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Xiubo Yu
Chinese Academy of Sciences

Luguang Jiang
Chinese Academy of Sciences

Yu Liu
Chinese Academy of Sciences

Xiyong Hou
Chinese Academy of Sciences

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How important are the wetlands in the middle-lower Yangtze River region: An ecosystem service valuation approach

Xiaowei Li [a,b,1], Xiubo Yu [b,*], Luguang Jiang [c,2], Wenye Li [c,d,3], Yu Liu [b,4], Xiyong Hou [a,5]

[a] Yantai Institute of Coastal Zone Research (YIC), Chinese Academy of Sciences (CAS), Yantai 264003, China
[b] Key Laboratory of Ecosystem Network Observation and Modeling, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China
[c] Department of Natural Resources and Environmental Security, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China
[d] University of Chinese Academy of Sciences, Beijing 100049, China

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ABSTRACT

The middle-lower Yangtze River region, with its lake groups and river systems, is one of the important wetland regions in the world. In this study, physical dimension measurement and monetary evaluation were conducted to estimate the value of wetland services in this region. Results revealed that the total value of the wetland ecosystem services in the middle-lower Yangtze River region is US $162.5 billion per year, which reflects the irreplaceable importance of wetlands in this region. The wetland ecosystem service values revealed considerable spatial variability. Poyang Lake, Hong Lake, and Shijiu Lake have the most ecosystem service value. The value of human-made wetlands (2.62×10^4 US $/ha/yr) is 48% lower than that of natural wetlands (5.04×10^4 US $/ha/yr), indicating that the conversion of natural wetlands for aquaculture from the sustainability perspective is not significant. The direct and indirect values of wetland ecosystems are 46.17% and 53.83% of the total values, respectively. Recognizing that the value of wetlands in this region is mainly embodied as indirect use values, conservation of the regulating and supporting services should be prioritized in the design of future wetland ecosystem management plans.

1. Introduction

Wetlands provide valuable ecosystem services that contribute to human well-being, including provisioning (e.g., food, fuel wood and water), regulating (e.g., flood control, water quality and water supply), supporting (e.g., biodiversity), and cultural services (e.g., recreation and esthetic) (TEEB, 2010). Historically, wetlands have been viewed as a waste of valuable land that could only be "improved" by drainage and destruction of the wetland (Mitsch and Gosselink, 1986). While wetlands are known to provide valuable ecological services, the understanding on the value of wetland services has generally led to their omission in public decision making, specifically regarding the conservation of wetlands. In this context, a large and expanding number of studies have estimated the market and non-market benefits of wetland services. The value of some ecosystem services, such as wetland production, water supply, and shipping, can be directly estimated from their market value. Not all ecosystem services are subject to market transactions. Therefore, surrogate market valuation methods, such as the shadow project method, avoided cost method, carbon tax method, and travel cost method, are required to determine a monetary measure of their value. However, when valuation data are unavailable or lacking for some ecosystem services, such as soil formation and protection, climate regulation, habitat and biodiversity, and cultural service, the conduct of original valuation research on these services are expensive and time consuming. Therefore, benefit transfer provides a cost effective method of extending economic analysis (Brouwer, 2000; Groothuis, 2003).

The middle-lower Yangtze River region, with its lake groups and river systems, is one of the important wetland regions in China. This region suffered the most loss of wetlands during the last 50 years (e.g., 41.0% loss in Poyang Lake and 34.2% loss in the Jianghan–Dongting lake group) (CLD, 2005), primarily as an outcome of the reclamation policy by the Chinese government during the staid period (An, 2003). Although research on wetland service valuation has become one of the most significant areas in the last decade or so

* Corresponding author. Tel./fax: +86 10 6488 9820.
E-mail addresses: lixw0829@163.com (X. Li), yuxb@igsnrr.ac.cn (X. Yu), jianglg@igsnrr.ac.cn (L. Jiang), liwy.12s@igsnrr.ac.cn (W. Li), liuyu@igsnrr.ac.cn (Y. Liu), xyhou@yic.ac.cn (X. Hou).
[1] Tel: +86 0535 2109228.
[2] Tel: +86 10 64889471.
[3] Tel: +86 15120090948.
[4] Tel: +86 10 6488 9820.
[5] Tel: +86 0535 2109196.

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(Zhang et al., 2010), most research results, especially in the middle-lower Yangtze River region, are inaccessible to the global research community because they were not reported in English. A limited number of studies about this region have been published in English (Cui et al., 2012; Guo et al., 2000; Jing and Li, 2012; Su and Zhang, 2007; Yang et al., 2008). However, these studies do not necessarily reflect the overall picture of wetland service valuation in the middle-lower Yangtze River region, although this region has been characterized as one of the main wetland resource distribution areas in China and one of the world's most ecologically and socio-economically critical ecoregion for biodiversity, freshwater, and terrestrial ecosystems (An et al., 2007).

Thus, physical dimension measurement and monetary evaluation were used to reflect the overall picture of wetland service valuation in the middle-lower Yangtze River region, the results of which would help decision makers avoid inefficiencies in wetland management. Market-based valuation, surrogate market valuation, and benefit transfer methods were used as monetary evaluation methods in this study. To validate the value transfer method, the variation in empirical wetland values in this region was identified by combining the value transfer with Geographic Information System tools (GIS) and then published both in English and Chinese as a case study.

2. Methods

2.1. Study area

In this paper, the ecosystem services of wetlands in the middle-lower Yangtze River region were valuated (Fig. 1). This region, with its lake groups and river systems, is one of the eight important wetland regions in China (An, 2003). As the third longest in the world and the longest and largest river in China, the 6300 km long Yangtze River flows from west to east and drains into the eastern China Sea in Shanghai. The Yangtze River is divided into several reaches. The middle reach runs between Yichang and Hukou (Poyang Lake mouth), while the lower reach runs between Hukou and Datong. All sections downriver from Datong are considered as estuary. The middle-lower Yangtze River region, with its many bends, is connected with many lakes. This region is referred to as the “Water Realm” is China's major wetland district. The top five largest freshwater lakes in China (10800 km^2; dominated by species of *Potamogeton*, *Prgamites*, *Acorus*, *Juncus*, *Ranalisma*, *Brasenia*, *Miscanthus*, *Vallisneria*, and *Cyperus*) are all distributed in the middle-lower Yangtze River region (e.g., Poyang Lake and Dongting Lake), while the tidal wetlands are found near the estuaries of this river. These wetlands provide the most important ecosystem service for the middle-lower Yangtze River region, which has high densities of industry and population. Despite the provision of multiple valuable services, wetlands in this region encounter a number of anthropogenic threats, including destructive and non-sustainable fishing practices, pollution and waste, mining and dredging, and non-sustainable tourism practices.

2.2. Data description

The data used to estimate the size of wetland ecosystems were extracted from twelve cloud-free LANDSAT Thematic Mapper (TM)/Enhanced Thematic Mapper (ETM) images obtained in 2009/2010 (data source: http://glovis.usgs.gov/) and DEM data

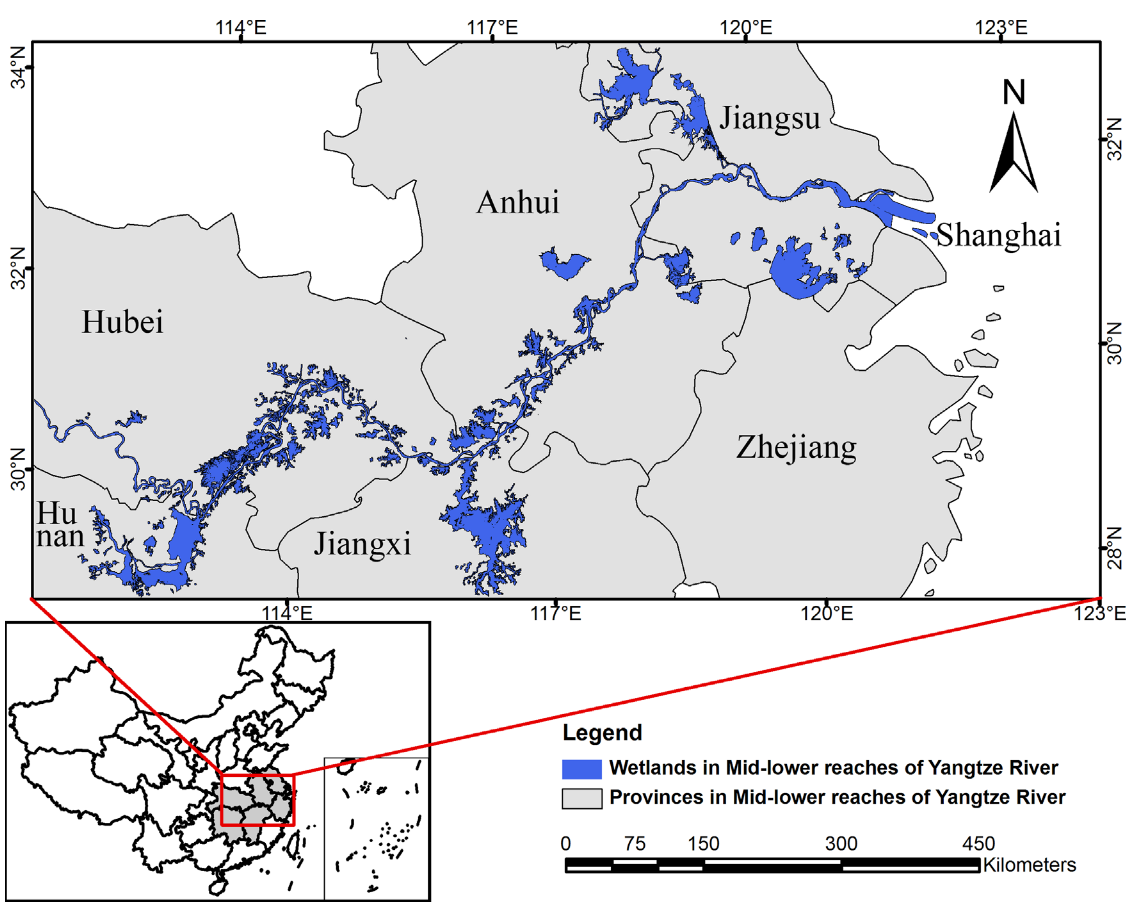

Fig. 1. Location of the study area and distribution of wetlands in the middle-lower Yangtze River region.

Table 1
method for the two steps.

Classification	Ecosystem services categories	Physical dimension estimate index	Calculation formulas	Parameter	Evaluation method	Value per unit(based on the 67 literature reviews)
Provisioning	wetland production (plant and animal)	Annual biomass of wetland plant (Wa)	$Wa = Si \times Wi$	Si (hm^2): area of wetland plant; Wi (t): wetland plant harvest per unit area;	Market value method	107 US $/t
		Amount of fishing (Qr)	$Qr = \sum Ai$	Ai (t): fishing amount of species i;	Market value method	2443 US $/t
	Water supply	Water supply capacity (Pw)	$Pw = Pwc + Pwv$	Pwc (m^3): water supply capacity in industry and daily life; Pwv (m^3): water supply capacity in agriculture;	Market value method	0.1629 US $/$m^3$ (average price for water in industry and daily life); 0.0049 US $/$m^3$ (average price for water in agriculture)
	Shipping	Waterway goods and passenger transportation	$Vn = P \times Vpv + G \times Vgv$	Vn (US $): Value of shipping; P (passenger/km): Waterway passenger transportation; Vpv (US $/passenger/km): Average price for waterway passenger transportation; G (t/km): Waterway goods transportation; Vgv (US $/t/km): Average price for waterway goods transportation;	Market value method	0.0391 US $/passenger/km (passenger) 0.0098 US $/t/km (goods)
Regulating	Flood control	Reservoir capacity	$Vt = 1/n \sum ciVi(1 + xi)$	Vt (US $): value of flood control; Vi (m^3): Reservoir capacity; ci (US $/$m^3$): Average price for 1 m^3 Reservoir project; xi: coefficient of price growth;	Shadow project method	0.26 US $/$m^3$
	Water quality improvement	Removal rates of N and P	$Vj = N \times Sc \times b1 + P \times Sc \times b2$	Vj (US $): value of water quality improvement; N (kg/hm^2): Removal rates of N; P (kg/hm^2): Removal rates of P; b1 (US $/kg): shadow price for N removal; b2 (US $/kg): shadow price for P removal; Sc (hm^2): wetland area;	Avoided cost method	0.24 US $/kg (N); 0.407 US $/kg (P)
	Soil formation and protection	Area of wetland	$Vr = Pr \times Sc$	Vr (US $): value of soil formation and erosion control (SFEC); Pr (US $/$hm^2$): value per unit area of SFEC; Sc (hm^2): wetland area;	Benefit transfer method	1469.19 US $/$hm^2$
	Climate regulation	Area of wetland	$Vm = Pm \times Sc$	Vm (US $): value of climate regulation; Pm (US $/$hm^2$): value per unit area of climate regulation; Sc (hm^2): wetland area;	Benefit transfer method	2464 US $/$hm^2$
	Gas regulation	Carbon fixation and oxygen release	$PCO_2 = NPP \times 1.63$ $PO_2 = NPP \times 1.20$	NPP (t): net primary productivity; PCO_2 (t): Carbon fixation; PO_2 (t): oxygen release;	Carbon tax method	40.3 US $/t (Carbon fixation); 65 US $/t (Oxygen release)
Supporting	Habitat and biodiversity (NHB)	Area of wetland habitat	$Vh = Ph \times Mh$	Vh (US $): value of NHB; Ph (US $/$hm^2$/yr): value perunit area of NHB; Mh (hm^2): Area of wetland habitat;	Benefit transfer method	304 US $/$hm^2$/yr
Cultural	Recreation and tourism	Area of wetland	$P = (P1,\ldots,Pn)$ $Pl = \sum Pi \times Ai$	Pl (US $): value of recreation and tourism; Ai (hm^2): area of tourism resource i; Pi (US $/$hm^2$): value per unit area of tourism resource i;	Travel cost method	
	Cultural	Area of wetland	$Vc = Pc \times Sc$	Vc (US $): value of cultural; Pc (US $/$hm^2$): value per unit area of cultural; Sc (hm^2): wetland area;	Benefit transfer method	634.1 US $/$hm^2$

ASTER Global Digital Elevation Model (ASTER GDEM) developed by the Ministry of Economy, Trade, and Industry of Japan (METI) and the National Aeronautics and Space Administration (NASA) (data source: http://gdem.ersdac.jspacesystems.or.jp/). Based on the data of the areas of each wetland, the net primary productivity (NPP) of each wetland was collected and calculated. The data used to estimate the

NPP of wetland ecosystem were extracted from MODIS/Terra Net Primary Production Yearly L4 Global 1 km SIN Grid V055 (data source: http://reverb.echo.nasa.gov/reverb/datasets).

Wetland valuation studies on the middle-lower Yangtze River region were obtained from online journal databases, libraries, and by personally communicating with authors to conduct the benefit transfer of wetland ecosystem service values (ESV). In total, 67 studies that contained sufficient information for the benefit transfer were identified. Table 2 lists the studies and their corresponding information on the wetland site, area, examined ecosystem type, and number of literature included.

2.3. Value assessment method

Although different approaches to ecosystem service classification are available (Turner et al., 2008), the widely accepted framework proposed by the Millennium Ecosystem Assessment (Millennium Ecosystem Assessment, 2005a) was used. This assessment classifies ecosystem services into provisioning, regulating, supporting, and cultural services.

The value of wetland ecosystem services was assessed in two steps: physical dimension measurement and monetary evaluation. The physical dimensions of the wetland ecosystem services were obtained from upscaling with the help of statistical data based on field-scale research in the middle-lower Yangtze River region. The physical dimensions included wetland plant harvest, fishing amount, water supply capacity, waterway passenger/goods transportation, reservoir capacity, and removal rates of N/P, which were obtained from the literature statistical data. Benefit transfer technique was used to obtain necessary coefficient(s) after the large-scale academic literature review to do the upscaling of the result of the field-scale studies. Carbon fixation and oxygen release were calculated based on the NPP data. In contrast to monetary evaluation, physical dimension estimates were more site-specific and data collection was more difficult. Thus, care was necessary when upscaling.

The second step is the monetary evaluation. The value of wetland production, water supply, and shipping were directly estimated from their market value. Surrogate market valuation methods were implemented to estimate the value of flood control, water quality improvement, gas regulation, and recreation service based on the costs of avoided damages emerging from lost ecosystem services, costs of replacing ecosystem services, or costs of providing substitute services. The values of other ecosystem services with limited or absent valuation data, such as soil formation and protection, climate regulation, habitat and biodiversity, and cultural service, were estimated by benefit transfer method. Benefit transfer is an economic valuation tool that obtains valuation estimates from other areas (study sites) and then applies them to a similar location (policy sites) (Brouwer, 2000). This method is conducted by adapting and applying estimates from existing studies that best suit the new context with the application of benefit transfer techniques (Groothuis, 2003). In this paper, benefit transfer was used to obtain necessary coefficient(s) for evaluation after large-scale academic literature review. Given the different characteristics of these wetland ecosystem services, more detailed information on valuation methods is shown in Table 1. All value estimates were standardized to US$/ha/yr at 2007 price levels to allow for direct comparison of the study results.

3. Results

Based on the combined characteristics of 17 widely accepted wetland ecosystem services, 11 important ecosystem services, namely, wetland production (fisheries and plant stuffs), water supply, shipping, flood control, water quality improvement, soil formation and protection, climate regulation, gas regulation, habitat and biodiversity, recreation and tourism, and cultural services, which are more universal in this region, were selected for the evaluation.

After determining the annual ESV per hectare, a map was created to illustrate the spatial distribution of ecosystem service (Fig. 2). This map shows considerable spatial variability of the wetlands providing ecosystem services. The highest values per hectare were observed in Hong Lake (1.32×10^5 US $/ha/yr) because of its contributions in flood control and wetland production, followed by Shijiu Lake (7.50×10^4 US $/ha/yr) for flood control and wetland production and then Poyang Lake (7.32×10^4 US $/ha/yr) for flood control, wetland production, and water quality improvement. The lowest values were observed in human-made wetlands that are mainly fishponds with low regulating, supporting, and cultural service values.

Table 2
List of studies included in the benefit transfer.

Province	Wetland site	Area (km^2)	Literature	Ecosystem type
Jiangsu	Tai Lake National Tourism Resort	160	**1**	Human-made
Jiangsu	Heavy Polluted Area in Tai Lake Basin	5271.56	**1**	Lacustrine
Jiangsu	Lake Tian-mu catchment, Tai Basin	8.23	**1**	Wetland reserve
Jiangsu	Tai lake	36940	**5**	Lacustrine
Shanghai	Qingpu, Dingshan lake	47.5	**1**	Human-made
Shanghai	Jiading, Shanghai	2.80	**1**	Human-made
Shanghai	Qingpu, Shanghai	39.72	**1**	Human-made
Shanghai	Fengxian, Shanghai	32.19	**1**	Human-made
Shanghai	Dingshan lake	39.7	**1**	Human-made
Jiangxi	Marsh in Poyang lake, Zhelin, Jiangkou, Hongmen reservoir	616.66	**1**	Palustrine
Anhui	Anqing Yangtze Riverine Weyland (Longgan Lake, Huangda Lake, Bo lake, Wuchang lake, Caizi lake)	1043.52	**1**	Lacustrine
Anhui	Shengjin lake	333.40	**1**	Lacustrine
Hubei	Natural reserve of Yangtze river dolphin at swan continent	19	**1**	Riverine
Shanghai	Yangtze river estuary	2150	**4**	Marine/Estuarine
Anhui	Chao lake Basin	15595.57	**4**	Lacustrine
Hunan	Dongting lake	2625	**19**	Lacustrine
Hubei	Baoan lake	39.3	**1**	Lacustrine
Hubei	Hong lake	414.12	**2**	Lacustrine
Hubei	Chinese Sturgeon Natural Reserve in Yichang Reach of the Yangtze River	80	**1**	Riverine
Hubei	Liangzi lake	379.46	**2**	Lacustrine
Hubei	Zhangdu lake	185	**1**	Lacustrine
Jiangsu	Hongze lake	2069	**7**	Lacustrine
Jiangsu	Baoying lake	42	**1**	Human-made
Jiangxi	Poyang lake	3950	**8**	Lacustrine

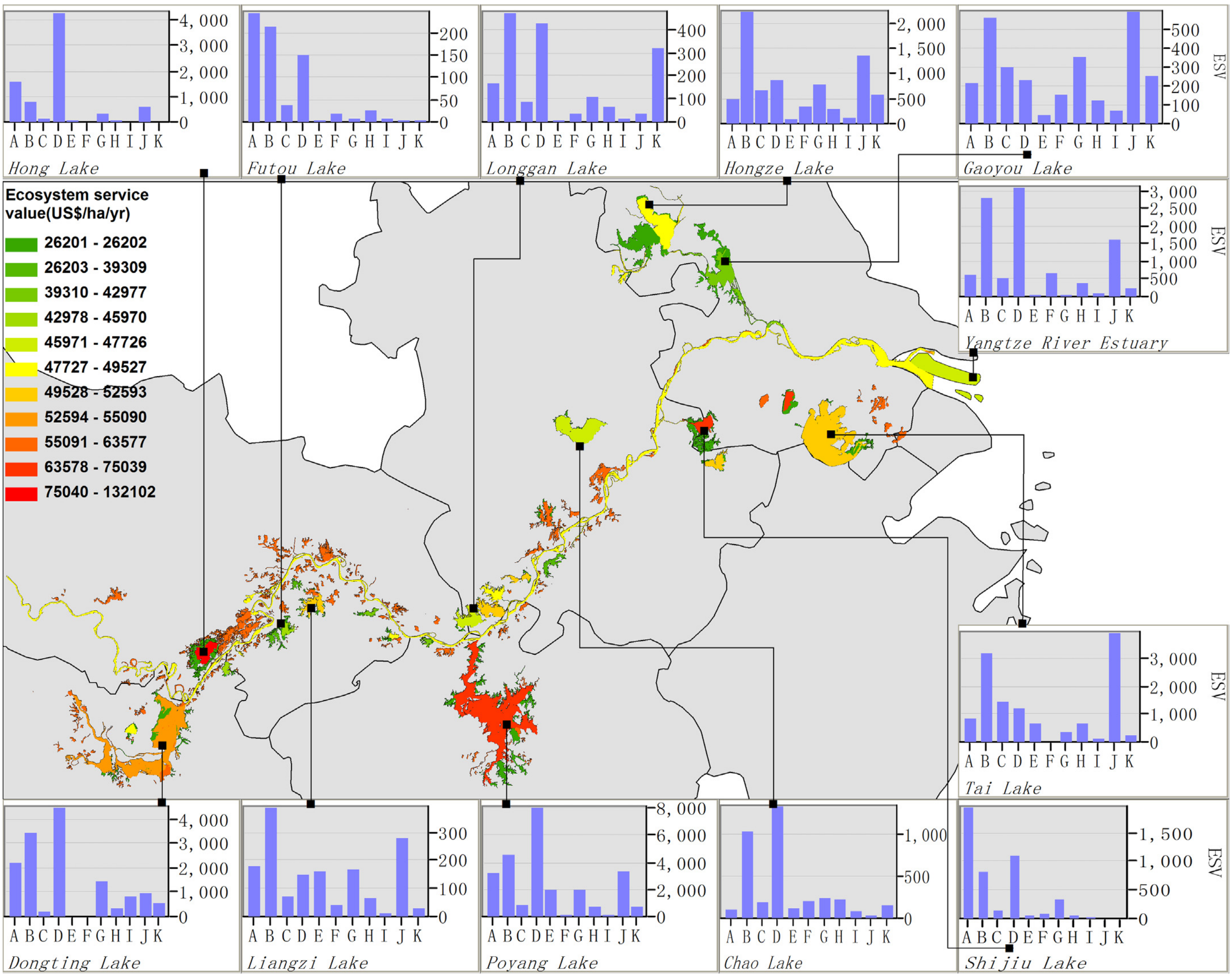

Fig. 2. Values for ecosystem services [A: Wetland plant and animal production, B: Water supply, C: Shipping, D: Flood control, E: Water quality improvement, F: Soil formation and Erosion control, G: Climate regulation, H: Gas regulation, I: Natural habitat and biodiversity, J: Recreation and tourism, K: Cultural (US$ × 10^6)] in the main wetlands and annual ESV per hectare in the middle-lower Yangtze River region.

The ESVs of the main wetlands are shown in Fig. 2. Poyang Lake is the region with the highest ESV (2.57×10^{10} US $) because of its valuable services of flood control and water supply, followed by Dongting Lake, Tai Lake, and Yangtze River Estuary because of their contributions of flood control and water supply, except for Tai Lake that has a high value for recreation and tourism service.

The values of natural and human-made wetlands in the middle-lower Yangtze River region were compared (Fig. 3). The wetland production value of human-made wetlands (1.99×10^4 US $/ha/yr) was greater than that of natural wetlands (7.72×10^3 U S$/ha/yr). The values for flood control, recreation and tourism, climate regulation, water supply, cultural service, gas regulation, water quality improvement, and habitat and biodiversity in human-made wetlands were between 71% and 99% lower than that in natural wetlands. The calculation results revealed that the value of natural wetlands (5.04×10^4 US $/ha/yr) is greater than that of human-made wetlands (2.62×10^4 US $/ha/yr). The value for the benefits of human-made wetlands was 48% lower than that for the benefits of natural wetlands.

The total value of the wetland ecosystem services in the middle-lower Yangtze River region was 1.62×10^{11} US $$\text{yr}^{-1}$ (Table 3).

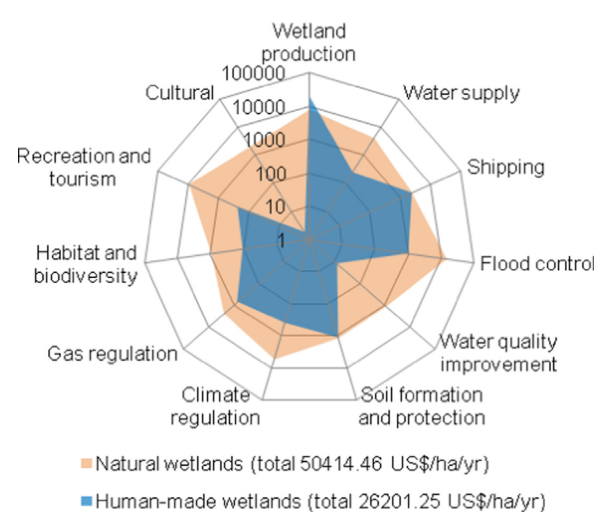

Fig. 3. Values for ecosystem services of natural and human-made wetlands in the middle-lower Yangtze river region.

Table 3
Value composition estimated by various methodologies for wetland ecosystem services of the middle-lower Yangtze River region.

Classification	Ecosystem services categories	Value (US $\$yr^{-1} \times 10^8$)	Proportion (%) of total value	Total (US $\$yr^{-1} \times 10^8$)	Proportion (%) of total value
Provisioning	Wetland production	176.911	10.89	580.349	35.71
	Water supply	337.894	20.79		
	Shipping	65.544	4.03		
Regulating	Flood control	401.936	24.73	638.393	39.28
	Water quality improvement	45.272	2.79		
	Soil formation and protection	29.299	1.80		
	Climate regulation	112.061	6.90		
	Gas regulation	49.826	3.07		
Supporting	Habitat and biodiversity	185.482	11.41	185.482	11.41
Cultural	Recreation and tourism	170.039	10.46	220.827	13.59
	Cultural	50.789	3.13		
Total value		1625.052			

In the middle-lower Yangtze River region, the wetland ESVs revealed considerable variability (Table 3). Flood control was the most valuable ecosystem service (4.02×10^{10} US $\$yr^{-1}$), followed by water supply and habitat biodiversity services (3.38×10^{10} and 1.85×10^{10} US $\$yr^{-1}$, respectively). Soil formation and protection was the least valuable ecosystem service (2.93×10^{9} US $\$yr^{-1}$).

The total values by ecosystem service classification also revealed variability. The regulating service provided the highest ESV (6.38×10^{10} US $\$yr^{-1}$) because of the contributions of flood control and climate regulation. Provisioning service also provided high ESV (5.80×10^{10} US $\$yr^{-1}$) because of the valuable services of water supply and wetland production. The cultural and supporting classes contributed low proportion of the total value (13.6% and 11.4%, respectively) because these services were valued by benefit transfer method based on the literature data in the middle-lower Yangtze River region. The low value of the cultural and supporting services revealed that further studies are necessary to fully assess the effects of these factors on the cultural and supporting service values in this region.

4. Discussion

The assessments in this study would lead people and government officials to realize the importance of wetlands in the middle-lower Yangtze River region and identify their core ecosystem services. The value of direct material production, often regarded as the primary service of an ecosystem, has been considered in a number of studies, whereas the values of indirect ecosystem services are usually ignored. In this study, the direct and indirect values of wetland ecosystems had been examined and represented 46.17% and 53.83%, respectively, of the total values. Recognizing that the value of wetlands in the middle-lower Yangtze River region is mainly embodied as indirect use values, the conservation of regulating and supporting services is argued to be prioritized in the design of future wetland ecosystem management plans.

The value of human-made wetlands obtained in this study was 48% lower than that of natural wetlands. Other studies also showed the same result, such as the values of converting Thai mangroves to shrimp farms, draining freshwater marshes for intensive agriculture in Canada, and operating unsustainable fishing practices on coral reefs in the Philippines, which were between 60% and 75% lower in terms of long-term benefits than those of wetland conservation and sustainable use (Millennium Ecosystem Assessment, 2005b). The result of this paper documents that "conversion of the remaining habitat for agriculture, aquaculture, or forestry often does not make sense based on the perspective of global sustainability"(Balmford et al., 2002). The valuation method of wetland ecosystem services for watershed could be used in other places such as the Mekong river region.

This study is the first to attempt to assess the value of wetlands in the middle-lower Yangtze River region. According to the calculation conducted in this research, the annual total economic value of wetlands in the middle-lower Yangtze River region is US $162.5 billion per year, which is higher than the calculation results obtained by Costanza et al. (1997). The value of wetlands in this region was found higher than that of other ecosystem types such as agricultural land (Lv et al., 2010). The total annual value can reflect the high ecological and economic value and irreplaceable importance of wetlands in the middle-lower Yangtze River region. Unfortunately, in the recent years, the in-flow of short-term profits has driven the degradation of wetlands in this region. Signs that wetlands and their ecosystem services in the middle-lower Yangtze River region are decreasing at a higher rate than in other areas in China have been observed (Niu et al., 2011; Wang et al., 2012). Therefore, the government must ensure the formulation and implementation of policies and legislation that will help to address the loss of wetlands in the middle-lower Yangtze River region. The study is supported by the Chinese Academy of Sciences "one three five" strategic planning project of science and technology. Based on the research findings, this study proposes policy recommendations for the middle-lower Yangtze River region wetland conservation (target audience: Wetland Conservation and Management Center of State Forestry Administration, among other central government agencies; as well as the forestry and environmental conservation authorities of wetland provinces/municipalities).

To a limited extent, this paper valued the ecosystem services based on physical dimension measurement and monetary evaluation. Future research may focus on the full assessment of the nonlinear effects of natural/society factors on the ESVs in the middle-lower Yangtze River region. The estimation of spatial changes could be significantly improved by analyzing society factors, including road density variables, population, and gross domestic product.

5. Conclusion

This study is the first to assess the value of wetlands in the middle-lower Yangtze River region. Based on the literature review and remote sensing data, two steps, namely, physical dimension measurement and monetary evaluation, were used in the assessment of 11 wetland service values. The results revealed that the total value of the wetland ecosystem services in the middle-lower Yangtze River region is US $162.5 billion per year, which reflects the irreplaceable important role of wetlands in this region. Flood control is the most valuable ecosystem service (4.02×10^{10} US \$yr^{-1}), followed by water supply and habitat biodiversity services (3.38×10^{10} and 1.85×10^{10} US \$yr^{-1}, respectively). In the middle-lower Yangtze River region, the wetland ESVs revealed considerable spatial variability. Poyang Lake, Hong Lake, and Shijiu Lake have the highest ESVs. The value of human-made wetlands (2.62×10^4 US \$/ha/yr) was 48% lower than that from natural wetlands (5.04×10^4 US \$/ha/yr), which reflects that conversion of natural wetlands for aquaculture does not make sense from the sustainability perspective. Recognizing that the value of wetlands in this region is mainly embodied as indirect use values, conservation of regulating and supporting services should be prioritized in the design of future wetland ecosystem management plans. The assessment results detailed in this paper would lead people and government officials to realize the importance of wetlands in the middle-lower Yangtze River region and identify their core ecosystem services from a socio-economic perspective. Further studies are necessary to fully evaluate the effects of natural/society factors on the ESVs in this region.

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