Chin. Geogra. Sci. 2014 Vol. 24 No. 3 pp. 269–278
doi: 10.1007/s11769-013-0648-z

Springer Science Press
www.springerlink.com/content/1002-0063

Valuation of Lake and Marsh Wetlands Ecosystem Services in China

ZHANG Yiran[1, 2], ZHOU Demin[1, 2], NIU Zhenguo[3], XU Fengjiao[1, 2]

(1. *Base of the State Key Laboratory of Urban Environmental Processes and Digital Modeling*, *Beijing* 100048, *China*; 2. *College of Resource Environment and Tourism*, *Capital Normal University*, *Beijing* 100048, *China*; 3. *Institute of Remote Sensing and Digital Earth*, *Chinese Academy of Sciences*, *Beijing* 100101, *China*)

Abstract: Wetlands are highly productive natural ecosystems, providing valuable goods and services. There is growing interest in transferring ecosystem service value from the existing wetlands studied to other wetlands ecosystems at a large geographic scale. The benefit transfer method uses the known values from wetlands to predict the value of other wetland sites. This methodology requires only limited time and resources. The present study calculated the value of the ecological services provided by lake and marsh wetlands in China in terms of biodiversity indices, water quality indices and economic indices. Basic data on wetlands were obtained through remote sensing images. The results show that: 1) The total ecosystem service value of the lake and marsh wetlands in 2008 was calculated to be 8.1841×10^{10} United States Dollars (USD), with the marsh and lake wetlands contributing 5.6329×10^{10} and 2.5512×10^{10} USD, respectively. Values of marsh ecosystem service were concentrated in Heilongjiang Province (2.5516×10^{10} USD), Qinghai Province (1.2014×10^{10} USD), and Inner Mongolia Autonomous Region (1.1884×10^{10} USD). The value of the lakes were concentrated in Tibet Autonomous Region (6.223×10^9 USD), Heilongjiang (5.810×10^9 USD), and Qinghai (5.500×10^9 USD). 2) Waste treatment and climate regulation services contributed to 26.29% and 24.74% respectively, of the total ecosystem service value of the marsh wetlands. Hydrological regulation and waste treatment contributed to 41.39% and 32.75%, respectively, of the total ecosystem service value of the lake wetlands. 3) The total ecological service value of the lake and marsh wetlands was 54.64% of the total service value of natural grassland ecosystems and 30.34% of the total service value of forests ecosystems in China.

Keywords: lake wetlands; marsh wetlands; ecosystem services

Citation: Zhang Yiran, Zhou Demin, Niu Zhenguo, Xu Fengjiao, 2014. Valuation of lake and marsh wetlands ecosystem services in China. *Chinese Geographical Science*, 24(3): 269–278. doi: 10.1007/s11769-013-0648-z

1 Introduction

Wetlands support ecosystems with significant biodiversity throughout the world. They are highly productive and provide a large array of benefits to human society (Bodegom *et al*., 2004; Liu *et al*., 2008; Huang *et al*., 2012). The global area of the wetlands has been decreasing sharply in recent decades as a result of the increased economic activity (Wilsom and Carpenter, 1999; William and James, 2007). Ecosystem services refer to the actual and potential benefits provided by the wetlands to humans, either directly or indirectly. These include the supply of freshwater and aquatic products, the provision of critical environmental functions such as flood protection, water and gas regulation, and preserving biodiversity (Rudolf *et al*., 2002; European Environment Agency, 2010). Many researchers have evaluated the economic value of wetland services and emphasized the importance of wetland ecosystems (Cedfeldt *et al*., 2000; Cui, 2004; Liu *et al*., 2010; Zhang and Ma, 2011). The quantitative evaluation on the economic value of wetland ecosystem services combines wetland

Received date: 2013-01-31; accepted date: 2013-04-23
Foundation item: Under the auspices of Forestry Public Interest Research Program (No. 201204201), National Natural Science Foundation of China (No. 41171415)
Corresponding author: ZHOU Demin. E-mail: zhoudemin@neigae.ac.cn

ecology and economics, and has become a key field of wetland research (Acharya, 2000; Barber, 2000; William and James, 2000; Millennium Ecosystem Assessment, 2008).

A number of methods, including the market valuation method, contingent valuation, and the consumer willingness to pay (WTP) method, have been used to evaluate the economic value of natural ecosystem services (Fennessy *et al.*, 2004; Farber *et al*., 2006; Luke *et al.*, 2011). These methods have been used extensively in case studies to evaluate the economic value of individual wetlands. Although determining the total value of all wetlands on a region or country scale is potentially more useful (Farely, 2008; Finnoff and Tschirhart, 2008; Ghermandi *et al.*, 2008; Yu *et al*., 2010; Zhao and Wang, 2011), it is challenging to determine the total value of wetlands on a large scale taking into account the diversity of location, size, type, scarcity and other attributes of the individual wetland ecosystems (Woodward and Wui, 2001; Lars *et al.*, 2006; Luke *et al.*, 2006; Gascoigne *et al*., 2011). The benefit transfer is the procedure of estimating the value of an ecosystem by borrowing an existing valuation estimate result of a similar ecosystem (Johnston and Rosenberger, 2010). There has an increasing need for benefit transfer as a cost-effective means of value estimation. Although the benefit transfer methodology was applied in natural resources as early as the 1980s, the methodology was formalized in the 1990s and used widely in the 21st century (Rosenberger and Loomis, 2003). From a methodological viewpoint, the benefit transfer methodology may provide a degree of consistency in decision-making for policy maker. Costanza *et al.* (1997) defined the theory and methodology of valuing ecosystem service, and the methodology has been adapted by Chinese researchers to value the ecosystem services provided by various types of wetlands. However, the results of Costanza *et al*. were criticized due to: 1) The value of ecosystem services reflected the economic level of developed countries such as United State and European countries, rather than developing countries such as China; 2) Although wetlands ecosystems provide significant functions, its value per unit area was overvalued; 3) Due to the geographic and social economic diversity in China, there would be unavoidable errors in valuation when applying the methodology of Costanza on a large geographical scale.

This paper proposed a methodology for scaling up wetland ecosystem service value at large geographical scale by using the existed primary valuation. This study was focused on marshes and lakes, the two dominant wetland types found in China, and remote sensing was used to identify wetlands boundary. Based on the method proposed by Costanza *et al.* (1997) and Xie *et al.* (2008), we evaluated wetland ecosystem services value through incorporating wetland structures, geological location, services type characteristics, and investigating the optimum methods of ecosystem service value on national scale.

2 Materials and Methodology

2.1 Study area and data sources

Data of lake and marsh wetlands were provided by Institute of Remote Sensing and Digital Earth (former Institute of Remote Sensing Applications), Chinese Academy of Sciences. Totally 1442 China and Brazil Earth Resource Satellite (CBERS) remote images collected in 2008 covering all of China at a pixel resolution of 20 m were selected as the original data resources. All of the images were processed after geometric correction (correction error: < 2 pixels). Geological data from the Administrative Map of China (a scale of 1∶4 000 000, National Administration of Surveying, Beijing, China) and socio-economic data from the China Statistical Yearbook 2008 (National Bureau of Statistics, 2009) were also used in data analyses.

Wetland boundaries were determined by algorithm recognition assisted by related software and human interpretation. More information and details about the methods of data processing and field validation work have been published previously (Niu *et al.*, 2009; Niu *et al.*, 2012). Based on the data processing, the total area of wetlands in China in 2008 (excluding farmlands) was 3.241×10^4 km^2, with lakes and marshes (the dominant type of wetlands) accounting for 26% and 35% of the total wetland area, respectively (Fig. 1).

2.2 Methodology

2.2.1 Types of wetland ecosystem services and their unit values

Ecosystem services are the conditions and processes of natural ecosystems, and the species that comprise them, sustain and fulfill human life (Daily, 1997; Li, 2008; Fu *et al.*, 2009; Chen *et al*., 2010; Bai *et al*., 2013). Wetland

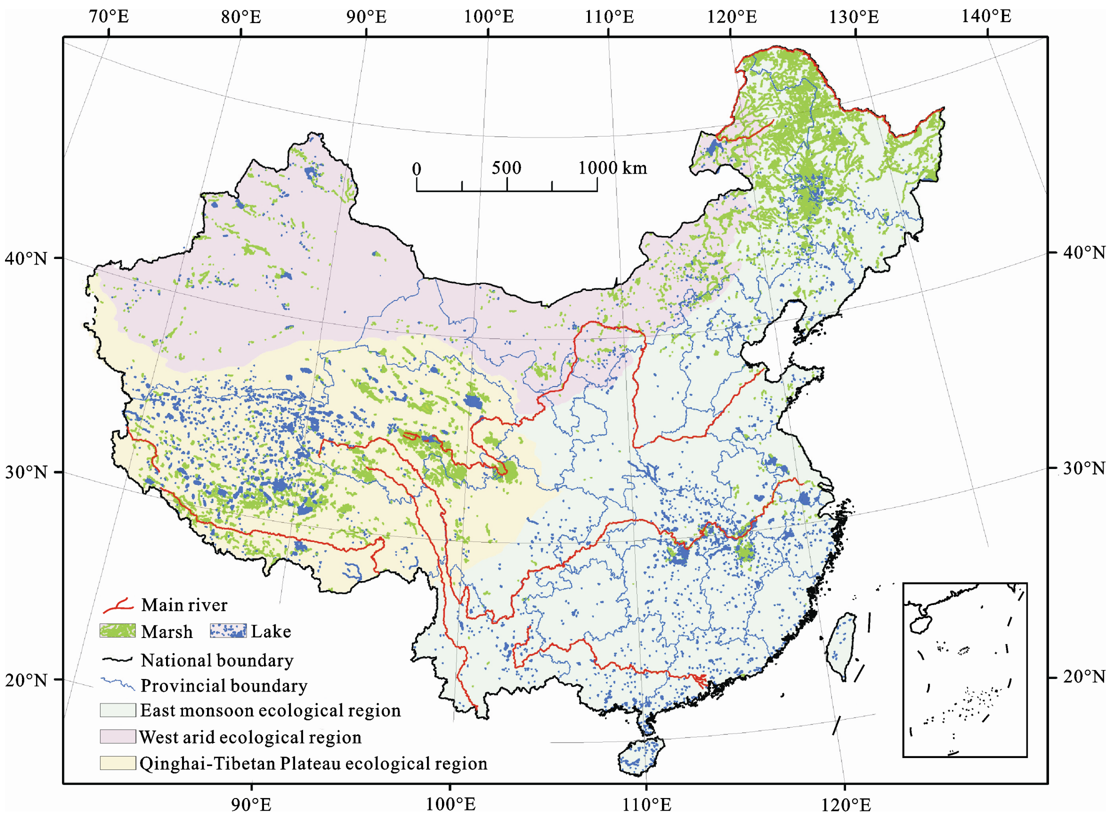

Fig. 1 Lake and marsh wetlands distribution in China in 2008

ecosystems provide the functions required for human survival, such as supplying freshwater for residential and agriculture use, supporting bio-geochemical cycling and energy exchanges, retaining nutrients and thus improving water quality, maintaining biological and genetic diversities and climate regulation (National Research Council (United States), Committee on Characterization of Wetlands, 1995; Yao *et al*., 2009). Researchers differed indices used to classify wetland ecosystem services. Costanza *et al.* (1997) identified 10 types of wetland ecosystem services in the world, and the ecosystem service types of marsh and lake wetlands and their values are shown in Table 1.

The ecosystem valuation method of Costanza *et al.* (1997) was controversial in China, with some ecosystem services poorly valued or ignored. Xie *et al.* (2008) classified ecosystem services into 9 types (Table 2), and extracted the equitant weight factor of ecosystem services in China, thus revised the 'unit value' of wetland ecosystem services based on Costanza's method (Table 2).

From Table 1 and Table 2, it was found that the unit value of marsh and lake wetlands ecosystem from Xie *et al*. (2008) was 15.1% and 28.8% of those from Costanza *et al.* (1997), respectively, reflecting that they were overvalued to certain extent for China's ecological and economic condition rather than a decline in the value of ecosystem services. As there is more detailed information in Table 2 than in Table 1, and the hydrological regulation services of marsh wetland were modified, the unit value provided in Table 2 was considered more

Table 1 Ecological service types of lake and marsh wetlands in world and their unit values (USD/(ha·yr))

Ecological service type	Marsh	Lake
Food production	47	41
Raw materials	49	–
Gas regulation	265	–
Disturbance regulation	7240	–
Water regulation	30	5445
Water supply	7600	2117
Waste treatment	1659	665
Habitat/refuge	439	–
Recreation	491	230
Culture	1761	–

Note: '–' denotes that the ecosystem service types are not valued
Source: Costanza *et al.* (1997)

Table 2 Ecological service types of lake and marsh wetlands in China and their unit values (USD/(ha·yr))

Service type	Marsh	Lake
Food production	19.4	28.6
Raw materials	13.0	18.9
Gas regulation	130.1	27.5
Climate regulation	731.7	111.2
Hydrological regulation	725.8	1013.6
Waste treatment	777.6	801.9
Soil formation and conservation	107.5	22.1
Biodiversity maintenance	199.3	185.2
Providing aesthetic value	253.3	239.8
Total	2957.6	2448.9

Source: Xie *et al.* (2008)

suitable to Chinese ecosystems and was used in this study.

2.2.2 Methods of value transfer

It was not feasible to investigate each wetland in China to evaluate the total wetland value. Value transfer is the procedure of estimating the value of an ecosystem of current policy interest (policy site) from existing researches of the similar ecosystem (study site) (Eshet *et al.*, 2007; Ojea *et al.*, 2012). The methods of value transfer can be divided into two categories as follows: 1) Direct unit value transfer, which involves estimating the value of an environmental service at the policy site by multiplying a mean unit value estimated at the study site. 2) Adjusted unit value transfer, which involves making simple adjustments to the transferred unit value to reflect the difference in the site characteristics. The most common adjustment method is the difference in economic indices such as the difference in the incomes at the study and policy sites. This method constructs a model describing the relationship between the economic value of an ecosystem and various factors related to that ecosystem (e.g., type and area of the ecosystem, socio-economic and population status, geological conditions). Then the value of the ecosystem under evaluation can be calculated by using the model. As the adjusted unit value transfer method is more accurate compared with the direct unit value transfer method, and it has been widely used to analyze the value of natural resources ecosystems.

Many factors, including environmental factors (e.g., vegetation, soil and hydrology status) and the social-economic conditions of the city near wetlands, influence the wetland ecosystem value. The diversity of wetland ecosystems is affected by wetlands environmental factors, such as geographical environment and geomorphology condition, moist or arid hydrology, the swampiness or saline vegetation, soils. Similarly, socio-economic conditions also influence the unit value of wetland services because the economic conditions had an effect on the Willingness to Pay (WTP), thus the unit value for similar wetlands varied under different social-economic levels (Fig. 2).

This study modified the unit value through the factors shown in Table 3, calculating the ecosystem service values of the lake and marsh wetlands in China by a method which is suitable to the geography of China.

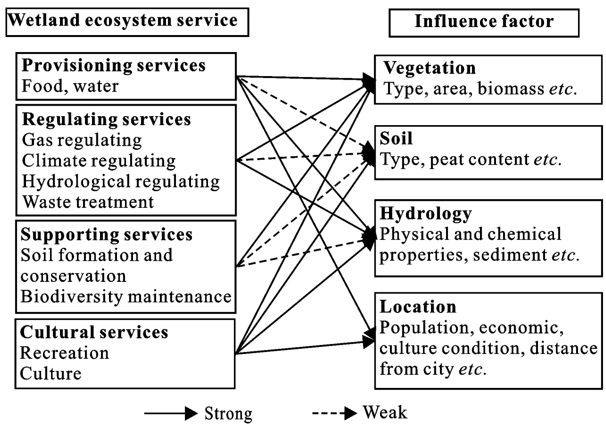

Fig. 2 Wetland ecosystem services and influence factors. Arrow-shaped denotes the influence factors of each ecosystem service, and the solid or dashed lines denote the intensity of linkages

Table 3 Modified factors of wetlands ecosystem service

Modified factor	Index	Data source
Social-economic condition	GDP per capita	National Bureau of Statistics (2000)
Wetland abundance	Area of wetlands within 50 km radius	Acquired from ArcGIS software
Distance from city	Distance between wetlands and city	Acquired from ArcGIS software
Biodiversity	Biodiversity indices	Wan *et al.* (2007)
Ecological regionalization	National ecosystem regionalization result	Database for ecosystems and ecosystem services zoning in China (http://www.ecosystem.csdb.cn/index.jsp)

Due to the complexity of wetland ecosystem and the data required available, as well as the diversity of China's geography, the ecological regionalization was used to modify the unit value, and China was divided into east monsoon ecological region, west arid ecological region and Qinghai-Tibet Plateau ecological region (Fig. 1) (Fu *et al*., 2001).

Regarding socio-economic and geographical context, the positive effect of the income variable (GDP per capita) indicates that most wetland ecosystem services have higher values in regions with higher incomes (Groot *et al*., 2012). And the unit value was adjusted by the following equation (Li, 2008; Xie *et al*., 2008):

$$p_{ij} = \frac{x_i}{X} P_j \tag{1}$$

where p_{ij} is the unit value of the jth service item of the ith wetland after adjusting by GDP; x_i is the GDP of the city which contains the ith wetland; X is the average GDP of the region; and P_j is the reference unit value of the jth service item.

The effect of the wetlands area within 50 km radius indicates the complements indicator to a specific wetland ecosystem services. The negative effect of the total area of other wetland sites in the vicinity of the study site indicates substitution effects between wetlands (Fig. 3). Thus the adjusted method is as follows:

$$p'_{ij} = \frac{B}{b_i} p_{ij} \tag{2}$$

where p'_{ij} is the unit value of the jth service item of the ith wetland after adjusting by wetland abundance; b_i is the abundance indicator of the ith wetland; and B is the average wetlands abundance at regional scale.

The ecosystem services from a specific wetland will be of higher value if it is nearer with residence place and with higher biodiversity. The adjusted method is similar to above. And the total wetlands ecosystem services value are calculated by the following equation:

$$V = \sum_{i=1}^{n} \sum_{j=1}^{m} A_i p'_{ij} \tag{3}$$

where V is the total wetlands value; A_i is the area of ith wetland.

3 Results and Analyses

3.1 Wetland ecosystem valuation results

The area is one of the most significant characteristic that may expect to determine wetlands ecosystem service value. Some ecological services require minimum thresholds of habitat area, thus may imply that wetlands value increase with area. There is the positive relationship between wetlands area and their value (Table 4).

The total economic value for the services of the lake and marsh wetlands in China in 2008 was calculated to be 8.1841 × 10^{10} USD, with the lake and marsh wetlands contributing 5.6329 × 10^{10} USD and 2.5512 × 10^{10} USD, respectively. The lake and marsh wetlands values were concentrated in regions with low population densities such as the northwestern and northeastern China, Tibet, and Qinghai. Heilongjiang has a large number of freshwater marshes and the largest marsh area in China. Qinghai is the origin birthplace of the Changjiang

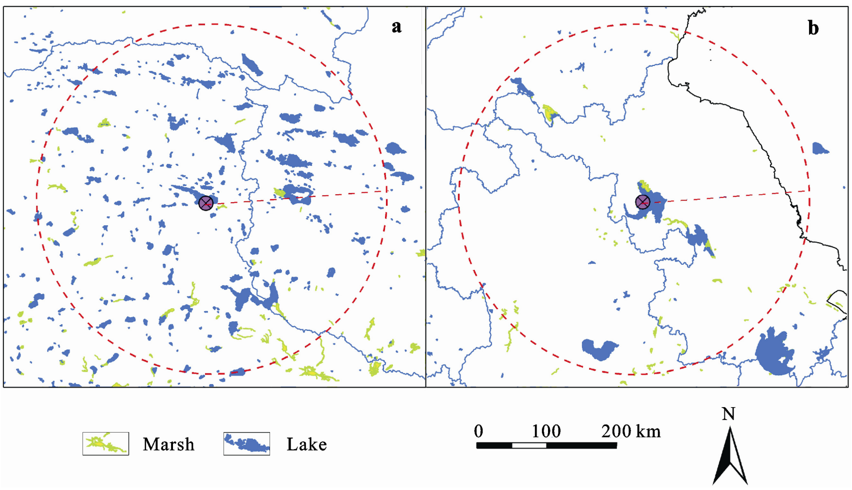

Fig. 3 Wetland abundance from Tibet Autonomous Region (a) and Jiangsu Province (b)

Table 4 Wetlands area and valuation result in each province of China in 2008

	Area (ha)		Ecological service value (10^8 USD)		
	Marsh	Lake	Marsh	Lake	Total
Anhui	5.23	16.95	0.67	1.80	2.47
Beijing	0.20	0.19	0.02	0.01	0.03
Chongqing	0.00	0.53	0.00	0.06	0.06
Fujian	0.03	1.61	0.01	0.30	0.31
Gansu	22.96	1.73	1.02	0.15	1.17
Guangdong	0.29	6.81	0.04	1.58	1.62
Guangxi	0.00	4.87	0.00	1.09	1.09
Guizhou	0.07	1.04	0.00	0.18	0.18
Hainan	0.00	2.31	0.00	0.05	0.05
Hebei	6.45	2.90	1.72	0.79	2.51
Henan	0.01	1.53	0.00	0.28	0.28
Heilongjiang	284.38	34.58	225.16	58.10	283.26
Hubei	4.66	17.12	1.22	5.15	6.37
Hunan	6.54	19.34	1.72	3.58	5.30
Inner Mongolia	244.54	38.91	118.84	15.57	134.41
Jilin	80.62	15.52	27.06	8.27	35.33
Jiangsu	3.03	39.47	0.61	10.45	11.06
Jiangxi	16.02	13.53	2.96	2.30	5.26
Liaoning	5.55	4.96	0.93	2.29	3.22
Ningxia	0.63	0.03	0.02	0.00	0.02
Qinghai	189.54	135.65	120.14	55.00	175.14
Shandong	2.41	3.88	0.70	1.09	1.79
Shanxi	0.88	0.57	0.32	0.19	0.51
Shaanxi	0.06	1.57	0.03	0.42	0.45
Shanghai	0.04	0.48	0.00	0.02	0.02
Sichuan	46.30	2.92	15.01	1.37	16.38
Tianjin	0.00	0.89	0.00	0.03	0.03
Tibet	141.00	285.72	34.81	62.23	97.04
Xinjiang	51.03	69.29	9.88	15.42	25.30
Yunnan	0.50	12.25	0.13	4.72	4.85
Zhejiang	0.51	6.74	0.27	2.64	2.91
Total	1113.48	743.88	563.29	255.12	818.41

Note: Hong Kong, Macao, and Taiwan are not included in calculation

(Yangtze) River (the longest river in China) and also has a large number of freshwater and salt marshes. The total value of the lake and marsh wetlands in Heilongjiang, Qinghai and Inner Mongolia contributed to 2.8326×10^{10} USD, 1.7514×10^{10} USD and 1.3441×10^{10} USD, respectively, accounting for 72.43% of the total national value. Heilongjiang, Qinghai and Inner Mongolia had higher marshland ecosystem service values (which is 2.2516×10^{10} USD, 1.2014×10^{10} USD and 1.1884×10^{10} USD, respectively). Also, Tibet, Heilongjiang and Qinghai had higher lake ecosystem service values (which is 6.223×10^9 USD, 5.810×10^9 USD and 5.500×10^9 USD, respectively).

Of all the ecological service types of the marsh and lake wetlands of China, the service value and proportion in 2008 are shown in Table 5. The marsh wetlands are highly valuable in waste treatment (26.29% of the total value of marsh ecosystem), which refers to the contributions of wetlands to cleaning water and settling the sediment. In addition, marsh wetlands are valuable in climate regulation and hydrological regulation, which occupying 24.74% and 24.54% of the total value of marsh wetland, respectively. In comparison, the lake wetlands are very valuable in hydrological regulation (41.39% of the total value of lakes), such as flood control, which refers to the control and integration of environmental disturbances. The unique soil and vegetation conditions of lakes allow accumulation and subsequent slow release of water. Due to these properties, the lakes can redistribute water resources in the temporal and spatial scale, thereby regulate runoff and prevent flooding. In addition, the lakes play the significant role in controlling hydrological cycles such as supplying water to industry, agriculture, and transportation. Wetlands contain a large volume of water resources and are an important water source for catchment areas, water reservoirs, and underground aquifers. The lake and marsh wetlands ecosystem provided different services because of the difference in energy and nutrient cycling.

Table 5 Ecological service value and proportion of lake and marsh wetlands of China in 2008

Service type	Marsh (10^8 USD)	Proportion (%)	Lake (10^8 USD)	Proportion (%)
Food production	3.70	0.66	2.99	1.17
Raw materials	2.47	0.44	1.96	0.77
Gas regulation	24.79	4.40	2.87	1.12
Climate regulation	139.36	24.74	11.59	4.54
Hydrological regulation	138.23	24.54	105.60	41.39
Waste treatment	148.10	26.29	83.54	32.75
Soil formation and conservation	20.47	3.63	2.30	0.90
Biodiversity maintenance	37.95	6.74	19.29	7.56
Providing aesthetic value	48.24	8.56	24.98	9.79
Total	563.29	100.00	255.12	100.00

3.2 Comparison with grassland and forest ecosystems

Wetlands, grasslands, and forests are important natural resources with important ecological benefits and large economic values on the earth. Our calculation results (Table 6) suggest that the total economic value of the lake and marsh wetlands ecosystem of China in 2008 is 54.64% of the grassland ecosystem and 30.34% of the forest ecosystem (2.6974×10^{11} USD) (the average of two evaluations from Yu *et al.* (2005) and Zhao *et al.* (2004)). Grasslands and forests take larger area in China (3.10×10^8 ha and 1.59×10^8 ha, respectively), and the wetlands area is only 1.977×10^7 ha, however, the wetlands produce the significant ecological benefit, especially in hydrological regulation and waste treatment service.

Table 6 Comparison of valuation results of lake and marsh ecosystems with those of grassland and forest ecosystems

Ecosystem	Ecological service value (10^8 USD)	Reference
Lakes and marsh ecosystem	818.41	Present study
Grassland ecosystem	1497.90	Xie *et al.* (2001)
Forest ecosystem	3696.24	Yu *et al.* (2005)
Forest ecosystem	1698.48	Zhao *et al.* (2004)

3.3 Comparison of valuation results between wetland ecosystem and similar ecosystem

The comparison of valuation results between wetland ecosystem and similar ecosystem was as follows (Table 7). The total value of wetland ecosystem in this study is higher than that of aquatic ecosystem in China reported by Ouyang *et al.* (2004), while lower than that determined by Zhao *et al.* (2003), Chen and Zhang (2000). These differences may be attributable to different methods of valuation used in these studies and also to the different service items included in the analyses. Also, Zhao *et al.* (2003) and Ouyang *et al.* (2004) only calculated the main ecosystem service value of the large lakes in the eastern China, and the wetlands in other areas were not included in the calculation. Data in their studies were largely obtained from data sources published during the 1980s and 1990s. Similarly, Chen and Zhang (2008) also relied on data from the Vegetation Distribution Map of China published in 1982. These different sources of basic data may be another major contributor of the differences among these studies. In this study, 20-m resolution remote sensing data were used, and the data were further validated by field surveys. Therefore, the data in this study are expected to be more accurate and up-to-date than those in the previous studies.

4 Discussion

Because of the limitation on data available, this study only evaluated the service values of the lake and marsh wetlands. Other wetland types, such as river, coastal wetland and artificial wetland, were not included in the calculation. Thus, the total value calculated in this study is lower than the real service value of China′s wetlands ecosystem. Nevertheless, the lakes and marshes represent a large proportion (61%) of the total wetlands area of China. Also, to ensure data accuracy, wetland lower than 1 km^2 was not identified. These small wetlands account for only < 5% of the total wetland area of the country, and their contribution to the total service value is expected to be limited.

Although many studies have attempted to determine the economic value of wetlands ecosystem, accurate methods of calculating their values remain inconclusive because of the inherent complexity of ecosystem services and the changes of market values over time. Most studies in China have adopted the unit values reported by Costanza *et al.* (1997). Whether these values are suitable for the conditions of natural sources in China

Table 7 Comparison of valuation results of lake and marsh ecosystems with those of similar ecosystem

Ecosystem	Total service value (10^8 USD)	Main data source	Year	Reference
Inner-land lake and marsh	818.41	Remote sensing data (20 m resolution)	2008	Present study
Aquatic ecosystem	1185.11	National Bureau of Statistics (2000); Wang (1998); Zhao (1999)	2000	Zhao *et al.* (2003)
Aquatic ecosystem	729.60	National Bureau of Statistics (2000); The Ministry of Water Resources of the P.R.C. (2000)	2000	Ouyang *et al.* (2004)
River, lake, and marsh	3537.39	Vegetation Distribution Map of China (1∶4 000000)	1994	Chen and Zhang (2000)

still needs to be confirmed. In addition, though many value transfer methods are applied for years, it was concluded that there is no clear evidence in current research that any of the value transfer method is inherently superior.

5 Conclusions

Conducting original valuation of wetlands is usually pricey and time-consuming. Value transfer has the advantage that reducing both time and financial resources in practice. Value transfer method has developed as an acceptable way to wetlands ecosystem valuation, enabling the welfare results from primary studies to the policy sites. However, there remains significant problem about methodology and uncertainty issues. When there are characteristic differences between the original study site and policy site, the precision of the data are diminished, which results in increased uncertainty. The degree of uncertainty should be related to the similarity between the study sites and policy sites. Certain conditions have to be met to limit the uncertainty parameters. First, the original study sites should be examined whether they are applicable for value transfer in terms of data collection and valuation methods. In addition, the transfer ability need to be evaluated for both the study sites and policy sites, regarding the similarity in ecosystem elements (such as hydrology, vegetation and soil condition), and the social-economic factors, such as population, are important in explaining wetlands value.

The value of a wetland ecosystem depends on many factors. In addition to the inherent properties (hydrology, soil, vegetation) of the wetland environment, the geographical conditions and socio-economic condition, population status of the wetland area also have significant impacts on ecosystem service value. This study determined the value of the lake and marsh ecosystem in China by using medium resolution remote sensing data, in an attempt to provide a basis for future studies, and will build the foundation for further investigation on wetland service valuation. For a more accurate evaluation of the total value of wetland ecosystem in China, the composition and structure of these wetlands as well as the natures of their service items should be investigated in depth. Reliable ecological data should be obtained and accurate methods of value determination should be developed. Nevertheless, the present study suggests that the total service value of the lakes and marshes of China are as high as 8.1841×10^{10} USD. This high value emphasizes the critical need to keep these regional ecological support systems intact. With the continuing loss of natural ecosystems, an accurate determination of the values of natural ecosystems is expected to play a key role in evaluating the benefits of these systems to society and losses which will occur if these natural resources are developed for other uses.

Acknowledgements

We are grateful to David Stanton, the specialist in Centre of Ecohydrology, University of Western Australia, and Martine Scheltema, for valuable comments and revising of this paper.

References

Acharya G, 2000. Approaches to valuing the hidden hydrological services of wetland ecosystems. *Ecological Economics*, 35(1): 63–74. doi: 10.1016/S0921-8009(00)00168-3

Bai J, Xiao R, Zhang K *et al*., 2013. Soil organic carbon as affected by land use in young and old reclaimed regions of a coastal estuary wetland, China. *Soil Use and Management*, 29(1): 57–64. doi: 10.1111/sum.12021

Barber E B, 2000. Valuing the environment as input: Application to mangrove-fishery linkages. *Ecological Economics*, 35(1): 47–61. doi: 10.1016/S0921-8009(00)00167-1

Bodegom P V, Bakker C, Gon H D, 2004. Identifying key issues in environmental wetland research using scaling and uncertainty analysis. *Regional Environmental Change*, 4(2–3): 100–106. doi: 10.1007/s10113-004-0069-8

Cedfeldt P T, Watzin M C, Richardson B C, 2000. Using GIS to identify functionally significant wetlands in the northeastern United States. *Environmental Management*, 26(1): 13–24. doi: 10.1007/s002670010067

Chen Y, Yu J, Khan S, 2010. Spatial sensitivity analysis of multi-criteria weights in GIS-based land suitability evaluation. *Environmental Modeling & Software*, 25(12): 1582–1591. doi: 10.1016/j.envsoft.2010.06.001

Chen Zhongxin, Zhang Shixin, 2000. Study on ecosystem benefit of china. *Chinese Science Bulletin*, 45(1): 17–22. (in Chinese)

Costanza R, d′Arge R, Groot R D *et al*., 1997. The value of the world′s ecosystem services and natural capital. *Nature*, 387: 253–260. doi: 10.1016/S0921-8009(98)00020-2

Cui Lijuan, 2004. Evaluation on functions of Poyang Lake ecosystems. *Chinese Journal of Ecology*, 23(4): 47–51. (in Chinese)

Daily G C, 1997. Introduction: What are ecosystem services? In: Daily G C. *Nature's Services*: *Societal Dependence on Natural*

Ecosystem. Washington D.C.: Island Press, 1–10.

Eshet T, Baron M G, Shechter M, 2007. Exploring benefit transfer: Disamenities of waste transfer stations. *Environmental & Resource Economics*, 37(3): 521–547. doi: 10.1007/s10640-006-9047-6

European Environment Agency, 2010. Scaling up ecosystem benefits—A contribution to the economics of ecosystem and biodiversity (TEEB) study. In: *European Environment Agency Report No. 4*. Available at: http: //www.eea.europa.eu/publications/scaling-up-ecosystem-benefits-a.

Farber S, Costanza R, Childers D L *et al*., 2006. Linking ecology and economics for ecosystem management. *Bioscience*, 56(2): 121–133. doi: 10.1641/0006-3568(2006)056[0121:LEAEFE]2.0.CO;2

Farely J, 2008. The role of prices in conserving critical natural capital. *Conservation Biology*, 22(6): 1399–1408. doi: 10.1111/j.1523-1739.2008.01090.x.

Fennessy M S, Jacobs A D, Kentula M E, 2004. Review of rapid methods for assessing wetland conditions. In: *US Environmental Production Agency Report No. EPA/620/R-04/009*. Available at: http: //www.epa.gov/nheerl/download_files/publications/rapidmethodreview.pdf.

Finnoff D, Tschirhart J, 2008. Linking dynamic economic and ecological general equilibrium models. *Resource and Energy Economics*, 30(2): 91–114. doi: 10.1016/j.reseneeco.2007.08.005

Fu Bojie, Liu Guohua, Chen Liding *et al.*, 2001. Scheme of ecological regionalization in China. *Ecological Acta*, 21(1): 1–6. (in Chinese)

Fu Bojie, Zhou Guoyi, Bai Yongfei *et al*., 2009. The main terrestrial ecosystem services and ecological security in china. *Advances in Earth Science*, 24(6): 571–576. (in Chinese)

Gascoigne W R, Hoag D, Koontz L *et al*., 2011. Valuing ecosystem and economic services across land-use scenarios in the Prairie Pothole Region of the Dakotas, USA. *Ecological Economic*, 70(10): 1715–1725. doi: 10.1016/j.ecolecon.2011.04.010

Ghermandi A, Bergh J M, Brander L M *et al.*, 2008. *The Economic Value of Wetland Conservation and Creation*: *A Meta-analysis*. *FEEM Working Paper No*. *79.2008*.

Groot R, Brande L, Ploeg S *et al*., 2012. Global estimates of the value of ecosystem and their services in monetary units. *Ecosystem Services*, 1(1): 50–61. doi: 10.1016/j.ecoser.2012.07.005

Huang L B, Bai J H, Gao H F *et al*., 2012. Soil organic carbon content and storage of raised field wetlands in different functional zones of a typical shallow freshwater lake, China. *Soil Research*, 50(8): 664–671.

Johnston R J, Rosenberger R S, 2010. Methods, trends and controversies in contemporary benefit transfer. *Journal of Economic Surveys*, 24(3): 479–510. doi: 10.1111/j.1467-6419.2009.00592.x

Lars H, Koppen K V, Groot R D *et al*., 2006. Spatial scale, stakeholders and the valuation of ecosystem services. *Ecological Economics*, 57(2): 209–228. doi: 10.1016/j.ecolecon.2005.04.005

Li Wenhua, 2008. *Ecosystem Service Valuation*: *Theory*, *Method and Application*. Beijing: China Renmin University Press, 37–51. (in Chinese)

Liu S, Costanza R, Troy A *et al*., 2010. Valuing New Jersey′s ecosystem services and natural capital: A spatially explicit benefit transfer. *Environment Management*, 45(6): 1271–1285. doi: 10.1007/s00267-010-9483-5

Liu Xiaohui, Lu Xianguo, Jiangming *et al*., 2008. Research on the valuation of wetland ecosystem services. *Acta Ecologica Sinica*, 28(11): 5625–5631. (in Chinese)

Luke M B, Florax R M, Vermaat J E *et al*., 2006. The empirics of wetland valuation: A comprehensive summary and a meta-analysis of the literature. *Environmental & Resources Economics*, 33(2): 223–250. doi: 10.1007/s10640-005-3104-4

Luke M, Brauer I, Gerdes H *et al*., 2011. Using meta-analysis and GIS for value transfer and scaling up: Valuing climate change induced losses of European wetlands. *Environment Resource Economic*, 52(3): 395–413. doi: 10.1007/s 10640-011-9535-1

Millennium Ecosystem Assessment, 2008. *Ecosystems and Human Well-being*: *A Framework for Assessment*. Washington D.C.: Island Press, 49–70.

National Bureau of Statistics, 2000. *China Statistical Yearbook 2000*. Beijing: China Statistic Press. (in Chinese)

National Bureau of Statistics, 2008. *China Statistical Yearbook 2008*. Beijing: China Statistic Press. (in Chinese)

National Research Council (United States), Committee on Characterization of Wetlands, 1995. *Wetlands*: *Characteristics and Boundaries*. Washington D.C.: National Academy Press, 215–220.

Niu Z G, Gong P, Cheng X *et al*., 2009. Geographical characteristics of China′s wetlands derived from remotely sensed data. *Science in China Series D*: *Earth Science*, 52(6): 723–738. doi: 10.1007/s11430-009-0075-2

Niu Z G, Zhang H Y, Wang X W *et al*., 2012. Mapping wetland changes in China between 1978 and 2008. *Chinese Science Bulletin*, 57(22): 2813–2823. doi: 10.1007/s11434-012-5093-3

Ojea E, Ruiz-Benito P, Markandya A *et al*., 2012. Wood provisioning in Mediterranean forests: A bottom-up spatial valuation approach. *Forest Policy and Economics*, 20: 78–88. doi: 10.1016/j.forpol.2012.03.003

Ouyang Zhiyun, Zhao Tongqian, Wang Xiaoke *et al*., 2004. Ecosystem services analyses and valuation of china terrestrial surface water system. *Acta Ecological Sinica*, 24(10): 2091–2099. (in Chinese)

Rosenberger R S, Loomis J B, 2003. Benefit transfer. In: Champ P A (ed.). *A Primer on Non-market Valuation*. Dordrecht: Kluwer, 445–482.

Rudolf S G, Wilson M A, Boumans R J *et al*., 2002. A typology for the classification, description and valuation of ecosystem functions, goods and services. *Ecological Economics*, 41(3): 393–408. doi: 10.1016/S0921-8009(02)00089-7

The Ministry of Water Resources of the P. R. C., 2000. *Statistical Bulletin of Chinese Water Conservancy 2000*. Availabe at: http: //www.cws.net.cn.

Wan Bentai, Xu Haigen, Ding Hui *et al*., 2007. Methodology of comprehensive biodiversity assessment. *Biodiversity Science*, 15(1): 97–106. (in Chinese)

Wang Sumin, Dou Hongshen, 1998. *Chinese Lakes*. Beijing: Science Press. (in Chinese)

William J M, James G G, 2000. The value of wetlands: Importance of scale and landscape setting. *Ecological Economics*, 35(1): 25–33. doi: 10.1016/S0921-8009(00)00165-8

William J M, James G G, 2007. *Wetlands* (*4th edition*). New Jersey: John Wiley & Sons Inc., 35–42.

Wilsom M A, Carpenter S R, 1999. Economics valuation of freshwater ecosystem services in the United States: 1971–1997. *Ecological Applications*, 9(3): 772–783. doi: 10.1890/1051-0761(1999)009[0772:EVOFES]2.0.CO;2

Woodward R T, Wui Y S, 2001. The economic value of wetland services: A meta-analysis. *Ecological Economics*, 37(2): 257–270. doi: 10.1016/S0921-8009(00)00276-7

Xie Gaodi Zhang Yili, Lu Chunxia *et al*., 2001. Study on valuation of rangeland ecosystem services of China. *Journal of Natural Resources*, 16(1): 47–53. (in Chinese)

Xie G D, Zhen L, Lu C X *et al*., 2008. Expert knowledge based valuation method of ecosystem services in China. *Journal of Natural Resources*, 23(5): 911–919.

Yao Weihao, Su Chunhua, Chen Bin, 2009. Progress of wetlands ecosystem service evaluation. *Research of Soil and Water Conservation*,16(3): 245–249. (in Chinese)

Yu Xiaofei, Zhang Yuxia, Zhao Hongmei *et al.*, 2010. Freeze-thaw effects on sorption/desorption of dissolved organic carbon in wetland soils. *Chinese Geographical Science*, 20(3): 209–217. doi: 10.1007/S11769-010-0209-7

Yu Xinxiao, Lu Shaowei, Ji Fang *et al*., 2005. The assessment of the forest ecosystem services evaluation in China. *Acta Ecological Sinica*, 25(8): 2096–2102. (in Chinese)

Zhang Ping, Ma Tao, 2011. A comment on studies on evaluation of services value of wetland ecosystem in China. *Wetland Science*, 9(2): 203–208. (in Chinese)

Zhao Kuiyi, 1999. *Chinese Marsh*. Beijing: Science Press. (in Chinese)

Zhao Ling, Wang Erda, 2011. An empirical study of meta-regression benefit transfer of natural resources. *Resources Science*, 33(1): 31–40. (in Chinese)

Zhao Tongqian, Ouyang Zhiyun, Wang Xiaoke *et al*., 2003. Ecosystem services and their valuation of terrestrial surface water system in China. *Journal of Natural Resources*, 18(4): 443–452. (in Chinese)

Zhao Tongqian, Ouyang Zhiyun, Zheng Hua *et al*., 2004. Forest ecosystem services and their valuation in china. *Journal of Natural Resources*, 19(4): 480–491. (in Chinese)