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Main Achievements, Challenges, and Recommendations of Biodiversity Conservation in China

Fuwen WEI
Institute of Zoology, Chinese Academy of Sciences, Beijing 100101, China, weifw@ioz.ac.cn

See next page for additional authors

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Main Achievements, Challenges, and Recommendations of Biodiversity Conservation in China

Abstract

After nearly 30 years of development, China has basically realized the comprehensive conservation of biodiversity. Biodiversity conservation has been upgraded to a national strategy and incorporated into the top-level design, with laws and regulations gradually being improved and major scientific breakthroughs continuously being achieved. Through the implementation of major biodiversity conservation and ecological restoration projects, establishment of protected area system, and delineation of ecological red line, important ecosystems and endangered species have been effectively protected, and social participation and public awareness have been significantly improved. In addition, by signing a number of biodiversity-related international conventions and agreements and proposing the “Belt and Road Initiative International Green Development Coalition”, China has transformed from an important participant to an active contributor of international agreements. However, there are still problems to be solved and areas for further improvement in biodiversity conservation, such as pursuing quantitative targets while ignoring ecosystem structure and connectivity, insufficient conservation input on marine ecosystem, single source conservation funding mechanism, and non-uniform monitoring data which cannot be effectively integrated and analyzed. In the future, conservation strategies should focus on strengthening toplevel design; promoting the synergy between conventions; integrating biodiversity conservation into the territorial and spatial planning, and pollution control; improving quality instead of pursuing quantitative targets; reinforcing marine biodiversity conservation, the construction of wild animal genetic resources bank and field stations, and the research in invasive species and wildlife infectious diseases; and building a big data platform to facilitate the sharing and data mining of biodiversity information. These Chinese wisdom and solutions will contribute to the construction of global ecological civilization.

Keywords

Convention on Biological Diversity; ecological civilization; wildlife; protected area system; synergy; marine conservation

Authors

Fuwen WEI, Xiaoge PING, Yibo HU, Yonggang NIE, Yan ZENG, and Guangping HUANG

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WEI Fuwen, PING Xiaoge, HU Yibo, NIE Yonggang, ZENG Yan, HUANG Guangping

Institute of Zoology, Chinese Academy of Sciences, Beijing 100101, China

Abstract: After nearly 30 years of development, China has basically realized the comprehensive conservation of biodiversity. Biodiversity conservation has been upgraded to a national strategy and incorporated into the top-level design, with laws and regulations gradually being improved and major scientific breakthroughs continuously being achieved. Through the implementation of major biodiversity conservation and ecological restoration projects, establishment of protected area system, and delineation of ecological red line, important ecosystems and endangered species have been effectively protected, and social participation and public awareness have been significantly improved. In addition, by signing a number of biodiversity-related international conventions and agreements and proposing the Belt and Road Initiative International Green Development Coalition, China has transformed from an important participant to an active contributor of international agreements. However, there are still problems to be solved and areas for further improvement in biodiversity conservation, such as pursuing quantitative targets while ignoring ecosystem structure and connectivity, insufficient conservation input on marine ecosystem, single source conservation funding mechanism, and non-uniform monitoring data which cannot be effectively integrated and analyzed. In the future, conservation strategies should focus on strengthening top-level design; promoting the synergy between conventions; integrating biodiversity conservation into the territorial and spatial planning and pollution control; improving quality instead of pursuing quantitative targets; reinforcing marine biodiversity conservation, the construction of wild animal genetic resources bank and field stations, and the research on invasive species and wildlife infectious diseases; and building a big data platform to facilitate the sharing and data mining of biodiversity information. These Chinese wisdom and solutions will contribute to the construction of global ecological civilization.
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Biodiversity is related to human well-being and provides an important basis for human survival and development. At present, the international community has generally recognized the importance of biodiversity conservation as we are facing the biodiversity loss and the sixth mass extinction. In 2010, the 10th meeting of the Conference of the Parties to the United Nations Convention on Biological Diversity adopted the Aichi Biodiversity Targets. In the same year, the United Nations General Assembly declared 2010–2020 as the United Nations Decade on Biodiversity. Since signing the Convention on Biological Diversity in 1992, China has attached great importance to biodiversity conservation. In the upcoming 15th meeting of the Conference of the Parties to the Convention on Biological Diversity in Kunming, the Post-2020 Global Biodiversity Framework will be developed to create a blueprint for biodiversity conservation over the next 10 years or even longer. This initiative will serve as an important link between the past and the future and will be an important milestone in biodiversity conservation.

China is one of the mega-biodiversity countries, with rich species, and a high proportion of endemic species. To protect the treasure of biodiversity, the Chinese government adheres to the idea of ecological civilization which is consistent with the traditional concept of “unity of nature and man” and has implemented a series of effective measures to mainstream biodiversity in all departments and fields. Many achievements have been made in biodiversity conservation as the Chinese government strengthens biodiversity research and implements ecological protection projects to promote effective restoration and protection of ecosystem. China’s experience in biodiversity conservation provides a model for international community in finding solutions, developing a robust Post-2020 Global Biodiversity Framework, and building a shared future for all life on Earth [1].

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1 Major achievements of biodiversity conservation in China

China has taken a series of effective measures in biodiversity conservation and made good progress by insisting that mountains, rivers, forests, farmlands, lakes, and grasslands are a life community.

1.1 Mainstreaming of biodiversity conservation

Over the years, China has actively mainstreamed biodiversity conservation. In 2011, the China National Committee for Biodiversity Conservation, composed of 23 departments under the State Council and headed by a Vice Premier, was established to coordinate and promote biodiversity conservation. China has improved laws, regulations, and policy systems, legislated to eliminate the bad habit of eating wild animals, enacted and revised laws and regulations related to biodiversity conservation such as the Biosecurity Law, the Environment Protection Law, the Wildlife Protection Law, and the Animal Epidemic Prevention Law. A number of policies and measures have been introduced to clearly establish "basically controlled rate of biodiversity loss and significantly enhanced stability of ecosystems in China" as one of the main objectives of ecological civilization construction, which provides policy support for biodiversity conservation. Formulation and implementation of strategic plans for biodiversity conservation, integration of biodiversity conservation into economic and social development, ecological protection and restoration, and spatial planning of land use have become important tasks of relevant departments of the State Council and local governments.

1.2 Research on biodiversity and conservation biology

The research on biodiversity in China has developed rapidly. The Endangered Species Scientific Commission (Scientific Authority of CITES in China) and the Biodiversity Committee of the Chinese Academy of Sciences were established. Furthermore, Chinese Academy of Sciences has built a strategic biological resource platform, and a number of germplasm banks, in addition to leading the foundation of the Chinese Union of Botanical Gardens and launching the journal *Biodiversity Science*. Since the 1960s, nationwide survey, evaluation, and monitoring of biological resources have been carried out in China and books such as *Flora Reipublicae Popularis Sinicae*, *Flora of China*, and *Fauna Sinica* have been published. Since the 1980s, several biodiversity and ecosystem monitoring networks have been established, including the China Ecosystem Research Network (CERN), the Chinese Biodiversity Monitoring and Research Network (SinoBON), and the China Biodiversity Observing Network (China BON). Based on the survey and monitoring results, the national extinction risk of species in China have been assessed, leading to the publication of *China Plant Red Data Book*, *China Red Data Book of Endangered Animals*, *China Species Red List*, and *China Biodiversity Red List*. Moreover, with the increase in national investment in scientific research, scientists in China have made important progress in conservation biology, such as the origin, evolution, and maintenance mechanisms of biodiversity, ecosystem services and functions, mechanisms of species and ecosystems responding to global changes, and mechanisms of species endangerment [2,3]. A number of important original achievements have been published in *Nature*, *Science*, and *Cell*, and the research level and international influence have been rapidly improved, which provide strong scientific and technological support for decision-making related to biodiversity and endangered species conservation. In addition, to meet the needs of global biodiversity conservation, Chinese researchers have put forward a new vision and a conceptual framework for biodiversity conservation based on the idea of "unity of nature and man" [4], as well as the proportion of minimum natural area required for basic human survival and development, to balance the nature conservation and social development [5].

1.3 Ecological restoration

Since 1978, China has implemented a series of major ecological restoration projects, including Three-North Shelter Forest Program, Natural Forest Conservation Program, Grain-for-Green Program, and ban on the commercial logging of natural forests nationwide in 2017. The implementation of these projects has greatly increased forest coverage and ecosystem carbon sequestration, and improved the natural environment and people's living environment. In the meanwhile, China is committed to the realization of multiple sustainable development goals [6] and the improvement of ecosystem services [7]. In addition, civil organizations and the public are widely involved in ecological restoration activities. For example, in August 2016, "Ant Forest" was launched online, and as of May 2020, 550 million people have participated in planting and maintaining over 200 million trees ①. Satellite data from 2000 to 2017 showed that the vegetation area in China accounted for only 6.6% of the global vegetation area but contributed 25% of the global net increase in leaf area, and 42% of the increase in China's leaf area was from forests [8]. As of January 2021, China's forest coverage has reached 23.04%; the forest stock volume has exceeded 17.5 billion cubic meters, achieving the goal by 2030 ahead of schedule. Forest area and stock volume have increased for more than 30 consecutive years ①.

① People.com. 550 million pairs of feet "planted" this "ant forest". http://env.people.com.cn/n1/2020/0629/c1010-31762639.html. (in Chinese).

1.4 Wildlife conservation and protected area system

Since the establishment of the first nature reserve in 1956, China has taken a series of important measures, including the formulation and revision of laws and regulations such as the Wildlife Protection Law and the List of Wild Animals under Special State Protection in China, the summer fishing moratorium and fishing ban in the key areas of the Yangtze River, and major projects or actions such as National Wild Animal/Plant Protection, Nature Reserve Construction Project, and national park construction [3]. By the end of 2018, there have been a total of 11 800 natural protected areas in China, covering an area of more than 1.728 million square kilometers and more than 18% of the land area. Among these, nature reserves accounted for 15% of the land area and formed a multi-level, multi-type natural protected area system. In 2017, 23 civil organizations established the Protected Natural Area Alliance for Public Welfare, which aims to unite the social forces for public welfare and protect at least 1% of the land area of China by 2030. In terms of *ex situ* conservation, China has established nearly 200 botanical gardens (arboretums), more than 240 zoos (animal exhibition sites), and 250 wild animal rescue and breeding centers ②. Moreover, China has actively carried out joint enforcement actions at the departmental, regional, and international levels to crack down on illegal trade in wild animals and plants that threatens biodiversity, as well as the Green Shield special action to supervise and inspect national nature reserves.

With the advancement of conservation projects and the construction of natural protected area system, the coverage of nature reserves for endangered species, especially endangered mammals, has gradually increased [9]. From 2004 to 2014, the threat to 109 mammalian species was mitigated [10]. For example, the number of giant pandas in the wild increased from 1 114 in the 1980s to 1 864. Nine captive-bred giant pandas were released back to nature and successfully integrated into the wild populations. The population of *Nipponia nippon* reached more than 4 000. The wild populations of *Panthelops hodgsonii* recovered to more than 300 000. *Equus ferus* and *Elaphurus davidianus*, once became extinct in the wild, have established wild populations. Nearly 100 extremely endangered wild plant species such as *Cycas debaoensis* have been protected from extinction, and about 120 species of rare plants have been returned to the wild ③.

1.5 Ecological conservation red line

Delineating and strictly abiding by the ecological conservation red line is an institutional innovation in the spatial management and control of land use in China. The concept of ecological conservation red line was first proposed in 2011 and formally adopted in 2017, and is expanding into the marine sector. By the end of 2019, the preliminarily delineated area of national ecological conservation red line was not less than 25% of China's land area, covering key ecologically functional zones, ecologically sensitive areas and ecologically vulnerable areas. The complete system of ecological conservation red line is expected to protect more than 95% of China's most valuable ecosystems, 100% of the habitats of plants and animals under state key protection, 95% of the best natural landscape resources, the sources of 210 important rivers, and all ecologically fragile areas and regions with important ecological functions [11].

1.6 Ecological benefit assessment

As a common resource, biodiversity has a characteristic of externality. In recent years, ecological benefit assessment has made great progress in China, and the ecological value of mountains and rivers has been gradually transformed into economic value. Researchers have established quantitative evaluation methods to evaluate the regional ecosystem services from 2000 to 2010 [7]. The ecosystem service value of giant pandas and their habitats was estimated to be 2.6–6.9 billion US dollars per year, which was 10–27 times of the investment in the protected areas [12]. Meanwhile, gross ecosystem product (GEP) was developed as a scientific approach to quantify the contribution of nature to human [13]. In addition, China has established a transfer system for key ecological function areas. From 2008 to 2019, the central government transferred CNY 523.5 billion in total, which covered 818 counties annually to maintain the quality and ecological benefit in national key ecologically functional zones ④.

1.7 Implementation of international conventions and agreements

China is deeply involved in international exchange and cooperation, earnestly fulfills international conventions and agreements related to biodiversity, and is among the first countries to sign the Convention on Biological Diversity. Over the years, China has adopted a number of measures to

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①People.com. Carbon and emission reduction in action: China's total carbon stock in forest vegetation has reached 9.2 billion tons. http://finance.people.com.cn/n1/2021/0114/c1004-31999064.html. (in Chinese).

②Xinhuanet.com. China issued the position paper for the United Nations Summit on Biodiversity, "Building a Shared Future for All Life on Earth: China in Action". http://www.xinhuanet.com/world/2020-09/21/c_1126520996.htm. (in Chinese).

③Xinhuanet.com. The populations of rare and endangered wild animals and plants, such as giant pandas and cycads, restored and increased during the 13th Five-Year Plan Period. http://www.xinhuanet.com/local/2021-01/04/c_1126945215.htm. (in Chinese).

④Xinhuanet.com. China issued the position paper for the United Nations Summit on Biodiversity, "Building a Shared Future for All Life on Earth: China in Action". http://www.xinhuanet.com/world/2020-09/21/c_1126520996.htm. (in Chinese).

strictly implement conventions and agreements, including issuing conservation action plans, completing national reports, and hosting conferences of parties. Meanwhile, China has taken the lead in promoting Nature-Based Solution, advocated the establishment of The Belt and Road Initiative International Green Development Coalition, cooperated with more than 100 countries, and implemented a large number of biodiversity cooperation projects. Besides, China has also promoted the integration of the topic of biodiversity conservation into national diplomatic activities and the mainstreaming of global biodiversity conservation. China has transformed from a follower and an important participant to an active contributor to international conventions and agreements [14].

2 Challenges

Despite the progress in biodiversity conservation, the trend of biodiversity loss has not been completely reversed, and biodiversity conservation in China still faces challenges. Most of these problems are worldwide and there is a pressing need to find common solutions.

2.1 Low species diversity and water use problem caused by afforestation

Biodiversity conservation in China used to be directed by quantitative indicators while ignoring system composition and ecological functions, which deviated from the goal of conservation. For example, ecological projects such as the Three-North Shelter Forest Program and Grain-for-Green Program pursued quantitative targets in the early stage but ignored tree species selection and water supply, resulting pure forests planted in large areas. However, large-scale afforestation in arid or semi-arid ecologically fragile areas may pose a threat to the ecosystem and water resource [15]. The density of afforestation on the Loess Plateau has approached the limit of sustainable use of water resource [16]. Artificial pure forests may rapidly improve local eco-environment in the short term, while may trigger ecological crises such as decreases in carbon stocks and land productivity and increases in pests and diseases in the long term [17]. In addition, pure forests may reduce animal diversity and forest biodiversity [18]. Multispecies afforestation has been proved superior to pure forests, which can achieve the dual effects of biodiversity conservation and climate change mitigation [19].

2.2 Large variations in conservation input of different taxa and insufficient attention to aquatic species (especially marine species)

The implementation of ecological projects such as wildlife conservation and nature reserve construction, and natural forest conservation has resulted in the recovery of some species in forests, especially endemic and narrowly distributed species [8]. However, the distribution areas of some species such as large carnivores shrunk, which fail to keep their population size [20]. The proportion and input of protection vary among different taxa. Specifically, the proportion of protected habitats of mammals is higher than that of amphibians and reptiles [21]. The conservation input of aquatic species, especially marine species, are even lower, and many species are still at risk of extinction. For example, more than 30% of fish species in the Yangtze River are on the verge of extinction [22]. Although the construction of marine reserves has achieved some progress, there are still problems that need to be solved [23]. China initiated transnational protected areas as early as in 2010 and carried out cross-border cooperation with Russia, Mongolia, and countries along the southwest borders, though the construction of cross-border protection networks needs to be strengthened urgently. In addition, there are problems such as insufficient research on cryptic species and failure of existing conservation measures to adequately account for the results of research on cryptic species and genetic diversity [24].

2.3 Limited funding sources and insufficient combination of top-down and bottom-up conservation

With the development of social economy, the awareness and social responsibility of enterprises and the public to participate in biodiversity conservation have gradually increased. Conservation foundations and funds are growing rapidly. In 2015, China joined the Global Partnership for Business and Biodiversity (GPBB) launched by the Secretariat of the Convention on Biological Diversity, allowing companies to promote biodiversity conservation by setting up special funds, collaborating with research institutions, and raising funds for ecological conservation. The public participates in biodiversity conservation through projects like Ant Forest, nature observation, construction of small protected area, and community co-management. In general, biodiversity conservation in China is mainly led by the government in a top-down manner, with limited funding sources and lack of participation by enterprises and associations, and the combination of top-down and bottom-up conservation needs to be strengthened.

2.4 Lack of top-level design of protected area system and presence of conservation overlaps and gaps

The number and coverage of protected areas have increased year by year, and the coverage has achieved the Aichi Biodiversity Targets in advance. However, the main aim of early protection of wildlife and construction of protected areas in China is rescuing species from extinction, with emphasis on quantity rather than quality. The background resources of some protected areas remained unclear, with overlaps and gaps in the protected areas due to irrational delineation [25]. There are still problems in protected area system, such as lack of general development strategies and plans, fragmentation and isolation, spatial overlap of different

types of protected areas, unclear land ownership [26], and worldwide poor connectivity of protected area network [27]. In addition, the protected area system was directed by area indicators while neglecting ecosystem integrity and process continuity. Less than 20% of key areas for the protection of mammal and bird habitats are covered by the nature reserve network. The coverage of amphibian and reptile habitats as well as key areas for ecosystem service are even lower [21].

2.5 Insufficient sharing, integration, and analysis of monitoring data

With the increase in protection input and the development of monitoring technologies, a number of biodiversity monitoring networks or platforms have been established in China. These include more than 10 regional or national infrared camera monitoring networks or platforms, which have accumulated a large amount of data. However, owing to the wide range of organizations involved in construction, the metadata format and management/operation mechanisms varied across monitoring networks, making data sharing extremely difficult. Moreover, biodiversity monitoring has overlaps and gaps due to the lack of a systematic plan and a big data platform and the fusion, integration, and in-depth analysis of large-scale biodiversity information have not been performed [28].

3 Countermeasures and recommendations

3.1 Promoting Chinese wisdom and solutions to help global ecological civilization construction

Measures such as mainstreaming of biodiversity conservation, ecological conservation red line, major ecological restoration projects, and ecological benefit assessment have not only accumulated valuable experience in ecological governance in China but also provided high-quality and referential Chinese solutions for global biodiversity conservation and sustainable development. The 15th meeting of the Conference of the Parties to the Convention on Biological Diversity and the Belt and Road Initiative should be taken as opportunities to promote the Chinese wisdom and solutions. We should make full use of the advantages of multidisciplinary integration to set ambitious but practical goals for biodiversity conservation, to protect the nature while supporting human well-being, thus realizing the unity of nature and man.

3.2 Enhancing the synergy of conventions to achieve sustainable development

Climate change and biodiversity conservation are hot spots of global environmental governance [29]. Therefore, synergy among conventions should be promoted to integrate climate change, biodiversity conservation, and spatial planning of land use. At the national level, we should establish a synergistic strategy for the implementation of international biodiversity conventions, promote biodiversity conservation that incorporates climate change risk management, nature-based solutions, and global ecological civilization construction to achieve the goals in United Nations 2030 Agenda for Sustainable Development.

3.3 Combining biodiversity conservation with top-level designs such as spatial planning of land use

It is necessary to timely update the ideas of conservation, strengthen top-level designs, and shift from rescuing species to systematic protection. In addition to the area and other quantitative targets, protected area plans should enhance the connectivity of existing protected areas and provide a robust network for biodiversity conservation. In addition, spatial planning of land use and pollution control based on biodiversity conservation should be strengthened. Biodiversity conservation targets should be incorporated into regional sustainable development plans. Natural protected areas, basic farmland, and other land spaces should be coordinated to promote the comprehensive management of eco-environment.

3.4 Broadening funding sources and enhancing the protection of areas with conservation priority and gaps

We should establish the policies and mechanisms for ecological compensation, transfer payment, and benefit sharing, broaden the funding sources of biodiversity conservation, and stimulate the enthusiasm of enterprises and the public to achieve comprehensive conservation of biodiversity with the participation of all parties. Meanwhile, input should be increased in the areas with conservation priority and gaps, such as areas with high genetic diversity of vertebrates in Southwest and South China [30], as well as habitats of amphibians, reptiles, and aquatic species and cross-border areas. Further, we should establish cross-border reserves and ecological corridors to optimize, integrate, and improve natural protected area system in combination with national strategies such as national park construction.

3.5 Strengthening field station construction and conducting long-term observation and research on biodiversity

Field stations for observation and research are important infrastructures for the research on biodiversity, resources, environment, and ecosystem protection. Various types of field stations should be built in hot spots and sensitive areas of biodiversity in China to broaden the network of biodiversity observation and investigation. Through the integration of multidisciplinary efforts and new technologies and methods, long-term observational investigation should be conducted for endangered species and their habitats. We should strengthen the research on the process and mechanism of

species endangerment as well as the origin, evolution, and maintenance of biodiversity, systematically elucidate major present and future threats facing biodiversity conservation in China, and on this basis develop scientific countermeasures.

3.6 Establishing big data platforms to promote the sharing and deep mining of biodiversity data

We should improve top-level designs, set standardized monitoring protocols, optimize monitoring networks, and integrate monitoring data on large scales. New technologies such as unmanned aerial vehicles, small satellite low-altitude remote sensing, thermal infrared remote sensing, and satellite data should be combined with traditional monitoring methods to establish a big data platform. Real-time sharing, deep mining, and visualization of biodiversity information can be achieved by taking the advantage of big data analysis involving other forms of big Earth data, by advanced technologies such as the Internet of Things, automatic data transmission, automatic image identification, cloud computing, artificial intelligence, and model simulation. These technologies support the quantification, refinement, and intelligentization of decision-making and management in biodiversity conservation.

3.7 Strengthening the study and protection of genetic diversity and building a genetic resource bank for wild animals

Genetic diversity is an important component of biodiversity and a key factor in the survival of species and the functioning of ecosystems. Although the Convention on Biological Diversity involves the protection and benefit-sharing of genetic resource, the focus remains on the protection of genetic resources of cultivated plants and domestic animals, with little attention paid to the genetic diversity of wild animals and plants. Therefore, it is necessary to strengthen the protection of genetic diversity of wildlife, which can be achieved mainly by constructing a genetic resource bank for wildlife. China has invested and established the Germplasm Bank of Wild Species in Kunming while has no specific plan for the construction of wild animal resource bank, especially genetic resource bank. Therefore, China should step up the construction of wild animal genetic resource bank and preserve the genetic resources of endemic, rare, and endangered animals to provide resources for the strategic conservation of germplasm and biodiversity in China.

3.8 Promoting the construction of marine national parks and strengthening the protection of marine biodiversity

Marine biodiversity conservation has become a global focus and requires cooperation with the international community [31]. We should continue to actively participate in the negotiation on the conservation and sustainable use of Marine Biodiversity of Areas Beyond National Jurisdiction (BBNJ), and promote the construction of marine national parks as well as the delineation of marine ecological conservation red line in China. Not only the area of marine reserves but also the quality factors such as connectivity and representativeness should be increased. Furthermore, we should control fishing intensity, strengthen the prevention and control of marine pollution, and promote ecological compensation for marine reserves and special protected areas. According to the principle of land-sea coordination, the "Bay Chief System" can be explored to strengthen the construction of beautiful bays and comprehensive marine management, which can facilitate the protection of marine biodiversity. With the implementation of "Go to The Deep Blue" as a marine development strategy of China and the enhancement of deep-sea exploration capability, it is necessary to strengthen marine biodiversity monitoring network construction and deep-sea biodiversity monitoring research.

3.9 Strengthening the research on invasive species and wildlife infectious diseases

Invasion of alien species due to human activities has become a major eco-environmental problem. In view of the major national strategic needs of prevention and control of invasive species, it is necessary to strengthen the research on the invasion process, ecological damage, rapid evolution, early warning, and prevention of invasive species in biodiversity conservation hot spots in China, and to build a framework for early warning and prevention of species invasion in the current and future scenarios. Given that about 70% of new outbreaks of human infectious diseases are closely related to wild animals, which pose a serious threat to the health of wild animals and human beings, we should conduct background investigation for the wild animal populations carrying key epidemic sources and pathogenic microorganisms, and explore the ecological paths and key factors of cross-species transmission of epidemic diseases originated from wild animals. Additionally, we should develop key technologies to cutoff cross-species transmission, to provide early warning, and to reduce the risk of epidemic diseases. These technologies can be used to support the strategies of biodiversity conservation, ecological safety, and public health safety.

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WEI Fuwen, corresponding author, Academician of Chinese Academy of Sciences (CAS), Fellow of the World Academy of Sciences for the Advancement of Science in Developing Countries (TWAS), Professor of Institute of Zoology, CAS. Professor Wei is currently the Executive Deputy Director of the Endangered Species Scientific Commission of the People's Republic of China (Scientific Authority of CITES in China), Deputy Chairman and Secretary General of the China Zoological Society, and Chairman of the Mammal Branch, China Zoological Society. He is mainly engaged in the conservation biology research of endangered animals such as giant panda and red panda. He initiated the subdisciplines of Conservation Evolutionary Biology and Conservation Metagenomics. E-mail: weifw@ioz.ac.cn

