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Achievements, challenges, and recommendations for waterbird conservation in China's coastal wetlands

Zhijun Ma [a,*], Chi-Yeung Choi [b], Xiaojing Gan [c], Jing Li [d], Yang Liu [e], David S. Melville [f], Tong Mu [g], Theunis Piersma [h,i,j], Zhengwang Zhang [k]

[a] Ministry of Education Key Laboratory for Biodiversity Science and Ecological Engineering, National Observation and Research Station for Wetland Ecosystems of the Yangtze Estuary, Fudan University, Shanghai, 200438, China
[b] Division of Natural and Applied Sciences, Environmental Research Centre, Duke Kunshan University, Kunshan, 215316, Jiangsu, China
[c] The Paulson Institute Beijing Representative Office, Beijing, 100006, China
[d] Spoon-Billed Sandpiper, Shanghai Environmental Protection Technology Co., Ltd., Shanghai, 201100, China
[e] State Key Laboratory of Biocontrol, School of Ecology, Sun Yat-Sen University, Guangzhou, 510275, China
[f] Global Flyway Network, Wakefield, 7096, New Zealand
[g] Princeton School of Public and International Affairs, Princeton University, Princeton, NJ, 08544, USA
[h] NIOZ Royal Netherlands Institute for Sea Research, Department of Coastal Systems, P.O. Box 59, 1790, AB Den Burg, Texel, the Netherlands
[i] BirdEyes, Centre for Global Ecological Change, and Conservation Ecology Group, Groningen Institute for Evolutionary Life Sciences (GELIFES), University of Groningen, 9700, CC Groningen, the Netherlands
[j] CEAAF Center for East Asian-Australasian Flyway Studies, Beijing Forestry University, Qinghua East Road 35, Haidian District, Beijing, 100083, China
[k] Ministry of Education Key Laboratory for Biodiversity Science and Ecological Engineering, School of Life Sciences, Beijing Normal University, Beijing, 100875, China

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ABSTRACT

China's coastal wetlands provide breeding, migration stopover, and wintering habitats for about 230 waterbird species, which is more than a quarter of all waterbirds in the world. Large-scale and high intensity human activities have resulted in serious loss and degradation of coastal wetlands over the past half century, causing population declines in many waterbirds. Through a literature review and expert surveys, this article reviews conservation measures taken in recent decades to protect waterbirds in China's coastal wetlands and provides recommendations for future conservation action from three aspects: policy and administration, habitat conservation and management, and multiparty participation. Over the past decades, many conservation legislation, regulations and action plans at the national level and more site-specific measures and interventions have been implemented, with notable improvement in the effectiveness in policy making and multi-stakeholder participation. Accordingly, some threats to waterbirds have been mitigated and many key sites for waterbirds have been designated as strictly protected nature reserves. However, some critical issues still remain, mostly related to habitat conservation and management, such as coastal wetland restoration, control of invasive *Spartina alterniflora*, control of environmental pollution, and improvement of artificial habitat quality. We highlight that protecting natural tidal wetlands and improving habitat quality are critical for the conservation of coastal waterbirds, especially those highly dependent on the intertidal wetlands. China has demonstrated strong commitment to ecological conservation and restoration for the future, in terms of both funding and policies for biodiversity and wetland ecosystems. It is important that this commitment to conserve coastal waterbirds is supported continuously by science- and evidence-based decisions and actions.

1. Introduction

The coastal wetlands between land and sea are among the most valuable ecosystem types on Earth for a number of reasons (Costanza et al., 1997). They play an important role in maintaining the carbon cycle, reducing damage from typhoons and other natural disasters to coastal regions, providing livelihoods to local communities, and supporting abundant biodiversity (Barbier et al., 2011). Waterbirds, which are highly dependent on wetlands, are a representative biological group inhabiting coastal wetlands and their diversity and abundance are often

* Corresponding author.
E-mail address: zhijunm@fudan.edu.cn (Z. Ma).

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used as an indicator of the quality and health of wetland ecosystems (Peron et al., 2013). Many waterbirds are now threatened and the focus of conservation actions, some of which have become the flagship species of biodiversity conservation (Wetlands International, 2012). Therefore, the status of waterbirds to a large extent reflects the status of coastal wetland conservation and management.

Along China's 18,400-km coastline, the area of coastal wetlands covers 58,000 km^2 (data up to 2010; Ma, 2015). A total of 230 waterbird species, including both swimming and wading birds according to the definition of Wetlands International (2012), have been recorded in China's coastal wetlands, including 26 Threatened and 12 Near Threatened species in the International Union for Conservation of Nature Red List (Wang et al., 2018). Coastal waterbirds, that is waterbirds that use coastal wetlands, account for 80% of the waterbird species found in China and for more than one quarter of all waterbird species worldwide (Wang et al., 2018). Most waterbirds are migratory and may use different habitats throughout their annual cycle. Located in the center of the East Asian–Australasian Flyway (EAAF), China's coastal wetlands provide breeding, migration stopover, and wintering habitats for tens of millions of waterbirds (Xia et al., 2017; Wang et al., 2018; Mundkur and Langendoen, 2022). Some species (especially sandpipers in Family Scolopacidae) exclusively rely on coastal wetlands during the nonbreeding season and even throughout their entire life cycle (Wang et al., 2018). They have appropriate sensory systems to exploit the food types in such areas, and coastal wetlands with high salinity and fewer pathogens provide the "clean" environments which would allow these birds to invest more resources in their epic long-distance migrations. With relatively weak immunity, those tideland specialists are likely to be more vulnerable in "dirty" inland freshwater wetlands (Piersma, 1997). In these various adaptions to coastal life, they are thus sensitive to the loss and degradation of coastal wetlands. A total of 172 sites with abundant waterbirds and used by threatened species have been identified as important bird areas along China's coast (Lei et al., 2017; Xia et al., 2017; Choi et al., 2022a). The rich diversity and high abundance of many threatened waterbird species confer China's coastal wetlands a critical position in waterbird conservation along the Flyway.

Contributing only 13% of China's total land area whilst supporting 40% of the national human population and producing 60% of the gross domestic product, China's coastal region is the most densely populated and economically developed region in the country (Ma et al., 2014b). In the past several decades, as a consequence of intensive and large-scale human activities, China's coastal wetlands have undergone dramatic changes. Excessive coastal land claims have depleted more than half of the coastal wetlands in China from mid-1900s to early 2000s (Ma et al., 2014b; Lei et al., 2017). Chemical pollution, including organic and inorganic pollutants as well as emerging pollutants, and high concentrations of nutrients considerably degraded the environmental conditions of coastal wetlands for a long time (Jiang et al., 2015; Sun et al., 2015). Smooth cordgrass (*Spartina alterniflora*, hereafter *Spartina*), an alien invasive plant, has expanded rapidly (Mao et al., 2019), changing the natural landscape, biological communities, and ecological processes of coastal wetlands (Li et al., 2009). The production activities of local people, such as shellfish aquaculture on tidelands, have dramatically altered the benthic communities of coastal wetlands (Peng et al., 2021). Bycatch from nets set up on intertidal flats for catching fish during high tide when nets were submerged and for protecting shellfish stocks, although has not been well studied, might be a serious threat to waterbirds (Crighton, 2016; Melville et al., 2016). These multiple stressors faced by coastal wetlands have resulted in declines in both the biodiversity supported and the ecosystem services provided (Jiang et al., 2015; Sun et al., 2015). The EAAF has the highest proportion (23%) of threatened waterbirds of any flyway (Kirby et al., 2008), and many shorebird populations have declined dramatically, largely due to habitat loss and degradation along China's coast (Piersma et al., 2016; Studds et al., 2017; Wang et al., 2018).

In recent years, while recognizing the importance of biodiversity conservation and the implementation of ecological civilization strategies, China's central and local governments have formulated policies and regulations and have taken practical actions to protect waterbirds and their coastal habitats (Huang et al., 2021). Many measures have made obvious achievements. Many key habitats of waterbirds have been protected by being designated as nature reserves, Ramsar sites, and UNESCO world heritage sites (Fig. 1; Lei et al., 2017; World Heritage Committee, 2019; Li et al., 2020), some threats to waterbirds have been mitigated (Wang et al., 2018; Choi et al., 2022). Meanwhile, there are still many issues to be solved, these include protecting important waterbird sites that were identified recently (Mu et al., 2022), improving habitat quality of artificial wetlands (Cheng et al., 2022), and balancing the needs from different ecosystem components during habitat restoration (Choi et al., 2022b). Along with the continuous advancement of China's ecological civilization construction, ecological conservation and ecosystem restoration of coastal wetlands will be strengthened by both policies and funds in the future (The Central Government of the PRC, 2021). This provides great opportunities for further improving the efficacy of waterbird conservation and coastal wetland protection in China.

The management policy and practice should be adaptive and reviewed regularly, to understand the effectiveness, to identify the issues to be addressed, and to provide flexibility for change so that conservation effort will remain effective when new information becomes available or when environmental conditions have changed (Fazey et al., 2013). To understand the measures and effectiveness of coastal waterbird conservation in China's coastal wetlands in recent decades, to discover the existing challenges, and to make recommendations for coastal waterbird conservation in the future, we conducted literature reviews and expert surveys on the topic. Reviews and recommendations are grouped into three broad topics: policy and administration; habitat conservation and management, and multiparty participation.

2. Materials and methods

We conducted a systematic review of the literature, including academic peer-reviewed journal articles, official reports, laws, regulations, and documents issued by the departments of central and local governments, about waterbirds and their habitat conservation along China's coasts. To gather information on the measures and recommendations for coastal waterbird conservation, articles published between January 2010 and December 2022 in the Web of Science (WOS) database (www.webofscience.com/wos/alldb/basic-search) were searched using "(China OR Chinese) AND (bird* OR waterbird*) AND (coast* OR estuar* OR tideland OR tidal OR intertidal) AND (conserv* OR threat OR protect*)". Considering the regional feature of this topic, literatures (including academic journal articles and graduate dissertations) were also searched in the China National Knowledge Infrastructure (CNKI) Database (https://www.cnki.net/) by topics using "bird AND wetland AND (coast OR tidal OR intertidal OR estuary) AND (conservation OR threat)" in Chinese characters. A total of 876 literature sources were obtained, comprising 469 in WOS and 407 in CNKI. We excluded duplicated literature, literature unrelated to the research topic, and government gazettes and circulars after inspecting the titles and/or abstracts. The number of remaining literature items was 523 (Appendix A).

After reading all texts, we summarized the measures, issues and suggestions on the conservation of waterbirds and their habitats from the 523 literature sources into 10 topics grouped under three aspects: policy and administration, habitat conservation and management, and multiparty participation (Table 1). Seven Chinese experts with long-term experience in China's coastal waterbird conservation from different institutes (including universities, international and domestic non-governmental organizations) scored the effectiveness of actions already taken and priorities in the future of the 10 topics (rank 1–5, 1 refers to the least effective or important and 5 as the most effective or important;

Fig. 1. The 35 national nature reserves, 16 wetlands of international importance, and 2 UNESCO world heritage sites along China's coastal wetlands (till the end of 2022). Some national nature reserves are also wetlands of international importance. E, M, and L represent the national nature reserves that were designated in the 1980s, 1990s, and after 2000, respectively.

Table 1
Measures, effectiveness, and recommendations for China's coastal waterbird conservation according to literature reviews and expert surveys.

Aspect	Topic	Literature review	Expert survey	
			Effectiveness	Recommendation
Policy and administration	Legislation and regulations	14.5%	**3.71**	2.86
	Protecting key sites for waterbirds	49.5%	**4.29**	2.86
	Filling conservation gaps in coastal wetlands	20.1%	2.57	**4.14**
	Trade-off among various ecosystem services of coastal wetlands	23.9%	1.57	**4.43**
Habitat conservation and management	Coastal wetland restoration	27.9%	1.86	**4.00**
	Control of invasive *Spartina alterniflora*	14.3%	1.86	**4.86**
	Control of environmental pollution	14.9%	2.57	**3.29**
	Reducing impacts of human activities on birds	24.9%	1.71	**3.57**
Multiparty participation	International cooperation and domestic participation	16.6%	**3.86**	**3.29**
	Participation of researchers	22.8%	**3.86**	**3.86**

The literature review exhibits the percentage of the measurements mentioned in all the literature ($n = 523$). Expert survey exhibits the average score (1–5, $n = 7$) for effectiveness of implementation and conservation recommendations. The scores greater than 3, which are considered as effective measures and important recommendations, are shown in bold.

Appendix B: Table S1). For the degree of implementation, we considered that the conservation effectiveness is obvious if the average expert score of the topic is greater than 3 (60% of full score), while further improvement is required if the average expert score is less than 3 (Table 1). For the conservation recommendations, an average expert score of greater than 3 is considered as the priority topics.

3. Conservation measures taken for coastal waterbird conservation

Among the 10 topics, "Protecting key sites" was the most mentioned topic in the literature, followed by "coastal wetland restoration", "reducing impacts of human activities on birds", "trade-off among various ecosystem services of coastal wetlands", and "participation of researchers" (Table 1). In the expert surveys for conservation effectiveness, "Protecting key sites" also obtained the highest score, followed by topics including "legislation and regulations", "international cooperation and domestic participation", and "participation of researchers". Although many measures have been implemented in habitat conservation and management, all the four topics in this aspect obtained relatively low scores in expert surveys for effectiveness of implementation, suggesting that more efforts are required in this aspect in the future (Table 1).

3.1. Policy and administration

Legislation and regulations. Conversion of coastal wetlands, especially large-scale land claims, has caused a dramatic loss of wetland habitat for waterbirds and a serious decline in biodiversity and ecosystem services (CCICED, 2010; Ma et al., 2014b). To curb excessive land claims of coastal wetlands, the State Council and the State Oceanic Administration have issued policy documents many times since 2010 (Lei et al., 2017). In particular, the State Council issued a notice on "strengthening the protection of coastal wetlands and strictly controlling land claim", highlighting to "completely stop the approval of new land claim projects" in 2018 (The State Council, 2018). In 2017, the Wildlife Protection Law of the PRC was revised and improved, after consultation with experts and incorporating concerns raised by the public. While continuing to emphasize protecting threatened species, the amendment also proposed to protect habitat for wildlife (The National People's Congress of PRC, 2020) and thus supports the conservation of coastal wetlands being critical habitats for waterbirds. In 2021, the revised list of key wildlife under state protection was released by the National Forestry and Grassland Administration and Ministry of Agriculture and Rural Affairs of China, and 37 more waterbird species have been added into the new list. The Wetland Protection Law of PRC was enacted since June 2022, which emphasizes the strengthening of management and protection of coastal wetlands and protecting waterbirds and their habitats (The National People's Congress of PRC, 2021). In February 2023, the National Forestry and Grassland Administration issued the National Action Plan for Protecting the Migration Corridors of Migratory Birds (2021–2035) (The National Forestry and Grassland Administration of PRC, 2023). Because most coastal waterbird species are migratory, the action plan promotes their conservation.

All these laws and documents provide legislative and policy support for waterbird conservation, with some regulations playing obvious roles. The excessive reclamation of intertidal lands has posed the most serious threat to waterbirds, but now such losses have largely been averted, as evidenced by the total area of coastal wetlands remaining stable over the past decade, with a significant increase in the extent of mangroves (Wang et al., 2021). Illegal hunting has been severely punished by law, although the phenomenon still exists in many regions (Wang et al., 2018). Results from expert surveys also recognized the contribution of legislation and regulations to waterbird conservation (score 3.71/5; Table 1).

Protecting key sites. The protection of wetland areas is a cornerstone of the protection of both biodiversity and wetland ecosystems. A total of 35 national nature reserves (NRs) and 16 wetlands of international importance (Ramsar sites) have been designated along China's coastal wetlands (till the end of 2022; Fig. 1). Most of them have waterbird conservation listed as their main objective (Li et al., 2020). Of the total 35 national NRs, 30 were designated in the recent three decades, including 15 being designated in the 1990s and 15 after the 2000 (Fig. 1). In 2014, the Ministry of Natural Resources of China proposed a new conservation framework of the Ecological Conservation Red Line (ECRL), which aims to ensure no net change in land cover, no net loss of biodiversity, and no degradation of ecosystem services within areas that are critical for maintaining ecological safety and functions (Huang et al., 2021; Choi et al., 2022a). As an example of "other effective area-based conservation measure" beyond strictly protected NRs, the ECRL can greatly expand the areal coverage of protected areas, especially in areas where it is impractical to designate NRs (Choi et al., 2022a). The combination of NRs and the ECRL covers 73% of important bird sites in the coastal region, which is much larger than the coverage of 24% by NRs alone, thus greatly improving conservation effectiveness (Choi et al., 2022a). To improve the conservation of key waterbird habitats in the Yellow Sea region, which have high conservation priority for migratory birds in the EAAF, two sites in the region have been inscribed as UNESCO World Heritage Site, "Migratory bird sanctuaries along the coast of the Yellow Sea-Bohai Gulf of China (Phase I)", in 2019 (Fig. 1; World Heritage Committee, 2019), and 11 sites have been included in the list of Phase II applications.

All these measures focus on protecting coastal wetland habitats on which waterbirds highly rely for survival and reproduction, thus have played important roles for waterbird conservation in long term, which is also reflected from expert surveys (Table 1). The topic of protecting key sites was the most mentioned in the literature and obtained the highest score (4.29/5) in expert surveys on the effectiveness of implementation of the 10 topics (Table 1), suggesting the importance and the experts' recognition of the achievements in protecting key sites for waterbirds in China.

Filling conservation gaps in coastal wetlands. Although many key sites for waterbirds have been designated as strictly protected NRs, there are still conservation gaps in China's coastal wetlands. Some critical regions for waterbirds, such as the major migration refueling and moulting sites for the Critically Endangered Spoon-billed Sandpiper (*Calidris pygmaea*, in Rudong, Jiangsu; Peng et al., 2017; Yang et al., 2020) and for the Near Threatened Red Knot (*Calidris canutus*, in Nanpu, Hebei; Rogers et al., 2010) in the flyway, have been recognized for many years, however, these sites were eventually designated as local wetland parks with weak protection instead of strictly protected NRs. From 2014 onwards, a total of 90 national NRs have been designated in China, but surprisingly, none of these NRs are coastal wetlands (NPA Data, 2022). China has recently modified its protected area system with national parks as the primary administrative mechanism, but all of the 10 national parks in the first batch of pilot projects are located in inland regions. Because World Natural Heritage sites can obtain strict protection and international supervision (Conradin et al., 2015), the ongoing application for the World Natural Heritage Sites Phase II represents another opportunity to strengthen the conservation of critical habitats for coastal waterbirds, but some important sites (e.g., Lianyungang coasts in Jiangsu) have not yet been included in the list, despite supporting nearly the entire global population of Asian Dowitcher (*Limnodromus semipalmatus*) on northward migration (Yang et al., 2021; Mu et al., 2022). Existing conservation gaps leave uncertainty for the conservation of some threatened and endemic species that inhabit China's coast. The expert score on the effectiveness of implementation for this topic is relatively low (2.57/5).

Trade-off among various ecosystem services of coastal wetlands. The concept of giving full play to the ecosystem services of coastal wetlands has been widely recognized, while there are still challenges in how to put it into practice, particularly when different ecosystem services provided by coastal wetlands conflict with each other. Over the past two decades, the rapid expansion of offshore wind power, photovoltaic and other clean energy facilities in coastal areas has reduced the consumption of

nonrenewable energy and production of greenhouse gas emissions, contributing to achieve the target of carbon neutrality. However, these facilities may occupy habitats for waterbirds and cause the risk of collisions (Melville et al., 2016). The widely distributed intertidal aquaculture along the coasts is important for maintaining food security and local economic development, while the homogenized zoobenthos unlikely support diverse waterbirds with varying food requirements (Peng et al., 2021).

Another issue of concern is mangrove planting and restoration. The area of mangrove wetlands has increased significantly in the coastal area in south China due to mangrove restoration and afforestation (Wang et al., 2021). Although mangroves have important ecosystem services such as protection from storms and supporting rich biodiversity, mangroves in some areas have encroached bare tidelands, which are the key foraging habitat for many shorebirds and thus cause habitat loss for those tideland specialists (Choi et al., 2022b). Supported by funds and policies, mangroves are planted and expanded in coastal regions (The Central Government of the PRC, 2021). This will change the coastal landscape and influence habitat for waterbirds. Mangrove planting is necessary at present but need to be done with proper planning and zoning to ensure that key habitats for shorebirds are not lost to replanting.

The lowest expert score for the effectiveness of implementation in this topic (1.57/5; Table 1) also suggests that there are great challenges in turning ideas into practice. How to balance the different ecological functions requires science-based and evidence-based decision making in planning and managing coastal wetlands.

3.2. Habitat conservation and management

Coastal wetland restoration. China's coastal wetlands have seriously degraded in terms of their quality and ecosystem services over time (CCICED, 2010; Jiang et al., 2015; Sun et al., 2015). As a consequence, ecological restoration is a critical measure to enhance ecosystem services and to improve habitat quality for waterbirds (Lei et al., 2017; United Nations, 2019). Over the past two decades, ecological restoration has gained increasing attentions in China. Both central and local governments have provided funds and formulated policies to implement wetland restoration projects (Liu et al., 2016). During the 13th Five Year Plan period from 2016 to 2020, the central government invested and subsidized over 18 billion RMB (about 2.6 billion US$) to wetland restoration, including the restoration of 1200 km of coastline and 23,000 ha of coastal wetlands (Ministry of National Resources of PRC, 2021). Many wetland restoration projects aimed at habitat construction and improvement for waterbirds through topographic modification, vegetation planting and water system construction (e.g., Sun et al., 2015; Lei et al., 2017; Fan et al., 2021). Although waterbird diversity generally increased in restored wetlands, most wetland restoration projects targeting waterbird conservation were implemented by constructing human-managed wetlands rather than restoring natural tidal wetlands (Melville et al., 2016; Fan et al., 2021; Jiang et al., 2021), which are critical habitats for intertidal soft-sediment specialists (e.g., foraging habitats for shorebirds) and have suffered serious loss over the past half century.

In addition, assessments of the effectiveness of wetland restoration often rely on physical and chemical indicators (e.g., water quality, extent of vegetation cover) while overlooking indicators that better reflect the habitat quality for waterbirds (such as food condition, habitat preference, foraging efficiency and breeding success rate) (Johnson, 2007). Very worryingly, some projects which have been promoted as being “ecological restoration” and that invested large amounts of money at important waterbird sites were poorly-designed without thorough consultation with scientific experts and reference to published materials, and have simply converted natural tidelands into artificial landscapes, which is in effect destroying natural wetland and is harmful to waterbird conservation (Yang et al., 2021). The low score of expert surveys in the effectiveness of implementation (1.86/5; Table 1) suggests that coastal wetland restoration has not significantly contributed to waterbird conservation in general, despite the investments and opportunities being available.

Control of invasive *Spartina*. The rapid spread of invasive *Spartina* is a serious threat to coastal wetland ecosystems and biodiversity in China (Li et al., 2009). Over the past three decades, *Spartina* has expanded rapidly through invasive spread and artificial introduction. At present, *Spartina* is distributed in most of the tidal areas along China's coast, in 2019 covering a total area of more than 600 km^2 (Hu et al., 2021). It can outcompete native plants, many of which are food source for herbivorous birds, as well as expanding across the bare intertidal flats, which is critical foraging habitat for shorebirds. Although a few songbird species can use *Spartina* habitat (Ma et al., 2014a), the tall and dense vegetation makes *Spartina* habitat inaccessible by most waterbirds (Gan et al., 2009). Recent studies have shown that nature reserves in the Yellow Sea region are vulnerable to *Spartina* invasions (Ren et al., 2021). This is not surprising because these nature reserves have large areas of intertidal wetlands, which are suitable for the settlement of *Spartina*.

Spartina eradication projects have been launched in some coastal wetlands using physical, chemical, and biological measures, as well as the combination of various measures (e.g., Zhou et al., 2015; Feng et al., 2018; Zhao et al., 2020). These measures can be effective at the local scale (Yuan et al., 2011; Xie et al., 2019; Fan et al., 2021), but it might be difficult to scale them up to cover large areas along the entire coast. Moreover, *Spartina* can re-invade an area where it has been eradicated (Peng et al., 2022), and thus reduce the effectiveness of control measures. The tide movements function as a carrier for the *Spartina* propagules to spread along the coast. The wide distribution and rapid expansion of *Spartina* have greatly increased the difficulty and cost of control. The expert score is low in the effectiveness of implementation (1.86/5; Table 1), also suggesting that the spread of *Spartina* is still a major challenge to waterbird conservation.

Control of environmental pollution. China's coastal wetlands were once seriously polluted in the last century (CCICED, 2010; Jiang et al., 2015). In recent years, China has strengthened the monitoring of sewage discharge to rivers and seas, and coordinately prevent and control terrestrial and marine pollutants. As a whole, the environmental condition of coastal wetlands has improved significantly (Sun et al., 2015; Ministry of Ecology and Environment of PRC, 2021). However, newly emerging contaminants, including persistent organic pollutants, endocrine disruptors, antibiotics, and microplastics, have been increasingly recorded in water, sediments, and many biological groups including birds in coastal wetlands over the past decades (Melville et al., 2016; Jiang et al., 2022; Sun et al., 2023). Many studies have indicated that contaminants have multiple adverse impacts on wildlife (e.g., Vos et al., 2000), while there is still a lack of study on their impacts on waterbirds (Ma et al., 2022).

Many coastal waterbirds are long-distance migratory species, which consume a large amount of food for fuel deposition before migration, when they may accumulate significant amounts of contaminants in their body through ingesting polluted prey. During migratory flights, a large amount of fat is consumed and thus lipid-soluble pollutants are released, which can rapidly increase pollutant concentration in the body and might cause serious impacts on birds (Ma et al., 2022). The relatively low score in the expert surveys on the implement effectiveness (2.57/5) suggests that there is more work to do in the control of environmental pollution.

Reducing impacts of human activities on birds. Local people and birds have shared coastal wetlands for centuries, and human-bird interactions are common along the coast. Human activities and resource exploitation have occurred frequently even in NRs (Ma et al., 2019). To prevent the overexploitation of natural resources inside NRs, since 2017, the Ministry of Ecology and Environment has launched “green shield” supervision and inspection of NRs to investigate and penalize illegal exploitations in NRs (Huang et al., 2021). This measure has substantially improved the management effectiveness of NRs. Habitat destruction and other violations of laws and regulations, once occurring frequently, have been curbed to a large extent (Huang et al., 2021), although there

remains a problem where 'land use rights' of local people persist on land within the NRs (Ma et al., 2019).

However, many waterbirds, including threatened species, also occur outside protected areas and use human-managed habitats, such as aquaculture ponds, salt pans and paddy fields, as foraging, roosting, and even nesting sites (Wang et al., 2022b). While providing birds with supplementary habitat and food, human activities may negatively affect birds in both natural and artificial habitats (Jackson et al., 2020; Cheng et al., 2022). For example, China's coastal region is the largest aquaculture area in the world and aquaculture takes place both in fish ponds and on intertidal and subtidal zones (Melville et al., 2016; Peng et al., 2021). To mitigate economic loss by bird predation on cultured aquatic products, some aquafarm managers use destructive measures, which can kill waterbirds including threatened species (Cheng et al., 2022). Nets set on the intertidal flats for catching fish and shrimp and for protecting shellfish that are being farmed from birds can entangle birds at low tide, causing birds to drown at high tide, which may be an overlooked but serious threat (Crighton, 2016; Melville et al., 2016). Moreover, some aquaculture involved the spraying of organophosphate insecticides on tidal flats, with adverse impacts on birds and their food webs (Melville et al., 2016). An expert score of 1.71/5 on the implementing effectiveness is the second lowest score among all 10 topics, suggesting that the current effort in reducing impacts of human activities on birds is insufficient.

3.3. Multiparty participation

International cooperation and the participation of stakeholders. Most waterbirds in China's coastal wetlands are transboundary migrants and visit many countries during their annual cycle (Wang et al., 2018). As a consequence, regional and international cooperation are important for waterbird conservation. The Chinese government has signed bilateral agreements with Japan, Australia, South Korea, Russia, and New Zealand on the protection of migratory birds and their habitats. China was one of the first countries to join the EAAF Partnership, which was established by governments, intergovernmental agencies, and NGOs, and provides a flyway-wide framework to promote the conservation of migratory waterbirds and their habitats (Lei et al., 2017). Many international conservation organizations, such as World Wide Fund for Nature, Wetland International, International Crane Foundation, BirdLife International, the Paulson Institute, and the Royal Society for the Protection of Birds, have actively participated in China's coastal wetland conservation in various forms, including funding provision, technological support, capacity building and public education. The Yancheng International Symposium, a platform of domestic and international representatives to exchange knowledge on issues and solutions of coastal waterbirds and wetland conservation, has been hold annually in Yancheng since 2017. Because the symposium includes many high-level political players and decision-makers, it has largely raised the profile of waterbirds and coastal wetlands and promoted waterbird conservation in China's coastal region.

Domestic NGOs have also sprung up in China in the past two decades, such as the Society of Entrepreneurs and Ecology, the Shenzhen Mangrove Wetlands Conservation Foundation, Hong Kong Bird Watching Society, and the Zhilan Foundation. They have not only provided funds for conservation activities but also encouraged more people to participate in conservation by cultivating local grass-root conservation organizations. In 2005, a group of birdwatchers launched monthly waterbird censuses at 11 sites along China's coasts (Bai et al., 2015), and now the census has grown to include 25 sites with the participation of nearly 500 volunteer surveyors (Choi et al., 2020). The results from the census have provided important information about the distribution and population status of waterbirds along China's coast, especially by identifying previously unknown crucial waterbird sites with high conservation priority (Choi et al., 2020; Yang et al., 2021), filling in a critical knowledge gap in coastal waterbird conservation and accumulating long-term datasets, which can be used to infer population trends.

Local birdwatching groups also actively participate in waterbird conservation, such as putting forward proposals to the government, regularly patrolling unprotected key sites, and initiating public interest litigations (Chen, 2021). The contribution of international cooperation and domestic participation to waterbird conservation was also recognized in expert surveys (score 3.86/5).

Participation of researchers. Before the 1990s, there were limited studies on coastal waterbirds in China, except for a few rare and endangered species, such as the Red-crowned Crane (*Grus japonensis*). More and more domestic and international researchers have studied waterbirds and their habitats along China's coasts over the past 30 years, including the population numbers and spatial distribution (Barter, 2002; Bai et al., 2015; Xia et al., 2017), habitat requirements and quality (Jing et al., 2007; Yang et al., 2013; Zhang et al., 2019; Mu and Wilcove, 2020), wetland habitat changes (Mao et al., 2019; Hu et al., 2021; Wang et al., 2021) and their impacts on waterbirds (Piersma et al., 2016; Studds et al., 2017; Wang et al., 2022a). Results from these studies provide the scientific basis for policy-making and practical interventions in waterbird conservation. The contribution of researchers to waterbird conservation was also recognized in expert surveys (score 3.86/5).

4. Recommendations for future conservation effort

According to expert scores on conservation recommendations, eight out of the total ten topics, including two topics in policy and administration, all the four topics in habitat conservation and management, and both topics in multiparty participation, obtained an average score of greater than 3 (Table 1). These topics are identified as priorities for coastal waterbird conservation in the future.

4.1. Policy and administration

Filling conservation gaps in coastal wetlands. The coverage of protected areas and the conservation gaps in waterbird conservation have been well identified on coastal wetlands at the national level (Lei et al., 2017; Xia et al., 2017; Choi et al., 2022). Coastal wetlands with conservation priority should be stringently protected by establishing national parks or strictly protected NRs to ensure no net loss in both habitat area and quality. Other regions with high conservation values should be involved in the ECRL and can be designated as other types of protected areas, such as wetland parks, to meet the targets of both conservation and sustainable use. The unique environmental conditions shape the spatiotemporal differences in waterbirds using different areas along the coasts, suggesting that habitat loss at one site is unlikely to be offset by protecting others (Wang et al., 2022a). Moreover, once the habitat is damaged, it is difficult to restore it to its original state (Jones et al., 2018). As a consequence, protecting the existing important sites is crucial for the conservation of waterbirds, especially those highly dependent on coastal wetland habitats.

Trade-off among different ecosystem services of coastal wetlands. The outline of China's coastal wetland conservation and development has been formulated at the national level (The Central Government of the PRC, 2021). In the future, while filling the conservation gaps along the coasts, it is necessary to coordinate and trade-off among the multiple ecosystem services of coastal wetlands, including providing habitats for various wildlife, carbon sequestration, clean energy use, livelihood of local people, and supporting economic development. More active participation and communication between decision makers, researchers from different fields, wetland managers, conservation practitioners, local and international stakeholders are critical to avoid overemphasis on one aspect of ecosystem service while overlooking other services (Choi et al., 2022b).

The formulation of conservation planning by the central government is particularly important for protecting waterbirds and their habitats under China's top-down management approach. The conservation planning not only need to benefit priority waterbird species, but also to take in account the impacts of changes in sediment flow to the coasts, climate

change, and sea level rise on the dynamics of coastal wetlands. The conservation planning can be combined with restoration planning, identifying priority areas for coastal wetland restoration at national scale. It is also recommended that governments formulate guiding policies to encourage the development of bird-friendly livelihood, such as ecotourism and birdwatching, obtaining the cultural services of birds as well as raising the public awareness of conservation. Moreover, a supervision mechanism is required to ensure that conservation planning of the central government can be implemented by the local governments, as generally local governments focus on resource exploitation and economic development.

4.2. Habitat conservation and management

Coastal wetland restoration. Since the loss and degradation of natural intertidal wetland areas is the most serious threat to waterbirds, tidal wetland restoration should be the priority and tailored to improve the habitat for waterbirds, especially those tideland specialists. Managed realignment, the landward relocation of dikes to re-establish tidal exchange on formerly reclaimed land, is an effective measure that combines intertidal wetland restoration, flood defense, and other ecosystem services (van den Hoven et al., 2022). This measure is crucial for the restoration of habitats for those tideland specialists, but is missing in China. Restoration projects should be designed based on the local situation and give priority to the most cost-effective approaches, with natural restoration as the main and active restoration auxiliary, to give full play to the self-restoration ability of the ecosystem (Jones et al., 2018) and thus enhance capital use efficiency. It is also important to establish a reasonable assessment system that can reflect the restoration targets and effectiveness. In addition to the standard thresholds for physical and chemical indicators, biological indicators that indicate habitat requirement and quality of waterbirds, especially those threatened species, should also be assessed. It is crucial to put an end to "pseudo ecology" and "pseudo restoration" projects, which was named after ecology or restoration but actually causing ecological destruction and loss of natural wetland habitats for waterbirds. These projects generally invest huge amount of money to create artificial landscapes at the cost of natural landscapes, which have aroused doubts and opposition from many conservation organizations (Chen, 2021; Liu et al., 2023).

Control of invasive *Spartina*. The wide distribution and rapid spread of *Spartina* makes it difficult to fully eliminate the species. Areas that have not been invaded by *Spartina* should be monitored regularly to ensure timely detection once the invasion occurs. *Spartina* should be completely eradicated at the earliest opportunity when it is still sparsely distributed before it spreads widely – the careful use of approved herbicides is the most effective method for eradication. In areas where *Spartina* has occupied a large area, it is necessary to control its spread and eradicate as soon as possible. Some successful practices of *Spartina* control can be referred to (e.g., Taylor and Hastings, 2004; Yuan et al., 2011; Xie et al., 2019; Zhao et al., 2020; Peng et al., 2022). *Spartina* control actions in the same region should be carefully coordinated to reduce the possibility of re-invasion caused by the spread of *Spartina* from adjacent areas.

In the late 2022, China's central government has decided to eliminate *Spartina* throughout the coastal region and has set an ambitious goal of 90% reduction in the *Spartina* invaded area by 2025. Enough funds will be provided by the central and local governments to support the projects (The National Forestry and Grassland Administration of PRC, 2022; Stokstad, 2023). However, there are still many issues to be solved, including finding feasible methods based on the specific conditions at each region to achieve the targets, reducing adverse impacts caused by the large-scale projects on local environment and biodiversity, and preventing the re-invasion and recurrence of *Spartina* in the future (Wang et al., 2023). Moreover, habitat restoration should be implemented soon after *Spartina* eradication, thus providing suitable habitats for waterbirds.

Control of environmental pollution. It is suggested to conduct regular monitoring on pollutants in the water, sediment and organisms in coastal wetlands. This helps clarify the types, concentrations, sources and main geographical distribution areas of pollutants, and analyze the impacts of various pollutants on birds and their associated habitats and food. While it is important to continue to control and monitor the input of inland and marine pollutants to coastal wetlands, it is also important to implement environment-friendly economic development models, and restrict the use of agrochemicals, insecticides, fungicides and antibiotics in coastal region. The environmental impacts and the risk of industrial accidents on key sites should be considered in planning future industrial development. Environmental restoration should be carried out in heavily polluted areas.

Improving habitat quality of artificial wetlands. Expanding artificial wetlands have enormous potential in providing habitat and food for waterbirds (Jackson et al., 2020; Lei et al., 2021; Cheng and Ma, 2022; Wang et al., 2022b). As a consequence, assessing and mitigating adverse impacts of human activities on birds and improving the habitat quality of artificial wetlands can be important supplementary measures to natural wetland conservation (Cheng and Ma, 2022; Wang et al., 2022b). This is critical for waterbird conservation in China's coastal region, where natural wetlands have suffered dramatic losses. Some management practices in artificial wetlands can be beneficial to waterbirds, for example, lowering water level in aquaculture ponds facilitates the feeding of waders (Cheng et al., 2022). Different forms of financial compensation schemes including payments for ecological services (Salzman et al., 2018), such as enhancing the added value of products, can be used for the economic losses caused by waterbirds in mitigating human-bird conflicts and coordinating between conservation and local economic development. Meanwhile, the nature of addressing habitat quality in artificial wetlands tends to be site specific and thus targeted measurements are required.

Habitat conservation and management should adopt targeted measures based on the habitat requirements of waterbirds. Many studies have indicated that loss and degradation of intertidal flats, which are critical foraging habitats for many waterbirds especially shorebirds, are the major issue of conservation (Gan et al., 2009; Piersma et al., 2016; Studds et al., 2017). Meanwhile human disturbance and land exploitation along the coasts have reduced availability of roosting sites during high tide, which are used by shorebirds when intertidal flats are submerged by tidewater (Melville et al., 2016; Jackson et al., 2019). Therefore, providing foraging habitats with rich food and safe roosting habitats near the foraging sites by habitat restoration and management are important measures for the conservation of threatened shorebirds in coastal regions.

4.3. Multiparty participation

Mainstream biodiversity and encourage multiparty participation. Mainstreaming biodiversity into the plans, strategies and policies of government agencies is crucial to achieve no net loss of biodiversity while meeting the development goals of the economy and the society (Milner-Gulland et al., 2021). This approach is also applicable to coastal waterbird conservation. It is essential to realize a concerted participation of the whole society and give full play to the forces of law, administration, market and society. As most waterbirds are migratory, China can join "Convention on the Conservation of Migratory Species of Wild Animals (Bonn Convention)" (Jiang et al., 2019), thus to strengthen exchanges and cooperation with other countries in migratory waterbirds and their habitat conservation. The participation of local communities should be especially encouraged and community development with waterbird conservation should be combined (Fuller et al., 2020). Since local governments are the implementers of the central government's policies and the makers of specific measures (Ma et al., 2019), it is essential to enhance the ecological and conservation awareness of local government officers. Domestic and international NGOs have played and will continue to play an important role in waterbird conservation.

Participation of researchers. Although the distribution of important waterbird sites along the coast have been identified, the habitat quality, especially food availability for waterbirds, in most of these sites remain unknown (Peng et al., 2021; Mu et al., 2022; Wang et al., 2022a). The change in areal extent of coastal wetlands in the future under the dual impacts of human activities and global changes remain unclear. Over the past two decades, the amount of sediment runoffs has kept decreasing in China, mainly due to afforestation and dam construction in watersheds (Wu et al., 2020). The constructed seawalls, ports and wharves have altered the hydrological pattern in the coastal region. Both changes have impact on the sediment deposition and thus the erosion and expansion of coastal wetlands. Moreover, climate changes will alter bird distribution, phenology, and habitat use, as well as the interaction between birds and other organisms at local community. Predicting these changes help formulate conservation measures in the future (Muller et al., 2020).

In recent years, advances in technology and methodology (e.g., tracking of bird movements and identification of intertidal wetlands using remote sensing data) have provided new and powerful tools for studying and monitoring waterbirds and their habitats, which facilitate conservation and management practices. In the future, multidisciplinary collaboration that involves experts from geoscience, ecology, environmental science and ornithology will be necessary to design systematic monitoring programs so as to guide targeted conservation decisions and management planning. Moreover, many waterbirds, especially gulls and terns, inhabit islands along the coast but there is limited knowledge on island waterbirds, on which surveys and studies are required in the future.

Coastal waterbird conservation involves professional knowledge in many fields, especially in terms of bird habitat ecology and wetland ecosystem management. However, there is a shortage of experts in this area in China. In recent decades, the infrastructure of many nature reserves has been largely improved due to the significant investment of the central and local governments. In the future, it is necessary to increase investment in talent cultivation and improve the professional level of coastal wetland managers. Organizing regular international symposiums, such as the Yancheng international symposium, and inviting domestic and international experts to jointly explore the challenges and opportunities in coastal waterbird conservation is an effective way to find a solution. Moreover, sharing knowledge and best practices in coastal waterbird and wetland conservation among experts, local authorities, NGOs, and stakeholders help make evidence-based decision and achieve conservation targets.

5. Conclusions

The importance of China's coastal wetlands for population maintenance of waterbirds along the EAAF has been widely recognized. Many conservation measures have been put into practice and some measures, especially those in the aspects of policy and administration and multi-party participation, have achieved obvious effectiveness. Many knowledge gaps on coastal waterbird distribution, abundances, behaviour and habitat requirements have been filled rapidly in the last three decades, with many important sites for waterbirds being discovered and conserved. However, habitat loss and deterioration at many sites are still worrying. Although the loss of coastal wetlands through land claim has been curbed, tidal wetlands still face multiple threats, such as *Spartina* invasion, human disturbance including competition between intertidal aquaculture and waterbirds, and environmental pollution. These will lead to a decline in habitat quality and seriously affect waterbirds that highly rely on tidal wetlands. Conserving tidal wetlands and improving both natural and artificial habitat quality are critical for coastal waterbird conservation in the future.

The Chinese government has supported biodiversity conservation with both funds and policies over a long period and demonstrated strong commitment to ecological conservation and restoration for the future. During China's 14th Five Year Plan period from 2021 to 2025, the central government will continue to increase investment in ecological conservation and restoration and encourage diversified investment by the private sector and social organizations (The Central Government of the PRC, 2021). This provides ample opportunities for conserving waterbirds and their wetland habitats along China's coasts. Healthy wetlands benefit both waterbirds and human-beings. China has achieved obvious effectiveness in protecting wildlife and has saved many threatened species from the edge of extinction (Huang et al., 2021). What is needed for future coastal waterbird and wetland conservation is more science-based and evidence-based decision making and actions, so that effort to eradicate invasive *Spartina*, to balance the needs of different ecosystem components and livelihood of local people will be more effective, efficient and sustainable. All of these actions will require more active participation and communication between researchers from different disciplines, decision makers, wetland managers, conservation practitioners, local and international stakeholders.

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Ethics Statement

Not applicable.

Authors' contributions

ZM designed and led the review study, collected and analysed the data, and wrote the manuscript with contributions from all of the co-authors. ZM, CYC, XG, JL, YL, TM, and ZZ scored the conservation effectiveness of conducted work and conservation recommendations in the future. All authors read and approved the final manuscript.

Declaration of competing interest

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

Appendix. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.avrs.2023.100123.

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