



Perspective

More than just pandas: Urgent research needed on China's native plant biodiversity

Yu-heng Chen^a, Yao Li^a, Yu-ran Dong^a, Min Zhang^a, Yong Yang^a, Richard B. Primack^b,
Kathryn E. Barry^c, Lingfeng Mao^{a,*}

^a Co-Innovation Center for Sustainable Forestry in Southern China, Laboratory of Biodiversity and Conservation, College of Ecology and Environment, Nanjing Forestry University, Nanjing 210037, China

^b Biology Department, Boston University, 5 Cummington Mall, Boston, MA 02215, USA

^c Ecology and Biodiversity, Department of Biology, Utrecht University, Utrecht 3584CS, Netherlands

ARTICLE INFO

Keywords:

Biodiversity conservation
International collaborations
Endemic plants
Conservation funding
Conservation bias
Ecological civilization

ABSTRACT

Conservation of threatened species is essential for achieving sustainable development goals and realizing ecological civilization in China. However, our new survey on endemic threatened angiosperms in the scientific publication database showed that there is still a serious bias in the species' selection and research topics. China's 2117 endemic threatened angiosperm species remain relatively understudied with 41 % of them being not included in any Chinese-language and English-language scientific publications. Furthermore, only 2 % of the 44,383 publications that mention threatened plant species are related to conservation research and over 75 % of them are found behind a paywall. We propose measures to increase and advance conservation research and protection for China's threatened plants, 1) improve long-term and comprehensive research on endemic threatened angiosperms in China, 2) combine conservation research and practices and transfer conservation knowledge to practices timely, 3) promote inter-governmental communication and cooperation, and 4) apply new technologies and methods to conservation studies and practices.

1. Introduction

China is home to incredible native biodiversity. Three of the 36 global biodiversity hotspots and over 35,000 vascular plants have been recorded in China (Mi et al., 2021). However, following decades of rapid economic development and urbanization, China is now facing a biodiversity crisis (Zhang et al., 2015). In the latest Chinese Higher Plant Biodiversity Red List, 8 % of club mosses and ferns, 51 % of gymnosperms, and 11 % of angiosperms are considered threatened species (Qin et al., 2017). Hence, protecting populations of threatened species and improving their conditions is becoming an important part of biodiversity conservation in China.

China appears committed to reaching sweeping conservation changes. Protecting so many threatened plants requires a comprehensive research strategy. The number of international papers on biodiversity research in China has increased from a few dozen at the beginning of the century to nearly 2000 each year currently (Mi et al.,

2021). China has invested about \$378 billion USD in sustainable development and biodiversity conservation projects in recent decades (Bryan et al., 2018). At the 15th meeting of the Conference of the Parties to the Convention on Biological Diversity, China promised to carry out a series of ambitious species conservation plans to protect native biodiversity. As a result, a network of protected areas and national park systems has been developed to cover most biodiversity hotspots in China (Mi et al., 2021).

Considering the urgency of the conservation work and the imbalance of regional economic and educational development, China must bolster its conservation strategies to effectively protect its native biodiversity. However, research on endangered plant species is lagging behind many other areas of ecology and conservation. The vast majority of attention and resources have been devoted to flagship animal species such as the giant panda, tigers and elephants rather than these endangered plant species. Too many resources concentrated on flagship species may reduce the living space of those unknown species, and conservation

* Corresponding author at: Co-Innovation Center for Sustainable Forestry in Southern China, College of Biology and the Environment, Nanjing Forestry University, Nanjing 210037, China.

E-mail addresses: liyaoisanu@njfu.edu.cn (Y. Li), zhangmin@njfu.edu.cn (M. Zhang), yangyong@njfu.edu.cn (Y. Yang), primack@bu.edu (R.B. Primack), k.e.barry@uu.nl (K.E. Barry), maolingfeng2008@163.com (L. Mao).

<https://doi.org/10.1016/j.biocon.2023.110388>

Received 25 February 2023; Received in revised form 31 August 2023; Accepted 21 November 2023

Available online 6 December 2023

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design for flagship species may affect the migration and foraging of sympatric species (Shen et al., 2020). For example, the protection of giant pandas had a negative impact on other carnivores (Li et al., 2020a). Further, none of the top 1 % of Chinese researchers is currently engaged in plant conservation as of 2021 (Highly Cited Chinese Researchers (HCCR), 2022). This lack of interest by highly cited researchers suggests that field plant conservation is not a priority research area. The lack of research on threatened plant species may reduce the budget of the China government to effectively manage these endangered species, and fulfill the goals of ecological civilization advanced by the goal of the Chinese government (Ren et al., 2019).

2. Research gaps: angiosperms as a case study

Threatened angiosperms represent 75 % of all the threatened species in China (Qin et al., 2017). Among the 30,068 known angiosperms in China, 3363 angiosperms were threatened (critically endangered, endangered, and vulnerable), of which about two-thirds are endemic to China (henceforth, endemic threatened angiosperms or ETA) (Qin et al., 2017). Although some iconic ETAs, such as the huagaimu (*Pachylarnax sinica*) and the Chinese goldenthread (*Coptis chinensis*) (Li et al., 2020b) have been extensively studied as charismatic megaflores, or for their ornamental and medicinal value, most ETAs are unknown to the public. However, these ETAs play an important role in maintaining the biodiversity of Chinese ecosystems, supporting ecosystem functions, and providing economic value to the people of the whole world (Duan et al., 2021). To better understand the extent to which the ETAs of China have been investigated for their basic biology, as well as ecology and conservations, we surveyed publications of all Chinese ETAs, including in both the Chinese and English language literature.

3. Research status of ETAs in China

Using the China Biodiversity Red List (Qin et al., 2017), we identified 2117 ETA species, accounting for 63 % of all threatened angiosperms in China. Species also occurring outside of China were not included, and we merged varieties, subspecies, and synonyms for each species based on the Catalogue of Life China (The Catalogue of Life China, 2022).

To identify relevant publications, we used the WOS (Web of Science: www.webofscience.com) and the CNKI (China National Knowledge Infrastructure: www.cnki.net) databases for assessing ETAs research in the English and Chinese languages, respectively. We used our species checklist to retrieve publications pertaining to each species available before July 1st, 2022 in the WOS and CNKI by their scientific names and Chinese names, respectively. Considering the different sources of databases, English research literature was solely obtained from journals, while the Chinese literature was obtained from journals, theses, and dissertations. In CNKI, we also used the Chinese vernacular names of species as keywords to avoid missing papers related to these species. We manually excluded articles unrelated to the target species, which were generally concerned with commodities (usually Chinese herbal medicine) with the same name as the species, or when the retrieval system mistakenly returned similar species names or additional unrelated species.

Our final list contained 44,383 research papers related to our list of 2117 species of Chinese ETAs (see Appendix 1-1 for details). We manually classified publications into categories based on the title, abstract, and keywords. We divided these publications into 6 categories based on research topic (Fig. S1):

1. Basic research, which includes plant survey reports and traditional taxonomic research, such as reports of new species, morphology, taxonomy, and regional plant checklists. Such studies are often based on online transect surveys as well as data obtained from herbarium specimen collections and lack detailed information about the species.

2. Applied research, which focuses on the material, ethnological, horticultural, edible, and medicinal uses of the plants.
3. Cultivation and physiology research, which describes plant growth, horticulture, development, and metabolism.
4. Evolution and molecular biology research, which investigates the genetics and evolutionary history of plants.
5. Ecology and biogeography research which involves the relationship between plant communities and the environment, and sometimes includes fieldwork.
6. Review papers, which are usually written by experts to summarize the current literature on specific taxa and inform future research directions. In practice, most of the conservation biology publications are classified as review papers because they summarized the risk factors and protection measures based on previous investigators' data.

We also identified the dates of the first publication and the most recent publication for each species to characterize the timelines of research effort. We set two cutoffs for publications (the last publication for a species was 5 or 10 years ago) to identify species for which research is current or not active. We consider species mentioned in papers published within the last 5 years to be currently receiving attention from research institutions and government departments as these likely were funded during this period. We consider species that lack publications in the last 10 years to be no longer actively researched.

Although all publications are related to ETAs, most of them only describe the species current status in their introduction. We classify all publications as conservation publications if they mention conservation in their discussion section. Finally, 1050 out of all 44,383 articles were classified as conservation publications. Then we classified conservation publications, which are mainly in the category of review papers, into four conservation categories:

1. The analysis of risk factors of a species, including internal threats caused by the biology of the species and external threats caused by external factors.
2. Protection measures, that propose specific actions and programs to protect species.
3. Genetic diversity to inform protection measures.
4. Research using species distribution models, including species migration models or spatial analysis models to analyze current, past, and future habitats of threatened species, sometimes with a goal of providing more accurate predictions for planning reserves in the face of climate change and ongoing economic development (Duan et al., 2021).

We also checked the relationship between conservation publications and China's ongoing Plant Species with Extremely Small Populations (PSESP). PSESP is currently one of the most important plant conservation programs in China. This program aims to quickly evaluate, research, and protect China's most endangered endemic plant populations (Xu and Zang, 2023). We used 'PSESP' and 'Plant Species with Extremely Small Populations' as a topic to conduct a secondary search on all conservation publications and counted the number of publications.

4. Results

4.1. Despite increasing efforts, a huge gap remains for ETA research

Out of the 2117 ETAs in China, 1240 of these species or 59 %, were mentioned in research from 1900 to 2022. Among them, 392 species have only one related research publication. The situation is improving as only 40 of these species, around 2 %, were included in publications prior to China's open and reform policy and the recovery of higher education in 1978, just after the period known as the Cultural Revolution, and prior to China's recent economic expansion. ETA research accelerated

after China adopted the Global Strategy for Plant Conservation and formulated relevant protection policies in 2002 (Fig. 1A), increasing from about 20 new species per year to about 36 new species per year. However, we also found out that research on many of these species did not continue (Fig. 1B). Out of the 1247 species mentioned in research publications, 251 species were not mentioned in the past 10 years. 806 of these species were first mentioned in the past 5 years, accounting for 65 % of all researched species and 38 % of all ETAs.

We also explored the relationship between the spatial distribution pattern of ETAs and the local economic level. Provinces with more ETAs had more research publications, especially in the southwest area (Fig. 1C) which is a hotspot of biodiversity. Furthermore, the species in this area were the most intensely studied. The extent of ETA research was also related to the economy of their home provinces (Fig. 1D). After excluding the small municipalities directly under the central government (Beijing, Shanghai and Tianjin), the Special Administrative Regions of Macao and Hongkong, and the island of Taiwan, we found that in inland provinces with low per capita GDP, such as Guangxi, Yunnan and Sichuan in southwest China, the proportion of researched species in the total number of local ETAs is low.

4.2. ETA conservation research was disproportionately underrepresented

The most common topic of Chinese publications about ETAs involved the use of plants, especially their use in Chinese herbal medicine (Fig. 2A). Chinese publications also attached importance to the cultivation of plants, such as breeding, raising seedlings, and horticultural techniques. Many English-language publications similarly described plant uses, and their most common topic was reporting the natural products of these species. Many English-language publications, especially those in genetics journals, also reported on plant genetics. Meanwhile, we also found 142 English publications and 105 Chinese publications related to the Plant Species with Extremely Small Populations program.

Of 44,383 publications that we found, only 794 Chinese publications and 256 English publications, or around 2 %, were related to the conservation of ETAs (Fig. S2). Among all 305 species having conservation-related publications, 42 endangered species have only English language literature. In the Chinese CNKI, most studies focused on risk factors, and many studies proposed protection measures, such as the establishment of protected areas and controls against collection. Similarly, the English-language WOS contained a large number of studies proposing conservation suggestions, though nearly half of these publications were centered on the genetic diversity of ETAs. In both Chinese and English

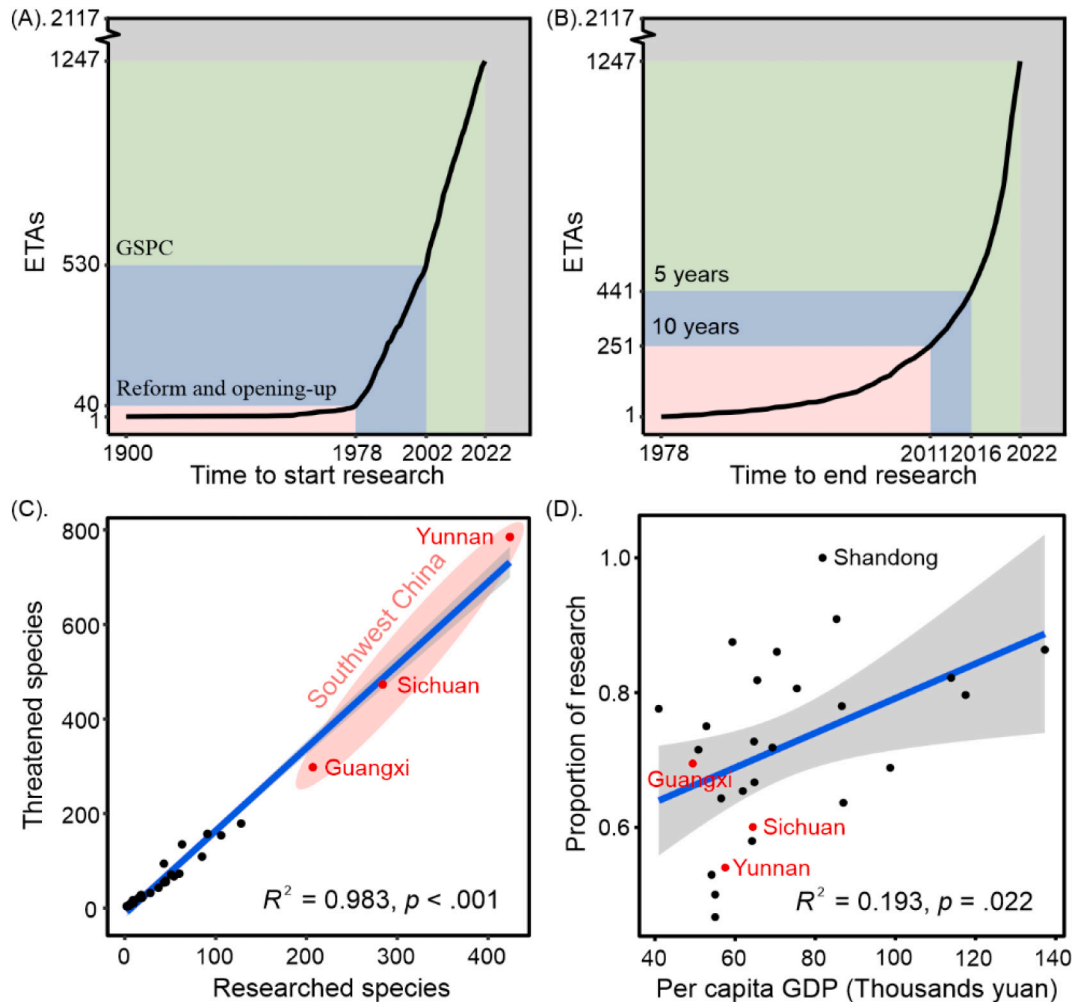


Fig. 1. The number of ETA species mentioned in scientific publications based on study start time (A) and end time (B), and, for individual provinces in China, the relationship of the number of ETA species mentioned in scientific publications with the proportion of threatened species in the province (C) and the per capita GDP of the province in relation to the proportion of the studied species in the total ETAs. (D). For (A) we also include the timing of reform and opening up of higher education in China in 1978 and the signing of the Global Strategy for Plant Conservation. For (B), we report the proportion of species that have not been reported on in 5 years (from 2016 to 2022) to all species and all studied species, respectively.

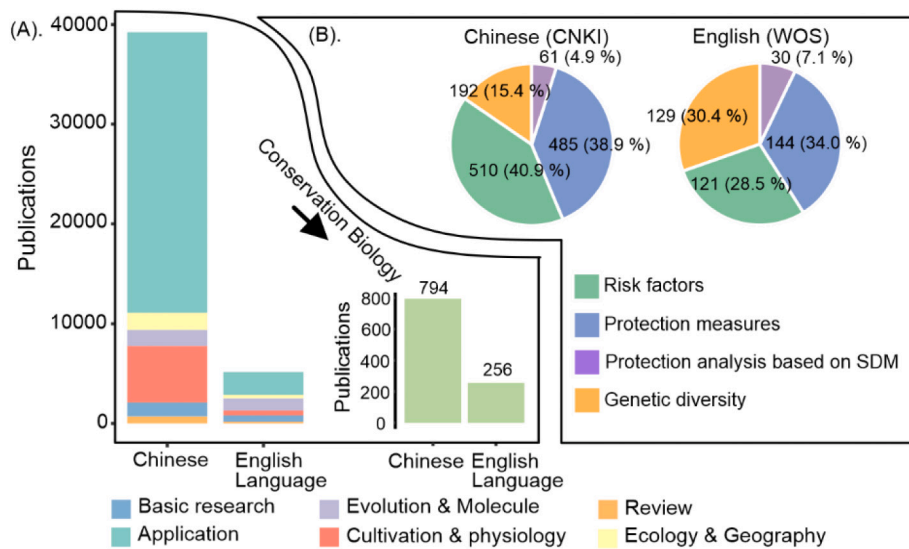


Fig. 2. Categorization of (A) all publications concerning endemic threatened angiosperms (ETAs) and (B) a focus on conservation studies.

databases, studies using species distribution models and other advanced methods for conservation research, were quite rare, accounting for only 9 % of all conservation-related publications or 0.2 % of overall publications.

5. Improving research on ETAs in China

5.1. Long-term and comprehensive research

We call on the government and research institutions to allocate financial support for new systematic plant surveys by professional scientists to rediscover, map, and better describe these neglected species. China has made important progress in plant research and investigation, nearly 200 species were published every year and the threatened status of nearly all new species was assessed using IUCN Categories and Criteria (Du et al., 2021). However, many species recorded in the Flora have rarely been re-studied and assessed. The biodiversity resource survey currently being promoted by the Chinese local government may be a feasible solution to this problem. Biodiversity resource survey investigates and documents the local biodiversity and habitat conditions, and produces checklists of threatened species, which provides valuable data for species conservation (Xiao et al., 2022). However, biodiversity resource survey methods are expensive and the access to relevant data is also restricted (Qian et al., 2018). Also, funding for biodiversity resource survey is done by local governments, which often has other priorities and may not allocate special budgets for scientific research, especially for those poor provinces. Hence, we suggest that the biodiversity resource survey activities should be funded and regulated by bottom-up governments at all levels so that provinces with weaker economies can carry out surveys of ETAs as well. In particular, these surveys can help less affluent provinces in southwestern China to better understand local endangered species and biomes, plan conservation measures, and develop eco-tourism. Moreover, these surveys can also help local botanical gardens and universities receive more funding and resources for studies of conservation biology.

We also need to develop long-term projects in the field of plant conservation research and programs. In China, the Ministry of Science and Technology, the National Natural Science Foundation of China (NSFC), the National Forestry and Grassland Administration, and the Ministry of Ecology and Environment substantially supported conservation research. Among them, NSFC is the largest sponsor in Chinese research, however it mainly funds short-term projects lasting just a few years (Hu, 2020). In addition, very few conservation projects in NSFC

were allocated to plants. China's GDP has increased from 9.6 trillion in 2010 to 14.7 trillion in 2020. However, the number of funds in NSFC's sub-project of conservation biology (Subject number: C0312) in 2020 did not significantly increase compared to 2010 (Fig. 3, Appendix 1-2). In the past 10 years (2010–2020), NSFC has approved an average of seven projects and allocated 2.61 million CNY to conservation biology per year, and the average duration of these projects is 3.5 years. Only five plants have been studied multiple times, and there is no long-term (over seven years) research funding related to endangered plants. Hence, we call for more long-term and multi-dimensional research projects on these endangered plants. Long term projects not only require the support of national research funds, but also require the cooperation of local governments and institutions. Long-term research projects on threatened plants and plant communities in native habitats, nature

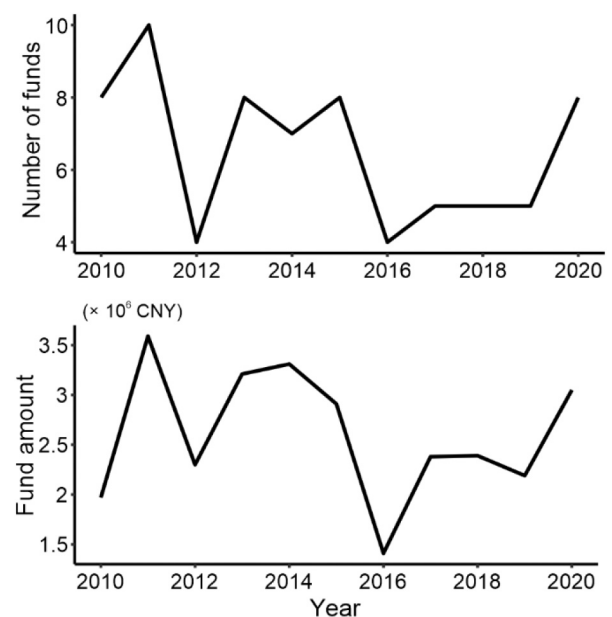


Fig. 3. Number and amount of projects of the Natural Science Foundation of China (NSFC) in the sub-project of conservation biology in the past decade (2010–2020). We searched all NSFC's projects on the conservation biology theme from 2010 to 2020 on the unofficial query platform (<https://www.izaiwen.cn/>) of the NSFC, and filtered all studies related to threatened plants (involving specific endangered species and taxa).

reserves, and botanical gardens (Li et al., 2020c) can provide unique insights into conservation measures and actions of these threatened species. Where possible such projects should address the environmental, economic and cultural concerns of local people, let local people be involved in decision-making processes, and provide jobs, training and other economic opportunities for the local community. Such long-term projects will result in better opportunities for successful conservation and management.

5.2. Combining research and practices

We need to prevent further decoupling between conservation research and practices. At present, 18.5 % of publications focus on the physiological and ecological characteristics of threatened plants, and only 2.8 % of publications point out their risk factors and protection measures. We need a framework to integrate and accelerate research and practice on these endangered plants. China's conservation program on Plant Species with Extremely Small Populations (PSESP) provides us with an excellent platform for integrating conservation research and practices. It aims to protect plants with extremely small populations (Xu and Zang, 2023). National, provincial, and local authorities need to determine the species checklist in PSESP based on local conditions. Subsequently, public institutions and private organizations at all levels will also fund related conservation research. Then, protected areas, research institutions, and local governments are all involved in their breeding and conservation research. Ultimately, superior government will evaluate the effectiveness of ex-situ and in situ conservation in the PSESP project. Currently, over 120 species have been well protected under the PSESP program, and over 10,000 conservation staff have been trained (Yang et al., 2020). A large number of publications have been published under the PSESP program, many of them evaluate the current situation of threatened species and provide corresponding conservation plan (Yang et al., 2023). However, many articles also only describe the chloroplast genome of threatened species (Qin et al., 2021). We hereby call for accelerating the promotion of PSESP and expanding this framework as a model for protection practice to all threatened plants as soon as possible. Meanwhile, we also need to diversify the evaluation system of projects to encourage researchers to publish comprehensive conservation publications from species evaluation to protection.

We also need to strengthen the role of botanical gardens in conservation research and practice. Plants can be conserved in situ, in protected areas, and ex-situ, in living collections, seed banks, or cryogenic storage (Corlett, 2023). Botanical gardens play an important role in ex situ conservation and have transplanted over 45 % of known China's threatened species (Zhao et al., 2022). In 2013, the Chinese Union of Botanical Gardens launched the ambitious 'Native Plant Full Coverage Protection Program' (also known as the Zero Extinction Program) to explore effective ways to protect Chinese endangered plants through a series of botanical gardens in different geographical and climatic regions (Li et al., 2020c). Our research shows that there are 8228 papers describing the physiological and ecological characteristics of 545 ETAs. These studies will provide important references for the zero extinction program. However, there is still a gap between these species and the current checklist of transplanted species in the botanical garden. We still need lots of work and funding to fully research and protect these transplanted plants, and special attention should be paid to protecting the genetic diversity of these plants with extremely small populations. Hence, we need to promote communication between botanical gardens and universities, and strengthen our ability to translate research results into practices.

5.3. International communication and cooperation

There are significant differences in the number and themes of Chinese and English publications related to ETAs. We need to remove barriers to international cooperation between Chinese and foreign

conservationists. Currently, many publications in Chinese are not known to conservationists outside of China, and most articles by foreign scientists are published in English, often in international journals that are not accessible to Chinese authors due to both language barriers and paywalls. This is not conducive for China's biological conservation workers to master the latest technology and trends (Christie et al., 2021). Meanwhile, foreign conservationists have difficulty accessing Chinese articles for similar reasons. This will lead the international community to underestimate the conservation status of threatened species in China (Chowdhury et al., 2022). It would benefit both sides if the best articles about ETAs in English were regularly translated into Chinese and published in academic and mass media. Similarly, the best articles in Chinese should be translated and promoted to their Western counterparts on English social media.

There also needs to be improved research cooperation between the Chinese government and the governments of other countries. Scientific cooperation on ETAs should not be jeopardized, postponed and cancelled when there are political and economic disagreements between governments. Whenever possible, cooperative international research should be encouraged, with research permits and visas approved promptly. Besides the practical value of cooperative research among scientists, such research also facilitates better relationships among countries and demonstrates the value of cooperation which can then be applied in other more difficult sectors (Fan et al., 2020).

5.4. Access to advanced technology and methods

The application of new technologies and methods is important for species conservation. In particular, the Plant Species with Extremely Small Populations project needs the help of spatial distribution models and other tools to develop management strategies that will protect species in the face of climate change (Li et al., 2020b). Other methods include the use of environmental DNA, DNA barcoding, and citizen science networks, and the analysis of big data sets. However, these advanced technologies and approaches are not widely used in the current conservation research of ETAs in China. Cooperation between Chinese and foreign scientists could promote conservation research in all of these areas, providing valuable training opportunities and international exposure for Chinese scientists and students. For students and staff related to conservation biology, new generation GIS tools such as Google Earth Engine (Evans and Malcom, 2021), and programming languages such as Python and R will significantly reduce the workload of data processing and map drawing. Hence, we also recommend adding these contents to university courses and grassroots training to prepare for future conservation biology research.

Through these suggestions, we believe that China's conservation research can make a big promotion and achieve its ambitious sustainable development goals, such as the implementation of the Convention on Biological Diversity and providing for the needs of its people. China must take effective measures to strengthen the protection and research of endemic threatened species, to achieve its long-term goals of biodiversity conservation.

Declaration of competing interest

The authors declare that there is no conflict of interest that could be perceived as prejudicing the impartiality of the research reported.

Data availability

Data will be made available on request.

Acknowledgements

This research was supported by Jiangsu Social Development Project (BE2022792) and the Strategic Priority Research Program of the Chinese

Academy of Sciences (XDB31000000).

Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.biocon.2023.110388>.

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