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Ex situ Flora of China

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ABSTRACT

The role of living collections-based research and discovery has been a prominent feature throughout the history of evolution and advance of botanical science: such research is the core and soul of the botanical gardens. Currently, there are c. 162 Chinese botanical gardens, harboring c. 20,000 species in China. As an example of initiatives to utilize the garden cultivated flora to address plant diversity conservation and germplasm discovery for sustainable agriculture and the bio-industries, the *Ex situ* Flora of China project aims to catalog and document this mega-diversity of plants that are cultivated in the Chinese botanical gardens. The concept of *Ex situ* Flora of China is a complete new formulation of species, based on garden cultivated individuals and populations, to obtain better morphological descriptions, provide multi-purpose applicability and a fundamental data service that will support national bio-strategies and bio-industries. It emphasises integrative information, accurately collected from living collections across different Chinese botanical gardens, on biology, phenology, cultivation requirements and uses of plant resources, which are normally not available from traditional Floras based on herbarium specimens. The *ex situ* flora should provide better information coverage for taxonomy, biological and introduction and collection data and color photos of stems, leaves, flowers, fruits and seed, as well as useful information of cultivation key points and main use of each plant. In general, the *Ex situ* Flora of China provides more useful information than the traditional Flora Reipublicae Popularis Sinicae. The project of *Ex situ* Flora of China is planned to be one of the most important initiatives of the plant diversity research platform for sustainable economic and social development in China.

1. Introduction

In the history of botany during the past 500 years, the botanical garden, as a specialized research institution of botany, has always been in the mainstream of botanical research, conservation and discovery of uses of plant resources. The botanical garden has a profound scientific connotation, with a comprehensive engagement in the basic biological research on plant, collections and the evaluation, exploration and sustainable utilization of plant resources. In particular, the role of living collections-based research and discovery has been a prominent feature throughout the history of evolution and advance of botanical sciences. Botanical research is the core and soul of the botanical gardens. Much of the historical literature has recorded that botanical gardens and living collections were inspiring places and research resources which had inspired many great scientists, such as, Carl Linnaeus (1707–1778), Charles Darwin (1809–1882), Gregor Mendel (1822–1884), Liberty Hyde Bailey (1858–1954), and Barbara McClintock (1902–1992), etc.

There are about 3000 botanical gardens in the world, widely across different climatic zones and floristic regions. Most importantly they provide habitats for >120,000 vascular plants in *ex situ* cultivation, accounting for about a third of known world plant species, including many economically important taxa or groups, such Aceraceae, Ericaceae, Fagaceae, Leguminosae, Magnoliaceae, as well as a large number of crop wild relatives, medicinal and aromatic, and ornamental plants. This *ex situ* cultivated flora contains an enormous amount of plant diversity in many well documented living collections in different botanical gardens and plays a critical role in maintaining the security of plant diversity, and in conservation, sustainable agriculture and other related bio-industries.

Currently, there are c. 162 botanical gardens in China (Fig. 1), harboring c. 20,000 species in China (Huang and Zhang, 2012). As an example of initiatives to utilize the garden cultivated flora to address plant diversity conservation and germplasm discovery for sustainable

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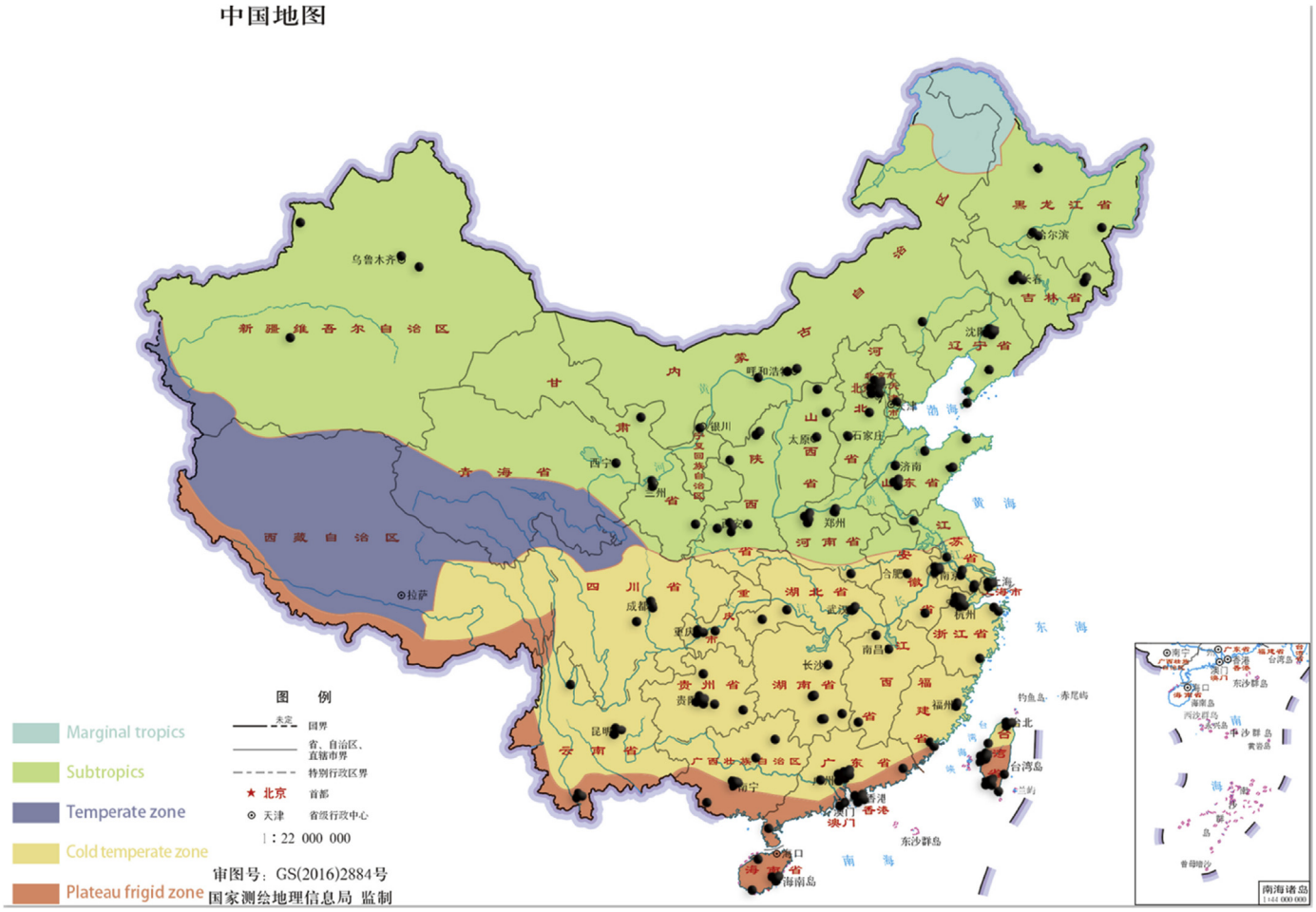

Fig. 1. Map of distribution of Chinese botanical gardens.

agriculture and the bio-industries, the *Ex situ* Flora of China project aims to catalog and document this mega-diversity of plants that are cultivated in the Chinese botanical gardens. The project of *Ex situ* Flora of China is planned to be one of the most important initiatives of the plant diversity research platform for sustainable economic and social development in China (Huang, 2011).

China probably has one of the largest garden cultivated floras in the world. Even dated back to centuries ago when many western plant hunters (such as Pehr Osbeck during 1750–1752; Robert Fortune 1842–1861; Augustine Henry 1882–1890; Ernest Henry Wilson 1876–1930; George Forrest 1904–1932; Joseph F. Rock 1922–1949, etc.) were exploring in China, their first impressions was the huge garden cultivated flora, which was mostly grown in numerous private Chinese traditional gardens a century ago. Nowadays, botanical gardens in China have played key role for plant conservation, and a huge garden cultivated flora has been assembled in the past century (Huang and Zhang, 2012). However, unfortunately no national list or inventory of garden cultivated plants exist in Chinese history, even if many kinds of native Chinese plants that provide food, utility, and pleasure have been widely recognized worldwide. Ernest H. Wilson dubbed China the 'Mother of Gardens' because 'anywhere in the temperate zone of the northern hemisphere, no garden does not cultivate several species derived from Chinese plants' (Wilson, 1929). Today gardens and parks throughout the world showcase flowering plants like rhododendrons, camellias, magnolias, peonies, primroses, viburnums, and many others that originated in China.

Obviously, we need accurate information pertaining to plants found growing in China, both native and introduced. A complete inventory of garden cultivated plants and project of *Ex Situ* Flora of China should provide needed supports to future of these scientific and concomitant databasing efforts, along with other national mega-databases and contribute to China's national strategies of sciences and technologies in 21st century, as well as in accordance with China's government commitments to the Convention on Biological Diversity.

2. Concept and vision of *Ex situ* Flora of China

When we began formulating a strategy and project planning, the project concept differed from other known projects including the six-volume European Garden Flora, a project whose six volumes were published 1998–2000 and second edition released in 2011 (Cullen et al., 2011). The project of *Ex situ* Flora of China is different from the European Garden Flora, in at least these five aspects: 1) The initiation of *Ex situ* Flora of China is a state funded project aiming to a complete inventory of garden cultivated plants of Chinese botanical gardens but the renewed project continued into the *Ex situ* Flora of China while European Garden Flora started as a group of botanists on a voluntary basis for accurate identification of cultivated ornamental plants found growing in Europe; 2) starting point of raw materials, database and information are significantly difference. *Ex situ* Flora of China started with documented databases from the national inventory of garden cultivated

plants in China while European Garden Flora initiated with catalogs or other similar materials and data from many European nurseries; 3) the priority *Ex situ* Flora of China is mostly on plants native to China where majority of plants found growing in the country is native while majority of plants found growing in Europe is exotics or introduced from other parts of the world; 4) The project of *Ex situ* Flora of China has an obvious advantage of availability of Flora Reipublicae Popularis Sinicae (FRPS, Chinese version flora of China) and Flora of China (an updated English version of FRPS) as benchmark while European flora is not such complete during compilation of European Garden Flora; 5) *Ex situ* Flora of China has formulated an integrative editorial strategy for inclusion of taxonomic information, natural distribution, morphological descriptions from living collections, passport information, and phenological and biological information and cultivation information while European Garden Flora is mostly a checklist of plant names and concise descriptions.

Our core concept of *Ex situ* Flora of China is a complete new formulation of species found in living collections, based botanical garden cultivated individuals and populations to obtain better morphological descriptions, and provide multi-purpose applicability and a fundamental data service that will support national bio-strategies and bio-industries. It emphasises integrative information, accurately collected from living collection across different botanical gardens in China, on biology, phenology, cultivation requirements and uses of plant resource, that are normally not available from traditional Floras based on herbarium specimens. The *ex situ* Flora should provide better information coverage for taxonomy, biological and introduction and collection data and color photos of stems, leaves, flowers, fruits and seed, as well as useful information of cultivation key points and main use of each plant (Fig. 2). In general, the *Ex situ* Flora of China provides more useful information compared with the traditional Flora Reipublicae Popularis Sinicae.

The formulation of the *Ex situ* Flora of China has obvious advantages and unique features that differ from other garden Floras or cultivated Floras, for example, the delimitation of species boundaries is also flexible, allowing for the possible inclusion of a list of cultivars for some species of special horticultural or ornamental interest, such as lotus, chrysanthemum, Rhododendron, etc. of which many cultivars have been developed from single species. The project also conforms to the trends of national and international *ex situ* conservation, public awareness and education and is consistent with the principle of long-term accumulation of biological data as well as in line with the country's strategic planning needs for baseline data converge.

In practice, the *Ex situ* Flora of China should provide significant support to botanical research and plant germplasm discovery and sustainable use: 1) Enhancement of taxonomic research with common-garden-based living specimens. The morphological and biological data collecting from living collections of different botanical gardens should provide both adequate and accurate descriptions and the delimitation of difficult taxa where traditional taxonomic revisions were based on herbarium specimens; 2) Support of comparative biology and frontline plant science research: for example, with increasing awareness of environmental and habitat changes in the overall context of climate change on plant distributions *in situ*, the *Ex situ* Flora project should provide intensive plant biological information from different botanical gardens across a wide spectrum of different latitudes, regional climates and habitats in relation to research on species' adaptive evolution, plant migration and distribution shifts and physiological or/and biochemical changes, etc.; 3) Strengthening germplasm discovery and sustainability of plant resource, which should enhance our current ongoing efforts in the case of medicinal plants, industrial bio-energy plants, landscaping and ornamental plants, new functional fruits and vegetables, environmental meliorating plants, etc.

The *Ex situ* Flora of China Project will include c. 300 families, >3000 genera and approximately 16,000–20,000 species from *ex situ* living collections across 30–60 botanical gardens in China (Huang, 2014, 2015–2017). Both electronic and hard copy versions are simultaneously available, with the e-version periodically updated. Hard copy publication has been arranged by large families or genera and combined small families. A total of approximate 80 volumes are expected within time frame about 15–20 years.

Our vision for the *ex situ* Flora is that although initiated as a national project for China, it might eventually become an *ex situ* Flora of the world after the successful completion of the Chinese *ex situ* Flora and regional *ex situ* Floras such as an Asian *ex situ* Flora because the concept of the *Ex situ* Flora of China is versatile and adaptable to any scale.

3. Comparisons between *Ex situ* Flora of China and Flora Reipublicae Popularis Sinicae

The project of *Ex situ* Flora of China should have benefits for both scientific research and applications of using plant resources. Documenting the data well collected from sites of *ex situ* living collections across different botanical gardens would enhance both traditional botanical research and frontline research which largely depend on sufficient and accurate data of plant growth and development, such plant taxonomy and climate change biology. In particular, phenological data of many plants collected from different botanical gardens in different latitudes and longitudes would provide solid evidence of climate changes over decades and centuries. Meanwhile, the formulation of *Ex situ* Flora of China is largely designed for supporting plant resource exploration and utilization and for services provided by importance of plant resources for human survival and sustainability, such as wild relatives for crop breeding and genetic improvement, resources for new specialist crops, local indigenous plants for reforestation and wetland restoration, biodiesel plants and medicinal resources, etc. which are highly valued in China.

Nevertheless, *Ex situ* Flora of China is different from traditional Flora Reipublicae Popularis Sinicae in many aspects:

3.1. Exotic plants

The 10 largest families in *ex situ* cultivation are these commonly seen families in China, i.e. Orchidaceae, Poaceae, Rosaceae, Fabaceae, Asteraceae, Liliaceae, Arecaceae, Euphorbiaceae, Cactaceae and Asclepiadaceae. However, two families, Cactaceae and Arecaceae, are non-native. Obviously, all species of Cactaceae were introduced from desert areas of other parts of the world, whereas more than 90% species in Arecaceae came from South America. In comparison, the 10 largest families in Flora of China (FOC) are Asteraceae, Poaceae, Fabaceae, Orchidaceae, Rosaceae, Ranunculaceae, Lamiaceae, Ericaceae, Cyperaceae and Liliaceae, six of them are the same top ten in *ex situ* conservation. The Flora of China has some unique features, such as the 10 largest families of FOC accounting for >1/3 of the total number of Chinese native plant, that is c. 12,404 out of 31,365. About two thirds of the 312 families contain 50 or fewer species, i.e. 212 families in China contains only c. 900 out of 31,365 (2.9%), average c. 23 species/family. Many other families also contain alien plants introduced form other countries.

Nonetheless, an inventory of garden flora of China showed a relative low percentage of exotic species in China (Huang and Zhang, 2012), i.e. about 10% of total number garden cultivated species, which is quite different from the situation in US and

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黄山木兰

Magnolia cylindrica Wils., J. Arnold Arbor. 8: 109. 1927.

【自然分布】 Natural distribution

分布安徽、浙江、江西、福建，生于海拔 700–1 600m 的山地林间。

【迁地栽培形态特征】 Morphological characters

落叶乔木。树高 3–13m，胸径 4–34cm。

茎 树皮灰色至灰黑色，平滑；幼枝绿色或黄绿色，平滑无毛或被淡黄色至黄褐色平伏短柔毛，老枝紫褐色或灰褐色，无毛，具明显皮孔，皮揉碎有辛辣香气；芽密被淡黄色或黄褐色长柔毛。

叶 纸质，倒卵形、倒卵状长圆形或椭圆形，长 5–15cm，宽 2–7.5cm，先端渐尖、急尖或钝圆，2/3 以下渐狭，基部楔形或宽楔形，上面绿色，除中脉偶被毛外，其余无毛，下面灰绿色，疏被淡黄色或黄白色平伏短毛；叶脉在上面多少凹陷；叶柄长 0.5–2cm，被淡黄色或黄白色平伏短柔毛；托叶痕为叶柄长的 1/6–1/2。

花 芳香，直立，先叶开放；花蕾卵形，被灰黄色或银灰色柔毛；花梗粗壮，密被淡黄色绒毛；花被片 9，外轮 3 片膜质或薄肉质，萼片状，淡绿色或粉红色，小，舌形，中内轮 6 片花瓣状，白色或粉红色，基部淡紫红色至紫红色或具淡紫红色至紫红色中肋，椭圆状匙形或倒卵状匙形；雄蕊多数，玫红色或紫红色，花药侧向开裂，药隔伸出呈三角形尖头；雌蕊群淡绿色或黄绿色，心皮先端玫红色或紫红色倒卵形。

图 1. 黄山木兰的植株、树干、叶背

西安植物园 1996 年从安徽黄山引种枝条。生长速度中等，长势良好。

【物　候】 Phenology

华南植物园 2 月中旬叶芽萌动，3 月上旬开始展叶，4 月中旬进入展叶盛期；7 月中旬现花蕾，次年 2 月中旬始花，2 月下旬盛花，3 月上旬末花；8 月中旬果熟；10 月上旬开始落叶。花白色，基部及中肋紫红色。

仙湖植物园 2 月开花；果实未见。

桂林植物园 2 月下旬叶芽萌动，3 月上旬开始展叶，3 月中旬进入展叶盛期；尚未开花；9 月下旬开始落叶。

昆明植物园 3 月叶芽萌动，3–4 月抽档、展叶；8 月花蕾显现，次年 2 月开花；9 月果熟，顶芽饱满；10–11 月落叶。花白色，基部及中肋紫红色。

贵州植物园 3 月上旬叶芽萌动，3 月上旬开始展叶，3 月中旬进入展叶盛期；3 月上旬始花，3 月中旬盛花，3 月下旬末花；8 月中旬果熟。花被红色，基部及中肋紫红色。

庐山植物园 4 月中旬开始展叶，4 月下旬进入展叶盛期；3 月下旬盛花，4 月上旬末花；10 月下旬果熟；10 月下旬开始落叶。花白色，基部及中肋紫红色。

南京中山植物园 4 月中旬开始展叶；3 月上旬花蕾膨大，3 月下旬–4 月上旬开花；9 月上旬果熟；10 月下旬开始落叶。花白色，基部及中肋紫红色。

图 4. 黄山木兰的叶面、果

西安植物园 4 月上旬开始展叶；3 月中下旬始花；8 月中下旬果熟；10 月中下旬开始落叶。花白色，基部及中肋淡紫红色。

【迁地栽培要点】 Cultivation techniques

能耐一定的高温，抗寒性较强，较耐干旱和贫瘠，适于我国暖温带南部至亚热带地区栽培。繁殖以播种和嫁接为主。常见木兰类细菌和炭疽病危害。

【主要用途】 Main uses

本种为易危种（VU），中国特有；树姿优美，早春开花，花大芳香，花色素雅美丽，耐寒，适应性较好，可作园林绿化树种；花蕾可入药，花可提取浸膏；材质好而作材用。

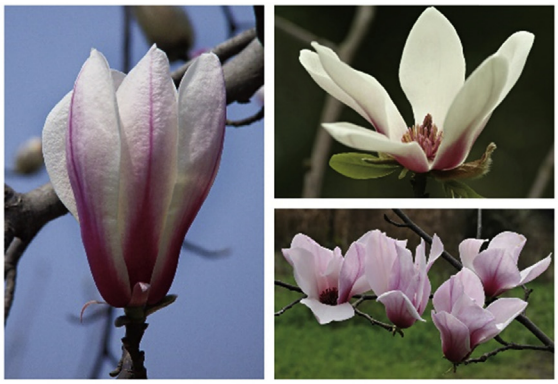

图 2. 黄山木兰的花（左图摄于南京中山植物园，右上图摄于华南植物园，右下图摄于贵州植物园）

果实 聚合果圆柱形，长 5–13cm，径 2–3.5cm，果梗被淡褐色短柔毛；骨突大型，初绿色，成熟时紫红色，表面具小瘤状皮孔凸起，顶端具短尖，沿背缝线或腹缝线开裂，或沿背同时开裂；每骨突具种子 1–2 粒，外种皮肉质，红色，内种皮黑褐色。

【引种信息】 Passport data

华南植物园 从杭州植物园（登录号 19790036）、昆明植物园（登录号 20010009）引种种子；从福建新宁林科所（登录号 20000104）引种苗；从西安植物园（登录号 20030024）引种枝条。生长速度中等，长势良好。

仙湖植物园 1991 年从安徽黄山引种。生长速度中等，长势一般。

桂林植物园 1992 年从湖南新宁县雪山珍稀植物园引种。生长速度中等，长势良好。

昆明植物园 从安徽吉林科所（引种号 1985–073）、杭州植物园（引种号 1988–104）引种种子，播种育苗较易，长势良好。

贵州植物园 引种记录不详。生长较快，长势良好。

庐山植物园 20 世纪 80 年代前引种；2007 年引种苗。生长速度中等，长势较好。

武汉植物园 从湖南省新宁县引种实生苗（引种号 20032534）。生长速度中等，长势良好。

南京中山植物园 从杭州植物园（引种号 19791401–07、19881154–20）、浙江凤阳山（引种号 19811154–36）、安徽省歙县清凉峰（引种号 19811153–31、19821153–08）、上海植物园（引种号 19821510?–008）、安徽黄山（引种号 19881153–49）引种；1982 年（引种号 1982F41020–176）引种。生长较快，长势良好。

Fig. 2. Example of information included for each species and format in *Ex situ* Flora of China.

Europe. The possible explanation is that China is rich in plant diversity and has approximately one and a half and twice as many vascular plants than US and Europe, respectively. North America and Europe have been active in plant hunting and introduction of plants from over the world in past 400–500 years. In fact, there are 3–4 times more introduced plants than native plants in the US (Elias, personal communication) and same probably is true in Europe (Table 1).

3.2. Importance of economic and useful plant species

The 15 largest genera in *ex situ* cultivation are mostly economic and useful plant species, including those of horticultural, medicinal, industrial raw materials and other economic value, such as *Hoya*, *Begonia*, *Rhododendron*, *Ficus*, *Rubus*, *Camellia Euphorbia*, *Aloe*, *Acer*, *Dendrobium*, *Ilex*, *Rosa*, *Berberis*, *Bulbophyllum*, and *primulina* (Table 2). In contrast, four largest genera from the 15 largest genera in Flora of China are the same of those in *ex situ*. The 15 largest genera of wild species in nature include 4642 species, accounting for c. 15% of the species in the Flora of China. In fact, the 45 largest genera with over 100 species include more than a quarter of the total species of the native flora. In addition, c. 1283 out of a total 3329 genera consist of only a single species. Evidently, the *Ex situ* Flora of China highlights much more economic and valuable species.

3.3. Taxa entry and boundary

The principles for inclusion and circumscription of taxa have been well formulated and standardized. The *Ex situ* Flora of China is species based inventory and documents living collections in botanical gardens. Unlike other cultivated floras, a large percentage of cultivars have to be included. A typical example is the Cultivated Flora of North America, a project initiated 2001 but terminated in 2006. Difficulties and impediments experienced by the project are obvious, including the fact that more introduced than native species exist in North America, and that there is a large percentage of cultivars and disagreement between taxonomists or botanists and horticulturists or agriculturists on which taxa to include and how they should be delimited, as well as insufficient financial support, etc. (Elias and Raven, personal communication). In the initial guidance of the *Ex situ* Flora of China during early stage of project

Table 1
Comparison of 15 largest families between in *Ex situ* Flora of China and in Flora Of China.

Ex situ Flora of China			Flora of China		
	Family name	Number of species		Family name	Number of species
1	Orchidaceae	702	1	Asteraceae	2165
2	Poaceae	639	2	Poaceae	1906
3	Rosaceae	629	3	Fabaceae	1710
4	Fabaceae	574	4	Orchidaceae	1378
5	Asteraceae	495	5	Rosaceae	954
6	Liliaceae	477	6	Ranunculaceae	941
7	Arecaceae	405	7	Lamiaceae	900
8	Euphorbiaceae	356	8	Ericaceae	861
9	Cactaceae	352	9	Cyperaceae	825
10	Asclepiadaceae	326	10	Liliaceae	764
11	Zingiberaceae	303	11	Scrophulariaceae	704
12	Rubiaceae	301	12	Apiaceae	636
13	Lamiaceae	274	13	Dryopteridaceae	589
14	Lauraceae	265	14	Saxifragaceae	572
15	Gesneriaceae	264	15	Lauraceae	543

Table 2
Comparison of 20 largest genera in the *Ex situ* Flora of China and the Flora of China.

Ex situ Flora of China			Flora of China		
	Genus name	Number of species		Genus name	Number of species
1	*Hoya*	202	1	*Rhododendron*	570
2	*Begonia*	201	2	*Carex*	505
3	*Rhododendron*	155	3	*Corydalis*	364
4	*Ficus*	122	4	*Pedicularis*	363
5	*Rubus*	114	5	*Astragalus*	355
6	*Camellia*	104	6	*Primula*	304
7	*Euphorbia*	102	7	*Salix*	282
8	*Aloe*	98	8	*Saussurea*	274
9	*Acer*	98	9	*Gentiana*	254
10	*Dendrobium*	92	10	*Impatiens*	254
11	*Ilex*	91	11	*Saxifraga*	239
12	*Rosa*	91	12	*Berberis*	216
13	*Berberis*	86	13	*Aconitum*	211
14	*Bulbophyllum*	81	14	*Rubus*	209
15	*Primulina*	76	15	*Ilex*	208
16	*Carex*	70	16	*Dryopteris*	199
17	*Aechmea*	63	17	*Artemisia*	189
18	*Viburnum*	63	18	*Begonia*	188
19	*Dryopteris*	62	19	*Athyrium*	180
20	*Polystichum*	62	20	*Oxytropis*	177

planning, species level entry has been officially determined so as to exclude cultivars under any terms, although a list of cultivars might be allowed as an appendix in some special horticultural species.

However, in view of the unique situation of *ex situ* living collections, below species level, subspecies and varieties or forms are accepted with strict definitions and terminology, which are more appropriate for some families and genera in *ex situ* cultivation because the *Ex situ* Flora of China is partially driven by applications of plant germplasm evaluation and discovery. In any cases, voucher specimens are required and collecting and depositing voucher specimens of each taxon entry have well formulated and guided.

All species entries are referenced from Flora Reipublicae Popularis Sinicae and Flora of China for verification of taxonomic names. However, taxonomic treatments in some families and genera are different between the earlier Chinese version of Flora Reipublicae Popularis Sinicae and the updated English version of Flora of China, and also controversies exist regarding species names found between plants in Floras and living collections due to many taxonomic revision made after plants were brought into *ex situ* cultivation. In such cases, prioritized references are recommended, with the Flora Reipublicae Popularis Sinicae having highest authority for species name verification because it is more accepted by Chinese botanist and gardeners. In documenting and data collecting process for any families and genera of the *Ex situ* Flora of China, publishing new taxa, new combinations and new names are discouraged unless there are substantial studies conducted in natural populations in the wild and sufficient evidence is obtained.

3.4. Passport data

Passport data have been considered as critical information for an *ex situ* Flora because this information provides important indications of origin, time, locality, geographical data and some habitat information, as well as important historical information on vegetation and environment. The design and inclusion of this data differentiates other checklists like garden Flora or cultivated Flora for better information for various users in the botanical, forest, agricultural, horticultural, industrial, private sectors, etc. in line with our concept or principle of multi-purpose services as an end product. In principle, the passport data is a mandatory requirement in the *Ex situ* Flora of China, and in turn enforces participating botanical gardens to enhance their data management ability and capacity building and higher standard botanical garden management, although difficult exist for many historical introductions and those plants introduced in past decades.

Although botanical gardens in China began to pay attention to records and data management of living collections from the 1960s (Yu et al., 1965), it has never reached a proper level in a standardized, uniform and persistent maintenance. For example, a recent survey shows that only 48% of Chinese botanical gardens (78 of the total 162 gardens) have maintained collecting records (Huang, 2017). The *Ex Situ* Flora of China is designed to rescue historical data, both of living plant accessions and *ex situ* cultivation to promote a collection strategy and standardize *ex situ* management of living conservations, in particularly with emphasis on documenting of material types collected, provenances, sampling methods and health status of living plants, and garden conservation policies. One of the primary functions of the living collections is to provide a reference source of correctly named plants for taxonomy, horticulture and many other purposes and the *Ex Situ* Flora of China will also have a further focus on morphology and taxonomic verification, cultivation techniques, and sustainable utilization of plant resources based on 'common garden' conditions, which will eventually improve the management and quality of living collections and enhance scientific and research values and the efficiency of *ex situ* conservation.

3.5. Phenological data

Inclusion of phenological data for each entry is probably an idealistic goal but requires that the role of botanical gardens in accumulating data for research into climate change biology is a key goal for long term planning. The basic idea is that a number of botanical gardens should engage in studying and monitoring the phenology and adaptive changes of certain keystone species in *ex situ* living collections. The data collected across different botanical gardens in different latitudes, longitudes and elevations would provide solid biological evidence of climate changes and plant adaptive response and important real data from living collections supports long term monitoring climate change biology.

For example, *Magnolia cylindrica* E. H. Wilson originally occurred in Anhui, Zhejiang, Jiangxi and Fujian provinces, and was cultivated in at least seven botanical gardens since 1980s. Its passport data and phenological data were documented from the seven botanical gardens. The phenological data showed that spring phenophases (budburst and leafing) were mostly consistent with changes of latitudes, c. 7 ± 3 days in every latitude (Yang et al., 2015). However, some species have multiple individuals in *ex situ* cultivation and showed large variation of phenophases, e.g. more than 20 days difference even in the same habitat. For example, *Rhododendron fortunei* in Lushan Botanical Garden exhibited variation of flowering time ranging from end of April to mid of May. Thus, calibration of individuals for monitoring and collecting phenological data would be important measure to be taken such as labeling individuals for phenological data collection or even cloned genotypes in different gardens for quantity control of rigid phenological data for *Ex situ* Flora across botanical gardens. BBCH codes (Germany; Meier, 2001) may be adopted as standards and guidelines for phenological observation.

3.6. Taxonomic system

The Flora Reipublicae Popularis Sinicae (FRPS) and updated English revision Flora of China (FOC) are important references for the *Ex situ* Flora of China and provide basic information benchmark for taxonomic system and systematic arrangement of Chinese plant families. Therefore, the *Ex Situ* Flora of China inherits the systematic arrangement of angiosperm families of the FRPS and FOC as benchmark reference and also adopted Engler's system for angiosperms (1964), Ching's system for pteridophytes (1978) and Cheng's system for gymnosperms (1978) in consistency with FRPS and FOC. However, reasonable adjustments in individual genera or species treatment are encouraged based on the latest rational revision of some families with advanced botanical research. While systematic arrangements of genera within a family or species within a genus are also in principle consistent with those in FRPS and FOC, phylogenetically primitive groups should be placed before the advanced groups, closely related groups in evolution should be arranged together, or follow the latest monographic systematic research. In the compilation of each volume of the *Ex situ* Flora of China taxonomic revisions have been encouraged to reflect advances of new information from the *Ex situ* flora. To verify each accepted name and taxonomic status of living collections, besides database FRPS and FOC, additional references are also available from the Chinese Field Herbarium (http://www.cfh.ac.cn/default.html), Tropicos (http://www.tropicos.org/) and The Plant List (http://www.theplantlist.org/). Although the Angiosperm Phylogeny Group System (APG) has advanced and made many changes to the circumscription and placing of several families and

consequently of many genera, the *Ex situ* Flora of China might not necessarily compromise the concept and principles in this early stage. APG III or higher version might need to be adopted in certain circumstances in later stage.

4. A three-phase planning strategy

4.1. Checklist of ex situ cultivated plants in China

Since the *Ex situ* Flora of China is a long term project, a three-phase outputs of project have been formulated and implemented. The checklist of *ex situ* cultivated plants in China was the first phase output of the *Ex situ* Flora of China and published in 2014 as a benchmark of the project.

The checklist mostly reflected results of the inventory of garden cultivated species of living collections across Chinese botanical gardens. It lists 15,844 species (including 179 subspecies, 940 varieties, 74 forms) belonging to 314 families and 3182 genera. Pteridophyte plants based on Qin's system (Ching, 1978) are consist of 59 families, 167 genera, 835 species (including 26 subspecies, 1 varieties and 5 forms), gymnosperms based on Cheng's system (Cheng et al., 1975) comprise a total of 12 families, 54 genera and 299 species (including 29 and 1 form) whereas angiosperm plants according to Engler system (Diels, 1936) account a total of 243 families, 2972 genera and 14,710 species (including 180 subspecies, 877 varieties and 67 forms).

Although tremendous efforts have invested in the checklist for taxonomic accuracy of each entry with both software screening and experts manual checking, some inaccuracy and mistakes are still be unavoidable due to the complications of using historic handwritten records of *ex situ* data and management of different gardens, and conflicts between *ex situ* records and changes from recent revision and treatments of many taxa. Thus, there are remaining 2000–3000 species not included in the checklist because of controversy of taxonomic treatments, or not yet explicitly described but tentatively designated as questionable species, etc. With the *Ex situ* Flora of China each family or genera volumes in progress, those uncertain species will be resolved in future. 'Completion of the checklist of *ex situ* cultivated plants of China is the beginning of the *Ex Situ* Flora of China and the checklist is the key to opening the floral world of the country' (Zhang, 2015).

4.2. Encyclopedia of Chinese garden flora

The second phase of the three planned outputs the *Ex situ* Flora of China was implementing and completion of 13-volume Encyclopedia Chinese garden flora by 2017 (Table 3). As a curtain-raiser for the *Ex situ* Flora of China, the encyclopedia aimed concise formatting each species consisting of brief text description with color photographs from living collections for brief and clear illustration of main features of each species. The contents mainly include the Chinese name, Latin name, brief text of identification feature and an on-site photograph of living plant. These 13 volumes Encyclopedia Chinese garden flora are equivalently comparable to European garden flora in terms of contents, but with addition of more living collection based feature descriptions and color photographs for each entry.

Table 3
Volumes of encyclopedia Chinese garden Flora.

Volume	Families range	Amount			Year
		Family	Genus	Species	
1	Acanthaceae – Aquifolianceae	15	228	1008	2015
2	Araceae – Basellaceae	8	238	1177	2017
3	Begoniaceae – Cactaceae	16	183	1187	2016
4	Callitrichaceae – Convolvulaceae	23	306	1125	2017
5	Coriariaceae – Eucommiaceae	30	166	1103	2017
6	Euphorbiaceae – Gramineae	9	327	1546	2015
7	Guttiferae – Leguminosae	21	338	1458	2017
8	Lemnaceae – Myoporaceae	22	230	1293	2017
9	Myricaceae – Phytolaccaceae	26	249	1232	2017
10	Piperaceae – Rosaceae	22	163	1346	2017
11	Rubiaceae – Symplocaceae	26	314	1180	2015
12	Taccaceae – Zygophyllaceae	22	197	1280	2017
13	Pteridophytes and Gymnosperms	71	229	1291	2016
	Total	311	3168	16,226	

However, in view of long history and original records of *ex situ* living collections, some entries are not synchronized with updated taxonomic revisions so that the editorial strategy of encyclopedia has been insisting on the principle of 'respect historical facts and move with the times', and some taxa have reasonably been adjusted and combined according to updated revisions of systematics.

The encyclopedia Chinese garden flora comprises one volume for ferns and gymnosperms (Volume 13), 12 volumes for angiosperms (volumes 1–12), all arranged in alphabetical order by the Latin name of families. In each volume, each family is also arranged alphabetically by the Latin names of genera and species. For convenient access, all books are indexed by Chinese plant names and Latin names. A total of 16,226 species belonging to 311 families and 3168 genera are included in the encyclopedia (Table 3).

4.3. First two volumes of Ex situ Flora of China

The third phase of the three planned outputs of *Ex situ* Flora of China is the core component of the project. So far two family volumes have been published, Magnoliacease with 11 genera and 147 species (including 1 subspecies, 7 varieties and 3 hybrids); Myrsinaceae with 6 genera and 90 species (including 1 variety). These two out of approximate 80 volumes in next 15–20 years or even longer time frame have been considered a pioneer volumes and trials of compilation formats.

In the documentation and editorial process of the first trial volume of Magnoliaceae, particularly, many lessons have been learned that will lead to better understandings of status and facing problems of *ex situ* flora and garden living collections so that implementations of other volumes of the *Ex situ* Flora of China can be better organized in more focused efforts in future. Many difficulties and data bottlenecks need to be overcome such as:

1) Incomplete or missing introduction records and passport data
2) Undocumented or imprecise geographical provenances
3) Data management not standardized
4) Inadequate taxonomic information and species identification
5) Lack of continuity of phenology observation and incomplete phenology data
6) Lack details of description of plant growth and development data

To address these problems, measures have been taken to improve the situation so that details of compilation and editorial guidance are formulated at the beginning stage of each family volume when the editorial committee and compilation research group are organized because each family volume will take about 3–5 years or even longer. Currently 30–40 family volumes are organized and compilation research groups established.

5. Challenges and prospects

Ex situ Flora of China is multi-decade project. Although project initiation and progress in early phase are very promising and have

attracted much interest from both the botanical field and botanical gardens communities as well as the public. However, the project is still facing many challenges.

First, standardization of format and data collection across different taxa ranging from ferns to timber trees and across different gardens localities ranging from tropics to frigid is quite challenging although much detailed guidance has been given and many discussion meetings organized. Further gap analyses and more precise formatting are needed so that editing guidelines are more specifically established and all terminology, both scientific and botanical garden technical should be precisely defined. For example, many medicinal plants have special features linked with functional medicinal parts, in turn collecting morphological data need be modified to benefit to end users. Another example is the need to describe both male and female flower morphologically in dioecious species.

Second, the collection of phenological data aims to contribute to climate change research and monitoring climate changes over decades or centuries within botanical gardens settings. However, standardized protocols for a wide range of different latitudes, longitude and elevations of data collection are crucial for efficiency of monitoring and data quality. Besides many criteria of data standardization can be adopted from International Phenology Gardens (IPG) project, there are still many challenges on data collection from botanical gardens located in different latitudes in China. For example, flowering difference of different provenance of same species can be various as long as 10 days. Some different genotypes of same species can even have different flowering periods of up to two weeks, Apparently, standardized genotype or provenance with correction of statistic standard error are important criteria and practice for phenology data.

Third, coordination between botanical gardens is a top organizational bottleneck. Since data assembly and editing each family or volume is organized by different botanical gardens in different localities and latitudes, a well formulated working system is critical for a group of botanists, experts and gardeners from different gardens to work together and share information and build up a cordial and harmonious atmosphere that means failure or success for each volume of large families or genera. So far even after trials of the first two volumes, there are still many coordination issues to be solved and the Flora editing headquarter office also needs to be enhanced for coordination across many different gardens. For example, either morphological or phenological variation of individuals of same species or many other issues arise during data assembly and editing process, so that a harmonious working group is essential.

Fourth, taxonomic conflicts between Flora Reipublicae Popularis Sinicae and Flora of China have to be addressed. Even in the beginning of the *Ex situ* Flora of China, a determination that each entry must have a correct plant name (Latin name and widely accepted Chinese name) was formulated. However, there are many different treatments and name difference between Flora Reipublicae Popularis Sinicae and later updated English version Flora of China. Additional research is definitely needed in these situations although taxonomic research has not been prioritized in *Ex situ* Flora of China project because Editorial committee encouraged the *Ex situ* Flora of China to prioritize *ex situ* inventory and data collection as distinct from a traditional Flora based on herbarium specimens and less emphases on traditional Flora details such as, accepted name + literature cited, basionym + literature cited, synonym + year, type specimens, etc. This is true when many botanical garden staff involving the *Ex situ* Flora of China, highlight plant characteristics of *ex situ* collection without strong expertise in detailed taxonomic research. However, in cases of conflicts raised between names of Flora Reipublicae Popularis Sinicae and those of Flora of China, taxonomic research must be carried out without any choice. Coordinating taxonomic research between experts of living collections and taxonomist of herbaria is obviously a great challenge.

Nevertheless, since the project was initiated in 2012, significant progress has been made and many difficulties experienced and lessons learned. The *Ex situ* Flora of China is the first integrative *ex situ* Flora and will greatly benefit global *ex situ* conservation and provide needed basic and mega information services to agriculture, forestry, horticulture and medicinal industries in future.

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