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Ecological Offsetting in China's Coastal Wetlands: Existing Challenges and Strategies for Future Improvement

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Abstract: Land-use changes in coastal wetlands have led to a worldwide degradation of marine coastal ecosystems and a loss of the ecological services they provide. Ecological offsetting is a popular strategy and an effective mitigation measure for ecosystems that have been degraded, damaged, or destroyed and is critical for habitats where natural recovery is hindered. However, the current understanding of the theory and practice of ecological offsetting for coastal wetlands is extremely limited in many developing countries. We conducted a review of ecological offsetting for coastal wetlands projects and studies in China in 1979–2017 to explore the application and limitations of ecological offsetting theory. It was found that China's coastal ecological offsetting regime has recently entered a rapidly developing stage, with an increasing number of different types of offsetting projects conducted, but theoretical research lags behind practical applications. Considerable governmental, social, technological and ethical challenges remain to resolve. Coastal ecological offsetting schemes have been inconsistent in meeting conservation objectives or preventing net losses because of the challenges of ensuring they are fully consistent in practice (mainly in-kind offsets) and theory (mainly out-of-kind offsets). Ecological offsetting projects were primarily implemented by government, developers, and non-profit organizations. The available funding of coastal ecological offsetting projects is insufficient, which makes ecological offsetting a risky operation. Therefore, we propose strategies for improvement that integrate the consideration of theoretical and practical challenges in the offsetting process, while providing a scientific basis and directional guidance for the future practice of biodiversity conservation and environmental management.

Keywords: ecological offsetting; biodiversity offset; coastal wetlands; no net loss; mitigation; restoration

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1 Introduction

Coastal wetlands are ecosystems with complex interactions between terrestrial and marine processes, and where the water depth is less than 6 m at low tide along the coastline. China has a vast coastal area throughout its ten provinces (Liaoning, Hebei, Shandong, Jiangsu, Zhejiang, Fujian, Guangdong, Guangxi, Hainan and Taiwan) , two municipalities that are directly under the administration of central government (Tianjin and Shanghai) and the special territories of Hong Kong and Macau. The total area of coastal land in these regions is approximately 5.8×10^4 km^2 in 2014, accounting for 10.82% of the country's total area of natural wetlands (Wetland China, 2014; Sun et al., 2015) (Taiwan, Hong Kong and Macau were not included because of limitations on data collection, SFA, 2014). China had 18 983 km of coastline in 2013, from the Yalujiang Estuary,

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located on the border between China and Korea, to the Beilun Estuary (Taiwan was not included), located on the border between China and Vietnam (Liu et al., 2015). China's coastal wetlands provide a critical habitat for millions of individual migratory birds, especially shorebirds, which are often highly dependent on coastal wetlands (Barter, 2002; Mackinnon et al., 2012), with over 70% of globally threatened bird species dependent on China's coastal wetlands along the East Asian- Australasian Flyway (MacKinnon et al., 2012, China Coastal Waterbird Census Group et al., 2015). They also play an important role in promoting the economic growth of China (He et al., 2014).

However, coastal wetland ecosystems in China have been severely damaged and degraded through rapid urbanization and infrastructure development in the coastal zone of the country, and the continuing increase in population (Cui et al., 2017). A land area of 11 162.89 km^2 was reclaimed between 1979 and 2014. (Meng et al., 2017), which reflects the fast pace and large area of different types of land currently being reclaimed in China (Cui et al., 2017). The total area of natural coastal wetland in China decreased by 16% from 1990 to 2000 (Gong et al., 2010) and by 23% from 2003 to 2013 (State Forestry Administration of China (SFA), 2003, 2014; http://xzsp.forestry.gov.cn/), resulting in the loss of almost 40% of intertidal habitats since 1990 (Stroud et al., 2008; Murray et al., 2014). This has resulted in great changes in coastal wetland ecosystems (He et al., 2014), and has significantly influenced biodiversity conservation and the sustainable development of the coastal zone.

Ecological offsetting (also called biodiversity offsets, but mainly referred to as ecological offsetting in China) is becoming more common as a policy to manage the impacts of development on habitat loss in coastal wetlands (Maron et al., 2012; Yu et al., 2017). Ecological offsetting schemes are designed to compensate for unavoidable biodiversity or ecosystem service loss caused by economic activity in coastal wetlands by ensuring equivalent gains are made elsewhere (Ten Kate et al., 2004; Moilanen et al., 2009; Yu et al., 2018). Actions were to restore biodiversity (Maron et al., 2012; Curran et al., 2013) or avoid threats to biodiversity (Hockings et al., 2006; Joseph et al., 2009; Bottrill et al., 2011) to provide equal gains in future discounted terms could be determined, which means compensation for the diversity of the same species that was lost and a fixed proportion of habitat areas. They have the potential to simultaneously meet the objectives of biodiversity conservation and economic development (Bull et al., 2013). Ecological offsetting could also be an effective measure for pre-existing developments, and provide a potential strategy to mitigate the impacts of coastal reclamation on biodiversity. The ecological offsetting of coastal wetlands also refers to the institutional arrangements made for the protection of the coastal environment and its resources, the sustainable use of coastal ecosystem services, and the market and policy measures used to regulate the relationships among stakeholders in the environmental protection of coastal ecological resources. In recent decades, China has made great advances in ecological offsetting for coastal wetland, including studies of offsetting techniques and methods. The Chinese government has also implemented a series of policies and measures to protect and manage wetlands. However, China's ecological offsetting for coastal wetlands shows that the compensation effect is not obvious, there are still issues that need to be resolved (Cao and Wong, 2007). Substantial problems exist with the conception, design, and implementation of ecological offsetting for coastal wetland projects in China.

In this study, we reviewed the primary literature, reports, and databases to obtain offsetting project data for the last 40 years for the coastal wetland ecosystems of China. We undertook a systematic review in both Chinese and English using the Web of Science (http://apps.webofknowledge.com), Google Scholar (https://scholar.glgoo.org/), China National Knowledge Infrastructure (http://www.cnki.net/), online news articles, and project reports from the various webpages listed in Appendix Table S1. Databases were searched for peer-reviewed articles using the search terms '(coastal OR marine, coral OR coral reef, mangrove OR tidal marsh, saltmarsh OR salt marsh, shellfish OR oyster) and (ecological offsetting or ecological compensation or biodiversity offsets) and China', to account for all the literature on ecological offsetting for coastal wetland available by the 31st December 2017. The search was confined by focusing on the key terms in the title, the title and abstract of each reference were examined to assess their potential for meeting the selection criteria above for inclusion in the study, and resulted in the identification of 213 studies and 142 ecological offsetting pro-

jects. We reviewed the status of ecological offsetting for coastal wetlands in China, in terms of the disparate theoretical issues identified in the literature, and practical challenges that have arisen from the existing offsetting schemes. We aimed to identify the key governmental, social, technological, and ethical challenges, and determine the requirements for establishing comprehensive and integrated strategies for the development of offsetting mechanisms in a more systematic way in China.

2 Current Status of the Ecological Offsetting of China's Coastal Wetlands

2.1 Overview of the ecological offsetting of coastal wetlands in China

There have been many useful practical studies of ecological offsetting for coastal wetlands in China, but theoretical research has lagged behind practical studies. There have been great efforts made in theoretical studies since 2005, but these have not been synchronized with practical schemes (Fig. 1), resulting in the overall approach being unable to meet the needs of development.

Theoretical studies of ecological offsetting in coastal wetlands in China have mainly focused on the legislative regime of offsetting and the offsetting mechanism for coastal ecological damage. Studies of the compensation mechanism have focused on the definition of ecological offsetting, identification of the key stakeholders, the standards of offsetting, and the offsetting methods. Ecological offsetting in coastal wetlands in China can have an effect on resources and individuals, who are victims of coastal wetland development and resource utilization, as well as people who sacrifice their own interests or development opportunities for ecological or social benefits.

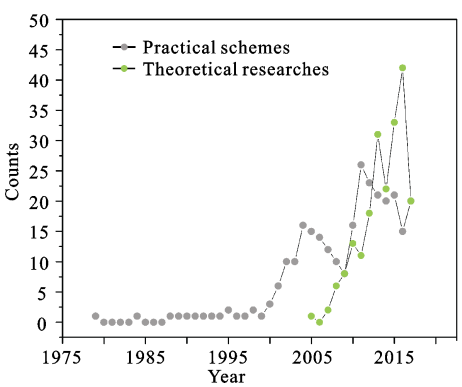

Fig. 1 The number of theoretical ecological offsetting studies and practical projects conducted in China

There were few ecological offsetting projects before 1989, except for in Guangdong and Guangxi, where there was a small-scale release of larvae and juveniles of aquatic species into coastal waters and the construction of artificial reefs, because China's legal system was still relatively underdeveloped (Fig. 2). China made great progress in the ecological offsetting of coastal wetlands after becoming a contracting party to the Ramsar Convention in 1992, and with the introduction and continuous improvement of laws such as the 'Fisheries Act' and 'Regulations on the Use of Sea Areas', with varying degrees of progress in different regions. After 2010, with the development of a marine power strategy in China, the state has paid increasing attention to marine ecological offsetting. Local governments have issued successive offsetting measures and regulations concerning marine ecological damage and loss. The number of ongoing offsetting projects is currently the highest ever (Fig. 1). There have been many practical ecological offsetting projects in Zhejiang, Liaoning, Jiangsu, and Shandong proviences, with a smaller number in Hebei, Hainan, Tianjin, and Shanghai (Fig. 2).

2.2 'In-kind' and 'out-of-kind' offsets of coastal wetlands in China

Ecological offsetting projects are often categorized as 'in-kind' or 'out-of-kind'. These terms refer to the biodiversity attributes being impacted and the compensation provided, and whether they are similar or different, respectively (Bull et al., 2016). In-kind offsets provides gains that are very similar to the losses (e.g., creation of an equivalent habitat or target the same species), while out-of-kind offsets can be economic compensation or education. The main in-kind offset methods for coastal wetlands in China are the release of larvae and juveniles into coastal waters to increase their natural supply; the construction of artificial reefs to enhance habitats; planting vegetation, which usually involves reintroducing native, habitat-forming plant species into degraded marshes, such as mangrove restoration and *Suaeda salsa* restoration; and other restoration measures (Liu et al., 2016). The main out-of-kind offsetting methods for coastal wetlands in China include economic compensation and fishermen converting to another vocation.

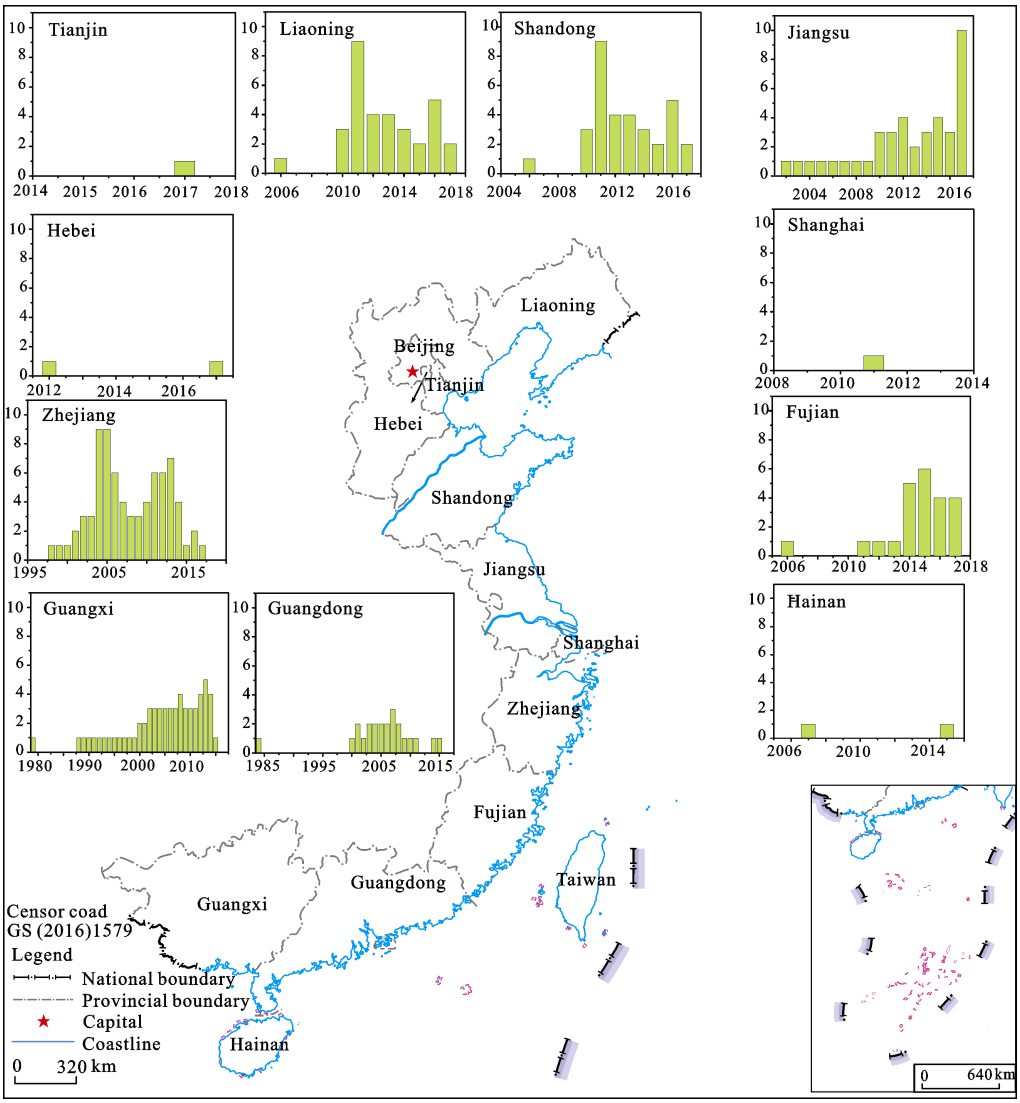

Fig. 2 The study area and the number of practical ecological offsetting projects in different provinces/municipalities (Data exclude the special territories of Hong Kong and Macau, and Taiwan Province).

There were more theoretical studies of out-of-kind offsets than theoretical studies of in-kind offsets (Fig. 3a). The opposite was true for practical projects, except for that in Shandong and Hebei provinces (Fig. 3b). The release of larvae and juveniles into coastal waters and the construction of artificial reefs was the most widely used offsetting measure. The main reasons were that the proliferation and release technology and construction of artificial reefs are relatively simple, with short-cycles and mature technologies available, respectively. These measures were mainly used in Zhejiang, Guangxi, Guangdong, Shandong, Jiangsu, and Fujian regions. The study of economic compensation measures accounted for a relatively high proportion of the theoretical research in China, and mainly included studies of ecological benefit compensation and ecological damage compensation. Economic compensation is the main mode of ecological offsetting for coastal wetlands in China, and is also the basis of other offsetting practice activities.

2.3 The funding of the ecological offsetting of coastal wetlands in China

The possible sources of funds for the ecological offsetting of coastal wetlands in China are as follows: 1) financial support provided by the central or local governments; 2) enterprises seeking to obtain materials from coastal wetland ecosystems and to engage in production and operation activities; 3) social mobilization by citizens of the coastal wetland environment and

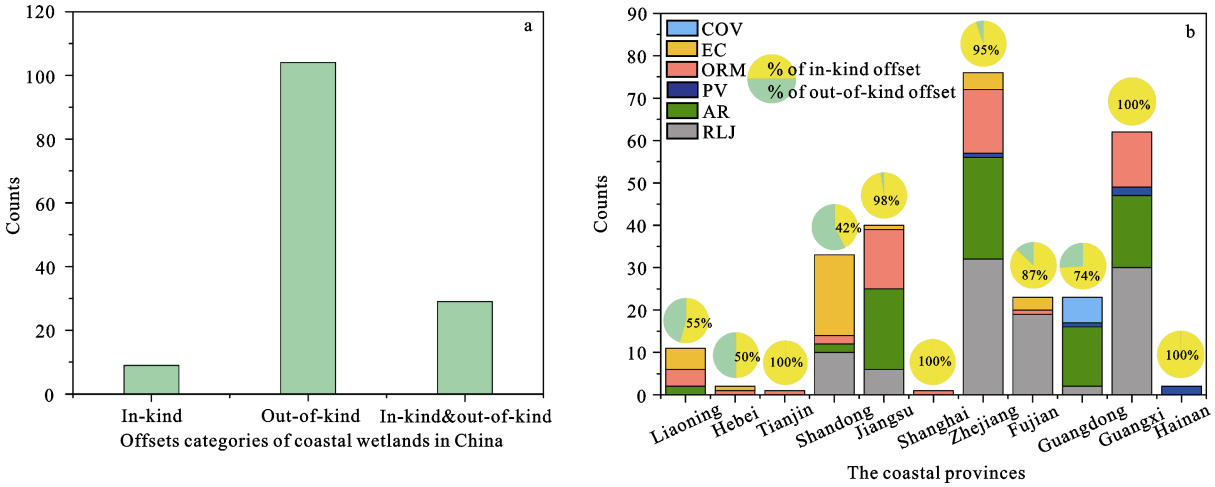

Fig. 3 The number of theoretical ecological offsetting studies of in-kind, out-of-kind, and combined in-kind & out-of-kind schemes (a) and the number of different types of ecological offsetting projects and the percentage of in-kind and out-of-kind offsetting projects in different provinces/municipalities (b) (RLJ , the release of larvae and juveniles into coastal waters ; AR , the construction of artificial reefs to enhance habitats; PV, planting vegetation; ORM, other restoration measures; EC, economic compensation ; COV, fishermen converting to other vocation). Data exclude the special territories of Hong Kong and Macau, and Taiwan Province.

natural resource users; and 4) donations or technical assistance from a foreign developed country or environmental organization.

In our assessment of 142 ecological offsetting projects, the key stakeholders in the ecological offsetting of coastal wetlands in China included government officials, enterprises, and both local and international non-profit organizations (NPOs). The number of projects funded by the government was 92, accounting for 63.89% of the total. The number of projects funded by development enterprises was 34 (23.61%); the number of projects funded by government and enterprise offsets was 15 (10.42%); and the number of projects funded by NPOs was 3 (2.08%) (Fig. 4). It was found that the ecological offsetting of coastal wetlands in China was mainly based on government offsets. Approximately 0.46×10^9 yuan RMB of funds per year were invested (Fig. 5). The funding of different ecological offsetting projects increased over time, with most funds available for artificial reefs and ecological restoration (Fig. 5).

3 Existing Challenges in China's Coastal Wetland Ecological offsetting

In recent decades, the Chinese government has recognized that ecological offsetting plays an important role in the sustainable development of coastal zones. Although China has had many noticeable achievements in the ecological offsetting of coastal wetlands, many challenges remain for effective ecological offsetting for coastal wetland. We considered the most controversial aspects of ecological offsetting in China to fall under four categories of governmental, social, technical, and ethical challenges.

3.1 Governmental challenges

Governmental challenges include the formulation of rules, policies, and institutions that guide the implementation of ecological offsetting. The government is the

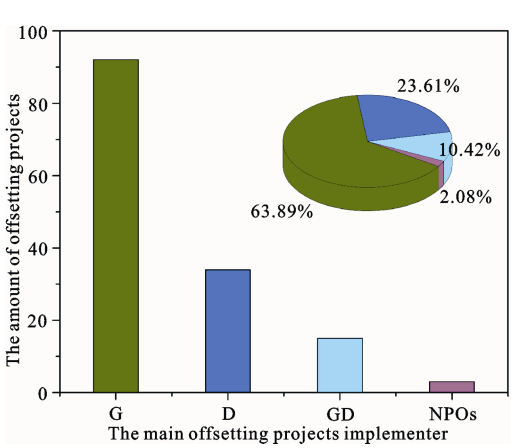

Fig. 4 The number of ecological offsetting projects funded by different offsetting implementers: government officials (G), development enterprises (D), joint government and development enterprise projects (GD), and local and international non-profit organizations (NPOs)

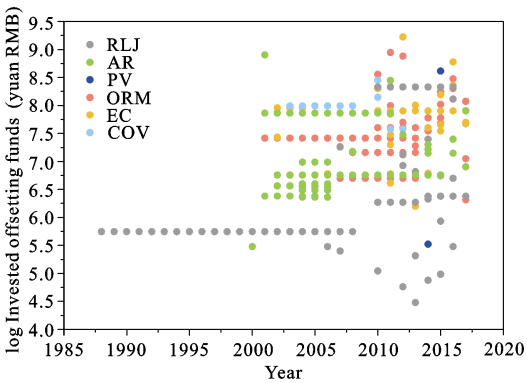

Fig. 5 Funds invested for different ecological offsetting projects in recent years (RLJ , the release of larvae and juveniles into coastal waters ; AR , the construction of artificial reefs to enhance habitats; PV, planting vegetation; ORM, other restoration measures; EC, economic compensation ; COV, fishermen converting to other vocation)

main offsetting implementation actor in China (Fig. 4), but multiple agencies with different functions are involved, such as the environmental protection department, the agricultural sector, and the marine and fishery sectors, which results in operational problems between these parties (Appendix Table S1). For example, there is a tendency for inconsistent estimates of the conservation benefits from a potential offset site to be made by Forestry department, Marine and fisheries department, nature reserve administration and water conservancy department, and there is a risk that the net loss of ecological function will therefore not be accurately determined. Compensation funds managed by government also risk being used to fund existing coastal wetland conservation or restoration projects leading to cost shifting.

In addition, there has been little focus on the monitoring of coastal wetlands due to the limited research funding. In particular, there is no national monitoring system, which prevents the government and other organizations from responding to the rapid changes in coastal wetlands, leading to the time lags from the ecological offsetting, or the amount of offsetting cannot be accurately calculated. Without such evaluations, it cannot be known whether offsets will result in no net loss of target natural resources, nor can the need for ongoing improvements be identified (Maron et al., 2016). Monitoring should occur over the life of the offsetting project, not just for the establishment phase (Maron et al., 2016). The lack of an empirical evaluation of projects and policies is a key challenge to the success of ecological offsetting (Bull et al., 2013). This situation has arisen due to the lack of institutional capacity to monitor and evaluate policies, which is a challenge for regulatory agencies.

There is also an imperfect legal and management system for coastal wetland ecological offsetting. Although the current laws or regulations of China play an important role in preventing large scale coastal wetland reclamation and pollution, there are no specific regulations for the ecological offsetting of coastal wetlands. The legal basis for the ecological offsetting of coastal wetlands is distributed throughout different pieces of legislation, such as the Constitution, Environmental Protection Law, Fishery Law, *etc*. The key constituents of ecological offsetting of coastal wetlands legislation, such as the definition, methods used to make judgments, standards for coastal ecological damage and coastal ecological offsetting management still lack a clear and operable specification. The property rights mechanisms that apply within coastal wetlands are still unclear. Coastal wetlands belong to the government but the main expropriating bodies are local governments. The existing security measures for fishermen and other users are not strong enough. The traditional uses of coastal areas and the protection of the rights and interests of those currently engaged in production in these areas are neglected in the relevant laws and regulations.

The imperfect legal and management system for ecological offsetting of coastal wetlands is not only due to the lack of development in the overall and nationwide ecological offsetting legislation, but also the late start that China has made with regard to the concept of ecological offsetting. Ecological offsetting involved a complicated relationships of different interest groups, and their cognition of ecological offsetting for coastal wetland is different, which makes it difficult to implement. The lack of legal norms and the basis for coastal ecological offsetting at the national level has greatly restricted the practice and institutional construction of coastal ecological offsetting in coastal areas (Sun et al., 2015). The conservation of the ecological environment is reliant on various institutions. The practical construction of ecological offsetting of coastal wetlands still remains under the one-way administrative control of the central government, lacks the participation of other bodies at the same level of administration, and lacks a strong ecological management concept. As a result, the construction of a system for the ecological offsetting of

coastal wetlands has lagged behind the urgent need for such a system.

3.2 Social challenges

There are social challenges in the insufficient funding and lack of cooperation among the various stakeholders of ecological offsetting of coastal wetlands in China. Approximately 0.46×10^9 yuan RMB per year was invested (Fig. 5) and 142 ecological offsetting projects in coastal wetlands were implemented by 2017 (Fig. 1). Approximately 318.94 km^2 per year of coastal wetlands were lost across all coastal provinces and metropolises from 1979 to 2014 due to land reclamation (Hong Kong, Macau and Taiwan were not included) (Meng et al., 2017), which means an average of 1.44×10^6 yuan RMB was spent on compensation per kilometer. This is lower than the world average of 1 600 000 USD (2010) per one- hectare marine coastal habitat (1.09×10^9 yuan RMB/km^2) (Bayraktarov et al., 2016), with China only investing 4.52×10^6 yuan RMB/km^2 for the same year. Therefore, China needs to increase the funds committed to wetland conservation, restoration, or reestablishment.

Funding for the ecological offsetting of coastal wetlands is solely provided by government. Although the Chinese government has already conducted ecological offsetting pilot projects in some coastal wetlands, the offsetting standards still need to be enhanced and a range of offsetting modes should be established, with all of society involved. Coastal wetlands are occupied, and there are often multiple beneficiaries that should contribute to the compensation fund. There is no scientific methodology to determine how much each beneficiary should contribute. Furthermore, there is little international cooperation in coastal wetland conservation. Advanced managements concepts and technologies need to be introduced to ensure effective coastal wetland conservation or restoration.

3.3 Technical challenges

The technical challenges in the ecological offsetting of coastal wetlands have received much attention in the scientific literature, but several of them are far from being resolved. There has been insufficient theoretical research on ecological offsetting, and the theoretical research clearly lags behind the practical research (Fig. 1). Although research on the ecological offsetting of coastal wetlands has gradually been enhanced in recent decades, some issues still remain.

The main issue to address is the question of what ecological offsetting of coastal wetlands actually is. In China, it has always been confused with restoration. The key difference between restoration and ecological offsetting is the mitigation hierarchy, which is: avoid development of important coastal areas through the careful spatial placement of elements of infrastructure; minimize the duration, intensity, or extent of impacts that cannot be completely avoided, such as increasing urban settlement density rather than the spread of distribution; reduce the impact of developments where they occur through the effective rehabilitation or restoration of impacted sites; and compensate for residual impacts where these impacts are unavoidable, through activities that protect and/or restore comparable biodiversity elsewhere (Yu et al., 2017; 2018). Restoration with respect to the mitigation hierarchy is undertaken on the development site, while restoration as a offset measure is undertaken elsewhere to compensate for the residual impacts of a development. However, there is limited research available regarding the mitigation hierarchy, and no explicit clarification is given in the existing rules and regulations of China. Ecological offsetting was formally introduced in China in 2006, but is based on financial compensation for restoring degraded ecosystems and is not underpinned by the principles usually associated with biodiversity offsetting such as the mitigation hierarchy (i.e., avoid, mitigate, offset), that outcomes should be equivalent or like-for-like and the overall objective is no net loss or net gain in biodiversity (Ali et al. 2018).

A second issue is the lack of research on in-kind offsets. The compensation method can be either an in-kind or out-of-kind offsets. However, theoretical research has mainly focused on out-of-kind offsets, with few studies of in-kind offsets (Fig. 3). The impact on biodiversity can never be exactly compensated because no two places will ever have identical biodiversity (Maron et al., 2016). However, it remains important to ensure that the valued components of biodiversity are not lost, which also remains a challenge for ecological offsetting. Ecological process research is a difficult problem in ecological research, and it is also a difficult problem in ecological offsetting. It is rarely involved in the literature on coastal wetland ecological offsetting published in China. This has resulted in limited research on the offset ratio, so that a lack of scientific research and

guidance on how much to restore or reestablish in offsets. The offset ratio can be used to determine how much biodiversity, relative to the quantity and quality affected, needs to be restored elsewhere to achieve no net loss. The offset ratio needs to encapsulate the ecological equivalence of losses and gains (Quétier and Lavorel, 2011), time lags (Bull et al., 2013), and the risk of failure (Moilanen et al., 2009; Gibbons et al., 2016). However, a offset ratio calculator relies on the political and legal context, and has not been established in China.

The final issue is the lack of guidance in the design of a monitoring program, which will affect the success of any offsetting program. Most research has taken the form of qualitative assessments rather than quantitative evaluations. Existing technologies cannot keep up with the demand for coastal wetland restoration and compensation (Liu et al., 2016). The theories and methods applied to the ecological offsetting of coastal wetlands should be systematically constructed, and the development and improvement of the practice cannot occur without the support and guidance of the theory.

3.4 Ethical challenges

Ethical challenges concern the rights and responsibilities regarding the natural resources of coastal wetlands. Offsets varies in different regions (Fig. 2), because the public awareness of coastal wetland conservation in some regions of China is still not very high. There are still many people that do not recognize the significance of coastal wetlands and regard them as barren areas. Many local managers have little knowledge of the ecological functions of coastal wetlands, which generally causes ecological offsetting of coastal wetlands to be overlooked (Sun et al., 2015). It is necessary to ensure the public understand what and how much ecosystem service value coastal wetlands provide, and to confirm whether compensating natural resource loss is related to the value of the use or non-use of nature by humans (Justus et al., 2009; Sullivan and Hannis, 2015). Although discussions of the value of coastal wetlands as a natural resource for humans are prominent in the literature (Barbier et al., 2011), the understanding of the ecological services provided by coastal wetlands is still insufficient, and an evaluation of the impacts of offsetting on the value of these services is limited.

4 Strategies for the Improvement of China's Ecological offsetting of Coastal Wetlands

China has become increasingly aware of the importance of coastal wetlands and ecological offsetting. The government's report on the 19th National Congress of the Communist Party of China stated that 'Green mountain is the golden hill', and recognized an urgent need to 'establish a market-based, diversified ecological offsetting mechanism'. The future of China's coastal wetlands therefore looks promising, and our study is of great significance to the establishment of an ecological offsetting mechanism for coastal wetlands. From a consideration of the issues covered in this study, future strategies for the improvement of China's ecological offsetting of coastal wetlands should consider the following actions.

(1) Clarify the property rights of coastal wetlands, establish a coastal wetland property rights exchange platform, and promote the marketization of ecological offsetting for coastal wetlands. Clarification of the property rights is the premise and foundation of ecological offsetting. Only when the property rights are clear, can we accurately determine the subject and object of an ecological offsetting project. The units that have the right to use the coastal wetland should be concentrated; otherwise the implementation of the ecological offsetting project will be unfavorable. The property rights of coastal wetlands can be unified through their transfer. To make full use of the market mechanism, China could establish a coastal wetland property rights exchange platform, which would permit fishermen to trade their land, beaches, and sea areas directly in the market and transfer them at normal prices. It would eliminate any 'secondary distribution' in the offsetting procedure, which would enable the government to expropriate tidal land from fishermen and place it back into the market.

(2) Improve the in-kind ecological offsetting mechanism for coastal wetland. The restoration of plant and animal communities is an important means to maintain the balance of an ecosystem. The target of restoration is usually the restoration of ecosystem resilience, structure, and function. Although it is difficult to obtain a complete recovery of the damaged ecosystem in terms of structure, function, and composition, there have been many policies operated worldwide in recent years to compensate for natural habitat loss, such as wetland

offsets in the United States (Hough and Robertson, 2009; Levrel et al., 2017), habitat offsets in Canada (Quigley and Harper, 2006; Favaro and Olszynski, 2017), green offset and biobanking systems in Australia (Chalmers, 2015), bird and habitat indications in Europe (McGillivray, 2012), and ecological offsettings in South Africa (Maron et al., 2018). China can learn from international experiences by introducing advanced concepts and techniques, and establishing an in-kind ecological offsetting mechanism based on biodiversity for coastal wetlands, which could involve the restoration of degraded habitats elsewhere (restoration offset), or the protection of areas where there is imminent or projected loss of biodiversity (avoid-loss offset) (Gibbons et al., 2016). The scale of offsetting projects needed to provide equal gains in species diversity in future discounted terms could be determined; therefore, fully compensating the losses, which includes offset for the diversity of the same species that was lost and a fixed proportion of habitat areas (Ten Kate et al., 2004). In addition, the restoration offset of ecosystem process is also important to the coastal ecosystem, theoretical and practical research on this aspect should also be strengthened in future research.

(3) Increase funds for research on the ecological offsetting of coastal wetlands. The purpose of ecological offsetting is to protect and improve the ecological environment. There have been suggestions made to innovate the financing of ecological offsetting and establish a financing mechanism for 'government guidance, market promotion and social participation'. To ease the shortage of funds, the government should encourage private companies, institutions, and organizations to invest, especially from most provincial or local wetlands. This special fund could be used for environmental protection in coastal areas, issuing government bonds, promoting preferential credit and economic cooperation, and to form a diversified financing pattern.

China should also increase its investment in coastal wetland research, including the funding of basic research to determine the ecological loss caused by different projects, to explore advanced restoration and compensation technologies, and to develop restoration offset and avoid-loss offset patterns that can resolve the contradiction between coastal wetland conservation and utilization, ensuring the sustainable development of coastal wetlands in China. Increasing investment in the protection of coastal wetland resources and the establishment of a coastal wetland biological resources, environment, and hydrology monitoring group (Wang et al., 2008), for the effective protection and sustainable utilization of wetland resources would provide a scientific and technical basis for the ecological offsetting of coastal wetlands. This would provide basic data for use in wetland ecological offsetting and make the concept of wetland ecological offsetting more scientifically valid.

(4) Improve ecological offsetting legislation and management for coastal wetlands. Strict legislation, science-based regulations, and effective management mechanisms are required to ensure smooth progress in the development of ecological offsetting for coastal wetlands. Ecological offsetting for coastal wetlands should be incorporated into legislative planning so that it can be implemented throughout the entire environment. On the basis of the 'Regulations on Ecological offsetting', a special coastal wetlands ecological offsetting system should be formulated, which contains the scope of the offsetting, the main actors in the offsetting, offsetting objects, offsetting content and methods, offsetting standards, implementation measures, and supervision of the offsetting. This would guarantee the standardization and effectiveness of ecological offsetting for coastal wetlands. A system to assess the effectiveness of laws, policies, and regulations must be established and the responsibility for funding projects should be established.

(5) Strengthen coastal wetland education and training for the public. Improving the publics' knowledge of the ecological functioning of coastal wetlands and their understanding of the importance of ecological offsetting for coastal wetlands would facilitate the success of coastal wetland restoration and ecological offsetting. This could be realized in various ways, such as through the media or by encouraging experts specialized in coastal wetlands research to participate in public education activities. To create feasible conditions for improving public knowledge, the funding of coastal wetlands education should also be greatly increased. To improve the management of coastal wetlands, the training of coastal wetland managers should be strengthened, and a technical consultation mechanism for the management of coastal wetlands should be established.

5 Conclusion

We reviewed the advances in ecological offsetting projects and theoretical studies of coastal wetlands in China in 1979–2017. There was an increasing number of different types of offsetting projects conducted, but theoretical research lags behind practical applications. A considerable number of governmental, social, technological and ethical challenges were identified to resolve. Coastal ecological offsetting schemes have the challenges of inconsistent in practice and theory, the practice were mainly in-kind offsets, but the theory were mainly out-of-kind offsets. The main stakeholder involved in implementation were government, developers, and nonprofit organizations. The available funding of coastal ecological offsetting projects is insufficient, which makes ecological offsetting a risky operation. We proposed strategies for the improvement of China's coastal wetlands ecological offsetting, which mainly consisted of clarifying the property rights of coastal wetlands, promoting the marketization of ecological offsetting for coastal wetlands, improving the in-kind ecological offsetting mechanism, increasing funding, improving coastal wetland monitoring and management systems, improving ecological offsetting legislation for coastal wetlands, and strengthening coastal wetland education and training for the public. It is extremely important to promote the practice of ecological offsetting of coastal wetlands and the sustainable use of resources and biodiversity protection. It is also necessary to develop the theory of ecological offsetting for coastal wetlands to improve the effectiveness of ecological offsetting measures in the future.

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Table S1 List of China's organizations related to coastal restoration

Local government authority	Websites
State Forestry Administration	http://www.forestry.gov.cn/
Ministry of Land and Resources	http://www.mlr.gov.cn/
Ministry of Ecology and Environment of the People's Republic of China	http://www.zhb.gov.cn/
State Intellectual Property Office of the People's Republic of China	http://www.sipo.gov.cn/
National Science and Technology Report Service	http://www.nstrs.cn/
Major Science and Technology Program for Water Pollution Control and Treatment	http://nwpcp.mep.gov.cn/
State Oceanic Administration	http://www.soa.gov.cn/
First Institute of Oceanography of State Oceanic Administration	http://www.fio.org.cn/
Second Institute of Oceanography of State Oceanic Administration	http://www.sio.org.cn/
Third Institute of Oceanography of State Oceanic Administration	http://www.tio.org.cn/
East China Sea Branch of State Oceanic Administration	http://www.eastsea.gov.cn/
South China Sea Branch of State Oceanic Administration	http://www.scsb.gov.cn/
North China Sea Branch of State Oceanic Administration	http://www.ncsb.gov.cn/
China Marine Economic Information Network	http://www.cme.gov.cn/
Information service platform for technology and the sea	http://www.kjxh.gov.cn/index.php
Department Of Ocean And Fisheries Of Liaoning Province	http://www.lnhyw.gov.cn/
Hebei Provincial Department of land and Resources (Oceanic Administration)	http://www.hebgt.gov.cn/
Tianjin Oceanic Administration	http://www.tjoa.gov.cn/
Shandong Provincial Oceanic and Fishery Information Network	http://www.hssd.gov.cn/
Jiangsu Oceanic and Fishery	http://www.jsof.gov.cn/
Shanghai Municipal Ocean Bureau	http://www.shanghaiwater.gov.cn
Zhejiang Province Ocean and Fisheries Bureau	http://www.zjoaf.gov.cn/
Fujian Provincial Department of Ocean and Fisheries	http://www.fjof.gov.cn/
Administration of Ocean and Fisheries of Guangdong Province	http://www.gdofa.gov.cn/
The Oceanic Administration of Guangxi	http://www.gxoa.gov.cn/
Department of Ocean and Fisheries of Hainan Province	http://dof.hainan.gov.cn/
Institute of Oceanology, Chinese Academy of Sciences	http://www.qdio.cas.cn/
Yantai Institute of Coastal Zone Research, Chinese Academy of Sciences	http://www.yic.ac.cn/
South China Sea Institute of Oceanology, Chinese Academy of Sciences	http://www.scsio.cas.cn/
Chinese Academy of Fisheries Sciences	http://www.cafs.ac.cn/
Yellow Sea Fisheries Research Institute, Chinese Academy of Fishery Sciences	http://www.ysfri.ac.cn/
East Sea Fisheries Research Institute, Chinese Academy of Fishery Sciences	http://www.eastfishery.ac.cn/
South China Sea Fisheries Research Institute, Chinese Academy of Fishery Sciences	http://www.southchinafish.ac.cn/
South China Sea Tropical Marine Biology and Disease Institute, Hainan	http://www.tmbcn.cn/index.asp
Wetland China	http://www.shidi.org/
Wetlands International	http://www.wetwonder.org/
Global Environment Facility in China	http://www.gefchina.org.cn/
Global Environment Facility Small Grants Programme China	http://www.gefsgp.cn/
The Chinese Ecological Restoration Networks	http://www.er-china.com/