



Contents lists available at ScienceDirect

Environmental Science and Ecotechnology

journal homepage: www.journals.elsevier.com/environmental-science-and-ecotechnology/



Review

Biodiversity conservation in China: A review of recent studies and practices



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ARTICLE INFO

Article history:

Received 3 January 2020

Received in revised form

19 March 2020

Accepted 23 March 2020

Keywords:

Ecological civilization

Mainstreaming

Mobile supervising system

Sustainable development

Protected areas

ABSTRACT

Biodiversity conservation plays an important role in the sustainable development of human society. China had made significant progress in biodiversity conservation studies and practices. This paper reviews major achievements in China in the past decades, especially those since 2010. In terms of the science behind biodiversity conservation, Chinese scholars have made significant contributions to priority research subjects, including mechanisms for maintaining biological communities and the relationship between biodiversity and ecosystem functioning. Simultaneously, biodiversity conservation and management systems specific to China have been basically established. The Chinese Government and researchers have undertaken a number of investigations, scientific studies, and monitoring, and have established relevant databases. With efforts taken to protect and restore biodiversity and ecosystems, the concept of biodiversity has gradually become popular in China. This review is an attempt to share with the world the learning from China's progress towards becoming an ecological civilization and highlights that the efforts towards biodiversity conservation need to be organically integrated with sustainable development goals.

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1. Introduction

Biodiversity refers to the ecological complex formed by living organisms (including animals, plants, and micro-organisms), the surrounding environment, and the sum of various ecological processes related to them, including ecosystem diversity, species diversity, and genetic diversity [1]. Biodiversity studies include the systematic examination of different kinds of living organisms and the technology by which biodiversity can be maintained and used sustainably for the benefit of humanity [2]. Biodiversity and sustainable development of human society are interrelated. Biodiversity is the common wealth of all mankind. In June 1992, more than 150 countries signed the Convention on Biological Diversity (CBD) for the common goals of conservation and sustainable use of biodiversity. China was one of the first parties to sign the CBD on June 11, 1992. In December 2016, China was chosen as the host

country for the 15th Conference of the Parties of CBD, which is to be held in Kunming, Yunnan Province, in 2020. The upcoming conference will determine the new global biodiversity conservation targets for the next decade [3].

As one of the global environmental issues of international concern, biodiversity conservation studies, including the theoretical bases and practical applications, involves multiple disciplines and research fields. The Chinese government and scholars have paid attention to the relationship between biodiversity and human well-being, and have regarded biodiversity as the material basis for sustainable development. China's Government has developed programs that promote ecological protection and environmental management under the background of rapid economic growth [4], which has greatly restored degraded ecological environments, improved provisions of critical ecosystem services, and increased rural livelihoods [5]. Chinese scientists have also made significant contributions to the world in the realm of conservation and sustainable use of biodiversity. For example, China increased the population of giant pandas (*Ailuropoda melanoleuca*) by establishing nature reserves [6], and succeeded in artificially breeding them. Yuan Longping, a famous rice breeding expert in China who made

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outstanding contributions to the world's food security, developed the first strain of hybrid rice in 1970 by crossing the sterile plants of wild rice (*Oryza rufipogon*) found in Hainan with cultivars. Tu Youyou, a Chinese female pharmacist, won the Nobel Prize for her discovery of Qinghaosu (artemisinin) that helped save millions of lives globally, especially in developing countries. Such achievements in biodiversity conservation have helped lay a solid foundation for the realization of China's 2030 sustainable development goals.

In this paper, we systematically review recent studies and applications in biodiversity conservation in China. Firstly, we summarize Chinese contributions to the theories of biodiversity conservation. Next, we highlight the significant progress made by the Chinese Government and scientists on the related issues such as the planning, implementation, and monitoring of conservation projects, *in-situ* and *ex-situ* conservation, ecological restoration, laws and regulations, and education and public awareness. Our objective with this review is to share with the world China's progress towards becoming an ecologically sustainable civilization and highlight the important role of biodiversity conservation in China's sustainable development.

2. Studies and practices of biodiversity conservation in China

China is one of the mega-biodiversity countries in the world. But at the same time, China is also one of the countries with the most threatened biodiversity. Over the past few decades, China has implemented a number of biodiversity conservation studies and practices. The progress made in the sphere of planning, survey and monitoring, *in-situ* and *ex-situ* conservation, ecological restoration, laws and regulations, education and public awareness (Fig. 1), etc., have been significant.

2.1. A brief summary of Chinese contributions to the theory for biodiversity conservation

Since concepts such as island biogeography, metapopulation, the Minimum Viable Population (MVP), were proposed, they have formed the theoretical bases of most studies on biodiversity conservation, in terms of biodiversity distribution patterns, sustainable use of biodiversity, designing protected areas, and so on. Based on the theory of Island Biogeography, many scientists have undertaken studies on the application of the model and have verified the conformity of different biological groups to the model [7]. With the

accelerated rates of degradation of natural habitats, the theory of metapopulation dynamics has gradually become a hot issue in biodiversity conservation, as well as in ecology, genetics, and evolution. Further, the introduction of some new techniques and technologies, such as molecular marking, geographic information systems, GPS, wireless communication, has further improved the depth and accuracy of the research undertaken [8]. Since the 1990s, with the development of VORTEX, RAMAS, ALEX, GAPPS, and INMAT models, the theory of MVP has received considerable attention [9].

Although China started research on biodiversity conservation relatively late when compared to other countries, a considerable contribution to publications on biodiversity has come from China in recent years (Fig. 2). The Chinese Academy of Sciences (CAS) established the Biodiversity Committee in 1992 and has been organizing a national conference on biodiversity conservation and sustainable utilization once every two years since 1994 [10]. The Biodiversity Committee has also published a reference book titled "Principles and Methodologies of Biodiversity Studies" in 1994, which explains in detail the important principles and methods used in biodiversity research. Further, in 2004, the Chinese National Committee for DIVERSITAS (an International Programme on Biodiversity Science) was created to coordinate and conduct local activities of DIVERSITAS in China, such as promoting domestic biodiversity research and academic exchange (<http://www.cncdiversitas.org/>).

At the same time, many Chinese experts carried out related studies at the level of genes, species, ecosystems and landscapes. At the landscape level, considerable contributions to landscape ecology, especially theoretical and methodological developments, have come from China [11]. In recent years, some unique research has gone into the development and towards elucidating landscape ecology concepts such as the tradeoff of ecological services in changing landscapes [12]. On the subject of ecosystem diversity and function, a series of large-scale field investigating platforms have been established, which have greatly promoted the development of related studies [10]. For example, the Chinese Forest Biodiversity Monitoring Network (CFor-Bio, <http://www.cfbiodiv.org>), initiated in 2004, has been investigating community assembly, evolutionary dynamics, effects of human activities on biodiversity and ecosystem services, and other mechanisms on ecosystem diversity [13]. At the species level, remarkable progress has been made, especially in the sphere of mechanisms for the maintenance of the biological community and the relationship between biodiversity

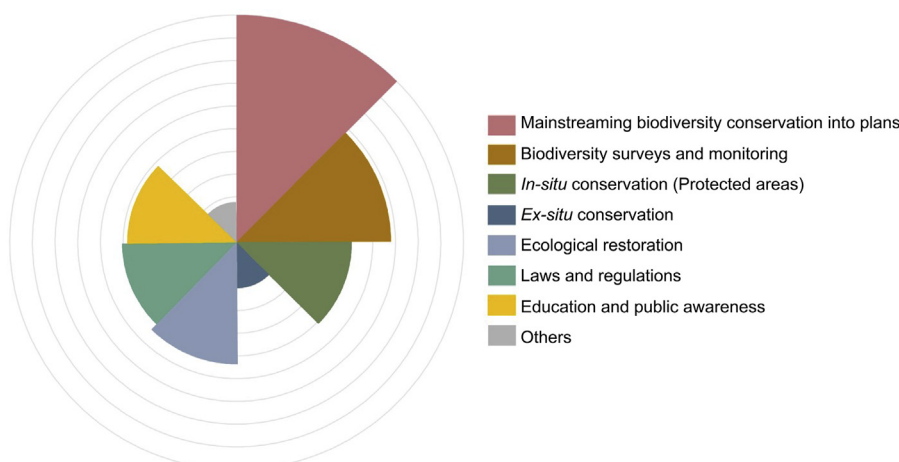


Fig. 1. The issues related to biodiversity conservation practices in China. The numbers of published articles on each issue (obtained from Google Scholar) are shown in the graph.

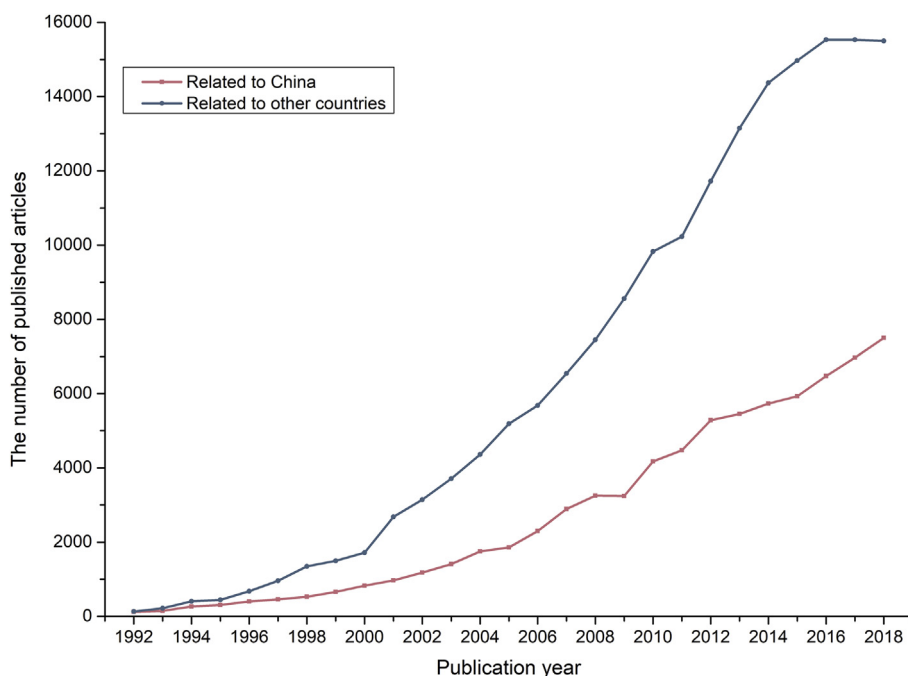


Fig. 2. The number of published articles (1992–2018) by searching for the keyword “biodiversity conservation” in Google Scholar.

and ecosystem functioning [14]. For example [15,16], indicated that elevation variability was the most important determinant of species richness of mammals, birds, and plants across China [17] found that tree species richness was strongly associated with forest productivity, which was driven by faster growth of live trees in a highly diverse subtropical forest in southeast China [18] also revealed the spatio-temporal divergence patterns of the Chinese angiosperm flora as well as the major factors, namely, water and temperature, driving this pattern. Additionally, along with the wide uses of genomics techniques and methods in ecology and evolutionary biology, the accumulation of genomic data has made it possible to solve the problem of species conservation at the genome level [19]. Experts have also suggested that a combination of macro and micro research methods, such as genomics, macrogenomics, transcriptome, proteomics, molecular biology, biochemistry, and cell biology, should be strengthened to address endangered species conservation [20]. These studies have provided theoretical bases for the development of China’s biodiversity sciences in terms of the biodiversity status, causes of threats, and protection and restoration strategies.

With the development of the theories and practices of biodiversity conservation, researchers have come to realize that the key issue is to coordinate the relationship between people and the ecological environment, and then to achieve sustainable development. In 1987, the World Commission on Environment and Development (WCED) published the Brundtland report “Our Common Future”, in which, sustainable development was defined as “paths of human progress that meet the needs and aspirations of the present generation without compromising the ability of future generations to meet their needs” [21]. Then the concept of sustainability science was brought forward to provide the theoretical basis and practical guidance for sustainable development, which focuses on the dynamic relationship between nature and society at local, regional, and global scales [22]. Additionally, many Chinese scholars also proposed that the focus of biodiversity conservation strategies should be expanded from a single target species approach to regional landscape approaches along with the rapid

development of China’s economy and society [23]. Sustainable development, biodiversity conservation, and climate change have become the three frontiers in ecology and environmental sciences in recent years [24].

2.2. Mainstreaming biodiversity conservation into plans

Under the concept of “green mountains and clean waters are gold and silver mountains” [25], the Chinese government has proposed a series of strategic ideas and goals to build an ecological civilization and a beautiful China. Clear national biodiversity conservation targets have been identified within both the overall national development plan and special ecological plans. These initiatives support China’s progress towards an ecologically-sound future based on sustainable growth models and ways of life.

After signing the CBD, in June 1994, the National Environmental Protection Agency (currently upgraded to the Ministry of Ecology and Environment, MEE) and other relevant Departments, brought out the “China Biodiversity Conservation Action Plan”. In 2010, the former Ministry of Environmental Protection (MEP, currently merged into the MEE), jointly with more than 20 Ministries and Departments, updated the “China National Biodiversity Conservation Strategy and Action Plan (NBSAP, 2011–2030)” [26]. The NBSAP identified the strategic goals, strategic tasks, and priority areas and actions for biodiversity conservation in China for the next two decades. And “The National Ecological Function Zoning” released in 2008, along with “The National Main-function Area Plan” released in 2010 have incorporated biodiversity conservation as an important aspect. In 2016, “The 13th Five-year Plan Outline of the People’s Republic of China for National Economic and Social Development (2016–2020)” emphasized the need to “strengthen ecological protection and restoration”, which requires incorporating major conservation initiatives including the creation of a new National Park system and red line designations for ecosystem conservation.

The above-mentioned mainstreaming processes have promoted biodiversity conservation efforts to some degree. However, the contradiction between economic & social development and

biodiversity conservation still exists. Sometimes economic development is often promoted at the expense of biodiversity when there is conflict. Thus, there is an urgent need to further promote the mainstreaming of biodiversity conservation in decision making and management at all levels of the government, and promote the integration of conservation effectiveness into the assessment system of governmental officers.

2.3. Biodiversity surveys and monitoring

Biodiversity surveys and monitoring are the fundamental approaches to establish baseline data on biodiversity, grasp the trends of dynamic changes, identify major threat factors, and analyze the effectiveness of conservation. The Chinese government and researchers have undertaken a number of investigations, scientific studies, and monitoring exercises, and have established relevant databases. To establish a complete biodiversity inventory for the whole country, a series of regional investigations were carried out since the 1950s. Series of books have also been published, such as the “China Vegetation” [27], “Flora of China” (<http://www.iplant.cn/foc/>), and “Fauna of China” (<http://www.zoology.csdb.cn/page/index.vpage>). The “Crops and their wild relatives in China (Vol. Name List)” has recorded 10,446 crops as well as their wild relatives that were closely related to human life [28]. However, many fundamental problems remained unsolved. For example, the baseline data on biological resources was far from completed, and a monitoring and warning system on biodiversity has not been set up [26]. It is necessary to systematically investigate the status of biodiversity in key areas and watersheds of China, identify the major threats, assess the status of conservation and management, and provide a scientific basis for China’s biodiversity conservation.

In the past 20 years, biodiversity surveys organized by relevant departments have mainly been conducted in some key areas or on important biodiversity groups. Since the 1990s, the former National Forestry Administration (NFA, currently National Forestry and Grassland Administration, NFGA) has been undertaking an investigation on the key protected wild animals and plants. The CAS conducted comprehensive scientific investigations in key areas such as the Qinghai-Tibet Plateau. Also, the MEP (currently MEE) surveyed key regions, important species, and genetic resources from 2004 to 2009, and carried out a pilot project for biodiversity inventory in 26 selected counties in Yunnan, Guangxi, and Guizhou from 2010 to 2011 [29]. According to the “Implementation Program for Biodiversity Conservation Major Projects”, special investigations on key areas, key species and habitats, and biological genetic resources are to be implemented by MEE from 2018 to 2023.

Effective biodiversity conservation requires a rapid understanding of how the elements of biodiversity are changing over time [30]. Monitoring change in biodiversity is one of the hot topics in biodiversity science, which has been the focus of many governments and researchers worldwide [31]. Many Chinese institutions have attached importance to long-term biodiversity monitoring. Several monitoring networks, such as the Chinese Forest Biodiversity Monitoring Network (CFoBio) [32], the Chinese Ecosystem Research Network (CERN) [33], China’s Biodiversity Observation Network (Sino BON) [34,35], and the China Biodiversity Observation Network (China BON) [36–38], have been developed to answer a series of scientific questions on changes in biodiversity. Additionally, some potential monitoring sites have also been suggested by complementarity analysis to cover as many species as possible [39]. At the same time, some new technologies have been developed, such as the low-altitude remote sensing by unmanned aerial vehicle [40] and the Mobile Supervising System app [41], which have greatly improved the ability to monitor biodiversity.

Assessing the status and major threats to biodiversity depends

on the accumulated survey and monitoring data, which can provide suggestions to improve conservation management and sustainable use measures [42]. In recent years, Chinese researchers have mainly focused on the assessments of biodiversity value, degree of threat, driving factors, and conservation outcomes. From the perspective of biodiversity value, the MEP officially launched the Economics of Ecosystems and Biodiversity (TEEB) of China in 2013 [43]. Some scholars assessed the major threats to biodiversity and published the books “China Red Data Book of Endangered Animals” [44–47] and “Chinese Species Red List” [48]. In 2008, the MEP and CAS started the project “China Biodiversity Red List” [49]. Until now, the Red list assessments of China’s vertebrates [50,51], higher plants [52,53], and Macrofungi [54,55] have been completed. In-depth studies on the influence of different factors (including human activities, climate change, invasive alien species, etc.) on biodiversity have been undertaken. For example, the MEP and CAS launched a national ecosystem assessment to quantify ecosystem status and trends, and ecosystem service provision between 2000 and 2010. The results showed that China’s national conservation policies contributed significantly to the increases in those ecosystem services [56]. Further, evaluation of the effectiveness of China’s Natural Forest Conservation Program (NFCP) has indicated that the forest cover had significantly increased in around 1.6% of China’s territory [57]. However, China’s existing survey and monitoring data platforms and research networks are relatively inadequate and lack unified planning and coordination, which prevents the in-depth mining and effective use of biodiversity information [58]. The periodic and accurate assessments of biodiversity still need properly planned partnerships and need to be subject to statistical analyses [42]. Thus, it is urgent to establish a comprehensive big data platform with biodiversity and ecological security data as the core information, which can provide strong support and services for the assessments [58].

2.4. In-situ and ex-situ conservation

In-situ and *ex-situ* conservation of biodiversity are two important approaches listed in the CBD. *In-situ* conservation refers to the implementation of conservation actions on ecosystems and natural habitats in their original habitats, and the recovery of species population in their natural environment. *Ex-situ* conservation refers to the transfer of ecosystems, endangered wild animals and plants, and genetic resources to artificial environments or off-site protection [59].

2.4.1. In-situ conservation

Protected areas are the foundation of the *in-situ* conservation system, which play an important role in maintaining national ecological security [60]. Since the establishment of the first protected area, the Dinghushan Nature Reserve, China has established more than 11,800 protected areas covering 18% of its land area and 4.6% of its sea area [61]. Before 2018, China had established more than ten types of protected areas including nature reserves (Fig. 3), scenic spots, forest parks, geological parks, wetland parks, and marine special reserves (including marine parks), which were managed by different Ministries and Departments [62]. This has led to a substantial replication of administrative efforts, a fragmentation of invaluable conservation expertise, and unclear rights and responsibilities [63]. To address the above problems, China’s government has been implementing institutional reforms since March 2018, with the aim of reestablishing a uniform, normative, and efficient system for protected area management [64]. In June 2019, the General Office of the Central Committee, along with the General Office of the State Council, unveiled the “Guideline to Establish the Mechanism of Natural Protected Areas with National Parks as a Major

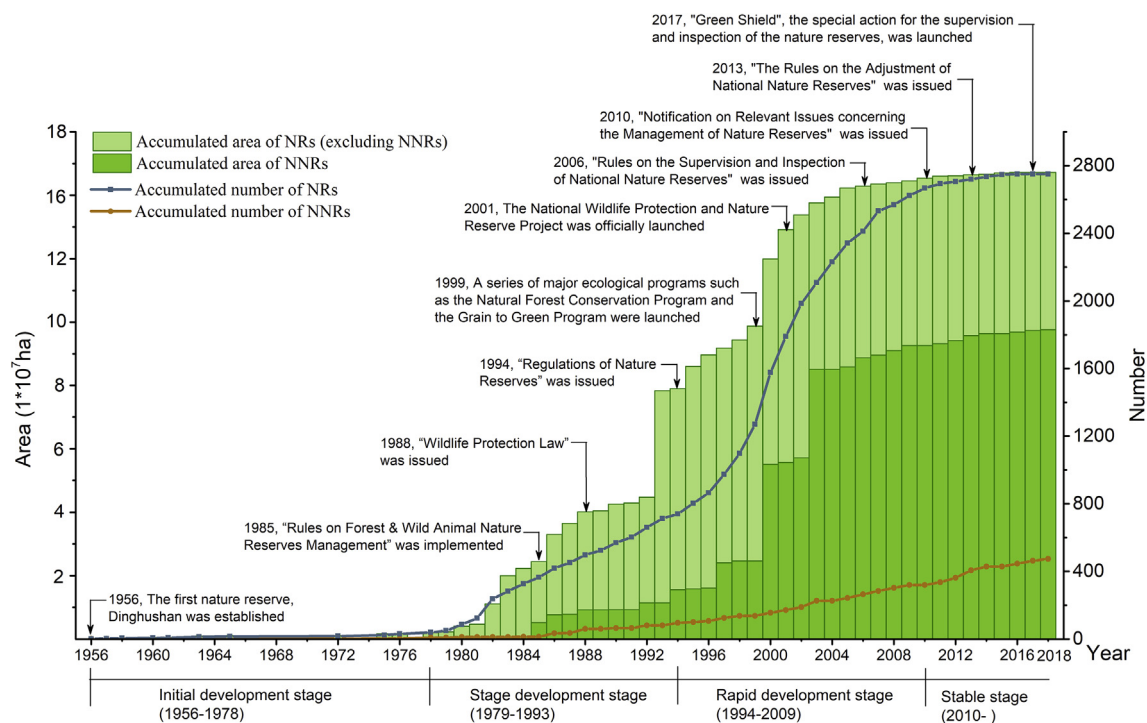


Fig. 3. The development history (1956–2018) of nature reserves (NRs) and national nature reserves (NNRs) of China.

Component” [65]. This guideline aims to build a unified protected area management system with three types of protected areas – national parks (comprising of areas that showcase ecosystems that are characteristic to China), nature reserves (including habitats of some endangered flora and fauna and regions with representative geological conditions), and natural parks (covering regions with natural scenery or relics that are prospective sites for scientific or cultural studies). The development of China’s natural protected areas also marked the entry into a new era of sustainable development.

Studies related to protected areas in China mainly concentrated on their representativeness and effectiveness. Several conservation approaches such as the gap analysis [66,67], hotspots [68,69], systematic conservation planning [70,71], have been applied to assess the representativeness. Before the institutional reforms, the former MEP and the former NFA had separately compiled the national nature reserve development plans. However, China still lacks a systematic plan to build a mechanism of protected areas that offers better biodiversity protection [64]. Except for nature reserves, roles of the other protected area types in conservation have not been widely recognized [72].

Another important question is whether the protected areas have achieved their original conservation goals. Early studies on the effectiveness assessments of nature reserves in China mostly focused on management assessments. The Rapid Assessment and Prioritization of Protected Area Management (RAPPAM) [73] and the Management Effectiveness Tracking Tool (METT) [74] were commonly used methods. Some standards have also been published by different ministries and departments, such as the “*Technical Regulations for the management effectiveness Evaluation of Nature Reserves*” released by the former NFA in 2008, and the “*Standard for Assessment of Nature Reserve Management*” released by the former MEP in 2017. In recent years, with the accumulation of long-term monitoring data and the application of technologies such as remote sensing and geographic information systems, the

assessment of the conservation effectiveness of nature reserves gradually became a hot subject for research. Some researchers studied the effectiveness of nature reserves to protect different ecosystems, such as the forest [75] and the wetland [76] of the whole country. The relevant ministries and departments also started to pay more attention to the conservation effectiveness of nature reserves and carried out a series of related projects [77]. After the establishment of the MEE, which was given the responsibility of monitoring and supervising the management performance and ecological conservation effectiveness for all types of protected areas, the assessment of the status and management of protected areas is likely to be more objective [64].

In addition to protected areas, there have been other forms of *in-situ* conservation measurements in China, such as the Ecological Conservation Red Line (ECRL), the Mini Natural Reserves (MNRs), the Non-commercial Forest (NCF), and the Civil Protected Areas (CPAs). The ECRL initiative began in 2011, with the aim of protecting more than one-quarter of the Chinese mainland and almost all rare and endangered species and their habitats outside the protected areas system [78]. The MNRs are established to protect the national or local key protected wild flora and fauna, and typical plant communities, with the area of no more than 1000 hm² [79]. The development of MNRs is essential to promote the recovery of narrow-ranged species, whose distribution ranges get easily reduced by human activities [80]. The NCF was established in early 2000, where no commercial harvesting was allowed to provide public welfare, social products, or services. When household-contracted forestland is designated as an NCF for generating public benefits, the forest ecological compensation is provided under certain schemes of payments [81]. The CPAs are governed or managed by civil institutions, communities, or individuals to promote ecological protection and sustainable development [82]. The CPAs promote non-governmental resources to participate in the establishment of the protected area system. In addition, some areas managed by local communities also play an important role in

biodiversity conservation, such as the sacred mountains [83] and community forests [84].

2.4.2. *Ex-situ* conservation

When the original habitats are damaged or cleared, and the species population and ecosystem in the wild state are difficult to maintain, *ex-situ* conservation could be used as the final backup [59]. This backup ensures that the potential biological resources needed by humans in the future are adequately protected, researched, evaluated, and used under human intervention and careful management. *Ex-situ* conservation plays an extremely important emergency rescue role for the conservation of endangered organisms with habitat loss or extremely small populations, which is one of the main guarantees for future biological genetic resources security and safeguards against the loss of biodiversity as a result of climate change. In addition, the *ex-situ* conservation is also the basis for the return and reintroduction of rare and endangered animals and plants to their natural habitats, and the guarantee of the restoration and reconstruction of wild populations, which can provide the last chance for survival for organisms that have gone extinct in their natural habitats.

China has been developing zoos, botanical gardens, seed and gene banks, and other types of *ex-situ* conservation activities in the past 30 years. According to statistics, there are 243 zoos established in China, of which, the Wansheng Garden (the predecessor of the Beijing Zoo) affiliated to the Beijing Experimental Farm established in 1906 was the earliest zoo in China [85]. A survey of 68 zoos has recorded as many as 789 wild animal species in their holding [86]. China has also established 250 botanical gardens, 195 of which were reviewed and reported with roughly 288 families, 2911 genera, and 22,104 species of native Chinese plants [87]. CAS has established a comprehensive *ex-situ* conservation program to address the conservation of China's indigenous plant species, especially within its 12 botanical gardens serving as leaders in conservation, research, and public education for all Chinese gardens [88]. Different Ministries and institutions have been continuously strengthening the establishment of seed and gene banks to conserve the forest germplasm resources, medicinal plant germplasm resources, aquatic genetic resources, microbial resources, and wild animal and plant genes. For example, China's Rural Revitalization Strategy 2018–2022 already aims to enhance crop diversity through the protection of crop genetic resources. The China Ordinary Microbial Culture Collection Management Center, one of the main institutions collecting and sharing microbial resources, has kept more than 5000 kinds of microbial resources and a total of more than 46,000 strains [89]. In addition, the Science & Technology Basic Resources Investigation Program of China has been implementing a project to protect the rare plants in tropical China through *ex-situ* conservation [90].

However, there are still some problems and deficiencies in China's current *ex-situ* conservation system. The baseline data and the effectiveness of *ex-situ* conservation for biological genetic resources are still unclear. New challenges including alien invasive species, climate change, and access to biological genetic resources and benefit sharing have exacerbated the loss of biological genetic resources. Thus, the NBSAP (2011–2030) has required to establish and improve systems for preserving biological and genetic resources, and to scientifically protect and reasonably use important biological resources [26]).

2.5. Ecological restoration

In recent years, ecological restoration has been encouraged to aid in the recovery of various degraded ecosystems, such as forest, grassland, wetland, etc. [91]. To address the deterioration of forest

ecosystems and the reduction in biodiversity, China has been restoring natural forests through the six key forest conservation programs [92], especially the Natural Forest Conservation Program (NFCP) and the Grain to Green Program (GTGP) [57,93]. These restoration programs have generated positive ecological effects by increasing vegetation cover, enhancing carbon sequestration, and controlling soil erosion [94]. Many satellite-derived observations have also verified the corresponding results that most regions of China had experienced a greening trend over the past three decades [95,96]. For example, the overall forest area in the Loess Plateau grew at an average rate of 600 km² per year during the period of the GTGP (from 2007 to 2017) [97]. Also, numerous farmers were encouraged to change their income sources from being directly dependent on the land to off-farm jobs, which in turn helped to alleviate the direct dependence on forest resources [57,94].

The Chinese government has also been implementing other projects to restore degraded grasslands, such as the Beijing-Tianjin Sandstorm Source Grassland Treatment Project since 2002, and the Returning Grazing to Grassland Project since 2003. China is striving to raise the vegetation coverage ratio of grasslands to over 57% by 2025. It is reported that these ecological restoration projects in Inner Mongolia showed a more positive effect than those in Mongolia [98]. Also, some practical techniques have been developed to restore special degraded ecosystems, especially the alkaline-saline grassland in the Songnen Plain and the degraded black-soil grassland in the Qinghai-Tibetan Plateau [99].

After the massive flooding in the middle and lower reaches of the Yangtze River in 1998, China initiated several large-scale wetland restoration projects to convert reclaimed low-yield croplands back to wetlands [100]. In 2016, the General Office of the State Council issued the "Scheme on Wetlands Protection and Restoration System". The former State Oceanic Administration also issued a guideline for strengthening the management and protection of coastal wetlands in 2017 with the aim of restoring no less than 8500 ha of coastal wetlands by 2020. Further, a series of short-term and efficient technologies, such as the construction of circle dike to clear *Spartina alterniflora* in the nature reserve of Chong-ming Dongtan [101], were adopted to restore the structure and functions of wetland ecosystems.

At the same time, many Chinese researchers also noticed that it is essential to monitor restoration outcomes to evaluate restoration success. For example, a meta-analysis evaluated the biodiversity changes of restored ecosystems and found that ecological restoration can increase biodiversity by 43% compared to a degraded ecosystem [102]. [103] evaluated the effectiveness of the six key ecological restoration projects, which covered 44.8% of China's forests and 23.2% of China's grasslands, and found that these projects had substantially contributed to CO₂ mitigation in China [104]. Reviewed the effectiveness of several restoration approaches on the Inner Mongolian Steppe, such as the adaptive grazing management, fertilization, and mowing, and reseeding and cultivation, and found that grazing exclusions led to the fastest and most successful recovery of the degraded steppe [105]. Developed a holistic biodiversity index to provide valuable guidance for the management of the freshwater restoration.

Due to the division of departments and decentralized functioning, China set up the Ministry of Natural Resources since the institutional reforms in 2018, which was given the responsibility of coordinating land and space ecological restoration and implementing major projects related to ecological restoration. This is likely to open up new opportunities for ecological restoration to adopt "a holistic approach to conserving our mountains, rivers, forests, farmlands, lakes, and grasslands" in the new era.

2.6. Laws and regulations

The effective conservation of biodiversity needs a complete system of laws, regulations, and policies to guarantee that related activities can be carried out. The Chinese government highly regards biodiversity as an important part of the construction of ecological civilization progress. The mainstreaming of biodiversity has achieved significant effectiveness by establishing a series of laws, regulations, and policies.

Although China has not yet formulated specific laws on biodiversity conservation, there are many related laws and regulations. For example, the “*Environmental Protection Law of the People’s Republic of China*” requires that “the development and utilization of natural resources should be rationally developed to protect biodiversity and ensure ecological security, and formulate and implement relevant ecological protection and restoration governance programs in accordance with the law”, and “the introduction of alien species and the research, development and use of biotechnology should take measures to prevent damage to biodiversity”. Others, such as the Forest Law, Grassland Law, Law on Wildlife Protection, and Nature Reserve Regulations, also make provisions related to biodiversity conservation. It is estimated that China has formulated and implemented more than 20 laws, more than 40 administrative regulations, and more than 50 departmental regulations concerning biodiversity conservation. Meanwhile, some local governments have also formulated several regulations applicable locally. For example, Yunnan Province formulated “*the Regulations on Biodiversity Conservation in Yunnan Province*” in 2018, which is the first provincial-level special regulations [106]. The measures for the conservation and sustainable use of biodiversity, as well as the requirements for the access to biological genetic resources and benefit-sharing, were covered in the regulations for the first time.

At the same time, the Central Committee of the Communist Party and the State Council have formulated a series of policies related to biodiversity conservation in recent years. In 2011, the State Council approved the establishment of China’s National Committee for Biodiversity Conservation, which was chaired by the State Council and composed of 25 Ministries and units. The National Committee for Biodiversity Conservation is responsible for coordinating overall national biodiversity conservation work, such as the adoption of the “*Implementation Program for Biodiversity Conservation Major Projects*”. In 2012, the report of the 18th National Congress of the Communist Party incorporated ecological civilization into the overall development for the first time, and explicitly stated that “the area of forests, lakes, and wetlands should be expanded to protect biological diversity” [107]. In September 2015, the Central Committee of the Communist Party of China and the State Council announced the “*Overall Plan for the Reform of the Ecological Civilization System*”, which requires that “fresh air, clean water, beautiful mountains and rivers, fertile land, and biodiversity are the ecological environments necessary for human survival” [108]. In 2017, the report of the 19th National Congress of the Communist Party further emphasized that “we will carry out major projects to protect and restore key ecosystems, improve the system of shields for ecological security, and develop ecological corridors and biodiversity protection networks, so as to strengthen the quality and stability of our ecosystems” [25].

In general, although the legislation on biodiversity protection has been continuously improved and perfected in China, most of them were developed piecemeal. Current biodiversity laws still have the problems of incomplete legislation and incomplete system [109,110]. And there is inadequate connectivity and integrity between separate laws. Particularly, the lack of basic law on biodiversity conservation at this stage remains a key issue that needs to

be addressed. Also, there are still gaps between the current system of laws and regulations and the actual needs in terms of biodiversity conservation [111]. Existing laws may be ineffectively executed, resulting in a relatively low overall prosecution rate and sentence of cases involving biodiversity was relatively low, and resulting in the ineffectiveness of the punishment and low social prevention effects of the penalty [112].

2.7. Education and public awareness

Public education and awareness dissemination are important elements that were explicitly proposed by the CBD. Addressing the crisis of biodiversity loss requires changes in the behavior of individuals, organizations, and governments. Therefore, the first task of the “Aichi Biodiversity Targets” is that “people are aware of the values of biodiversity and the steps they can take to conserve and use it sustainably” [113]. This requires people not only to recognize the concept and value of biodiversity, and the specific contribution of biodiversity to their lives, but also to transit from willingness to action for the conservation and sustainable use of biodiversity.

In recent years, with the “Beautiful China” initiative to ensure “harmony between human and nature”, the concept of biodiversity has gradually become popular in China. The communicators included government officials, non-governmental environmental protection organizations, enterprises, and individuals. Television, internet, newspapers, radio, and other media have also increased their coverage on the importance and knowledge of biodiversity conservation. New media such as the WeChat platform have become the main way for the public to obtain and disseminate relevant information. From the perspective of communication effectiveness, conservation awareness has significantly improved among the public. Especially after the initiative to build an ecological civilization in 2012, the number of searches using “biodiversity” or “protected area” as keywords on the search engine such as Baidu increased rapidly. For example, the news on “Management Assessment of National Nature Reserves in the Yangtze River Economic Belt” had been reported more than 2,000,000 times by various media, including the website of the State Council, CCTV news, People’s Daily Online, Xinhuanet, and so on.

China is still in a critical period of fighting poverty, and the regions with rich biodiversity often overlap with the regions with poor economic development. Field investigations highlight that the transmission effectiveness of biodiversity-related concept from the central to some remote and isolated villages was weak. As a hot issue of common interest, awareness regarding biodiversity conservation and sustainable development still needs more effort.

3. Conclusion

China has made significant progress in biodiversity conservation studies and practices. A biodiversity conservation and management system, taking the local conditions in China into account, has been established [114,115], which has resulted in the significant improvement of the ecological environment. The country has already initiated globally unprecedented reforestation efforts that have accounted for 25% of the global net increase in leaf area [116]. China’s wild populations of iconic threatened species like the giant panda and the crested ibis (*Nipponia nippon*) have seen strong, recent population increases and are reported to be expanding their distribution ranges. Along with protecting and restoring biodiversity, decisive progress has been made in the fight against poverty, with more than 60 million people having been lifted out of poverty.

Despite the great achievements that have attracted worldwide attention, there are still contradictions between economic development and biodiversity conservation, and the general trend of

decline in biodiversity has not been effectively contained [4]. China still faces many problems, such as climate change, rapid economic growth, and growing middle-class consumption, which have brought growing pressure on the environment and natural resources [117]. The ecological civilization ethos to mainstream biodiversity conservation may represent a possible way forward. The ecological civilization concept points out that the purpose of biodiversity conservation is for the long-term sustainable development of mankind. This will ideally be combined with enhanced efforts to tackle China's persisting environmental issues that are still threatening biodiversity.

The success or failure of ecological and environmental protection has an important relationship with the mode of economic structure and economic development. The efforts of biodiversity conservation need to be organically integrated with sustainable development goals. Thus, we suggest that: 1) Under the framework of the ecological civilization system, incorporating biodiversity conservation effectiveness into the performance appraisal system may further promote the mainstreaming process in government and departments; 2) In the fight against poverty, embodying ecological value and developing ecological industrialization can make sustainable use of high-quality ecological resources in areas with rich biodiversity; 3) Based on ecosystem service values, developing the eco-friendly growth models and ways of life will integrate mankind into the community of life including mountains, rivers, forests, farmlands, lakes, and grasslands; 4) A continued practice of the theory of "lucid waters and lush mountains are invaluable assets" will tell beautiful stories of China's ecological civilization to the whole world in the new era.

Funding

This work was supported by National Key R&D Program of China (No.2016YFC0503304).

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.

Acknowledgements

This work was supported by the National Key R&D Program of China (No. 2016YFC0503304). We are grateful to two reviewers for their insightful comments and suggestions that improved the manuscript quality. We also thank the Elsevier Language Editing Services (<https://webshop.elsevier.com/language-editing-services/>) for editing this manuscript.

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