Services value evaluation of wetland ecosystem in Guangdong Haifeng Avian Provincial Nature Reserve

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Abstract Guangdong Haifeng Avian Provincial Nature Reserve is a typical representative of coastal wetlands in subtropical regions of southern China, and it plays an important role in material production, environmental regulation, humanistic society and so on. Based on the comprehensive analysis of the present situation of Haifeng wetlands, this paper used the ecological economic value assessment method, such as market value method, field survey method, benefit transfer method, shadow project method, afforestation cost method, carbon tax method, industrial oxygen generation method and replacement cost method, etc. to classify the systematically evaluation of the value and composition of Haifeng wetland ecosystem services. The results showed that the total value of wetland ecosystem service in Guangdong Haifeng Avian Provincial Nature Reserve in 2013 was 107.861×10^6 yuan with an average value of 1.69 yuan$\cdot m^{-2}$. The greatest among the indexes was biological diversity maintenance, accounting for 44.67% of the total value, and followed by recreation, food supply service, climate regulation, water purification, nutrient accumulation, carbon sequestration, water supply, scientific research, atmospheric constituent regulation, and raw material supply.

Keywords Wetland · Service function · Haifeng Reserve · Value assessment

Introduction

Coastal wetlands, locate in the transition zone between terrestrial and oceanic environments, are unique ecosystems with abundant natural resources and important ecological functions (Levenson 1991). According to statistics (Mitsch and Gosselink 2000), the area of wetland accounts for only 5% to 8% of the global land surface, but its function takes up 14.7% of that of the global ecosystem. Especially, the mangrove and other coastal types are one of the world's most valuable ecosystems with the most abundant biodiversity, and the highest biomass (Zhang et al. 2013). However, coastal wetlands are still in declining and losing habitats. For

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example, under the dual impact of natural and human activities, like typhoons, seawater erosion, reclamation, aquaculture, and coastal port expansion, about 50% of China's coastal wetland area suffers varying degrees of degradation or even disappearance, leading to serious damage to its service function (Zhang et al. 2014). The research on the evaluation of coastal wetland service is based on the thorough study of the function mechanism of coastal wetland service. It evaluates scientifically the coastal wetland service value. The research results can provide data support and theoretical basis for protecting and repairing the present residual or damaged coastal wetlands. At present, related researchers on the evaluation of coastal wetland ecosystem services are mainly focused on the following aspects, such as the discussion of value evaluation theories, screening and deductibility of evaluation methods and the scale effect of value evaluation (Barbier 2015; Brouwer et al.1999; Li et al. 2014; Zhang and Ma 2011). There are many cases about coastal wetland value evaluation, but evaluation cases with the coastal wetland ecosystem as the study object are relatively fewer (Xu et al. 2015).

Artificial wetlands dominate the Guangdong Haifeng Avian Provincial Nature Reserve such as aquaculture ponds. It is also a typical representative of the coastal wetlands in subtropical area of southern China. It plays an important role in providing habitat for migratory birds. In the past, the related researches have paid more attention to the population and quantity changes of birds in the reserve (Gao et al. 2014; Hu et al. 2009; Zeng et al. 2016 a). The research on the ecosystem service value of that reserve dominated by artificial wetlands has not been reported. Based on the present most widely recognized and widely used Millennium Ecosystem Assessment System, this paper uses the market value method and the actual survey method to scientifically evaluate the main service value of the wetland ecosystem of reserve, with a view to providing important scientific material for protecting, managing, and scientific and educational promoting wetlands in reserve.

Data and methods

An overview of the study area

The Guangdong Haifeng Avian Provincial Nature Reserve is located in the eastern coastal area of China, and in Haifeng county, Shanwei city, Guangdong province, with a total area of 11 590.5 hm^2. It is composed of three districts: Gongping, Dahu and Dongguan Lian′anwei （hereafter ′Dongguan′） (Fig. 1). Among them, Gongping partition is situated in the upper reaches of the Huangjiang River, while Dahu and Dongguan Lian'anwei districts are in the two estuaries of the Huangjiang River. The three zones of the reserve are complementary in terms of wetland types, hydrological conditions, waterfowl resources and vegetation types, and constitute the complicated and diverse complex wetland ecosystem of Haifeng Nature Reserve (Zeng et al. 2016 b). The reserve features south subtropical monsoon, with an average annual temperature of 21 – 22 ℃ and an average annual rainfall of 1 800 – 2 400 mm. The climate is suitable and the precipitation is abundant. It relies on the Huangjiang River Basin, created various types of wetlands, including rivers, swamps, tidal flats, estuaries, aquaculture ponds, mangroves and shallow waters. It is an important component and a typical representative of wetlands in Guangdong province (Guo 2011), playing an irreplaceable service role and having great value in providing bird habitat, etc.

Data sources

This paper takes the Dahu and Dongguan Lian'anwei partition in Haifeng Avian Provincial Nature Reserve as the studying area: with the Quickbird image (resolution 0.6 m) as the basic data source. The image is from the Google earth platform, and shot on January 11, 2013. Based on the GPS control points obtained from field survey, the geometric correction of the Quickbird image was conducted with ArcGIS 9.3 software, with error controlled in 0.5 pixels or less. The projection coordinate system of the image adopts the commonly used map projection WGS-1984-Web-Mercator in network geography, such as Google Earth. The image

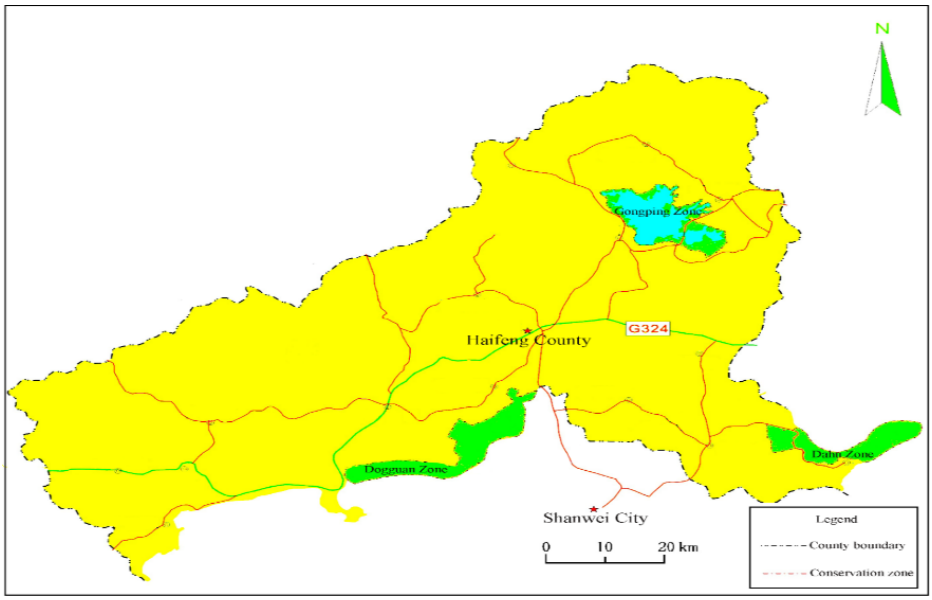

Fig.1 The position of Guangdong Haifeng Avian Provincial Nature Reserve

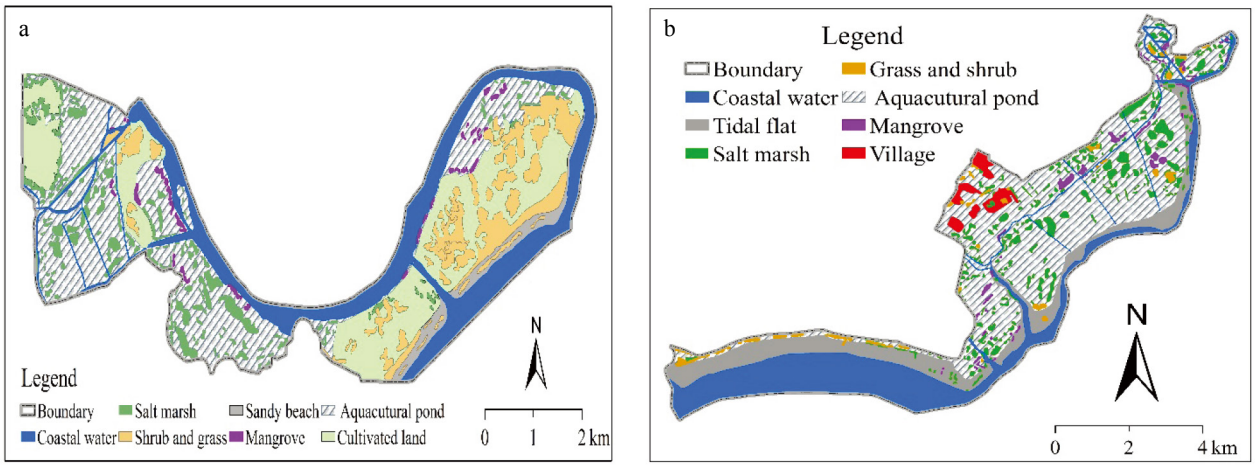

Fig.2 Classification maps of wetland types in Guangdong Haifeng Avian Provincial Nature Reserve. a: Dongguan partition; b: Dahu partition

Table 1 Summary for wetland area in Guangdong Haifeng Avian Provincial Nature Reserve

Wetland type	Dongguan / hm^2	Dahu / hm^2	Percentage of study area / %
Coastal waters	1139.09	549.47	23.99
Salt marsh wetlands	388.81	202.65	8.40
Shrubs	100.16	307.81	5.80
Beaches (silt and gravel)	683.10	73.79	10.75
Mangroves	79.03	26.82	1.50
Ponds	2060.37	758.96	40.05

classification is mainly done by visual interpretation in ArcGIS 9.3. According to the landscape characteristics of the Dongguan Lian'anwei and Dahu partition, they are divided into seven types of wetlands, i.e., coastal waters, muddy beaches, beaches (silt and gravel), salt marsh wetlands, shrubs, ponds, and mangroves. (Fig. 2 and Table 1). To ensure the accuracy of maps classified, the screen resolution is controlled within 1: 1 000. The field study time is mainly from June to October in 2016. After three times and 6 days of field verification tests, the overall accuracy of image interpretation meets the research needs.

Statistical data for wetland type, area and distribution of the reserve derived from the results of image interpretation. Some auxiliary evaluation parameters and field survey data were also selected to calculate services value of the study area, and detailed computational process can be found as follows. All data were based on 2013 as a statistical base year.

The wetland service value evaluation index system and methods

The Millennium Ecosystem Assessment (MA) divided ecosystem services into four categories: supply, regulation, support, and culture. Its value estimation method

Table 2 The Haifeng wetland service value evaluation index system

Service type	Evaluation indicators	The meaning of indicators	Evaluation methods
Supply	Food supply	Wetlands can supply fish, crustaceans, shellfish, algae, and other marine aquaculture products.	The market value method
	Water supply	The unique water conservation function of mangrove wetland is reflected in providing farmland irrigation water for the residents by shallow groundwater.	The market value method
	Raw material supply	The annual amount growth of mangrove.	The market value method
Regulation	Climate regulation	wetland regulates its regional climate in terms of cooling and humidification mainly through surface evapotranspiration.	The shadow project & The benefit transfer method
	Water purification	Wetland accepts sewage and degrades and removes it by physical, chemical, or biological action.	The benefit transfer method
	Carbon sequestration	Wetland plants and algae are fixed CO_2 by photosynthesis and shellfish growth.	The Afforestation cost method & The international carbon tax method
	Atmospheric constituent regulation	Wetland plants and algae release O_2 and CO_2 and CH_4 through the respiration of wetland soil through photosynthesis.	The industrial oxygen method & The replacement cost method
Support	Biodiversity maintenance	It is used to protect wetland habitats and to maintain the input cost of wetland ecosystem health operation.	The benefit transfer method
	Nutrient accumulation	Absorption of N and P elements in seawater by phytoplankton.	The market value method
Culture	Leisure tourism	Direct and indirect tourism income from wetland tourism resources.	The benefit transfer method
	Scientific research education	Research funding for wetland related research.	The actual survey method

Table 3 The assessment parameters of food supply value in the Haifeng Avian Provincial Nature Reserve in 2012

Breeding type	Production / ($t \cdot hm^{-2} \cdot a^{-1}$)	Unit price / ($Yuan \cdot t^{-1}$)	Value / ($Yuan \cdot a^{-1}$)
Penaeus monodonp	0.750	20×10^4	4.229×10^6
Scylla serrata	1.250	16×10^4	5.639×10^6
Cichlidae sp.	10.125	2×10^4	5.709×10^6
Ostrea gigas thunberg	2.000	1×10^4	4.564×10^6
Total	14.125		16.141×10^6

was the most widely recognized and used method at present (Assessment 2005). Basing on the Millennium Ecosystem Assessment System, and combining the wetlands characteristics of the Haifeng Avian Provincial Nature Reserve, this paper divided the Haifeng wetland service into four types, i.e., supply (food supply, water supply and raw material supply), regulation (climate regulation, water purification, carbon sequestration and atmospheric constituent regulation), support (biodiversity maintenance and nutrient accumulation) and culture (leisure tourism and scientific research education), including 11 indicators (Table 2).

Supply service

(1) The Food supply value

In the Dongguan and Dahu partition of the Haifeng Avian Provincial Nature Reserve, the embanked natural aquaculture area accounting for 1/100 of the total area of the ponds in the reserve, is about 28.19 hm^2. With high production capacity of aquaculture products, the common breeding products are *Penaeus monodonp*, *Scylla serrata*, *Cichlidae* sp., *Mugilidae* sp., *Ostrea gigas thunberg* and so on. Its food (seafood) supply function can be estimated by the market value method.

The formula is as follow:

$$V_s = \sum_{i=1}^{n} Y_i \times S \times P_i$$

In the formula, V_s refers to the value of food supply, Yuan; i is the type of product; Y_i is the number of the i type product per area; S is the area of the pond, hm^2; P_i is the price of the i type product, Yuan·t^{-1}. The seafood species, unit production and price are obtained by fishermen in the field investigation and the surrounding markets. The result of ponds area is interpreted in accordance with remote sensing images, with the assessment parameters shown in Table 3.

(2) Water supply value

The mangroves in the Haifeng Avain Provincial Nature Reserve have been subjected to seawater immersion for a long time and maintain moisture through their unique method of draining salt. The unique water conservation function of mangrove wetland is reflected in providing farmland irrigation water for the residents by shallow groundwater. The value of its water supply can be estimated by the market value method:

$$V = S \times Q \times P$$

In the formula, V is the value of water supply, Yuan; and S is the mangrove area of the reserve, hm^2; Q is the unit water storage of 8 100.00 $m^3 \cdot hm^{-2}$ (Lv 2004); P is the average price of agricultural water in Haifeng county in 2013, which is 1.45 Yuan·m^{-3}.

(3) The value of raw material supply

The wetland raw material supply service in Haifeng Avian Provincial Nature Reserve is mainly reflected in the wood products of mangrove wetland. It can be estimated by the market price of mangrove units.

$$V = S \times V_t \times P$$

In the formula, V is the value of raw material supply, and S is the mangrove area, hm^2; V_t is the annual average growth of mangrove, 4.39 $m^3 \cdot hm^{-2} \cdot a^{-1}$ (Han et al. 2000); P is the price of mangrove wood. By referring to literature (Liao et al. 2006), and combining with the price in the local timber market of the reserve, it was determined to be 996.725 yuan $\cdot m^{-3}$.

Regulatory services

(1) The value of climate regulation

The Haifeng Avain Provincial Nature Reserve wetland regulates its regional climate in terms of cooling and humidification mainly through surface evapotranspiration. The calculating formula is as follow:

$$V = (S_1 \times Q_1 + S_w Q_w) \times P$$

In the formula, V is the value of climate regulation, Yuan; Q_1 and Q_w are the average annual evaporation of the two types of wetlands: one with no clear water surface and one with clear water surface, 786 and 1 075 mm respectively (Fan 2011); S_1 and S_w are the area of two types of wetlands in Haifeng reserve, hm^2; P is the unit value of wetland climate's regulation function, 0.129 yuan $\cdot m^{-3}$ (Zhang and Kong 2013).

(2) The value of water purification

Mangroves have a strong adsorption and purification effect on harmful heavy metals, nitrogen and phosphorus nutrients and other pollutants. It is calculated as follow:

$$V = Q \times S$$

In the formula, V is the water purification value of mangrove in reserve, yuan; and Q is the adsorption val-

ue of the mangrove wetland on nitrogen, phosphorus, and heavy metals in the unit area, 3.770×10^4, yuan · hm^{-2} · a^{-1} (Zhang 2013); S is the area of mangrove, hm^2.

(3) The value of carbon sequestration

The carbon sequestration value of the Haifeng Avian Provincial Nature Reserve wetland is mainly reflected in the forms of the mangrove's aboveground vegetation, phytoplankton and soil organic carbon, sequestiation potential.

$$V = [S_1 \times (r_m + r_s) + S_c \times r_p] \times C_c$$

In the formula, V is the value of carbon sequestration, Yuan; r_m, r_s and r_p are the coefficients of the carbon sequestration of mangrove's aboveground vegetation 11.35 t·hm^{-2} ·a^{-1} (Han et al. 2000) with soil 2.789 t·hm^{-2} ·a^{-1} (Duan et al. 2008) and phytoplankton 2.3 t·hm^{-2} ·a^{-1} (Li et al. 2006). S_1 and S_c are the area of mangrove and coastal waters in the reserve, hm^2; Cc is the carbon tax rate, the mean value of afforestation cost in China (250 yuan·t^{-1}) and the international carbon tax standard (770 yuan·t^{-1}) (Wang et al. 2011).

(4) The value of atmospheric component regulation

The atmospheric regulation of Haifeng wetland includes the positive effects of wetland vegetation releasing oxygen through photosynthesis and the negative effects of wetland soil releasing greenhouse gases (CO_2 and CH_4) by respiration. According to the formula of photosynthesis, when the wetland plants produce 1 g of dry matter, it will release 1.07 g of O_2. The amounts of O_2 released from vegetation, mudflat (including mud beach and intertidal saltwater swamp) in the mangrove are calculated in this way. The amount of CO_2 discharged from the soils of mangroves and mudflats in protected areas (including the CH_4 greenhouse effect converted to CO_2) is used to estimate the quality of the greenhouse. The formula is:

$$V = (S_m \times O_m + S_t \times O_t + S_o \times O_p)C_o - (S_m \times C_m + S_t \times C_t)C_c$$

In the formula, V is the value of atmospheric components regulation in the reserve, Yuan; S_m, S_t and S_o are areas of mangroves, mudflats, and coastal waters of reserve (Table 1); O_m, O_t and O_P are the oxygen release coefficients of mangroves, mudflats vegetation, phytoplankton in coastal waters of the reserve. They were 12.14, 8.75 and 2.46 t·hm^{-2} ·a^{-1} respectively (Gao et al. 2017). C_m and C_t were the CO_2 unit emission coefficient of the two wetland soils, i.e., mangrove and mudflats in the reserve. They are 12.26 and 9.78 t·hm^{-2} ·a^{-1} respectively (Ren and Li 2004; Kang et al. 2008); C_O is the price of industrial oxygen in China, 400 yuan·t^{-1}; C_C is the carbon tax rate, 510 yuan·t^{-1} (Wang et al. 2011).

Support services

(1) The value of biodiversity conservation

Nature reserve is one of the main forms of wetland protection at present, and its value can be evaluated according to the cost of protecting such habitats. The formula is:

$$V = S \times C_n$$

In the formula, V is the value of biodiversity conservation, 10^6 yuan; S is the area of the reserve, hm^2; C_n is the average amount of the annual input cost for the nature reserve in developed and developing countries. It is 1 107.5 USD·km^{-2} (RMB exchange rate by 1: 6.83 $) (Costanza et al. 1997).

(2) The value of nutrient accumulation

The accumulation of nutrients in Haifeng wetland is mainly achieved by phytoplankton's photosynthesis of absorbing N and P (ratio 16 : 1) in seawater. The formula is:

$$V = S \times (A_n + A_p) \times P$$

In the formula, V is the value of nutrients accumulation, yuan; S is the area of coastal waters in Haifeng reserve, hm^2; A_N and A_P are the absorption rates of N and P elements by phytoplankton in Haifeng reserve offshore. They are 0.404 8 and 0.055 2 t·hm^{-2} ·a^{-1} (Li et al. 2006 and Zhang et al. 2008), P is the fertilizer price, 4 250 yuan·t^{-1}.

Culture services

(1) Leisure tourism value

Haifeng wetlands enjoys the name of *Guangdong's top ten beautiful wetlands*, *Chinese waterfowl town* and *wetland of international importance* etc. The variety of wetland resources and endangered waterfowls (such as *Platalea minor*) make it have a unique tourism value. The assessment of Costanza in wetland entertainment value (574 hm^{-2} ·a^{-1}) is used as the reference value. The formula is:

$$V = S \times R_1$$

In the formula, V is the value of leisure tourism, yuan; S is the area of the reserve, hm^2; R_1 is the wetland entertainment value standard defined by Costanza. The exchange rate of RMB in 2013 is 6.17 yuan.

(2) The value of scientific research and education

The value of scientific research and education in Haifeng wetlands is estimated by checking and calculating the total input cost of papers published annually related to Haifeng Avain Provincial Nature Reserve. The formula is:

$$V = N \times C_p$$

In the formula, V is the value of scientific research and education, yuan; N in the number of papers searched in CNKI by retrieving papers related to theme of *Haifeng wetland* or *Haifeng Avain Provincial Nature Reserve*. In 2013 there are 5 papers; C_p is the papers' input cost, using 1.192×10^5 yuan · per paper^{-1} as the standard (Pang et al. 2014).

Results and analyses

In 2013, the total value of wetland ecosystem services in the Dahu and Dongguan Lian'anwei partition of Haifeng Avain Provincial Nature Reserve was 107.861×10^6 yuan, and the unit value of wetland is 1.69 yuan $\cdot m^{-2}$. Among the various types of services provided by Haifeng wetland ecosystem, support services have the highest value of 51.49×10^6 yuan, accounting for 47.73% of the total service value, followed by cultural service value and supply service value, respectively, accounting for 21.47% and 16.55% of the total service value. The minimum service value is that of regulation service of 15.372×10^6 yuan, accounting for 14.25% of the total service value (Table 4).

In the components of Haifeng wetland ecosystem service value (Table 4), the biodiversity conservation value is the highest, 48.185×10^6 yuan$\cdot a^{-1}$, accounting for 44.67% of the total value, followed by leisure travel (22.56×10^6 yuan$\cdot a^{-1}$), food supply (16.141×10^6 yuan$\cdot a^{-1}$) and climate regulation service (8.139×10^6 yuan$\cdot a^{-1}$), accounting for 20.92%, 14.96% and 7.55% of the total value respectively. The sum of the remaining service functions value is 12.836×10^6 yuan$\cdot a^{-1}$, accounting for 11.90% of the total value.

Discussion and conclusion

The main service value of the wetland ecosystem in Haifeng Avain Nature Reserve consisted mainly of biodiversity conservation, leisure tourism, food supply and climate regulation. This was mainly due to the unique structure of Haifeng wetlands. The dominant components of Haifeng wetlands were aquaculture ponds and other types of artificial wetlands. The aquaculture pond was coastal mudflats and mangrove wetlands in intertidal zone in the past. But now it is an embanked extensive

Table 4 The service value of wetland ecosystem in the Haifeng Avian Provincial Nature Reserve in 2013

Service type	Evaluation indicators	Value / yuan	Ratio / %
Supply	Food supply	16.141×10^6	14.96
	Water supply	1.243×10^6	1.15
	Raw material supply	0.463×10^6	0.43
Regulation	Climate regulation	8.139×10^6	7.55
	Water purification	3.991×10^6	3.70
	Carbon sequestration	2.744×10^6	2.54
	Atmospheric constituent regulation	0.498×10^6	0.46
Support	Biodiversity maintenance	48.185×10^6	44.67
	Nutrient accumulation	3.301×10^6	3.06
Culture	Leisure tourism	22.560×10^6	20.92
	Scientific research education	0.596×10^6	0.55
Total		107.861×10^6	100

breeding area. It is a naturally mixed breeding method setting the waters embanked with the sea water back and forth (saline and dilute water alternating cycles). This breeding method provides not only good quality, and high value of seafood for the local fishermen, but also a good habitat for a larger number of migratory birds. The harmonious coexistence of breeding ponds and migratory birds also attracted many bird lovers and tourists. In addition, the higher water ratio of the pond with coastal waters, combining with the unique vegetation of the salt marsh wetlands, makes the wetland system play a significant climate regulation role in cooling and humidifying, releasing oxygen and so on. However, Haifeng wetland, as a typical wetland in the subtropical region of China, has less than 0.7% of the scientific research and education value, which indicates that the level of scientific research input and educational propaganda in this area is low and in great need to be improved.

The unit value of wetland ecosystem service of Guangdong Haifeng Avain Provincial Nature Reserve is 1.69 yuan·m^{-2}·a^{-1}, which is significantly lower than that of Liaoning province (2.916 yuan·m^{-2}·a^{-1}) (Zhang et al.2008), Zhejiang province (3.664 yuan·m^{-2}·a^{-1}) (Wang et al. 2014), Guangdong province (8.147 yuan·m^{-2}·a^{-1}) (Gao et al. 2017) and that of other coastal wetlands. It is also lower than that of mangroves in Zhangjiang estuary (5.999 yuan·m^{-2}·a^{-1}) (Zhang et al. 2013), Zhanjiang city (28.28 yuan·m^{-2}·a^{-1}) (Deng and Liu 2007) and Dongzhai port (22.55 yuan·m^{-2}·a^{-1}) (Ding et al. 2007) and other natural wetlands, as well as the paddy field of Suzhou city (7.31 yuan·m^{-2}·a^{-1}) (Liu et al. 2015) and other artificial ecosystems. This is mainly caused by three aspects. First is that the single type of wetland in Haifeng Nature Reserve, structural imbalance, the high proportion of artificial wetlands, such as aquaculture area accounting for 40.05% of the total area of the reserve. Second, the management and protection measures of the reserve are not effectively implemented. Some of the measures may be shelved when ecological protection and economic interests are in conflict. Third, there is no separate account of the existence value of the endangered species. Some of the service value (such as the maintenance cost of the reserve and the tourism value of birds) are counted by referring to previous studies, because data are not available. These reason may underestimate the value of ecosystem services.

In 2013, the total value of the wetland ecosystem services in the Dahu and Dongguan Lian'anwei partition of Guangdong Haifeng Avain Provincial Nature Reserve was 107.861×10^6 yuan. Haifeng wetlands provided 11 services, i.e., food supply, water supply, raw material supply, climate regulation, water purification, carbon sequestration, atmospheric component regulation, biodiversity conservation, nutrient accumulation, leisure tourism and research education, and their service values were 16.141×10^6, 1.243×10^6, 0.463×10^6, 8.139×10^6, 3.991×10^6, 2.744×10^6, 0.498×10^6, 48.185×10^6, 3.301×10^6, 22.560×10^6 and 0.596×10^6 yuan, respectively. In the future, some research directions should be strengthened e.g., the damaged Haifeng wetland or its weak service function, the field long-term positioning and observation experiment, new evaluation theory, index system and evaluation technology of ecosystem service value, to provide support for accurate quantification of wetland ecosystem service.

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