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Safeguarding China's native trees – A review of integrated conservation practices between 2008 and 2020

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ABSTRACT

As part of an integrated initiative to compile the world's tree species (GlobalTreeSearch), assess their conservation status (Global Tree Assessment, GTA) and devise practical conservation action for threatened taxa (Global Trees Campaign, GTC), this review provides a synthesis of the collaborative efforts carried out in China under this framework between 2008 and 2020 by the botanic garden community, the forestry sector, other conservation organisations, and Botanic Gardens Conservation International (BGCI). Using GlobalTreeSearch and GTA data, the analysis reveals that China boasts some 4886 native tree species of which virtually half, 2429, are endemic to the country. With nearly one in five Chinese tree species threatened, conservation action has been implemented under the umbrella of the GTC for some hundred taxa. This included development of best-practice in propagation, population recovery *in situ* and creation of *ex situ* conservation collections as an insurance policy for the future. Although urgency prevails to scale up conservation action for many more species at the brink of extinction, the GTC offers an ecologically more nuanced conceptual framework for application in China's large-scale tree planting and reforestation efforts. This integrated approach is especially opportune now, at a time when China is reviewing the effectiveness and plans for expansion of its protected area system, but is also compelled to increase forest cover for carbon capture and economic growth. The GTC provides a comprehensive method to ascertain planting the 'right tree in the right place', but also 'for the right purpose at the right time and with the right care'.

1. Introduction

1.1. A nation of remarkable plant diversity and endemism

China is among the 17 megadiverse countries in the world as defined by the main criterion of endemism, first at species level (≥ 5000 endemic plant species) and then at higher taxonomic organisation including genus and family (Mittermeier et al., 1997; UNEP-WCMC, 2014). With over 36150 higher plant species of which half are endemic to the nation (Ren, 2020), China ranks third as to plant diversity, after Brazil and Colombia (CBD (n.d.)). This status is mirrored also in the country's wealth of tree species. Based on data

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recorded by Botanic Gardens Conservation International (BGCI)'s GlobalTree Portal, there are 4886 tree species native to China representing nearly 8.3% of the world's tree diversity (58173 species) (BGCI, 2021). Some 2429 tree species – virtually 50% – are endemic to China, establishing the country after Brazil, Madagascar and Australia among the four nations with highest tree endemism (Beech et al., 2017; Botanic Gardens Conservation International, 2021). However, Gatti et al. (2022) and Qian et al. (2019) highlight that there are many more tree species yet to be discovered. Therefore, the number of tree species found in China is likely to increase as new discoveries are being made.

1.2. National policy frameworks of key importance for plant conservation

As one of the world's nations with the most threatened biodiversity (Wang et al., 2020), China was one of the first countries to sign the Convention on Biological Diversity in 1992. Since then, China has been developing and implementing a wealth of scientific research, practical *in* and *ex situ* conservation programmes, environmental advocacy campaigns, as well as new policies and laws to safeguard and restore biodiversity. These efforts continue to be realised through the implementation of the China National Biodiversity Conservation Strategy and Action Plan 2011–2030 (MEP, 2010), and a series of other policy, legal and technical frameworks including the Overall Plan of the Ecological Civilization System Reform (Central Committee of the Communist Party of China, the State Council of China, 2015). This plan requires that “fresh air, clean water, beautiful mountains and rivers, fertile land, and biodiversity are the ecological environments necessary for human survival”. Moreover, with the introduction of the “Beautiful China” strategy included in the 13th Five-Year Plan (2016–2020), China has initiated a profound change and shift from a focus on quantity to quality of growth and the environment by 2035, a complex and long-term venture involving multi-disciplinary and multi-sectoral efforts (Fang et al., 2020).

Encompassing more than 18% of the total land area, China has undertaken significant steps in recent years to strengthen its protected area system as a key measure to conserve biodiversity (Zhang et al., 2015). However, the degree of coverage across different regions remains unbalanced (Cao et al., 2015). This has led also to differences in the level of protection of various taxonomic groups. China's current protected area network has a relatively high representation for threatened mammals and birds, but only some 13.1% of the entire network area account for threatened plants (Xu et al., 2017). A complex hierarchy of administration and varying regulatory standards across different departments challenges effective communication and information sharing (Cao et al., 2015; Sheng et al., 2020). To streamline the creation and management of new and existing protected areas, the Chinese government issued further Guidance on Establishing a System of Protected Areas with National Parks as the Main Body (General Office of the Communist Party of China Central Committee and the General Office of the State Council, 2019). Work to more representatively designate, scale up and sustainably manage protected areas has been accompanied by major restoration initiatives especially over the last two decades, notably the Natural Forest Protection Program and the Grain to Green Program, aimed at reducing logging, increasing vegetation cover, enhancing carbon sequestration and controlling soil erosion. Despite these advances, further efforts will have to be made to improve overall management and legislation, promote public participation and establish a diversified funding guarantee system for protected areas management (He and Cliquet, 2020). This endeavour is also reflected in China's 14th Five-Year Plan (2021–2025) which includes enhanced safeguarding of natural ecosystems and the establishment of a national park-based nature reserve system. In addition, expanding forest coverage to 24.1% of China's total land area is sought for, requiring planting of more than 11 million hectares of new forest by 2025 (Cooper, 2021).

Against the backdrop of China's immense botanical wealth, the launch of China's Strategy for Plant Conservation (CSPC) (China's Strategy for Plant Conservation Editorial Committee, 2008) in 2008 has been a central foundation and milestone to bring the conservation needs of Chinese plant diversity into focus (Gratzfeld and Wen, 2012). A joint initiative of the Chinese Academy of Sciences, the State Forestry Administration (now, National Forestry and Grassland Administration) and the State Environmental Protection Agency (now, Ministry of Ecology and Environment), the CSPC has been developed based on the 16 measurable targets of the Global Strategy for Plant Conservation (GSPC) (CBD, 2002, 2010). The CSPC has served as a catalyst to implement, measure and monitor progress made in plant conservation, such as publishing and assessing the conservation status of the flora of China (CSPC Targets 1 and 2), and developing and implementing threatened species and habitat recovery programmes (especially CSPC Targets 7 and 8) (Ren et al., 2019; Sharrock, 2020). However, further mainstreaming at the national level is required to sustainably conserve and secure China's plant diversity into the future.

1.3. Advancing plant conservation remains a top priority need

As elsewhere in the world, despite positive trends in environmental protection and recovery of biodiversity in China, native species and ecosystems continue to be at threat from various drivers of change. Degradation and loss of wild habitats as a result of accelerated urbanization, industrialization, agricultural expansion, overexploitation of biological resources, exotic, single-species plantations, environmental pollution as well as invasive alien species, are the main risk factors to the survival of native biodiversity (Blackmore and Oldfield, 2017; Jiang and Ma, 2009; López-Pujol et al., 2006; Ren, 2020). Whilst climate change presents another key threat to species and habitats, current and future impacts on China's biological diversity require continuing study to improve understanding of their extent and potency to take suitable action (CBD (n.d.)). What is more, in spite of meritorious aspirations to reverse environmental degradation, scientists have also been warning of the potential negative effects of well-intentioned measures such as to plant billions of trees. In magnitudes and species compositions often non-representative and non-native to a given region, such schemes can exacerbate water scarcity and other detrimental effects including salinization, rather than combat desertification and improve biodiversity (Cao et al., 2010; Xu, 2011; Zhai et al., 2014; Bryan et al., 2018; Bond et al., 2019; Zastrow, 2019).

To advance prioritisation of plant species in urgent need of conservation, and building on previous threatened plants assessments

(SEPA and IB-CAS, 1987; Fu and Jin, 1992; Wang and Xie, 2004), the Chinese government published the Red List of China Higher Plants (MEP, 2013) followed by the revised catalogue Threatened Species List of China's Higher Plants (Qin et al., 2017). This list identifies some 3879 plant species as threatened but also records 4804 species as data deficient to evaluate their actual conservation status. In addition, the updated National Forestry and Grassland Administration (2021) includes 1101 species, with 125 and 976 species recorded as Grade I and II respectively, based on their level of threat (Ren et al., 2022).

In response to the need to accelerate conservation action for the most threatened species, the Chinese government has been developing and promoting the concept of Plant Species with Extremely Small Populations (PSESP) since 2005 (Ma et al., 2013; Sun, 2013; Sun et al., 2019; Yang et al., 2020). Based on the elevated extinction risk of species occurring in small populations restricted to few locations, plant species with less than 5000 mature individuals in total and fewer than 500 mature individuals in each isolated population account as PSESP (Ma et al., 2013; Sun, 2013; Sun et al., 2019). First promulgated in Yunnan province, to date, some 120 species have been identified as PSESP (Sun, 2013; Yang et al., 2020). Major investment from the central as well as local governments has been extended to their conservation (Sun et al., 2019; Yang et al., 2020). As only species promulgated by the State Council of China as National Key Protected Wild Plants enjoy full legal protection (Ma et al., 2013; Sun et al., 2019), with a revised list by the National Forestry and Grassland Administration (NFGA) and Ministry of Agriculture and Rural Affairs (MARA) published in 2021, the promotion of the PSESP conservation concept is expected to fill an important gap in fast-tracking highly threatened plant species for practical conservation action. However, further research and practical conservation trials are required to resolve methodological and technical hurdles related to biological and population demographic constraints especially encountered in PSESP, such as limited seedlings recruitment or even the complete absence of seed generation in some species (Volis, 2016; Ren, 2020). Based on a systematic review of PSESP, Sun et al. (2021) recommend priorities for future research and conservation in China, including the update of the PSESP list, the introduction of indicators and evaluation of conservation effectiveness, as well as further research on the conservation theory and technology.

Building on the momentum created by the implementation of China's Strategy for Plant Conservation over the past decade, and against the backdrop of the Post-2020 Biodiversity Framework (CBD, 2018), the next, scaled-up iteration the Chinese Strategy for Plant Conservation 2021–2030 is in preparation, expected to be launched in conjunction with the Fifteenth meeting of the Conference of the Parties to the CBD in China in 2022.

1.4. Promoting integrated conservation of native and threatened Chinese trees

Based on China's exceptional diversity in native plant species, Botanic Gardens Conservation International (BGCI) has been supporting plant conservation in close collaboration with Chinese botanic gardens and other botanical institutions and conservation partners for over 15 years. With a special focus on native and threatened Chinese trees, taxa recorded for protection by law (National Key Protected Wild Plants Checklist 1999; 2021) or identified as threatened in the national red lists (Red List of China Higher Plants 2013; Threatened Species of China's Higher Plants 2017) and by the Global Tree Assessment (GTA) (<https://globaltreeassessment.org/>) have been prioritised for urgent conservation action under the Global Trees Campaign (GTC) (<https://globaltrees.org/>). Launched in 1999 as a joint initiative of Fauna & Flora International (FFI) and BGCI, this integrated conservation programme aims to secure the survival of all tree species in their natural habitats. The overall objectives of the GTC are to 1) identify and prioritise the tree species of greatest conservation concern; 2) ensure that the world's most threatened tree species are protected with populations recovering *in situ* through direct, practical and innovative interventions; 3) build capacity, supporting local conservationists to develop skills for effective tree species conservation, and to become champions for threatened trees in their region; and 4) mobilise other groups, empowering and motivating individuals across the world to catalyse wider action for tree species conservation (Global Trees Campaign Strategy 2016–2020).

Here, we present a review of China's tree species diversity and conservation status, and the practical conservation work carried out by botanic gardens and other conservation partners in China and BGCI over more than a decade under the Global Trees Campaign. This is exemplified by selected case studies, followed by a discussion and conclusions on future policy and action in support of conservation of China's native and threatened tree flora.

2. Methodology

2.1. Data compilation and analysis of tree species, conservation assessment and *ex situ* collection status in China

The list of tree species native to China (including Hong Kong SAR and Chinese Taiwan) was collated based on GlobalTreeSearch (BGCI, 2021) accessed via BGCI's GlobalTree Portal (<https://www.bgci.org/resources/bgci-databases/globaltree-portal/country-search-for-china-hong-kong-sar-and-chinese-taiwan>). GlobalTreeSearch contains taxonomic information (family, taxon and author names) as well as data on country level endemism.

Conservation status provided by ThreatSearch (BGCI, 2021), for each taxon was added to the list. If a global IUCN Red List assessment exists for the species this was used, if no global IUCN Red List assessment has been published then the Chinese national Red List category was used (Qin et al., 2017; MEP, 2013), lastly other published assessments from ThreatSearch were used (BGCI, 2021). For taxa where no global IUCN Red List assessment is available yet and the latest national assessments refer to categories other than applied in the IUCN Red List (IUCN, 2012) these were given interpreted conservation status. Specifically, this concerns taxa evaluated as "Rare" which have been included in this category alongside Near Threatened species. For details of how the interpreted status is assigned see https://tools.bgci.org/threat_search.php?action=about.

To gauge the status of Chinese tree species in *ex situ* collections in China, the list was amalgamated with data recorded in PlantSearch (BGCI, 2021). These data include living plants, tissue cultures and seeds. This provides information on whether the taxa are cultivated and/or stored as seed in botanic gardens, arboreta, seed banks and other *ex situ* conservation institutions and facilities. PlantSearch is the most comprehensive source of data for *ex situ* collections of plants worldwide comprising over 1.5 million collection records representing over 640000 taxa. In 2018, in a concerted digitisation effort, a further 25944 Chinese *ex situ* collection records were added to PlantSearch. Nevertheless, it is expected that there is *ex situ* collection information in China that is not yet accounted for at the global level, including data recorded in the Big Data Platform for Ex Situ Plant Conservation under the Initiative for Collective Conservation in Chinese Botanical Gardens (ICCBG).

2.2. Review of projects implemented in China under the Global Trees Campaign

To review the impact and legacy of Global Trees Campaign (GTC) initiatives in China between 2008 and 2020, a comprehensive list of tree taxa included in GTC projects was compiled based on BGCI's project archive. The taxa were categorised into two groups: integrated *ex* and *in situ* single taxon conservation projects (Group 1), and taxa part of survey, conservation assessment and/or habitat recovery projects (Group 2). Based on the nature of the project interventions, a tag was assigned for improved taxon and population information following survey and assessment work, and, as applicable, for enhanced *in situ* recovery ensuing population reinforcement action. In addition, *ex situ* collection status in China and at the global level was recorded using PlantSearch and the Big Data Platform for Ex Situ Plant Conservation.

To exemplify the review findings with case studies, a questionnaire survey (Appendix A) made available in Chinese was sent to 17 former and present GTC partners. The survey was organised into taxon-related questions to gauge the status of *ex situ* and *in situ* conservation, and general questions especially pertaining to the legacy of the capacity building and public outreach efforts carried out under the projects. The survey selection of GTC partners targeted in particular projects implemented in the earlier part of the 2008–2020 period for the review to enable a longer, lapsed time horizon since completion of the projects. To confirm, clarify and/or fill gaps in the answers to the questionnaire, all respondents were contacted also *via* phone calls, emails and/or use of social media.

3. Results

3.1. Tree diversity in China

There are 4886 tree species recorded as native to China (Fig. 1). This represents 8.3% of the world's tree diversity (58173 species). Virtually half, 2429 tree species, are endemic to China.

The 4886 tree species are distributed over 139 families. The top 20 families with the most tree species in China comprise 3206 taxa (Fig. 2). The family with the most tree species in China is Lauraceae with 470 tree species, followed by Fagaceae (329) and Rosaceae (273).

Of the 24 families with only one tree species occurring in China (Table 1), two, Eucommiaceae and Ginkgoaceae are endemic. Moreover, the only tree species occurring in China in Centroplacaceae is the endemic *Bhesa sinica*.

For 17 plant families, the Chinese tree species represent more than half of the total, global tree species diversity found in these families (Fig. 3). They include Eucommiaceae, Ginkgoaceae, Trochodendraceae and Helwingiaceae where all (100%) species in the family are found in China. The most tree species diverse families in this category include Theaceae (122 species), Betulaceae (82 species), Elaeagnaceae (58 species) and Hamamelidaceae (44 species).

Among the top 20 tree genera with the most Chinese native species (Fig. 4), four stand out including *Ilex* (Aquifoliaceae) with 153 species, *Rhododendron* (Ericaceae) with 144 species as well as *Lithocarpus* with 129 species and *Quercus* (Fagaceae) with 122 species. Other genera with important numbers of species include *Magnolia*, *Acer* and *Salix*.

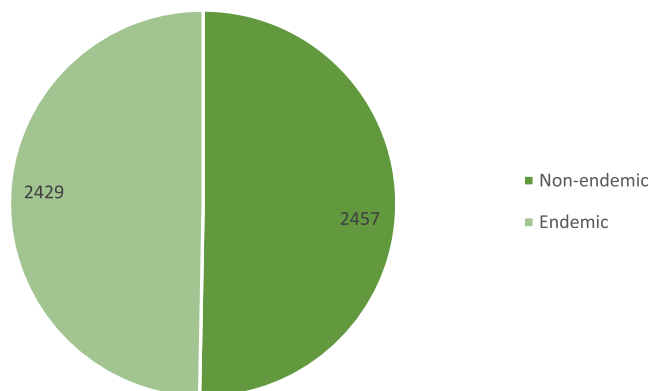


Fig. 1. Endemic and non-endemic tree species in China.

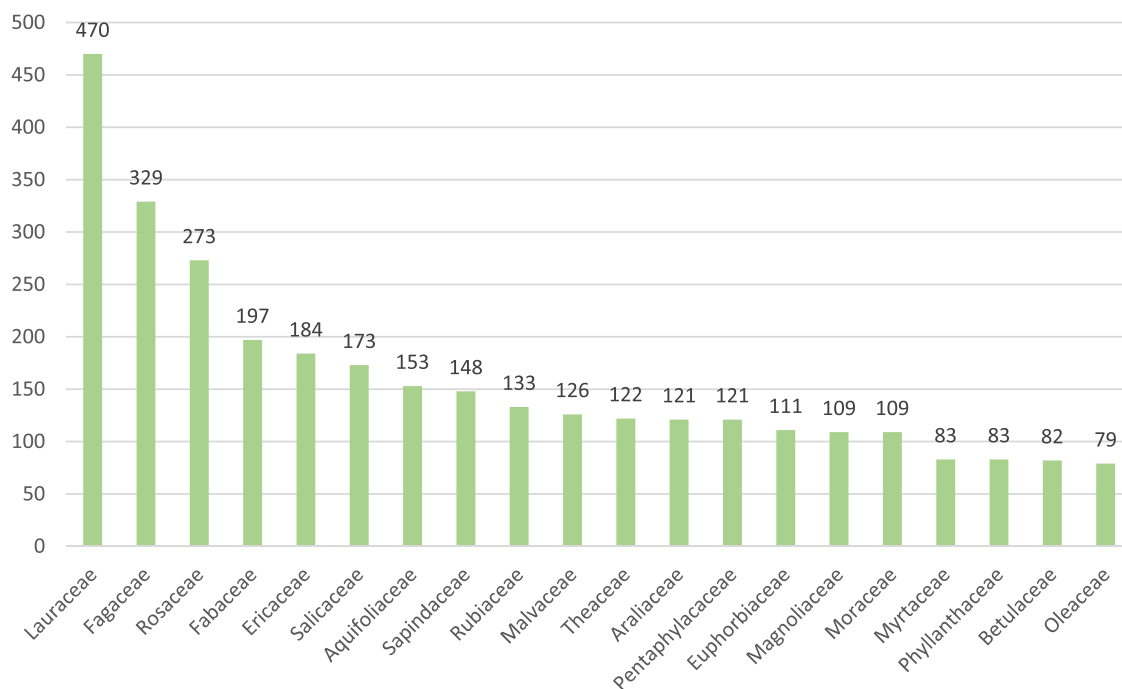


Fig. 2. The 20 families with the most tree species in China.

3.2. Conservation status of Chinese tree species

Of a total of 4886 tree species known from China, 19.7% (964) have been assessed as threatened, this includes 187 Critically Endangered (CR), 384 Endangered (EN) and 393 Vulnerable (VU) tree species (Fig. 5). A further 402 are categorised as Near Threatened (NT). Seven taxa are reported to be Extinct (EX) (*Beilschmiedia ningmingensis*, Lauraceae; *Elaeagnus liuzhouensis*, Elaeagnaceae; *Machilus salicoides*, Lauraceae; *Lepisanthes unilocularis*, Sapindaceae; *Ormosia howii*, Fabaceae; *Hopea shingkeng*, Dipterocarpaceae) or Regionally Extinct (RE) (*Lithocarpus cryptocarpus*, Fagaceae). 55.0% (2688) of the species are Least Concern, whilst

Table 1

Families with a single tree species native to China (endemic taxa highlighted with asterisk).

| Family | Species |
|-------------------|-----------------------------------|
| Acanthaceae | <i>Avicennia marina</i> |
| Akaniaceae | <i>Bretschneidera sinensis</i> |
| Amaranthaceae | <i>Haloxylon ammodendron</i> |
| Aristolochiaceae | <i>Aristolochia tagala</i> |
| Centropiaceae | <i>Bhesa sinica</i> * |
| Cercidiphyllaceae | <i>Cercidiphyllum japonicum</i> |
| Erythroxylaceae | <i>Erythroxylum sinense</i> |
| Eucommiaceae* | <i>Eucommia ulmoides</i> * |
| Eupteleaceae | <i>Euptelea pleiosperma</i> |
| Gentianaceae | <i>Fagraea ceilanica</i> |
| Ginkgoaceae* | <i>Ginkgo biloba</i> * |
| Gnetaceae | <i>Gnetum gnemon</i> |
| Hernandiaceae | <i>Hernandia nymphaeifolia</i> |
| Linaceae | <i>Tirpitzia sinensis</i> |
| Menispermaceae | <i>Cocculus laurifolius</i> |
| Pandaceae | <i>Microdesmis caseariifolia</i> |
| Penaeaceae | <i>Crypteronia paniculata</i> |
| Peraceae | <i>Chaetocarpus castanocarpus</i> |
| Platanaceae | <i>Platanus orientalis</i> |
| Polygonaceae | <i>Calligonum arborescens</i> |
| Resedaceae | <i>Borthwickia trifoliata</i> |
| Salvadoraceae | <i>Azima tetracantha</i> |
| Surianaceae | <i>Suriana maritima</i> |
| Tetramelaceae | <i>Tetrameles nudiflora</i> |

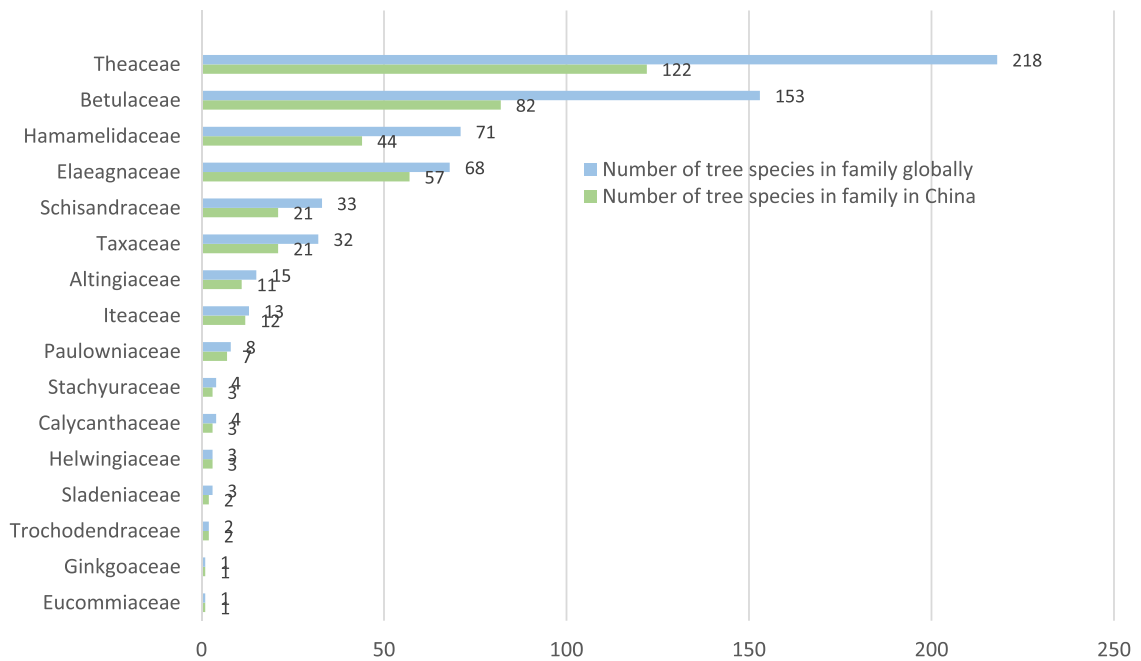


Fig. 3. Families with tree species present in China representing more than half of the global tree diversity in these families.

5.7% (280) are Data Deficient and 11.1% (545) have yet to be assessed.

3.3. Survey of native and endemic Chinese tree species in ex situ collections in botanic gardens and arboreta in China

Of a global total of 52912 *ex situ* collection records of tree species, 6060 are located in China. These figures represent the presence of a given taxon in a collection but do not take into account the number of accessions or individuals. In total, there are 3141 tree species recorded in *ex situ* collections in China (Fig. 6). This represents some 64.2% of native and endemic trees in Chinese botanic gardens and arboreta. Of the 964 threatened taxa, 50.2% (484) are reported in these *ex situ* collections. In addition, 66.1% (2076) and 3.9% (122) are Least Concern and Data Deficient respectively, whilst 7.8% (244) have no conservation assessment. 1746 Chinese tree species are not reported to be in collections, including 668 threatened and Near Threatened species, as well as 158 and 301 species being Data

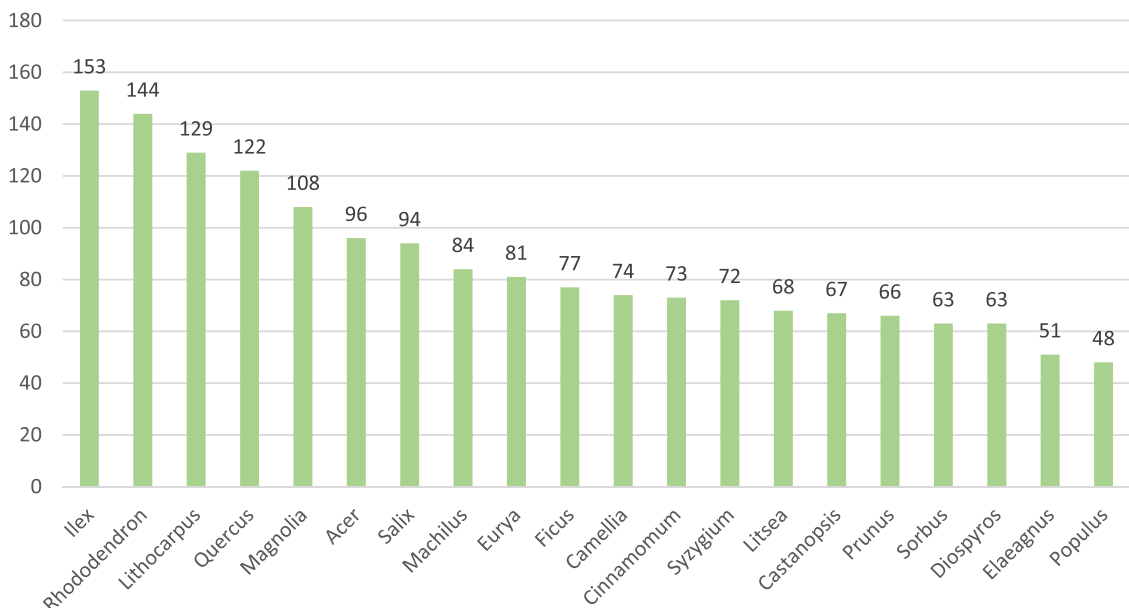


Fig. 4. The 20 genera with the most native Chinese tree species.

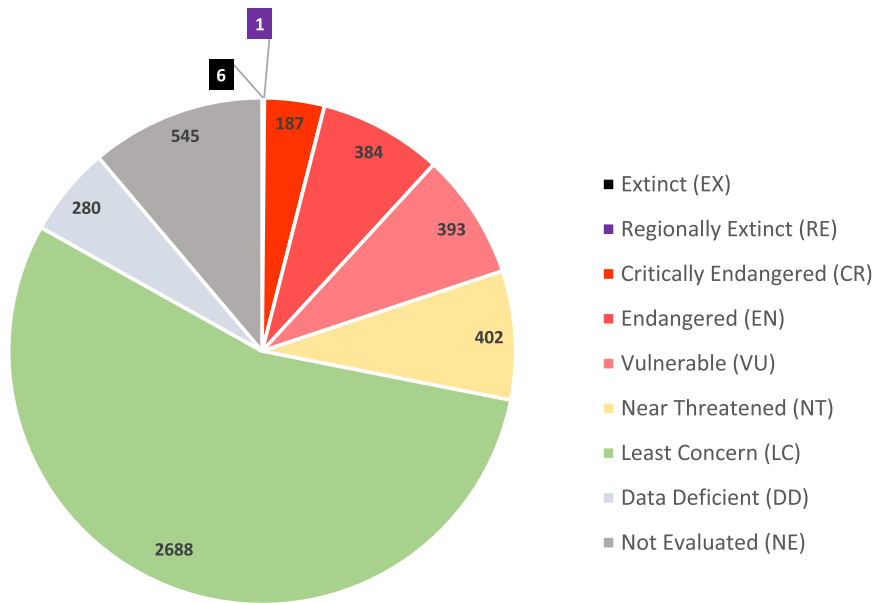


Fig. 5. Conservation assessment status of 4886 Chinese tree species.

Deficient or not assessed respectively.

3.4. Review of projects implemented in China under the Global Trees Campaign

From 2008 to 2020, some 102 taxa were included in projects in China under the Global Trees Campaign (GTC) (Table 2 and Fig. 7), on average for a three-year period per project. Of these, 35 (Group 1) formed part of integrated *ex* and *in situ* species recovery projects, whilst 67 (Group 2) were included in projects with varying scope, such as survey and conservation assessment work, and/or habitat restoration initiatives. Generally, species included in practical conservation projects (Group 1) were selected based on their threat status and urgency of conservation action, comprising 27 taxa (11 Critically Endangered (CR), 14 Endangered (EN) and two Vulnerable (VU)). A further five Least Concern (LC) and three Data Deficient (DD) were also included in this group of GTC projects. Species included in Group 2 include five Critically Endangered (CR), six Endangered (EN) and eight Vulnerable (VU), and three Near Threatened (NT). In addition, there are 41 Least Concern (LC), two Data Deficient (DD) and two Not Evaluated (NE). Group 1 and 2 considered together, the assessment categories with the highest proportion of species included in GTC projects between 2008 and 2020 are Critically Endangered (9.4%), Endangered (5.5%) and Vulnerable (2.6%) (Table 3).

The GTC interventions, including survey and inventory and conservation assessment, have contributed to improved knowledge (e.

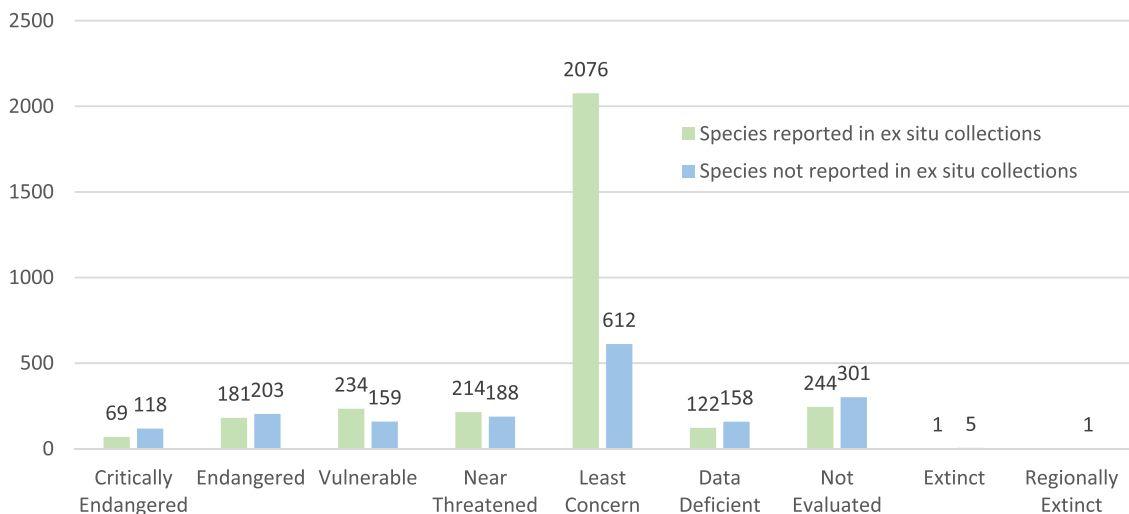


Fig. 6. Chinese tree species in *ex situ* collections in botanic gardens and arboreta in China per threat category.

Table 2

Overview of tree taxa included in Global Trees Campaign (GTC) projects in China between 2008 and 2020. 1–35 (Group 1): integrated *ex* and *in situ*, single taxon conservation projects; 36–102 (Group 2): taxa included in survey, conservation assessment and/or habitat recovery projects.

| | Family | Species | Endemic | Conservation status | Reference | Improved knowledge of taxa / populations | <i>Ex situ</i> collections in China | <i>Ex situ</i> collections globally | <i>In situ</i> population reinforcement |
|----|---------------|---|---------|-----------------------|--|--|-------------------------------------|-------------------------------------|---|
| 1 | Akaniaceae | <i>Bretschneidera sinensis</i> | NO | Endangered | IUCN Red List | ✓ | 17 | 24 | ✓ |
| 2 | Betulaceae | <i>Carpinus putoensis</i> | YES | Critically Endangered | IUCN Red List | ✓ | 6 | 6 | ✓ |
| 3 | Betulaceae | <i>Carpinus tientaiensis</i> | YES | Critically Endangered | IUCN Red List | ✓ | 1 | 1 | ✓ |
| 4 | Betulaceae | <i>Ostrya rehderiana</i> | YES | Critically Endangered | IUCN Red List | ✓ | 4 | 7 | ✓ |
| 5 | Cupressaceae | <i>Glyptostrobus pensilis</i> | NO | Critically Endangered | IUCN Red List | ✓ | 20 | 82 | ✓ |
| 6 | Ericaceae | <i>Rhododendron liboense</i> | YES | Critically Endangered | Threatened Species of China's Higher Plants (2017) | ✓ | 1 | 1 | ✓ |
| 7 | Fagaceae | <i>Lithocarpus formosanus</i> | YES | Critically Endangered | IUCN Red List | ✓ | 1 | 1 | |
| 8 | Magnoliaceae | <i>Magnolia angustiolonga</i> | YES | Endangered | IUCN Red List | ✓ | 3 | 3 | ✓ |
| 9 | Magnoliaceae | <i>Magnolia aromatica</i> | NO | Endangered | IUCN Red List | ✓ | 5 | 5 | ✓ |
| 10 | Magnoliaceae | <i>Magnolia cathartii</i> | NO | Least Concern | IUCN Red List | ✓ | 4 | 7 | ✓ |
| 11 | Magnoliaceae | <i>Magnolia coriacea</i> | NO | Endangered | IUCN Red List | ✓ | 2 | 3 | ✓ |
| 12 | Magnoliaceae | <i>Magnolia doltsopa</i> | NO | Data Deficient | IUCN Red List | | 4 | 22 | ✓ |
| 13 | Magnoliaceae | <i>Magnolia fistulosa</i> (<i>Magnolia phanerophlebia</i>) | NO | Data Deficient | IUCN Red List | | 1 | 1 | ✓ |
| 14 | Magnoliaceae | <i>Magnolia fulva</i> | NO | Data Deficient | IUCN Red List | | 4 | 7 | |
| 15 | Magnoliaceae | <i>Magnolia insignis</i> | NO | Least Concern | IUCN Red List | ✓ | 11 | 37 | ✓ |
| 16 | Magnoliaceae | <i>Magnolia longipedunculata</i> | YES | Critically Endangered | IUCN Red List | ✓ | 2 | 2 | ✓ |
| 17 | Magnoliaceae | <i>Magnolia nitida</i> | NO | Vulnerable | IUCN Red List | ✓ | 4 | 13 | ✓ |
| 18 | Magnoliaceae | <i>Magnolia odoratissima</i> | YES | Endangered | IUCN Red List | ✓ | 4 | 4 | ✓ |
| 19 | Magnoliaceae | <i>Magnolia omeiensis</i> | YES | Critically Endangered | IUCN Red List | ✓ | 8 | 8 | ✓ |
| 20 | Magnoliaceae | <i>Magnolia patungensis</i> | YES | Endangered | IUCN Red List | ✓ | 5 | 5 | ✓ |
| 21 | Magnoliaceae | <i>Magnolia sinostellata</i> | YES | Endangered | IUCN Red List | ✓ | 2 | 2 | ✓ |
| 22 | Magnoliaceae | <i>Magnolia ventii</i> (<i>Magnolia hebecarpa</i>) | YES | Endangered | IUCN Red List | ✓ | 3 | 3 | ✓ |
| 23 | Nyssaceae | <i>Davidia involucreta</i> var. <i>involucreta</i> | YES | Least Concern | Chinese Biodiversity Red List–Higher Plants (2013) | ✓ | 9 | 139 | ✓ |
| 24 | Salicaceae | <i>Populus euphratica</i> | NO | Least Concern | IUCN Red List | ✓ | 3 | 9 | ✓ |
| 25 | Sapindaceae | <i>Acer leipoense</i> | YES | Endangered | IUCN Red List | ✓ | 1 | 1 | ✓ |
| 26 | Sapindaceae | <i>Acer yangbiense</i> | YES | Endangered | IUCN Red List | ✓ | 3 | 4 | ✓ |
| 27 | Sapindaceae | <i>Dipteronia dyeriana</i> | YES | Endangered | IUCN Red List | ✓ | 6 | 4 | ✓ |
| 28 | Styracaceae | <i>Changiosyrax dolichocarpus</i> | YES | Vulnerable | IUCN Red List | ✓ | 3 | 3 | ✓ |
| 29 | Styracaceae | <i>Styrax zhejiangensis</i> | YES | Critically Endangered | Threatened Species of China's Higher Plants (2017) | ✓ | 2 | 2 | ✓ |
| 30 | Taxaceae | <i>Taxus cuspidata</i> | NO | Least Concern | IUCN Red List | ✓ | 8 | 171 | ✓ |
| 31 | Theaceae | <i>Camellia euphlebia</i> | NO | Endangered | IUCN Red List | ✓ | 9 | 13 | ✓ |
| 32 | Theaceae | <i>Camellia indochinensis</i> var. <i>tunghinensis</i> | NO | Endangered | Threatened Species of China's Higher Plants (2017) | ✓ | 3 | 3 | ✓ |
| 33 | Theaceae | <i>Camellia nitidissima</i> | NO | Endangered | IUCN Red List | ✓ | 9 | 12 | ✓ |
| 34 | Theaceae | <i>Euryodendron excelsum</i> | YES | Critically Endangered | IUCN Red List | ✓ | 2 | 2 | ✓ |
| 35 | Theaceae | <i>Pyrenaria buisanensis</i> | YES | Critically Endangered | IUCN Red List | ✓ | 1 | 1 | ✓ |
| 36 | Altingiaceae | <i>Liquidambar chingii</i> | NO | Least Concern | IUCN Red List | ✓ | 1 | 1 | ✓ |
| 37 | Altingiaceae | <i>Liquidambar formosana</i> | NO | Least Concern | IUCN Red List | ✓ | 9 | 79 | ✓ |
| 38 | Amaranthaceae | <i>Haloxylon ammodendron</i> | NO | Least Concern | | ✓ | 5 | 7 | ✓ |

(continued on next page)

Table 2 (continued)

| | Family | Species | Endemic | Conservation status | Reference | Improved knowledge of taxa / populations | Ex situ collections in China | Ex situ collections globally | In situ population reinforcement |
|----|-------------------|--|---------|-----------------------|--|--|------------------------------|------------------------------|----------------------------------|
| | | | | | Chinese Biodiversity Red List–Higher Plants (2013) | | | | |
| 39 | Anacardiaceae | <i>Pistacia weinmanniifolia</i> | NO | Data Deficient | IUCN Red List | ✓ | 8 | 8 | |
| 40 | Aquifoliaceae | <i>Ilex integra</i> | NO | Least Concern | Chinese Biodiversity Red List–Higher Plants (2013) | ✓ | 5 | 49 | ✓ |
| 41 | Arecaceae | <i>Caryota obtusa</i> | NO | Vulnerable | Threatened Species of China’s Higher Plants (2017) | ✓ | 18 | 36 | ✓ |
| 42 | Berberidaceae | <i>Dysosma versipellis</i> | YES | Vulnerable | IUCN Red List | ✓ | 14 | 21 | ✓ |
| 43 | Bignoniaceae | <i>Mayodendron igneum</i> | NO | Least Concern | Chinese Biodiversity Red List–Higher Plants (2013) | ✓ | 8 | 11 | |
| 44 | Cannabaceae | <i>Celtis philippensis</i> | NO | Least Concern | IUCN Red List | ✓ | 2 | 6 | |
| 45 | Cannabaceae | <i>Trema tomentosum</i> | NO | Least Concern | IUCN Red List | ✓ | 4 | 4 | |
| 46 | Cercidiphyllaceae | <i>Cercidiphyllum japonicum</i> | NO | Least Concern | IUCN Red List | ✓ | 12 | 248 | |
| 47 | Combretaceae | <i>Terminalia bellirica</i> | NO | Endangered | Threatened Species of China’s Higher Plants (2017) | ✓ | 3 | 19 | ✓ |
| 48 | Dilleniaceae | <i>Dillenia indica</i> | NO | Least Concern | IUCN Red List | ✓ | 5 | 57 | |
| 49 | Dipentodontaceae | <i>Dipentodon sinicus</i> | NO | Least Concern | IUCN Red List | ✓ | 3 | 5 | |
| 50 | Dipterocarpaceae | <i>Parashorea chinensis</i> | NO | Endangered | IUCN Red List | ✓ | 7 | 8 | |
| 51 | Ericaceae | <i>Rhododendron argyrophyllum</i> | YES | Not Evaluated | | | 3 | 40 | ✓ |
| 52 | Ericaceae | <i>Rhododendron beesianum</i> | NO | Least Concern | IUCN Red List | ✓ | 1 | 18 | |
| 53 | Ericaceae | <i>Rhododendron maddenii</i> | NO | Least Concern | IUCN Red List | ✓ | 3 | 23 | |
| 54 | Ericaceae | <i>Rhododendron sinogrande</i> | NO | Least Concern | IUCN Red List | ✓ | 3 | 39 | |
| 55 | Euphorbiaceae | <i>Mallotus paniculatus</i> | NO | Least Concern | IUCN Red List | ✓ | 4 | 11 | |
| 56 | Euphorbiaceae | <i>Trevia nudiflora (Mallotus nudiflorus)</i> | NO | Least Concern | IUCN Red List | | 4 | 4 | ✓ |
| 57 | Fabaceae | <i>Adenanthera microsperma</i> | NO | Least Concern | IUCN Red List | ✓ | 7 | 18 | |
| 58 | Fabaceae | <i>Dalbergia odorifera</i> | YES | Vulnerable | IUCN Red List | ✓ | 10 | 14 | ✓ |
| 59 | Fabaceae | <i>Erythrophleum fordii</i> | NO | Endangered | IUCN Red List | ✓ | 7 | 7 | |
| 60 | Fabaceae | <i>Ormosia pinnata</i> | YES | Least Concern | IUCN Red List | ✓ | 3 | 4 | |
| 61 | Fagaceae | <i>Castanopsis fissa</i> | NO | Least Concern | IUCN Red List | ✓ | 7 | 8 | |
| 62 | Fagaceae | <i>Quercus sichouensis (Cyclobalanopsis sichouensis)</i> | YES | Critically Endangered | IUCN Red List | ✓ | 1 | 1 | ✓ |
| 63 | Lauraceae | <i>Cinnamomum burmanni</i> | NO | Least Concern | IUCN Red List | ✓ | 8 | 17 | |
| 64 | Lauraceae | <i>Cinnamomum japonicum</i> | NO | Least Concern | IUCN Red List | ✓ | 10 | 33 | |
| 65 | Lauraceae | <i>Machilus chekiangensis</i> | YES | Near Threatened | Chinese Biodiversity Red List–Higher Plants (2013) | ✓ | 2 | 2 | |
| 66 | Lauraceae | <i>Machilus chinensis</i> | NO | Least Concern | IUCN Red List | ✓ | 4 | 4 | |
| 67 | Lauraceae | <i>Machilus thunbergii</i> | NO | Least Concern | IUCN Red List | ✓ | 9 | 27 | |
| 68 | Lauraceae | <i>Neolitsea sericea</i> | NO | Least Concern | IUCN Red List | ✓ | 6 | 72 | |
| 69 | Lauraceae | <i>Phoebe bournei</i> | YES | Near Threatened | IUCN Red List | ✓ | 12 | 14 | |
| 70 | Lauraceae | <i>Phoebe lanceolata</i> | NO | Least Concern | IUCN Red List | ✓ | 3 | 4 | |
| 71 | Lauraceae | <i>Phoebe zhenan</i> | YES | Vulnerable | IUCN Red List | ✓ | 8 | 10 | |
| 72 | Lecythidaceae | <i>Barringtonia racemosa</i> | NO | Least Concern | IUCN Red List | ✓ | 5 | 33 | |
| 73 | Lythraceae | <i>Lagerstroemia villosa</i> | NO | Vulnerable | Threatened Species of China’s Higher Plants (2017) | ✓ | 1 | 3 | |
| 74 | Magnoliaceae | <i>Liriodendron chinense</i> | NO | Near Threatened | IUCN Red List | ✓ | 24 | 120 | |

(continued on next page)

Table 2 (continued)

| | Family | Species | Endemic | Conservation status | Reference | Improved knowledge of taxa / populations | Ex situ collections in China | Ex situ collections globally | In situ population reinforcement |
|----|------------------|--|---------|-----------------------|--|--|------------------------------|------------------------------|----------------------------------|
| | Magnoliaceae | <i>Magnolia campbellii</i> | NO | Least Concern | IUCN Red List | ✓ | 1 | 38 | |
| | Magnoliaceae | <i>Magnolia grandis</i> | YES | Critically Endangered | IUCN Red List | ✓ | 9 | 9 | ✓ |
| | Magnoliaceae | <i>Magnolia officinalis</i> | YES | Endangered | IUCN Red List | ✓ | 12 | 65 | ✓ |
| | Magnoliaceae | <i>Magnolia sinica</i> | YES | Critically Endangered | IUCN Red List | ✓ | 6 | 9 | ✓ |
| | Malvaceae | <i>Craigia yunnanensis</i> | NO | Endangered | IUCN Red List | ✓ | 4 | 4 | ✓ |
| | Meliaceae | <i>Aphanamixis polystachya</i> | NO | Least Concern | IUCN Red List | ✓ | 5 | 22 | |
| | Meliaceae | <i>Chukrasia tabularis</i> | NO | Least Concern | IUCN Red List | ✓ | 5 | 18 | |
| | Moraceae | <i>Antiaris toxicaria</i> | NO | Least Concern | IUCN Red List | ✓ | 6 | 28 | |
| | Moraceae | <i>Ficus hookeriana</i> | NO | Critically Endangered | Threatened Species of China's Higher Plants (2017) | ✓ | 1 | 1 | ✓ |
| | Myristicaceae | <i>Horsfieldia amygdalina</i> | NO | Least Concern | Chinese Biodiversity Red List–Higher Plants (2013) | ✓ | 4 | 4 | |
| | Myristicaceae | <i>Knema tenuinervia</i> | NO | Vulnerable | IUCN Red List | ✓ | 2 | 2 | |
| | Nyssaceae | <i>Camptotheca acuminata</i> | YES | Least Concern | Chinese Biodiversity Red List–Higher Plants (2013) | ✓ | 13 | 64 | |
| 10 | Phyllanthaceae | <i>Bischofia polycarpa</i> | YES | Least Concern | IUCN Red List | ✓ | 7 | 22 | |
| | Phyllanthaceae | <i>Cleistanthus sumatranus</i> | NO | Least Concern | Chinese Biodiversity Red List–Higher Plants (2013) | ✓ | 3 | 5 | |
| | Pinaceae | <i>Pinus massoniana</i> | YES | Least Concern | IUCN Red List | ✓ | 11 | 36 | |
| | Pinaceae | <i>Pinus squamata</i> | YES | Critically Endangered | IUCN Red List | ✓ | 1 | 1 | ✓ |
| | Polygalaceae | <i>Polygala fallax</i> | YES | Least Concern | IUCN Red List | ✓ | 6 | 6 | ✓ |
| | Rosaceae | <i>Malus ombrophila</i> | YES | Data Deficient | IUCN Red List | ✓ | 2 | 4 | |
| | Rutaceae | <i>Phellodendron chinense</i> | YES | Least Concern | IUCN Red List | ✓ | 6 | 53 | |
| | Rutaceae | <i>Tetradium ruticarpum</i> | NO | Least Concern | IUCN Red List | ✓ | 9 | 24 | |
| | Salicaceae | <i>Homalium ceylanicum</i> | NO | Vulnerable | Threatened Species of China's Higher Plants (2017) | ✓ | 3 | 3 | |
| | Tamaricaceae | <i>Tamarix chinensis</i> | NO | Not Evaluated | | | 7 | 19 | ✓ |
| | Tamaricaceae | <i>Tamarix ramosissima</i> | NO | Least Concern | IUCN Red List | ✓ | 2 | 38 | |
| | Taxaceae | <i>Taxus wallichiana (Taxus yunnanensis)</i> | NO | Endangered | IUCN Red List | ✓ | 8 | 42 | ✓ |
| | Tetramelaceae | <i>Tetrameles nudiflora</i> | NO | Least Concern | IUCN Red List | ✓ | 4 | 6 | |
| | Theaceae | <i>Schima argentea</i> | NO | Least Concern | IUCN Red List | ✓ | 8 | 23 | |
| | Thymelaeaceae | <i>Aquilaria sinensis</i> | YES | Vulnerable | IUCN Red List | ✓ | 6 | 6 | |
| | Trochodendraceae | <i>Tetracentron sinense</i> | NO | Least Concern | Chinese Biodiversity Red List–Higher Plants (2013) | ✓ | 5 | 60 | |



Fig. 7. Selected Global Trees Campaign (GTC) projects. (1) *Camellia nitidissima*, Fangcheng, Guangxi (Xiangying Wen); (2) *Populus euphratica*, Xinjiang (Xiangying Wen); (3) *Glyptostrobus pensilis* (centre), Funing, Yunnan (Weibang Sun); (4) *Styrax zhejiangensis* seedlings, Zhejiang (Chuping Wu); (5) *Magnolia omeiensis* saplings transport to population reinforcement site, Emei Mountain, Sichuan (Daoping Yu); (6) *Rhododendron liboense* (Chengling Huang); (7) Training in *Rhododendron liboense* propagation techniques, Guizhou (Xiangying Wen); (8) Karst ecosystem assisted regeneration, Guangxi (Joachim Gratzfeld).

g. reproduction/population biology) for 92% of the target tree taxa. Seven taxa remain Data Deficient or have not been assessed yet. For almost half of the GTC taxa – 50 (49%) – *in situ* population reinforcement programmes through planting of saplings grown in *ex situ* collections have been implemented (Table 4). As exemplified in the selected case studies (Table 5), the mean survival rate is 68%, and

Table 3

Proportion of taxa included in Global Trees Campaign (GTC) projects between 2008 and 2020 by assessment category.

| Assessment category | GTC taxa Group 1 | GTC taxa Group 2 | Taxa not included in GTC projects | Proportion of taxa by assessment category included in GTC projects |
|---------------------|------------------|------------------|-----------------------------------|--|
| CR | 11 | 5 | 171 | 9.4% |
| EN | 14 | 6 | 364 | 5.5% |
| VU | 2 | 8 | 383 | 2.6% |
| NT | 0 | 3 | 399 | 0.8% |
| LC | 5 | 41 | 2642 | 1.7% |
| DD | 3 | 2 | 275 | 1.8% |
| NE | 0 | 2 | 543 | 0.4% |
| EX/RE | 0 | 0 | 7 | 0% |
| Total | 35 | 67 | 4784 | 2.1% |

in some taxa above 80% (e.g. *Bretschneidera sinensis*, *Acer yangbiense*, *Magnolia omeiensis*, *Dipteronia dyeriana*, *Camellia* spp.) but can also be much lower, e.g. 20% in *Magnolia coriacea*.

For more than 25% of the GTC project species, new *ex situ* conservation collections have been established, including for taxa for which no collections existed prior to the project (e.g. *Bretschneidera sinensis*, *Acer yangbiense*, *Magnolia omeiensis*, *Rhododendron liboense*, *Carpinus tientaiensis* and *Styrax zhejiangensis*) (Table 5). The case studies also illustrate that horticultural trials as vital foundations of *in situ* recovery programmes have very species-specific outcomes, e.g. both seed and vegetative propagation of *Euryodendron excelsum* are effectual, whilst vegetative propagation has had limited success or entirely failed in *Bretschneidera sinensis*, *Populus euphratica*, *Carpinus tientaiensis* and *Glyptostrobus pensilis*.

Capacity building and public outreach form an integral part of the GTC projects to ensure their long-term sustainability. The 15 case studies alone record over 3000 representatives from local authorities and communities who have been engaged in the technical training (such as plant propagule collection, propagation, cultivation, nursery management, *in situ* species recovery) and public outreach to raise awareness of the needs and benefits of the conservation of the target species. These efforts are not only vital to secure the future of highly threatened species such as the Critically Endangered *Magnolia omeiensis* or *Carpinus tientaiensis* in Sichuan and Zhejiang respectively. They are also of fundamental importance for the continued provision of goods and services supplied by ecosystems composed of keystone tree species as for instance the *Populus euphratica* riparian forests in the desert regions of Xinjiang.

Another indicator of the long-term legacy of the GTC projects implemented in China between 2008 and 2020 is their inspiration of new ideas for the conservation of other native plant taxa. For instance, the project on *Magnolia omeiensis* implemented in collaboration with Emeishan Botanical Garden, Sichuan, has acted as a catalyst for the development of new projects on *Magnolia wilsonii* and *M. sieboldii* subsp. *sinensis* supported by the Sichuan Science and Technology Department. In a similar vein, recognising the importance of the long-term conservation needs of the Critically Endangered *Styrax zhejiangensis*, the authorities in Zhejiang have included this species in Zhejiang's Five-Year Plan (2021–2025). In addition, further support has been mobilised from the Zhejiang Forest Bureau and Basic Public Welfare Research Program of Zhejiang Province for other threatened species, including the Endangered *Changiosyrax dolichocarpus*, and the Critically Endangered *Carpinus tientaiensis*, *Carpinus putoensis* and *Ostrya rehderiana*.

4. Discussion

With its huge land area and diversity in landscapes and ecological conditions, China predictably boasts a significant degree of plant endemism (Hong and Blackmore, 2013). It may therefore not come as a surprise that in effect half, 49.7% (2429 taxa) of China's tree flora is endemic. Whilst Ginkgoaceae and Eucommiaceae present two tree families unique to China, other charismatic endemic taxa include *Davidia involuocrata* (Nyssaceae) and the relict lineages *Ginkgo biloba* (Ginkgoaceae), *Cathaya argyrophylla* (Pinaceae) and *Metasequoia glyptostroboides* (Taxodiaceae). The three most diverse tree families in China include large numbers of species belonging to genera of major socio-economic importance, such as *Cinnamomum* spp. and *Machilus* spp. in Lauraceae, *Lithocarpus* spp. and *Quercus* spp. in Fagaceae as well as *Prunus* spp. and *Sorbus* spp. in Rosaceae, whilst *Ilex* in Aquifoliaceae and *Rhododendron* in Ericaceae are the two genera in China with the most tree species. Other socio-economically important families are Theaceae (122 Chinese tree species),

Table 4

Summary overview of Global Trees Campaign (GTC) project taxa in China between 2008 and 2020.

| | |
|---|------|
| Total of GTC project taxa | 102 |
| Total of GTC endemic taxa | 39 |
| Total of GTC threatened taxa | 46 |
| Total of GTC taxa with improved knowledge | 94 |
| Total of GTC taxa with <i>in situ</i> population reinforcement action | 50 |
| Total of <i>ex situ</i> collection records in China for GTC taxa | 576 |
| Total of <i>ex situ</i> collection records globally for GTC taxa | 2305 |

Table 5
Selected Global Trees Campaign (GTC) project case studies.

| Taxa and conservation status, incl. PSESP (Plant Species with Extremely Small Populations) | Habitat and distribution, incl. mature individuals remaining in the wild if known | Project period and main partners | <u>Ex situ conservation</u> | | | <u>In situ conservation</u> | | Number of representatives from local authorities and communities engaged and reached through training and public outreach | Project legacy: continued conservation support by Chinese institutions, and catalyst for the development of new projects targeting other native and threatened species |
|--|---|---|---|---|---|--|--|---|---|
| | | | <u>Ex situ conservation collections existing prior to project</u> | <u>Best practice propagation developed:</u> • seed (S) • vegetative (V) | <u>Ex situ living collection locations and numbers of individuals</u> | <u>Main location of in situ recovery action and type of recovery action:</u> • population reinforcement (PR) • new population establishment (PE) | <u>Total number of saplings planted and survival rate (%) at the end of 2020</u> | | |
| <i>Bretschneidera sinensis</i> Akaniaceae Endangered | Mixed forest; temperate to subtropical Hubei; Zhejiang; Hunan; Fujian; Jiangxi; Guangdong; Sichuan; Guangxi; Yunnan; Guizhou; Taiwan; Vietnam; Laos | 2008–2010 South China Botanical Garden; Dongguan Forest Park; and Shimen National Forest Park, Guangdong | No | S (vegetative unsuccessful) | South China Botanical Garden; Dongguan Forest Park; and Shimen National Forest Park, Guangdong ~520 | Nankun Shan Mountain Nature Reserve, Guangdong PR | ~300 100% | 350 | Guangdong Provincial Natural Science Foundation; Guangdong Provincial Science and Technology Research; National Natural Science Foundation; and Chinese Academy of Sciences |
| <i>Carpinus tientiensis</i> Betulaceae Critically Endangered PSESP | Mixed broad-leaved forest; temperate Tiantai, Panan, Jingning county; Zhejiang 397 mature individuals remaining (5 in Dapanshan Nature Reserve; 19 in Tiantai Huangding Forest Park; 373 in Jingning Shangshantou) | 2017–2019 Zhejiang Forestry Academy | No | S (vegetative unsuccessful) | Yunhe Wetland Park ~300 Wuchaoshan National Forest Park 45 | Tiantai Forest Farm; Dapanshan Nature Reserve; Jingning Shangshantou PR | 4,840 80% | 150 | Zhejiang Forestry Bureau <i>Parrotia subaequalis</i> (CR) |
| <i>Glyptostrobus pensilis</i> Cupressaceae Critically Endangered PSESP | Moist lowland swamp; subtropical to tropical Fujian, Guangdong, Guangxi, Hainan, Jiangxi, Sichuan, Yunnan; Laos; Viet Nam | 2017–2019 South China Botanical Garden, CAS | Yes (Zhuhai) | S (vegetative unsuccessful) | Guangzhou Shimen National Forest Park; Guangzhou Biodiversity Conservation Center; Guangzhou Haizhu Wetland Park; Hunan Forest Botanic Garden; Ruyuan | | | 20 | Guangzhou Wildlife Conservation Office; Guangdong Provincial Forestry Bureau |

(continued on next page)

Table 5 (continued)

| Taxa and conservation status, incl. PSESP (Plant Species with Extremely Small Populations) | Habitat and distribution, incl. mature individuals remaining in the wild if known | Project period and main partners | <i>Ex situ</i> conservation | | | <i>In situ</i> conservation | | Number of representatives from local authorities and communities engaged and reached through training and public outreach | Project legacy: continued conservation support by Chinese institutions, and catalyst for the development of new projects targeting other native and threatened species |
|--|--|---|---|--|---|--|---|---|---|
| | | | <i>Ex situ</i> conservation collections existing prior to project | Best practice propagation developed: • seed (S) • vegetative (V) | <i>Ex situ</i> living collection locations and numbers of individuals | Main location of <i>in situ</i> recovery action and type of recovery action: • population reinforcement (PR) • new population establishment (PE) | Total number of saplings planted and survival rate (%) at the end of 2020 | | |
| <i>Rhododendron liboense</i> Ericaceae Critically Endangered | 762 mature individuals remaining Mixed broad-leaved forest on karst; subtropical Maolan National Reserve; Guizhou | 2017–2019 Guizhou Minzu University | No | S and V (tissue culture) | Tianjingshan Farm ~1700 Guizhou Minzu University nursery ~2000 | Jia Yi, Maolan National Nature Reserve PR | 180 65% | 200 | National Natural Science Foundation of China <i>Rhododendron magniflorum</i> (DD) |
| Magnoliaceae Magnoliaceae Endangered | Evergreen broad-leaved forest; subtropical to tropical Yunnan (southwest) 300–500 mature individuals remaining | 2008–2010 Kunming Botanical Garden, CAS, Yunnan | Yes (Kunming Botanical Garden) | S and V (tissue culture) | Kunming Botanical Garden, CAS 4 | Daping Township, Malipo county, Yunnan PR | 40 20% | 30 | National Natural Science Foundation of China <i>Taxus wallichiana</i> (EN); <i>Magnolia campbellii</i> (LC); <i>Dipentodon sinicus</i> (LC); <i>Rhododendron protistum</i> var. <i>giganteum</i> (CR); <i>Acer yangbiense</i> (EN); <i>Cyclobalanopsis sichouensis</i> (CR); <i>Pinus squamata</i> (CR); <i>Craigia yunnanensis</i> (EN) |
| <i>Magnolia omeiensis</i> Magnoliaceae Critically Endangered PSESP | Evergreen broad-leaved forest; subtropical to tropical Sichuan 76 mature individuals remaining | 2016–2020 Emeishan Botanical Garden; Chengdu Botanical Garden; West China Subalpine Botanical Garden, Sichuan; Kunming Botanical Garden, Yunnan; Wuhan Botanical Garden, Hubei; Lushan | No | S and V | Emeishan Botanical Garden ~214 | Emei Mountain PR and PE | 800 95% | 300 | Sichuan Science and Technology Department <i>Magnolia wilsonii</i> (NT); <i>Magnolia sieboldii</i> subsp. <i>sinensis</i> (VU) |

(continued on next page)

Table 5 (continued)

| Taxa and conservation status, incl. PSESP (Plant Species with Extremely Small Populations) | Habitat and distribution, incl. mature individuals remaining in the wild if known | Project period and main partners | <i>Ex situ</i> conservation | | | <i>In situ</i> conservation | | Number of representatives from local authorities and communities engaged and reached through training and public outreach | Project legacy: continued conservation support by Chinese institutions, and catalyst for the development of new projects targeting other native and threatened species |
|---|--|---|--|--|---|--|---|---|---|
| | | | <i>Ex situ</i> conservation collections existing prior to project | Best practice propagation developed: • seed (S) • vegetative (V) | <i>Ex situ</i> living collection locations and numbers of individuals | Main location of <i>in situ</i> recovery action and type of recovery action: • population reinforcement (PR) • new population establishment (PE) | Total number of saplings planted and survival rate (%) at the end of 2020 | | |
| <i>Magnolia phanerophlebia</i> (<i>M. fistulosa</i>) Magnoliaceae Data Deficient | Evergreen broad-leaved forest; subtropical to tropical Yunnan (southeast) < 200 mature individuals remaining | 2008–2010 Botanical Garden, Jiangxi; Xi'an Botanical Garden, Shaanxi; Zhongshan Botanical Garden, Jiangsu Kunming Botanical Garden, CAS, Yunnan | Yes (Kunming Botanical Garden) | S and V (tissue culture) | Kunming Botanical Garden, CAS 12 | Gulinqing, Yunnan PR | 50 40% | 30 | National Natural Science Foundation of China <i>Taxus wallichiana</i> (EN); <i>Magnolia campbellii</i> (LC); <i>Dipentodon sinicus</i> (LC); <i>Rhododendron protistum</i> var. <i>giganteum</i> (CR); <i>Acer yangbiense</i> (EN); <i>Cyclobalanopsis sichouensis</i> (CR); <i>Pinus squamata</i> (CR); <i>Craigia yunnanensis</i> (EN) |
| <i>Dipteronia dyeriana</i> Sapindaceae Endangered PSESP | Evergreen broad-leaved forest; subtropical Yunnan (southeast) 4000 mature individuals remaining | 2008–2010 Kunming Rare Plants Introduction Base; Kunming Botanical Garden, CAS, Yunnan | Yes (Kunming Rare Plants Introduction Base) | S and V | Kunming Rare Plants Introduction Base; Kunming Botanical Garden, CAS ~100 | Daweishan National Nature Reserve, Yunnan PR | ~1300 (over 465 seedlings and 835 saplings obtained from cuttings) 80% | 200 | Ministry of Science and Technology <i>Magnolia hebecarpa</i> (EN); <i>Magnolia sinica</i> (CR); <i>Magnolia lucida</i> (EN) |
| <i>Populus euphratica</i> Salicaceae Least Concern (National Key Protected Wild Plants in Xinjiang Uygur | Riparian forest; temperate to continental Xinjiang; Gansu; Qinghai, Inner Mongolia; Mongolia to West Asia | 2012–2016 Tarim University; Forestry Bureaus of Luntai and Awati counties; Turpan Eremophytes Botanical Garden; Xinjiang | Yes (Turpan Eremophytes Botanical Garden; Gansu; Tarim University) | S and V (vegetative propagation low success rate) | | Luntai county PR | 4,000 60% | 900 | National Natural Science Foundation of China <i>Populus pruinosa</i> (NT); <i>Ammopiptanthus nanus</i> (CR); <i>Lycium ruthenicum</i> ; |

(continued on next page)

Table 5 (continued)

| Taxa and conservation status, incl. PSESP (Plant Species with Extremely Small Populations) | Habitat and distribution, incl. mature individuals remaining in the wild if known | Project period and main partners | <i>Ex situ</i> conservation | | | <i>In situ</i> conservation | | Number of representatives from local authorities and communities engaged and reached through training and public outreach | Project legacy: continued conservation support by Chinese institutions, and catalyst for the development of new projects targeting other native and threatened species |
|--|--|---|---|--|---|--|---|---|---|
| | | | <i>Ex situ</i> conservation collections existing prior to project | Best practice propagation developed: • seed (S) • vegetative (V) | <i>Ex situ</i> living collection locations and numbers of individuals | Main location of <i>in situ</i> recovery action and type of recovery action: • population reinforcement (PR) • new population establishment (PE) | Total number of saplings planted and survival rate (%) at the end of 2020 | | |
| Autonomous Region 2015) <i>Acer yangbiense</i> Sapindaceae Endangered | Mixed forest; subtropical Cangshan Malutang and Taiping Town, Yangbi county, Laowo Town, Lushui county; Yunnan 700 mature individuals remaining | 2013–2014 Kunming Botanical Garden; Cao-Jian Forestry Station, Dali Bai Autonomous Prefecture; Yunnan | No | S | Cao-Jian Forestry Station ~2,000 Kunming Botanical Garden 50 | Cangshan West Slope Taiping Town PR | 150 45% 2,000 90% | 50 | <i>Glycyrrhiza inflata</i> ; <i>Poacynum hendersonii</i> National Natural Science Foundation of China; Ministry of Science and Technology <i>Taxus wallichiana</i> (EN); <i>Magnolia campbellii</i> (LC); <i>Dipentodon sinicus</i> (LC); <i>Rhododendron protistum</i> var. <i>giganteum</i> (CR); <i>Acer yangbiense</i> (EN); <i>Cyclobalanopsis sichouensis</i> (CR); <i>Pinus squamata</i> (CR); <i>Craigia yunnanensis</i> (EN) |
| <i>Styrax zhejiangensis</i> Styracaceae Critically Endangered | Evergreen, broad-leaved forest; subtropical to tropical Jiande, Zhejiang ~106 mature individuals remaining | 2017–2019 Zhejiang Forestry Academy; China Jiliang University; Zhejiang University; Tiantai county Forestry Bureau; Panan county Dapan Mountain National Nature Reserve; Sanmen Botanical Garden | No | S and V (cuttings) | Wuchaoshan National Forest Park, Zhejiang 16 | Wuchao Mountain, Zhejiang PR and PE | ~590 85% | 130 | Zhejiang Forest Bureau; Basic Public Welfare Research Program of Zhejiang Province; this species is included in Zhejiang's new Five-Year Plan (2021–2025) <i>Changiosyrax dolichocarpus</i> (EN); <i>Carpinus tientaiensis</i> (CR); <i>Carpinus putoensis</i> (CR); <i>Ostrya rehderiana</i> (CR); <i>Isoetes sinensis</i> ; <i>Ardisia violacea</i> |
| | | | No | S and V | | | | 230 | |

(continued on next page)

Table 5 (continued)

| Taxa and conservation status, incl. PSESP (Plant Species with Extremely Small Populations) | Habitat and distribution, incl. mature individuals remaining in the wild if known | Project period and main partners | <i>Ex situ</i> conservation | | | <i>In situ</i> conservation | | Number of representatives from local authorities and communities engaged and reached through training and public outreach | Project legacy: continued conservation support by Chinese institutions, and catalyst for the development of new projects targeting other native and threatened species |
|--|--|---|---|--|---|--|---|---|--|
| | | | <i>Ex situ</i> conservation collections existing prior to project | Best practice propagation developed: • seed (S) • vegetative (V) | <i>Ex situ</i> living collection locations and numbers of individuals | Main location of <i>in situ</i> recovery action and type of recovery action: • population reinforcement (PR) • new population establishment (PE) | Total number of saplings planted and survival rate (%) at the end of 2020 | | |
| <i>Camellia euphlebia</i> Theaceae Endangered | Evergreen broad-leaved forest; tropical Guangxi (southwest); Viet Nam < 5000 mature individuals remaining | 2012–2016 Nanning Arboretum; Nanning Jinhua Tea Park; Guilin Botanical Garden; Fangcheng National Camellia Nature Reserve, Guangxi | | | Nanning Arboretum; Nanning Jinhua Tea Park; Guilin Botanical Garden; Fangcheng National Camellia Nature Reserve, Guangxi ~500 | Jiangping, Shangsi; Golden Camellia National Nature Reserve, Fangcheng, Guangxi PR | 2,000 90% | | National Natural Science Foundation of China |
| <i>Camellia indochninensis</i> var. <i>tunghinensis</i> Theaceae Endangered | Evergreen broad-leaved forest; tropical Guangxi (south) | 2012–2016 Nanning Arboretum; Nanning Jinhua Tea Park; Guilin Botanical Garden; Fangcheng National Camellia Nature Reserve, Guangxi | No | S and V | Nanning Arboretum; Nanning Jinhua Tea Park; Guilin Botanical Garden; Fangcheng National Camellia Nature Reserve, Guangxi ~200 | Jiangping, Shangsi; Golden Camellia National Nature Reserve, Fangcheng, Guangxi PR | 1,000 90% | 230 | National Natural Science Foundation of China <i>Reevesia rotundifolia</i> (CR); <i>Camellia fangchengensis</i> (CR) |
| <i>Camellia nitidissima</i> Theaceae Endangered | Evergreen broad-leaved forest; tropical Fangcheng, Guangxi; Viet Nam | 2012–2016 Nanning Arboretum; Nanning Jinhua Tea Park; Guilin Botanical Garden; Fangcheng National Camellia Nature Reserve, Guangxi | No | S and V | Nanning Arboretum; Nanning Jinhua Tea Park; Guilin Botanical Garden; Fangcheng National Camellia Nature Reserve, Guangxi ~2000 | Jiangping, Shangsi; Golden Camellia National Nature Reserve, Fangcheng, Guangxi PR | 20,000 90% | 230 | National Natural Science Foundation of China |
| <i>Euryodendron excelsum</i> Theaceae Critically Endangered PSESP | Evergreen broad-leaved forest; tropical Bajia town, Yangchun county, Guangdong; Pingnan and Bama counties, | 2011–2012 South China Botanical Garden, CAS; Ehuangzhang Nature Reserve of Yangchun county; Guangdong | Yes (South China Botanical Garden) | S and V (in particular airlayering) | South China Botanical Garden, CAS; Ehuangzhang Nature Reserve of the Yangchun county ~200 | Ehuangzhang Nature Reserve of Yangchun county PR | 120 60% | 40 | South China Botanical Garden (emphasis on tissue culture propagation) <i>Glyptostrobus pensilis</i> (CR) |

(continued on next page)

Table 5 (continued)

| Taxa and conservation status, incl. PSESP (Plant Species with Extremely Small Populations) | Habitat and distribution, incl. mature individuals remaining in the wild if known | Project period and main partners | <i>Ex situ</i> conservation | | | <i>In situ</i> conservation | | Number of representatives from local authorities and communities engaged and reached through training and public outreach | Project legacy: continued conservation support by Chinese institutions, and catalyst for the development of new projects targeting other native and threatened species |
|--|---|----------------------------------|---|--|---|--|---|---|--|
| | | | <i>Ex situ</i> conservation collections existing prior to project | Best practice propagation developed: <ul style="list-style-type: none"> • seed (S) • vegetative (V) | <i>Ex situ</i> living collection locations and numbers of individuals | Main location of <i>in situ</i> recovery action and type of recovery action: | Total number of saplings planted and survival rate (%) at the end of 2020 | | |
| | Guangxi ~100 mature individuals remaining | | | | | <ul style="list-style-type: none"> • population reinforcement (PR) • new population establishment (PE) | | | |

Betulaceae (82 Chinese tree species) and Hamamelidaceae (44 Chinese tree species), respectively representing more than half of the global tree diversity found in these families, as well as Magnoliaceae with over a third (109 tree species) of the total number of species at the global level. Many of the species in these groups are well-known for their ornamental value, in addition to a number of other native tree species used in amenity planting such as the monotypic *Bretschneidera sinensis* (Akaniaceae) or *Cercidiphyllum japonicum* (Cercidiphyllaceae) and *Liriodendron chinense* (Magnoliaceae), with only two species in these genera worldwide. With all forest biome types, from tropical to boreal, represented in China, the biggest diversity in tree species is found in the tropical, subtropical and temperate zones of southern China, especially in Yunnan, Sichuan, Guangxi, Hainan and Taiwan (López-Pujol et al., 2011; Zhang et al., 2018). This explains why the majority of GTC projects between 2008 and 2020 were situated in China's southern and southeastern provinces and administrative regions, with the exception of Xinjiang's unique *Populus euphratica* riparian forests or populations of *Haloxylon ammodendron* in northern China.

This review has highlighted the many efforts carried out or under way by the government of China to secure the nation's unique biological heritage into the future. However the analysis has also identified that one in five native Chinese tree species is at risk of extinction. This figure could be even significantly higher once the conservation status of the over 825 species recorded as Data Deficient or not assessed yet, is established. Besides the well-known, man-made drivers of change largely attributed to the loss and degradation of wild habitat, to a lesser yet not negligible extent some of the species' own reproductive biology may enhance their vulnerability to risks. This includes low seed setting, dispersal, and/or seedlings survival rates, slow growth, and low population density (Volis, 2016; Ren, 2020), especially found in a number of taxa identified by the government of China as Plant Species with Extremely Small Populations (PSESP), for instance *Euryodendron excelsum* and *Glyptostrobus pensilis*. Tree species with small natural reproduction rates are in particular need of further scientific study of their biology as well as systematic horticultural trials to establish best-practice in propagation tailored to the individual species. Both these components form an integral part of all GTC projects.

Against the backdrop of some 964 threatened and a further 402 Near Threatened trees native to China, the number of taxa in these categories included in GTC conservation projects between 2008 and 2020 may appear comparatively small. However, considering the taxon-specific and often lengthy survey and inventory efforts to establish distribution data, collect propagules, trial propagation methods and generate saplings for *in situ* recovery measures, the 46 threatened and three Near Threatened of a total of 102 GTC project taxa that were included in these efforts, present a significant achievement.

As the government of China has been giving more focused attention in recent years to ecological restoration in large-scale tree planting schemes, growing the 'right species in the right place' (Xu, 2011) through appropriate, native species selection and sourcing of germplasm that takes genetic diversity and provenance into account, are major prerequisites to increase ecosystem resilience and connectivity (Thomas et al., 2014). Integrated knowledge of seed collection, storage, germination requirements and seedling growth performance of native tree species is vital for location-specific conservation and restoration plans (Lu et al., 2016, 2017). The average, three-year project cycle and area size of intervention for target taxa under the GTC may at first glance appear modest when reflected in the context of billions of trees planted over millions of hectares. However, the GTC's integrated conservation model promoting the use of a wide variety of native and threatened trees in restoration activities supports a growing number of research findings regarding the value of this approach not only for biodiversity recovery but also for storing carbon and combating climate change. (Lewis et al., 2019; Di Sacco et al., 2021). Whilst the *in situ* recovery work under the GTC in China has focused on enrichment and population reinforcement planting, it will take many more years to decades for the planted trees to reach maturity. In view of this long-term undertaking, each project is subject to comprehensive monitoring and evaluation, part of a global system to measure progress in the implementation of the GTC worldwide, some of which is available through BGCI's GlobalTree Portal. This may also serve as a useful model for other conservation initiatives at a time when more evidence-based project progress is called for by the Chinese government (Bryan et al., 2018; Wang et al., 2020). Further, all GTC projects also include a major technical training and public outreach component, working with local authorities and communities to enhance conservation capacity and environmental sensitisation. Project efforts have also contributed to diversifying livelihoods of local community representatives through the propagation and sale of products derived from target species, such as leaves and flowers of the threatened *Camellia nitidissima* and *C. euphlebia* or the roots and whole plants of *Polygala fallax*.

Chinese botanic gardens and arboreta have been the key institutional partners leading the GTC projects, working on *ex situ* conservation and collaborating with local authorities including forestry bureaus, nature reserves, research stations, etc. and communities on the conservation measures on site. 179 botanic gardens, arboreta and seed banks are recorded in BGCI's GardenSearch database. As major conservation agents, these hold accessions related to some 3141 tree species in their *ex situ* collections. This represents more than half (64.2%) of China's tree diversity and includes some 484 (15.4%) threatened tree species. Although the species most frequently found in botanic gardens and arboreta at the global level are those that are at less risk of extinction and only 21% of threatened trees are held in *ex situ* collections (BGCI, 2021), this ratio indicates that threatened tree collections in China fare better. However, whilst some taxa are better protected than others through multiple collections at several institutions, small numbers of *ex situ* collections are unlikely to capture the full genetic diversity of a wild population and therefore do not supply adequate plant propagules for *in situ* recovery (Rivers et al., 2015). Single-species collections at one institution do not provide protection for threatened taxa in the event of stochastic hazards, and for greatest conservation impact, *ex situ* collections should be diverse and held at multiple institutions (Ren, 2020).

In summary, best-practice of integrated conservation as promoted by the GTC, presents an iterative process, involving both *in situ* and *ex situ* approaches. The selection of which conservation actions are appropriate in a particular case will vary between species, locations, their associated ecosystem and the resources available (Oldfield and Newton, 2012; Heywood et al., 2018). To be effective, integrated conservation approaches need to address the individual requisites and circumstances of each specific situation, including policy and/or legislation, active *in situ* protection and/or management such as population reinforcement planting or reintroduction,

propagation techniques, population-based *ex situ* collections, and public awareness and education programmes.

At a time when the Chinese government is realizing and introducing a series of new policy and legal frameworks for environmental recovery and conservation of biodiversity, the experiences garnered by the implementation of the GTC in China over the past decade provide valuable lessons and guidance to inform future policy related to ecological reforestation (Wen, 2020). These efforts can also be drawn on in the call for a more scientific definition of ‘forest’ that distinguishes between forest types based on species composition and ecosystem function and their role in the conservation of biodiversity (Zhai et al., 2014). China’s long and extensive tree planting programme ‘does show that building a forest is a complex and subtle task. It varies with local conditions, and it must provide economic and social benefits for those who will have to look after the trees for generations’ (Bloomberg News, 2020). To guide future policy, not only the experiences gained in China but brought together from the multiple GTC projects implemented in over 50 countries worldwide will be invaluable. This will offer a global perspective to inform and devise locally adapted, strategic frameworks for biodiversity conservation.

5. Conclusions

The joint efforts of the Chinese botanic garden community, the forestry sector, universities, other conservation institutions and BGCI to inventory, assess and conserve China’s tree diversity have served as an exemplar of integrated conservation best-practice while inspiring the development of new initiatives for the safeguard of threatened trees (Wen, 2020). However, although urgency prevails to scale up conservation action for many more species at the brink of extinction, the GTC initiative also offers an ecologically more nuanced conceptual framework for application in China’s large-scale tree planting and reforestation efforts. This integrated conservation approach is especially opportune now, at a time when China is reviewing the effectiveness and expansion plans of its protected area system and is promoting the mainstreaming of biodiversity protection in all sectors of society. But it is also very timely as the nation is compelled to increase forest cover for carbon capture and economic growth. With the collaborative work presented in this analysis we seek to give a more forceful voice to the conservation value of imperiled, wild tree species. The GTC provides a comprehensive method to ascertain planting the ‘right tree in the right place’, but also ‘for the right purpose at the right time and with the right care’. In turn, this will enhance ecosystem recovery and resilience, and guarantee the continued provision of goods and services. Above all, we hope that this approach will ensure the longevity of tree diversity and its intrinsic values for the well-being of people and the planet into the distant future.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A

Global Trees Campaign projects in China between 2008 and 2020 – Questionnaire survey

Part 1: Project taxa.

Ex situ conservation.

Had a propagation protocol been developed for the target species as part of the project?

Was all plant material used for the development of *ex situ* collections of wild origin?

Are your *ex situ* collections genetically/geographically representative?

What type of *ex situ* collections (vegetative/seed) were established as part of the project?

How many individuals of the target species are currently in your *ex situ* collection and are there other *ex situ* collections (give details of the total number of individuals in these too) in China?

Do you know whether there were *ex situ* collections already in place before the project started? If so, how many collections with how many individuals?

In situ conservation.

Has there been any *in situ* planting been conducted as part of the project?

Can you provide quantitative details about the *in situ* planting work? How many individuals were planted over the total duration of the project (or estimates)?

How many are surviving to this day?

Are the *in situ* established individuals still under active management and if so what kind of management activities are taking place?

Is there a national policy in place to protect this/these species? If so, please provide the source of the legislation.

If so, what percentage of the total wild population is now under protection?

Part 2: General questions.

Is the training that was provided as part of the project still being effective? Do you have any evidence that the knowledge acquired through the training is still being used?

Is there a particular member of the project team who excelled in tree conservation as part of this project? Can you provide examples of some of their achievements? Did this work inspire interest to initiate conservation work on further threatened tree species?

Were additional groups inspired to adopt a role in tree conservation, either inspired by this project or trained through this project? Were additional species brought under conservation as a result of this project?

Was any public awareness raising carried out in association with this project? How many people were reached? How effective and impactful do you think the awareness raising efforts were? Can you give examples of the impact?

Was any additional funding raised from other sources for the target species? Or, have any funding applications been developed that are pending? If possible, please provide the amount of funding and the source.

Is the former project partner interested to expand the work on the target species and/or are there additional threatened tree species that they are interested to work on if additional funding can be raised by BGCI? If so, can you name the species?

Thank you for your participation!

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