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Review

Wetlands in China: Evolution, Carbon Sequestrations and Services, Threats, and Preservation/Restoration

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Abstract: China has a wetland area of 53.42 million hectares, the fourth largest in the world; it includes all types of wetlands defined by the Ramsar Convention and has a carbon sink capacity of more than 1.71 million metric tons per year. Inland wetlands in China are mainly distributed in 10 major catchments, among which the Yellow River, the Yangtze River, the rivers in the northwest, and the rivers in the northeast each have more than 8 million hectares of wetlands. There are 4220 species of plants and 4015 species of animals in China's wetland ecosystem. The wetland resources that have been developed and utilized include edible products, reeds for paper making, peat for fertilizer, fuel for power generation, and chemical, pharmaceutical, ceramic, and building materials. However, wetland areas in China have shrunk by about 54% since 1980. In recent years, China's central government has set great store by Chinese wetlands, and although 49.03% of wetland area is now officially protected, many issues have confounded the implementation of that protection. It is imperative that knowledge gained from scientific research be used to formulate a sound wetland protection and management plan that takes into consideration social, economic, and ecological issues in a way that facilitates the sustainable use of wetland resources and informs decision-makers of the paths that must be followed to achieve that goal.

Keywords: wetland resources; function; sustainable use; strategies; protection

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1. Introduction

Wetlands, forests, grasslands, deserts, and oceans are among the major ecosystems of Earth. As a special natural complex formed through the interaction of land and water, wetlands are part and parcel of Earth's surface sphere. Wetlands are among the most productive of Earth's ecosystems and provide habitats for highly diverse biological communities and some of the most valuable ecosystem services on an areal basis [1]. Those ecological services include the regulation of water supplies, treatment of wastes, regulation of disturbances, and provision of recreational and cultural resources. It has been estimated that the economic value of global wetlands is about USD 5 trillion annually [1]. Realization of the value of wetlands explains why, in recent years, many countries have become proactive in identifying ways to manage wetlands sustainably.

At present, a complete, unified system for wetland definition and classification has yet to be established worldwide because of the natural variability of wetlands—their diverse causes of formation and wide distribution—as well as differences between research methods and purposes. The general system for wetland definition and classification, proposed by the Ramsar Convention and widely used by researchers in the international community, defines wetlands as "areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish, or salt including areas of marine water, the depth of which at low tide does not exceed 6 m". According to this definition, wetlands can be divided into three categories: marine/coastal wetlands, inland wetlands, and artificial wetlands. These three categories include 42 types of wetlands. China, which is among the countries with the most diverse types of wetlands, is the country with the fourth-largest wetland area in the world. Chinese wetlands include all the wetland types defined by the Ramsar Convention. China was among the earliest civilizations to recognize the value of wetlands in ancient times. Tao Yuanming, a scholar of the Wei and Jin Dynasties (circa AD 365–427), described in his work Peach Blossom Land that there was a "celestial peach blossom garden—wetland" at the end of the water source. There were abundant water sources, fertile soil suitable for farming, with luxuriant flowers and tweeting birds. The garden looked like a natural museum of flora and fauna. The place described in the article is now Taoyuan County in the Hunan Province of south-central China [2]. There were also discussions of wetlands in the Collection of Ancient and Modern Books: Kaogong Dian: people in the pre-Qin period were surprised to find that the shallow shoals and marsh waters left behind at low tide contained a mysterious power that prevented flooding and resisted bad weather [3]. During the Northern Wei Dynasty (A.D. 386–534), Li Daoyuan, in his annotations on the Classics of Water, recorded many details about gardens he noticed during his field trips to rivers, and he drew pictures of pre-Qin gardens and wetlands. At the same time, he also described the characteristics, valuable resources, agricultural productivity, ecological function, and the use and development of wetlands by people in the pre-Qin period [4].

China is also among the countries faced with the great challenge of balancing short-term interests and sustainable development when it comes to natural resource conservation. According to the results of two nationwide wetland surveys, between 2003 and 2013, the total wetland area in China decreased by almost 3.40 million hectares, a reduction of 8.8%. During this time, the natural wetland area decreased by 3.38 million hectares or 9.3% [5]. On the scale of the international classification of wetland ecological status, China is generally ranked at a medium level, with 15% of its wetlands rated as good, 53% as medium, and 32% as poor [5]. Globally, the decline of China's wetlands is just a case in point of humankind's inadequate stewardship of Earth's natural resources and one example of an increase of produced capital at the expense of natural capital. This paper reviews the status of wetland resources in China, including the evolution of their geographical distribution, ecosystem services and functions, and threats, as well as policies and steps taken to manage and protect them. Finally, we propose a strategy for the sustainable management and protection of wetlands that would strike a balance between ecological protection, economic development, and the use and treatment of water and wastewater. This strategy can serve as a template for other developing countries.

2. Data Sources and Study Methods

The data sources used in this study included the areas of 1337 national wetland parks and wetland nature reserves in 2017, provided by the Wetland China website (www.shidicn.com, accessed on 3 June 2018); the spatial distribution map of nationwide surface water systems (1:1,200,000) provided by the China Institute of Geo-Environment Monitoring under the China Geological Survey, Ministry of Natural Resources; the second nationwide wetland survey data released by the State Forestry Administration in 2014; and the 2019 nationwide coastal wetland survey report by the Qingdao Institute of Marine Geology, China Geological Survey. An ArcGIS spatial analysis was used to plot a geographical distribution map of wetlands in China with reference to drainage basin atlases. The wetland area of each drainage basin was estimated based on the distribution of national wetland parks and wetland nature reserves:

$$S_{idb} = (S_{ire} \times S_{wl})/S_{re} \quad (1)$$

where S_{idb} is the natural wetland area in each drainage catchment; S_{ire} is the area of wetland parks and wetland nature reserves in each drainage catchment; S_{wl} is the nationwide natural wetland area; and S_{re} is the area of nationwide wetland parks and wetland nature reserves. The current distribution of coastal wetlands was estimated by the Aero Geophysical Remote Sensing Center of the China Geological Survey via satellite remote sensing images, such as the Landsat Enhanced Thematic Mapper (ETM), Thematic Mapper (TM), Advanced Land Observing Satellite (ALOS), Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), and Satellite Pour l'Observation de la Terre (SPOT), based on the distribution of coastal wetlands in 2017. In accord with China's three-level classification system for coastal wetlands, we used the remote sensing inversion method as the main technological tool, supported by TM/ETM+ and SPOT5 remote sensing images, as well as large-scale vectorized topographic data (1:50,000) and DEM to interpret the main landscape types of coastal wetlands. We then used supervised classification and targeted information extraction to examine the main landscape types with an accuracy of up to 1:250,000 and, in this way, formed one-time phase remote sensing results of the wetland landscape types.

To get a comprehensive understanding of China's wetland resources, functions, and utilization status, we searched the Web of Science and China National Knowledge infrastructure (www.cnki.net, accessed on 1 December 2021) with the keywords "China", "wetland resources", "wetland functions", and "wetland status". Articles identified in the search and published in the past ten years were screened and summarized. In addition, China's wetland-related management policies were consulted from relevant government websites (www.gov.cn, accessed on 1 January 2022) and the literature published by the State Forestry Administration [5–8].

3. Results

3.1. Distribution and Evolution of Wetlands in China

China is located on the eastern side of the Eurasian continent and forms the west coast of much of the North Pacific Ocean. China is a vast territory with diversified climates and a complex topography. Its many rivers, numerous lakes, and long coastline have led to the creation of a variety of wetlands. According to the second Nationwide Wetland Survey (2009–2013), China's total area of surveyed wetlands (excluding paddy fields and the wetlands of Hong Kong, Macao, and Taiwan) was 53.5 million hectares and accounted for 5.6% of the total land area of China, of which 46.7 million hectares were natural wetlands that accounted for 87.4% of the total wetland area. According to the current classification statistics, among China's natural wetlands, there are 21.7 million hectares of inland marshes, 10.6 million hectares of riverside wetlands, 8.59 million hectares of lakeside wetlands, and 5.80 million hectares of coastal wetlands that account for 40.7%, 19.8%, 16.1%, and 10.9%, respectively, of the total natural wetland area [7]. Chinese wetlands are widely distributed, and there are significant regional differences between them. In this analysis, we divided China's wetlands into 10 zones with regard to their spatial distribution of surface water systems: the Yangtze River catchment (11.5 million hectares), Yellow River catchment (9.07 million hectares), northwest river catchment (11.3 million hectares), northeast river catchment (8.29 million hectares), southwest river catchment (1.80 million hectares), Yarlung Zangbo River and Tibetan river catchment (1.61 million hectares), Huaihe River catchment (1.31 million hectares), southeast river catchment (0.97 million hectares), Haihe River catchment (0.52 million hectares), and the Pearl River catchment (0.27 million hectares) (Figure 1). It is clear that natural wetland resources in China are distributed mainly in the catchments of the Yangtze River, the Yellow River, and rivers in the northwest and northeast.

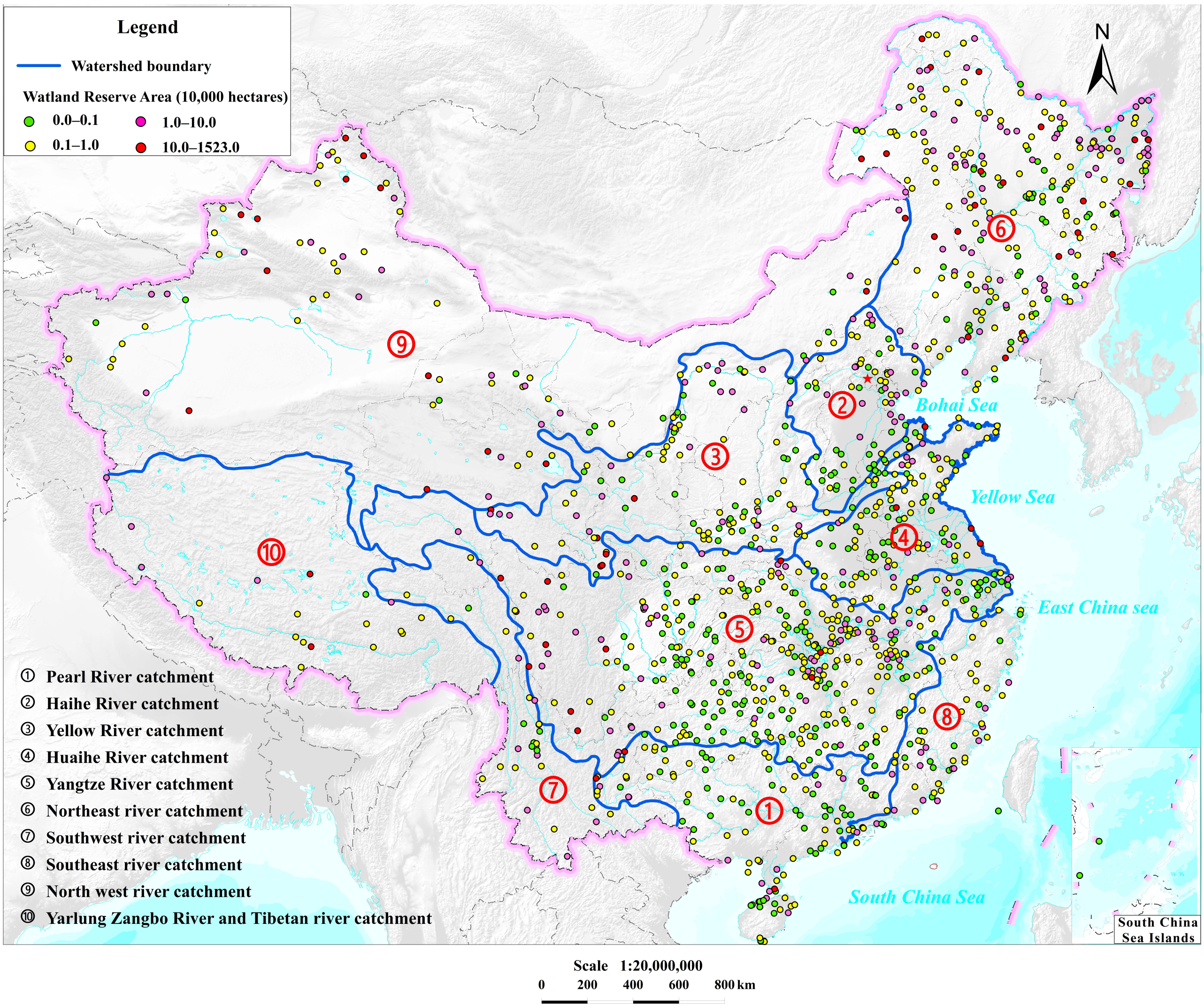

Figure 1. Distribution of China's natural wetlands.

Over the past half-century, serious degradation of wetlands has occurred because of the dual impacts of climate change and human activities. This wetland degradation has threatened regional ecological security and sustainable socioeconomic development. According to the Millennium Ecosystem Assessment of 2005, more than 50% of global wetlands were degraded in the last century. Between 1950 and 2010, 57% of China's coastal wetlands were degraded [9], and the total area of coastal wetlands (including wetlands covered by vegetation and tidal flats) shrunk by 54% from 1975 to 2017 [10].

Although awareness of the importance of wetlands has been increasing since 2000 and some wetland nature reserves have recently been established, the total wetland area shrunk by 36.2% between 2012 and 2017, and only 19 wetlands expanded during that time (Figure 2, Table S1) according to a comparative study of the 50 wetlands listed in the International Wetlands Convention.

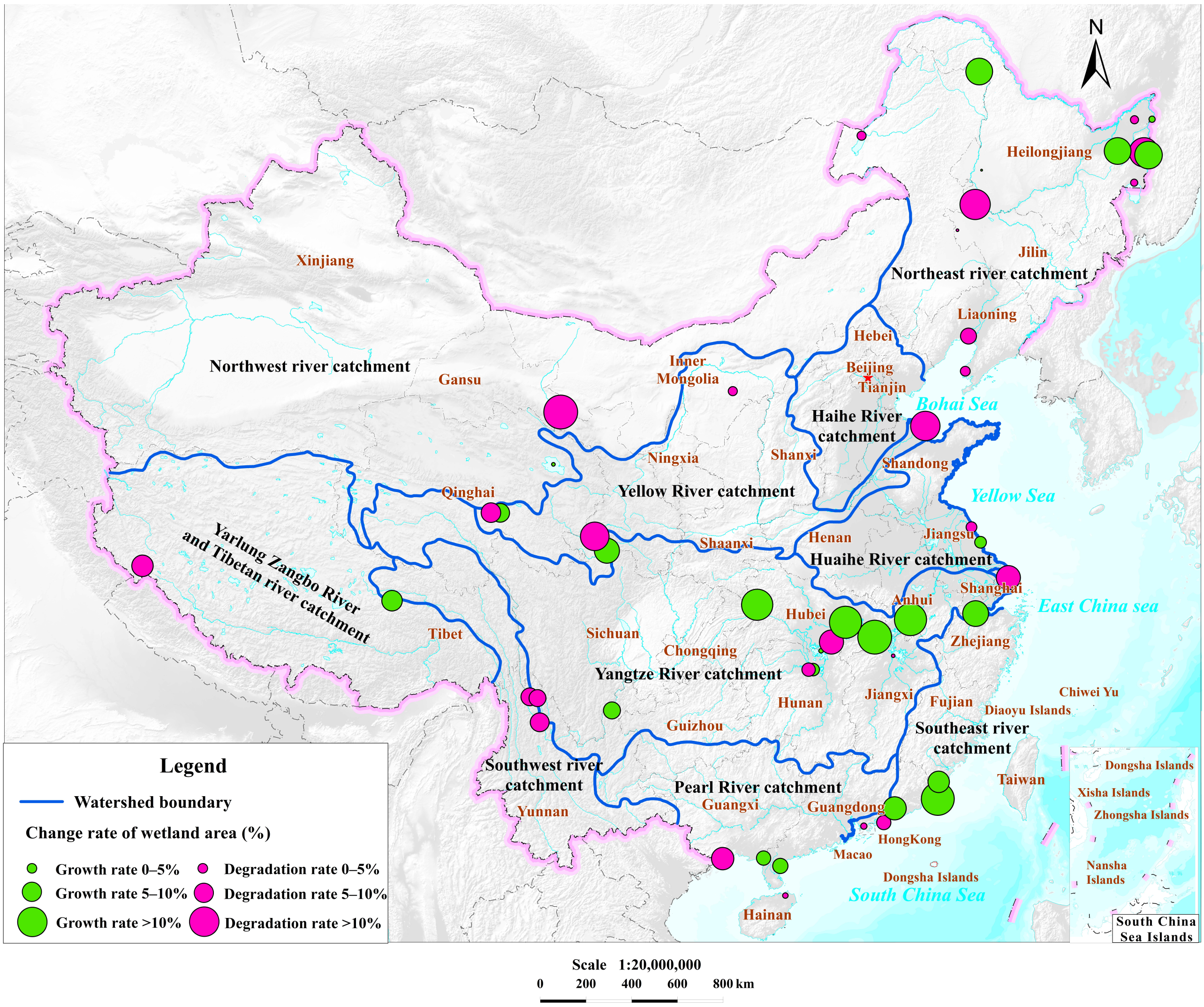

Figure 2. Rates of change of the 50 wetlands listed in the International Wetland Convention from 2012 to 2017 (red indicates a decrease in wetland area; green indicates an increase in wetland area).

3.2. Resources and Services of Wetland Ecosystems

As an important part of natural resources, wetlands have proved to be of great value to human society [11,12]. Inter alia, they help to store surface water, control flooding, trap silt, transform nutrients, regulate climate, decontaminate water, and protect coastlines. In addition, wetlands are important habitats for fish, shellfish, and many other wild fauna and flora, and they are sources of food, raw materials, and recreational resources for human beings [12]. That said, not all the functions of wetlands benefit humanity. For example, wetlands are breeding grounds for mosquitoes, which are vectors of many infectious diseases, including dengue fever, yellow fever, and malaria, that are a threat to human life and health [13,14]. Even so, the benefits of wetlands far outweigh their costs [1].

3.2.1. Biological Resources of Wetlands

Wetlands nurture a plethora of animals, plants, and microbial resources. At the very core of the wetland ecosystem are plants, the main source of materials and energy for metabolism, and natural shelters and habitats for other wildlife species. A total of 4220 species of higher plants belonging to 1255 genera, 239 families, and 3 phyla have been discovered in the wetlands in China. These plants include 2315 species of typical wetland plants belonging to 692 genera in about 200 families or, specifically, 6 species of gymnosperms, 96 species of ferns, 153 species of bryophytes, and 2060 species of angiosperms [5]. In terms of economic value and application, wetland vegetation may be divided into ornamental plants, dye plants, edible plants, medicinal plants, environmentally friendly plants, and plants that are genetic resources. In terms of their environmental distribution, wetland plants in China may be divided into five communities: vegetation in shallow water, mangrove vegetation, sea-grass vegetation, salt marsh vegetation, and marsh vegetation. Among ecosystems of various vegetation types, wetlands dominated by herbaceous plants constitute the mainstay and basic component of China's wetland ecosystems. Grass is the most common type of marsh vegetation; it covers the largest wetland area and is most widely distributed. Grass accounts for about 45.8% of China's total wetland area [5].

Animals play a vital role in the cycle of materials in wetlands, energy flow, and ecological stability. China enjoys a high diversity of wetland animal species, but their distributions are very uneven because of the disparities between different kinds of wetland ecosystems. By the end of 2013, the nationwide wetland survey recorded 1703 species of invertebrates and 2312 species of vertebrates in wetlands, among which the invertebrates fell into 297 families, 65 orders, 19 classes, and 9 phyla, including 3 species of coelenterates, 27 annelids, 1026 mollusks, 643 arthropods, 1 nemertean, 1 phoronidae, and 1 echinodermata; the vertebrates belonged to 226 families, 51 orders, and 5 classes, including 1763 species of fish, 215 amphibians, 83 reptiles, 231 species of birds, and 20 species of mammals [5].

Birds are the most charismatic of wetland animals. The wetland of Dongting Lake is a breeding ground for 258 species of birds, among which is the lesser white-fronted goose, one of the world's rarest waders. The white-footed geese that winter on Dongting Lake account for 30% of the white-footed geese in the world. The wetland of Sanjiang Plain is a breeding and migration sanctuary for endangered birds such as white-naped cranes, red-crowned cranes, oriental white storks, northern pipits, and Anatidae. China's Ruoergai (Zoige) wetland, the largest alpine marsh in the world, is the main habitat of black-necked cranes, a rare bird species under state protection level I. The Yancheng wetlands are home to almost 100% of the overwintering red-crowned crane species of China or 70% of the world's total number (data from http://www.yellowsea-wetland.com, accessed on 1 December 2021).

Wetland microorganisms include bacteria, archaea, fungi, viruses, some microscopic algae, and small protozoa [15]. Wetland soil may contain hundreds of millions of microbes that include tens of thousands of species per gram of soil. Those microbes may include bacteria that produce antibiotics or catabolize environmental pollutants [16]. However, unlike wetland plants and animals, wetland microorganisms are too tiny to be observed without a microscope. The vast majority of microbes cannot be isolated and cultured, and their sheer numbers and variety make a nationwide census very difficult [17,18]. In recent years, as their significance has become apparent, surveys of microbial resources and studies have been carried out in greater depth and breadth, thanks to the development of high-throughput sequencing technology and bioinformatics [19]. Surveys of 42 wetlands in the Qinghai-Tibet Plateau and other inland and coastal areas have indicated that Proteobacteria are the main bacterial groups in China's wetland soils, followed by Chloroflexi, Acidobacteria, Actinobacteria, and Bacteroidetes [20]. Among the fungi, Ascomycota and Basidiomycota dominate wetland soils in China [21,22]. An indisputable fact is that most published studies have been limited to local wetland microbes, and the research methods have differed between studies. It is, therefore, difficult to make a quantitative assessment of wetland microbial resources nationwide because of the lack of dynamic monitoring and data integration [23]. There is plenty of room for improvement in this respect.

3.2.2. The Role of Wetlands in Purifying Water and Decontaminating Wastewater

Wetlands have been called the "kidneys of Earth" because of their ability to decontaminate waste. Decontamination is a complex biochemical process that involves the disposal of pollutants in wetland soil, plants, and microorganisms through sedimentation, filtration, adsorption, biological assimilation, and transformation [24]. Research on this ecosystem service began in the 1950s. For example, nitrogen in pollutants is removed through soil adsorption and filtration, plant uptake, and nitrification and denitrification by microorganisms [25], while phosphorus is removed mainly through the adsorption and precipitation of soil particles and assimilation and utilization by plants and microorganisms [26]. It has been reported that 42% of the N and 65% of the P in terrigenous nutrients are captured by the reed wetland of Baiyangdian Lake in the Hebei province [27], and 53% of the N and 59% of the P in the incoming pollutants are removed by the Xiaoyezhang wetland of the Sanjiang Plain [28]. These percentages are indicative of the capacity of wetlands to remove N and P from nutrient-enriched wastewater. Heavy metal ions are normally converted into non-toxic substances through adsorption onto soil particles or precipitation and uptake by plants [29]. For example, Zhao et al. [30] constructed 15 kinds of wetlands with different wetland plants to treat farmland runoff in the Sanjiang Plain. Their experimental results showed that the average cumulative removal rates of Cr, Pb, Cu, and Zn by the constructed wetlands were 92%, 54%, 13%, and 73%, respectively. In Fankou, Shaoguan, Guangdong province, a 10-year monitoring study showed that a constructed wetland could remove 99% of the Pb, 97% of the Zn, and 95% of the Cd in wastewater from treating lead-zinc ore [31].

3.2.3. Water Conservation and Flood Control

Early in the Qin dynasty (221–206 BC), the Chinese people came to recognize the water conservation and flood control service of wetlands. According to the Collection of Ancient and Modern Books: Kaogong Dian, Qin businessmen were proud of their breeding wetland on the outskirts of the Yong capital and talked about how the country could ensure a continuous supply of water for the people in spite of severe drought in order to show the strength of their own country [3]. Wetlands function as regulators of water systems. They can control river runoff, recharge groundwater, maintain the regional water balance, and mitigate flooding. Especially in the case of controlling the risks of flooding, wetlands act as an important part of water management at the regional, national, and even international levels. Specifically, during flood seasons, wetlands can reduce flood risks, thanks to their high soil porosity and large capacity to absorb and store incoming water so as to reduce surface runoff, slow flow rates, and attenuate flood peaks. In non-flood seasons, wetlands can become sources of water as they release stored water slowly or recharge groundwater by way of downward and lateral infiltration. In the Sanjiang Plain of northeast China, the porosity of the grass root layer and peat layer of marsh soil is 72–93%, with a maximum water holding capacity of 400–600%. This means that the water storage capacity of marshes in the whole region may be as high as 3.84×10^9 m^3 [32,33]. Studies have shown that in the Poyang Lake region, peak flood flows may be attenuated by 15–30% by wetlands through regulation. In the catastrophic flood of 1954, wetlands reduced peak flows by as much as 53% [34]. These observations show that wetlands effectively reduce flood threats to the lower reaches of the Yangtze River. In the Ruoergai wetland, peat covers an area of more than 5000 km^2, with a maximum depth of 38 m and a gross reserve of seven billion m^3 [35]. Given the water storage of 800 kg/m^3 peat, the total water storage in the peat area may reach 5.6 billion m^3, sufficient for 1.4 billion Chinese people to consume for 11 years. The Ruoergai wetland is an important source of water in the Yellow River system. After flowing through this area, the flow of the Yellow River increases by 29% in normal seasons and by 45% in dry seasons [36]. As a source of water in the western plateau, the Ruoergai wetland is of great significance in regulating regional water resources and maintaining ecological and climate balance in the basin of northwest China.

3.2.4. Climate Regulation and Carbon Sequestration

Wetlands also play an important role in regulating regional climate and mitigating global climate change. This important ecological service reflects several different characteristics of wetlands: they are covered with water all or much of the time; their sediments are anoxic; and their soils that are exposed to the air are soft and typically covered with vegetation. On a regional scale, the regulation of climate by wetlands reflects the evaporation of water vapor from the liquid water that covers wetlands all or much of the time and evapotranspiration from peripheral vegetation. The evaporation and evapotranspiration of water change the air temperature and humidity of the surrounding area. The marsh wetland in the Sanjiang Plain, for example, is a region of relatively cool temperatures and high humidities compared with the surrounding dry land. The effect of the wetlands on local climate is increasingly apparent at lower elevations [37]. In Guangzhou, studies have revealed that air temperatures gradually increase and relative humidities decrease with increasing distance from the urban wetland landscape. The fact that the average wind speeds also decrease with increasing distance from the wetland reflects the role of wetlands in regulating microclimates [38]. On a global scale, wetlands regulate climate by fixing and sequestering carbon dioxide from the atmosphere and, in that way, mitigate global warming. The wetlands of China cover an area of 53.42 million hectares, the largest area of wetlands in Asia. Based on the carbon sequestration rate estimated by Wang et al. [39], Chinese wetlands sequester more than 1.71 million tons of carbon per year, about 5% of current CO_2 emission rates.

3.3. Food Production and Raw Materials

Wetlands provide the habitat for a wide range of food chains and are characterized by rich biodiversity. They have been a source of food and raw materials for human civilizations for thousands of years. As early as the pre-Qin period (~230 B.C.), wetlands were used to create magnificent imperial gardens [3]. Wetlands have served as sources of fresh water, plants, animals, peat, and minerals, and today, wetlands are also an important recreational resource. During the 21st century, population growth and rapid economic and social development have increased the demand for wetland resources, including food and medicine. A series of utilization models have been developed to ensure sustainable use of the economic and social services provided by wetlands.

3.3.1. Wetland Agriculture

Wetland agriculture has involved the cultivation of wetland animals and plants as food and raw materials for human society [5]. Rice farming and aquaculture, for example, are common forms of traditional wetland agriculture. More than 60% of food crops, cash crops, and animal products and more than 80% of freshwater fish in China are produced by wetland agriculture [40]. Wetland agriculture can be broadly assigned to one of four categories: animal/plant husbandry, resource conservation, environmental protection, and recreation [5]. Among these categories, animal/plant husbandry has focused mainly on the production of crops such as rice, fish, and shrimp. The priority of resource conservation has been the protection of the abundant wetland biological resources. Environmental protection has emphasized the ecosystem service of water treatment that wetlands provide, primarily through biological means. Examples include the cultivation and planting of aquatic organisms and aquatic vegetables with the ability to catabolize pollutants in constructed wetlands or multi-pond wetlands. The recreational type of wetland agriculture has involved the cultivation of wetland plants with ornamental value for tourism and sightseeing and, in the future, building wetland parks and restoring and protecting urban wetlands so as to create a beautiful environment with great economic value.

3.3.2. Wetland Products

Wetlands provide many edible products such as rice, fish, shrimps, shellfish, aquatic vegetables, and a large number of raw materials for building construction and everyday living, as well as pharmaceuticals and technological products [12]. For example, in Iraq, Japan, and Europe, wetland reeds are often used as building materials for roofs, walls, and fences. Coastal mangroves are often used as a source of wood and tannin in India, Malaysia, East Africa, and many countries in Central and South America. In the Liaohe River Delta in northeast China, wetlands are carefully managed to maximize reed yield for the paper-making industry. According to statistics, the biomass yield of reeds used for pulp production has reached 400,000 tons per year [41]. The strong, flexible stems, branches, and barks of wetland plants are good raw materials for knitting and handicraft products that account for a large share of Chinese markets. As living standards improve, the demand for these products has risen, and the market promises to be very broad. For example, mat grass and willow twigs are often used to make pillow mats, dustpans, and other daily necessities as well as crafts such as tapestries and carpets. In addition, many wetland animals and plants have been found to contain pharmacological components that are efficacious in therapy and healthcare. For example, the flowering plant Houttuynia cordata contains decanoyl acetaldehyde, which has been used as a diuretic, analgesic, and detoxifying agent. It is often used in the form of a liquid taken orally or via injection. Finally, beverages made from wetland plants or animal parts or their extracts are also popular. At present, there are many types of beverages derived from wetland plants in Chinese markets. Such beverages include drinks made from lotus and water chestnuts. Lotus root juice is one of the most popular drinks, and there are many famous brands in Jiangsu, such as "Heart", "Qianxian", and "Yiwei Lotus".

3.3.3. Peat

Peat is a kind of organic matter formed by plant and animal residues through a long sequence of biogeochemical reactions during the development of marsh wetlands. It is lightweight, has good water retention and aeration properties, and contains high concentrations of organic matter and humic acids. It is a good soil conditioner and cultivation substrate. Peat is widely used in China. In agriculture, peat is often used as an organic fertilizer and substrate for the cultivation of seedlings and flowers. In industry, it is used as a fuel for power generation and as a source of raw materials for the chemical, medical, pottery, and building industries. However, compared with the high-end moss peat from other countries, Chinese peat is mostly low-end meadow peat with a relatively high industrial cost and low profit. China, unfortunately, wastes peat resources because the domestic markets are unregulated, and there is much backyard, small-scale production. According to incomplete statistics, the peat produced in China in 2016 amounted to about 1 million cubic meters, equivalent to the amount of imported peat, half of which was used for landscape greening, nearly half for seedling cultivation, and a small amount for the production of fertilizer [42].

3.4. Wetland Protection Policy and Management Practices in China

Wetlands are among the three major ecosystems on Earth, and they contribute to ecological security and sustainable economic and social development [43]. Since its accession to the Ramsar Convention on Wetlands in 1992, China has made continuous efforts to strengthen the protection and management of wetlands. An agency for the implementation of wetland protection and the Ramsar Convention was established in the State Forestry Administration. The establishment of this agency was followed by the creation of similar agencies at local levels. Relevant policies and circulars were subsequently promulgated. A series of measures and action plans that provide strong support and guarantee wetland protection and restoration has, therefore, been implemented. After nearly 30 years of efforts, a wetland protection system was initially established with nature reserves as the mainstay and complementary wetland parks, protected areas, forest parks, and water source reserves. By the end of 2018, China had 57 important international wetlands, 602 wetland nature reserves, and 898 national wetland parks, with a protected wetland area of 26.28 million hectares that accounted for 49.03% of the total wetland area [10].

3.4.1. Wetland Protection Policy

The Chinese government attaches great importance to wetland protection and has launched a series of relevant policies, including the Action Plan for China's Wetland Protection in 2000, the Circular on Strengthening the Management of Wetland Protection in

2004, the Circular on Developing Wetland Parks in 2005, and the Guidelines for Promoting Ecological Civilization in 2013. In 2017, the National Forestry and Grassland Administration implemented the National Wetland Protection and Restoration Scheme and revised the Regulations on Wetland Protection and Management. Twenty-seven provincial-level governments have adopted legislation concerned with wetland protection. To further strengthen wetland protection and realize harmonious coexistence between humanity and nature, on 24 December 2021, the Wetland Protection Law of the People's Republic of China, the first special law of its kind, was adopted. That law provided a legal basis and paved the way for China's wetland protection. In terms of project planning, the approval by the State Council of the National Wetland Protection Project Plan (2002–2030) in 2003 marked the beginning of a new historical stage of China's wetland protection. Since then, wetland protection has been included in the five-year plan of national economic and social development. Examples include the National Wetland Protection Project during the 12th Five-Year Plan period (2012), National Wetland Protection during the 13th Five-Year Plan period (2016), and National Wetland Protection during the 14th Five-year Plan period (2021) [44]. Through exploration and research, China has successfully established and implemented a wetland ecological compensation system, which has greatly enhanced the capacity of China to protect and manage important wetlands. In addition, in terms of scientific research, the National Forestry Administration has set up a wetland monitoring center, a wetland research center, a national plateau wetland research center, and a national center for wetland protection and restoration technology; the Ministry of Natural Resources has set up an eco-geological field scientific research and monitoring station for coastal salt marshes in northern China; the China Geological Survey has set up the Key Laboratory of Eco-Geology of Coastal Wetlands, and some research institutes and universities have also set up wetland research institutes and disciplines. All this provides strong technical support for China's wetland protection and management.

3.4.2. Wetland Protection Practice in China

In 2017, as part of efforts to implement the National Wetland Protection and Restoration Scheme, the State Forestry and Grassland Administration carried out more than 1500 wetland protection and restoration projects and subsidized projects, restored 0.23 million hectares of wetlands, and returned 51,000 hectares of farmland to wetland. For instance, a series of degraded wetland restoration projects were carried out in northeastern China to convert farmland into wetlands, restore vegetation, and treat the water environment in an effort to solve the problems left behind by large-scale agricultural development, weak management capacity, and lack of unified planning and coordination mechanism in wetland protection and utilization [45,46]. As a result, the resilience of wetland ecosystems has been improved. In the middle and lower reaches of the Yellow River, large-scale water diversion and sediment control projects are carried out in June every year to supplement demands for water in the lower reaches of the river and the Yellow River Delta. At the same time, farmland was returned to wetlands to restore the ecological services of wetlands in terms of water conservation and storage [47–49]. In the middle and lower reaches of the Yangtze River, measures such as returning farmland to lakes, to rivers, and to beaches have been taken to expand wetland areas and realize the sustainable development of the regional ecology and economy [50–53]. In coastal areas, protection and restoration projects have focused mainly on key estuarine wetlands and important wetlands for migratory birds. These efforts have included setting up piles to prevent coastal erosion in the Yancheng Wetland Reserve and restoring vegetation to increase the carbon sink and biomass for paper-making in the Liaohe River Delta [41,54]. All of these efforts have helped to establish demonstration zones for wetland development and utilization with benign cycles and economic benefits. In southeastern and southern China, measures have been taken to strengthen the protection of key wetlands by controlling pollution sources from industry and agriculture and addressing sediment deposition, water pollution, and the decline of biodiversity [50,55]. In southwestern China, the issues of serious organic pollution of some lakes near cities and unreasonable wetland development must be addressed, and a monitoring system needs to be set up in those typical plateau wetlands to improve the protection and sustainable utilization of wetlands [56–58]. In northwestern China, a large area of wetlands has shrunk and dried up because of drought and the construction of upstream dams. The management and coordination of regional water resources must be improved to sustain the environment of wetlands in desert areas [59–62]. In the Qinghai-Tibet Plateau, wetlands must be restored and expanded through science-based control of grazing intensity in response to overgrazing, wetland shrinkage, and the decline of ecosystem services [63–65].

4. Discussion

4.1. Wetland Loss and Drivers of Degradation

The main driving factors of wetland loss and degradation in China have been human occupation and environmental pollution, along with some natural factors such as climate change [44].

4.1.1. Climate Change

Wetlands are ecosystems that are sensitive to climate change, and climate change is expected to become an important driver of the loss and alteration of wetlands [12]. Climate change may affect the distribution and functions of freshwater wetlands through changes in temperature and precipitation, but the results will depend on the means of water replenishment and the regions where wetlands are located [66]. For example, in the Erqisi River catchment in Xinjiang, marshes and lake wetland areas have expanded naturally because the river runoff is replenished mainly by seasonal snow melt water that increases in spring and winter due to the temperature rise caused by global warming and the precipitation that increases in summer and autumn. In the middle and lower reaches of the Yangtze River, however, there is an accelerating shrinkage of wetlands because the water for most wetlands is supplied by precipitation, which has been declining because of global climate change since the beginning of the 21st century [67]. Similarly, in northern China, climate change has caused a rise in temperature, a decrease in precipitation, and an increase in evaporation that has resulted in water shortage and the severe shrinkage of wetlands such as Baiyangdian Lake and the Zhalong Nature Reserve [68]. In addition, studies have pointed out that in the context of global warming, the wetland area in the Greater Khingan Mountains region will decline significantly: about a 30% decrease by 2050 and 60% by 2100 [69]. In general, the impact of climate change on inland wetlands varies between different regions and climate zones. Whether the increase in water supply caused by climate change has outpaced the rise of evapotranspiration due to temperature increases has determined whether inland freshwater wetlands have expanded or shrunk [66].

The distribution and services of coastal wetlands have been seriously threatened because climate change has caused a rise in sea level, an increase in sea surface temperature, a decrease in ocean pH, and increased damage from storm surges [70,71]. According to the 6th IPCC assessment report, the melting of ice sheets, caused by global warming, will make the average global sea level rise by as much as two meters by 2100 and five meters by 2150 [72]. If coastal wetlands do not accrete at the same rate, coastal wetlands will gradually disappear because of increasingly severe flooding, erosion, and saltwater intrusion [12,73–75]. It has been estimated that half of the wetlands of international importance, designated by the Wetland Convention, will be threatened if the sea level rises by even one meter [76]. Data show that the sea level along China's coastlines rose at a rate of 3.2 mm per year from 1980 to 2016, higher than the global average during the same period [77]. Predictions of possible sea-level rises and the submergence of areas have been made by analysis of regional differences and sea-level changes in China's coastal plains during recent decades [78,79]. Those predictions have suggested that the areas most vulnerable to coastal disasters are the following: the Yellow River Delta (including ancient, modern, and abandoned areas), the coastal areas of Laizhou Bay, the coastal areas of northern Jiangsu province, the Yangtze River Delta, the Pearl River Delta, and the coastal areas of western Taiwan. The total area of threatened land has been estimated to be about 3.5 million hectares. Apart from the impact of sea-level rise, the rise of seawater temperature and decrease of pH brought about by climate change also threaten the ecological environment of coastal wetlands [80,81]. For example, in the 1998 ENSO event, the abnormal rise of seawater temperature killed 16% of corals globally, including corals in the Dongsha atoll lagoon in the South China Sea [82]. Corals are sensitive to water temperature changes and have difficulty surviving in seawater above a temperature of 30 °C. Some studies have shown that by the end of the 21st century, the average annual surface temperature in the Pearl River Basin will have risen by 1.9–3.4 °C, and the higher temperatures will pose a serious threat to many corals [83]. In addition, frequent extreme weather in the context of climate change may cause the physical erosion and destruction of wetlands [84]. The increasing frequency and intensity of extreme weather disasters, such as low-temperature events in southern China in 2008 and tropical cyclones and typhoons from 1961 to 2010, have caused damage to large areas of mangrove wetlands [82,85].

4.1.2. Urbanization and Change of Land Use

With population increase and rapid economic and social development, more and more wetlands have been reclaimed for urban and commercial development to meet the ever-growing demand for food, housing, and business activity. At present, reclamation, urban development, and other changes of wetland use have led to significant natural wetland shrinkage and loss of wetland services [6,43]. For example, from the beginning of the founding of the People's Republic of China in 1949, a large-scale reclamation of lake wetlands was carried out to meet the need for food production and flood control. In the past half a century, the total area of natural inland wetlands in China has been reduced by about 13.5 million hectares. About 81% of that loss was caused by land reclamation and development on what had previously been lakes [5]. The area of riverine wetlands has declined because of a lack of planning, inadequate protection, and the construction of dams. The construction of some water conservation projects has blocked the conduits between natural rivers and wetlands, including lakes, and unregulated upstream diversions for irrigation as well as industrial and urban use have led to the rapid, widespread loss and fragmentation of inland wetlands. For example, the complete desiccation of the lower reaches of the Tarim River, Heihe River, and other important inland rivers has led to the death of vegetation and the disappearance of oases. These losses have resulted from unreasonable use of water resources. Wetland marshes have also suffered historically from reclamation and development projects [86]. The marshes in the Sanjiang Plain are good examples. After more than 50 years of development, the area of those wetlands has decreased to 906,900 hectares in 2000 from 5.34 million hectares in 1949, while its arable land area has increased to ~3.67 million hectares in 1996 from 796,000 hectares in 1949 [87]. The plateau wetland area, which is one of two areas in China where marshes are concentrated, has escaped large-scale reclamation, but tourism and urban development have taken a toll on wetland area and quality. The construction of roads, railways, and other linear infrastructure across the area has fragmented it and exacerbated the loss of wetlands. China's offshore and coastal natural wetlands have been in shrinking because of large-scale reclamation of coastal land, extensive nearshore aquaculture, evaporation ponds for salt recovery, as well as port and wharf development. Rapid economic development in coastal areas has led to increasing demand for land, especially since the 21st century [5,10]. According to statistical summaries of the types and areas of nationwide coastal wetlands in 1975, 2000, and 2017, issued by the China Geological Survey, the total area of coastal wetlands in China (excluding Hong Kong, Macao, and Taiwan) was 89,821 km^2 in 1975, 85,972 km^2 in 2000, and 83,561 km^2 in 2017. The area of natural coastal wetlands in China was about 21,394 km^2 in 1975, 14,905 km^2 in 2000, and only 9862 km^2 in 2017 [10].

4.1.3. Environmental Pollution

A large number of studies have shown that environmental pollution has posed a very serious threat to China's wetlands [7]. As water catchments, wetlands have been used as receptacles for large amounts of untreated domestic sewage, industrial wastewater, and agricultural runoff containing pesticides, fertilizers, and herbicides. The degree of pollution has gone well beyond the wetland tolerance threshold, disrupted wetland biodiversity, and caused a serious loss of wetland ecological services [88]. Before the 18th National Congress of the Communist Party of China in 2012, pollution of offshore and coastal wetlands was also severe because of sewage discharges, mariculture, oil pollution, and cultural eutrophication associated with pollutants containing inorganic nitrogen and phosphorus. From Liaodong Bay and Bohai Bay to the coastal areas of Jiangsu, Zhejiang, Fujian, and other regions, frequent red tides have caused serious damage to the coastal landscape, reduced the resilience of the wetlands to perturbations, and decreased wetland biodiversity. Cultural eutrophication caused by large-scale aquaculture has caused the roots of wetland plants to be shallower and, hence, more prone to uprooting by storm surges. Coastal erosion and wetland shrinkage have, therefore, become serious problems [10,89].

4.2. Implications for Carbon Neutrality in China

Research has shown that in order to achieve carbon neutrality by 2060, China must work to keep its annual CO_2 emissions from energy use below 500 million tons and non-CO_2 greenhouse gases and industrial emissions below 1 billion tons; China must also concomitantly remove about 1.5 billion tons of carbon via sequestration and geoengineering technologies [90]. The implication is that China will need to fill an annual carbon gap of 410 million tons [90]. Wetlands are ideal carbon sinks thanks to their high carbon sequestration rates and high primary productivity. Based on the carbon sequestration rate given by Wang et al. [39], the annual carbon sequestration of Chinese is 92.6 million tons, about 22.6% of the total gap. An important consideration is that 53.9% of Chinese coastal wetlands were degraded from 1975 to 2017. Ye et al. [10] have concluded that natural processes did not lead to a significant decrease in wetland area and that the continuous expansion of aquaculture and construction of ports and dams were mainly responsible for the degradation of the natural wetlands of China during that time. The degradation rate of Chinese coastal wetlands is typical of all the wetlands in China. If the area of Chinese wetlands could be restored to the pre-1975 area, the annual carbon sequestration would be 171 million tons or 42% of the gap of 410 million tons of carbon. The wetlands of China could, therefore, play a critical role in realizing the goal of carbon neutrality by 2060.

4.3. Problems in the Development and Utilization of Wetlands

China is presently making good progress toward wetland development and utilization, but under-development and over-utilization continue to be problems. A sound vision and correct understanding of sustainable utilization must be embraced. Many individuals and groups have sought to exploit Chinese wetlands at the cost of sustainable development. The result has been over-exploitation, despite repeated regulatory efforts. In wetland fisheries, overuse or even predatory utilization is commonplace. For example, according to data from the first and second wetland surveys, the number of species of indigenous fish in Guangdong decreased by 186 species, almost 30% of the total number of species in only 10 years [8,91]. Such excessive consumption has led to the depletion of wetland wild fish stocks, threatened biodiversity and ecological balance, and, ultimately, devastated natural fishery resources [92]. China's wetlands are under-developed because of insufficient scientific and technological support and a lack of managerial foresight. Relevant research projects are few in number, small in scale, and outdated in terms of technology. The result has been an unnecessary waste of precious resources [5]. For example, China has 4200 species of higher wetland plants and 2312 species of wetland vertebrates. Among these species are hundreds that could be utilized or have the potential for development as biological resources. However, only about 100 species are used on a regular basis, and a large number of species are underdeveloped resources [5]. In addition, aquatic vegetables are abundant in the middle and lower reaches of the Yangtze River and have a long cultivation history, but they are still in the initial stages of utilization. Management is poor, and most operations are small in scale. At the moment, most wetland products in Chinese markets are primary, lacking deep processing and comprehensive utilization.

Finally, the invasion of alien species such as Eichhornia crassipes, Ampullaria crossean, and Procambarus clarkii has alerted Chinese authorities to the need for the protection and sustainable utilization of China's wetland resources. These invasive alien species have brought obvious harm to many areas and are great ecological threats [5,93,94].

4.4. Problems in Wetland Protection

Although China has made remarkable progress in wetland protection, which protected 49% of Chinese wetlands by the end of 2018 [10], there is still a long, hard journey to protect the other 51% and even expand wetland areas. Compared with the protection of other traditional ecological systems such as forests, seas, and grasslands, wetland protection work started relatively late. Relevant laws and policies need to be refined, and publicity and education about wetlands are still inadequate. Some localities and departments have focused too much on economic returns and less on ecological well-being. There has been a failure to strike a balance between wetland protection and utilization.

China must raise public awareness of the need for wetland protection. Most of China's tourist-oriented wetlands, and even national wetland parks, lack relevant publicity and educational posters, facilities, and activities. According to surveys, only 25% of the public in China have some knowledge about wetlands, and many believe that wetlands are unused land and are inexhaustible [5]. It is worth noting that some local government leaders know little about the great value and important role of wetlands and, thus, have done nothing to protect them. The blind pursuit of short-term profits at the expense of wetlands has led to wetland reclamation, occupation, and unreasonable use. In addition, many wetland restoration projects have turned out to be ornamental landscapes without ecological restoration functions. A significant problem is the lack of scientific and technological support for wetland protection and management. After many years of field surveys, the authors discovered that the restoration of the Panjin Red Beach was misguided because the natural succession of vegetation during the progradation of the delta was mistaken as wetland degradation. In the Yellow River Delta, the oil wells Kandong 12 and Lao 168 were indiscriminately closed because of a failure to distinguish the geological process of wetland degradation from the factors induced by human activities. This failure caused huge and immediate economic losses. In the Yancheng Red-Crowned Crane Nature Reserve, Jiangsu Province, the restoration of Suaeda heteroptera vegetation failed repeatedly because of inappropriate habitat selection. In returning fishing/farmland to wetlands, permanent farmlands nearby coastal wetlands were wrongly classified as the object of protection. This mistake greatly constrained local economic growth. It is, therefore, essential to strengthen the comprehensive, multidisciplinary research of Earth systems and to expound on and demonstrate the law of formation, evolution, and decline of wetlands from multi-dimensional perspectives so as to formulate a sound, sustainable, eco-science-based conservation scheme that meets the requirements of social and economic development.

4.5. Solutions for Wetland Protection

As an indispensable material and environmental basis for human life and social progress, wise stewardship of wetlands will be required for global sustainable development. Over a long time, although China and most other countries have adopted numerous policies and measures to protect them, most wetlands have been degraded [95]. One of the main reasons for this is that wetland conservation has been forced to give way to economic growth. China is a developing country with the world's largest population and a rather low per capita share of natural resources. In the past 50 years, faced with rapid population and economic growth, China has accelerated the use of wetland resources in agricultural irrigation, production, aquaculture, and urban development to derive economic benefits and improve living standards. At the same time, the imbalance between wetland ecological protection and socioeconomic development has become increasingly apparent [96,97]. Therefore, in developing countries, in addition to following strict ecological laws (natural science) for wetland protection, it is critical to formulate a sound, sustainable, eco-science-based wetland conservation plan that meets the requirements of social and economic development. Economic and social conditions must be taken into account in solving environmental problems (Figure 3).

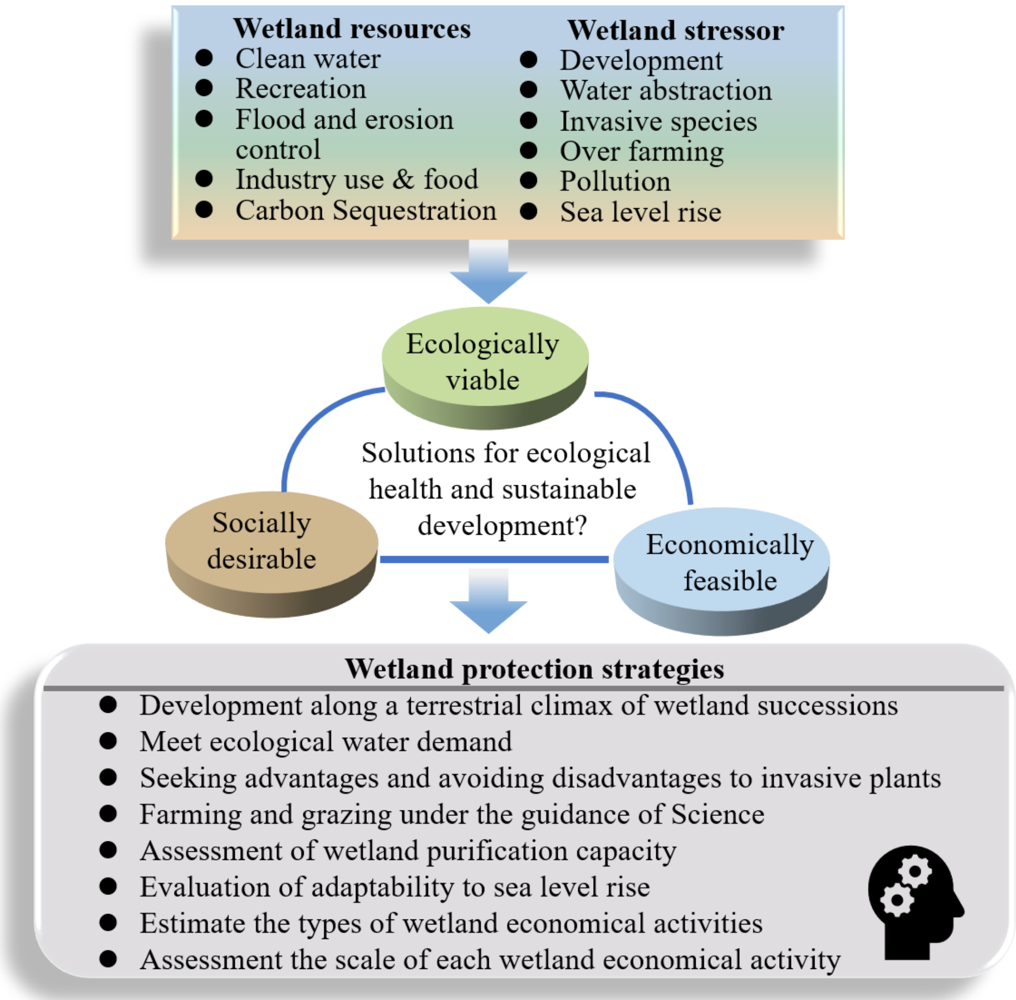

Figure 3. Concept of wetland protection in developing countries. In addition to following strict ecological laws (natural science), economic and social conditions must be taken into account in solving environmental problems.

A primary requirement for wetland protection will be knowledge gained from comprehensive investigation and research. On the one hand, permanent monitoring stations and networks must be well established to study the ecological problems of wetlands in real-time. On the other hand, in-depth studies must be conducted on hotspot scientific issues related to wetland stability in ways that inform restoration projects. In particular, given China's large population and shortage of resources, research on the development and utilization of wetlands must be carried out in line with the different geographical conditions of the wetlands. Potentials of renewable wetland resources must be identified and consideration given to their use for treating polluted water, producing food, supplying industrial raw materials, controlling flooding and erosion, and serving as recreational resources. The type and scale of economic activities must be assessed. In search of a sustainable wetland protection solution, we must base our efforts on ecological science and sound reasoning while taking into full account social demands and economic feasibility (Figure 3).

5. Conclusions

This paper has articulated a Chinese model: the best way to protect the wetlands is to manage the natural resources of wetlands in a sustainable way for the long-term benefit of the many people of China. The current policy—prohibition of activities in the wetland reserve—is not desirable. Several potential paths for sustainable management of wetlands are recommended as follows:

- Development can be allocated along the terrestrial climax of wetland successions;
- An assessment of ecological water demand must be carried out before water resources are allocated;
- We should exploit advantages and avoid disadvantages in the control of invasive plants and not apply a one-size-fits-all policy;
- Farming and grazing should be guided based on science;
- Wetlands can purify water, but their decontamination capacity needs to be scientifically evaluated in order to ensure the sustainable utilization of the water purification function;
- Climate change and sea-level rise will directly affect the evolution of both inland and coastal wetlands. For example, the inland wetlands in the north will increase due to the melting of glaciers, whereas in the coastal area, due to the rise of sea level and the economic development of the coastal zone, the wetlands will be squeezed. Therefore, adaptability will be essential for coping with climate change and sea-level rise;
- Each wetland has different resources. To make wise use of these resources, it is necessary to carry out a survey of the inventory of potential resources for each wetland;
- Insufficient utilization of wetland resources will limit economic development and human well-being, but excessive utilization will lead to the loss of wetland services. Therefore, before the development and utilization of wetland resources, it is necessary to make a scientific assessment of each wetland resource to determine a reasonable development and utilization scale.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/w14071152/s1, Table S1: Rates of change of the 50 wetlands listed in the International Wetland Convention from 2012 to 2017.

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