected Wild Plants and threatened species to fully leverage the conservation functions of national botanical gardens.

During SCNBG's development into a national botanical garden, ex-situ conservation should be strengthened by: (1) enhancing investigation, cataloging, evaluation, and research of living collections, strengthening introduction of rare/endangered, native, and economic plants in tropical/subtropical regions, increasing research-based collections of key groups, adaptable groups, and groups with strong research foundations, balancing strategic collections of core germplasm, ornamental plants, ecological restoration species, and wild relatives of crops, forestry, medicinal, and fruit plants to improve conservation quantity and quality; (2) conducting ecological and biological studies, research on plant diversity formation and maintenance mechanisms, and population and ecosystem restoration studies around key collection groups, developing sustainable utilization technologies to provide new varieties for high-quality development or reintroduction, and popularizing advanced information from introduction, conservation, research, and development; (3) establishing a South China plant ex-situ conservation network system beyond SCNBG, integrating with national parks and nature reserves to create combined ex-situ and in-situ protection systems; (4) further improving ex-situ conservation infrastructure and information management to enhance efficiency. Furthermore, we should coordinate multiple conservation functions through high-level research and sustainable utilization to efficiently advance national botanical garden system development.

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Note: Figure translations are in progress. See original paper for figures.