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ESTIMATION OF ECOLOGICAL SERVICE VALUES OF WETLANDS IN SHANGHAI, CHINA

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ABSTRACT: Shanghai is a coastal metropolitan city with various types of natural wetlands, which account for 23.5% of its total area. According to the definition of wetland in Ramsar Convention on Wetlands, the wetlands of Shanghai were classified into 4 types: coastal, riverine, lacustrine, and reservoir and pond wetlands. In order to examine the roles of wetlands in the life-support system of Shanghai, we calculated the area of each type of the wetlands using GIS technique, and then measured the ecological service values of different ecosystems in Shanghai based on the classification of ecosystem services proposed by COSTANZA *et al*. (1997). The estimated annual value of ecosystem services in the study area was 7.3×10^9US$/a for the total area of 1 356 700ha, among which about 97% was provided by the wetlands. Effective conservation and management of wetlands are therefore crucial to Shanghai's sustainable development. The limitations of the evaluation method for ecosystem service value were also discussed in the present paper.

KEY WORDS: ecosystem service; ecological service value; GIS; Shanghai

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1 INTRODUCTION

Wetlands provide many important services to human society, but are at the same time ecologically sensitive and adaptive systems. This explains why in recent years much attention has been paid to the formulation and operation of sustainable management strategies for wetlands. Both natural and social sciences can contribute to an increased understanding of relevant processes and problems associated with such strategies (TURNER *et al*., 2000; MITSCH and GOSSELINK, 2000). Despite the increasing recognition of the need to conserve wetlands, loss of natural wetlands is continuing. One main reason is that wetlands throughout the world are considered by many to be of little or no value, or even at times to be of negative value (EHRENFELD, 2000; MITSCH and GOSSELINK, 1986). This lack of awareness of the value of conserved wetlands and their subsequent low priority in the decision-making process has resulted in the destruction or substantial modification of wetlands, causing an unrecognized social cost (TURNER *et al*., 2000). The conservation of urban wetland habitat is challenging because of the specific threats to which these systems are subject and the desire to utilize those remaining sites for multiple and often incompatible purposes (ZEDLER and LEACH, 1998).

On the other hand, ecosystems serve human society in many different ways, and thus are envisaged as a part of the total economic value of our planet. However, attempts to put a price on ecosystems were made only recently (FABER and COSTANZA, 1987; COSTANZA *et al*., 1997; LOOMIS, 2000). COSTANZA *et al*. (1997) estimated the current economic value of 17 ecosystem services for 16 biomes, giving the estimated annual value of global ecosystem services, which, on average, accounted to US$$33\times10^{12}$, equaling to 1.82 times the GNP of the world. Ecosystem services and natural resources are in the focus of current debate (COSTANZA, 1998; PRIOR, 1998) for two reasons: first, the great value of biodiversity is arousing the enthusiasm of scientists to reconsider the wise utilization of biodiversity (PRIOR, 1998); second, the wetland e-

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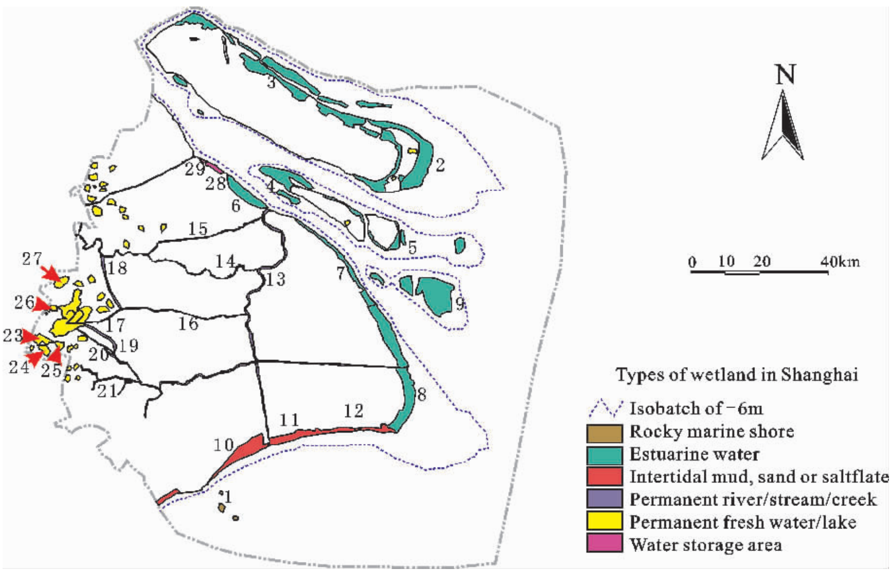
cosystems are receiving more attention as they provide a much higher value than other ecosystems through comparing service values of various ecosystems. The use of ecosystem services as a concept has great advantage in the communication between disciplines. But also, this concept has to be usable within disciplines if it is to remain scientifically credible (NORBERG, 1999).

In this study, we selected Shanghai as a study area to 1) evaluate the efficacy of using Landsat TM data to examine land-use pattern in Shanghai and quantify ecosystem service function, and 2) determine how important the wetlands are for the regional development of Shanghai. It aimed at providing scientific basis for making policies on wetland conservation and management in Shanghai.

2 METHODS

2.1 Study Area

Shanghai is located at 31°14′N and 121°29′E, extends about 120km from south to north, and about 100km from east to west. Shanghai possesses more than 300km^2 of natural wetlands, accounting for 23.5% of its total area, while the natural wetlands of China account only for 2.6% of the country's total area. The river, ocean, geographic locality, geological history, climatic conditions, as well as human activities in Shanghai have all played important roles in determining wetland type, distribution and function. The wetlands of this region are mainly coastal, including alongshore wetlands, alluvial island wetlands of the Changjiang (Yangtze) River mouth, low-lying riverine wetlands of Dianshanhu Lake, and artificial wetlands, situated at east tidelands of Chongming Island, Jiuduansha Island, Biandansha Island, Hengsha Island, Changxing Island of the Changjiang River mouth, eastern coastal areas and Dianshanhu Lake areas of Shanghai, respectively (Fig. 1). These wetland ecosystems have high biodiversity, providing habitats for 60%–70% of the endemic, rare and endangered species, including 157 species of birds, 112 species of fish, 58 species of macrobenthos, and 136 species of wetland plants. Obviously, Shanghai is a complex ecosystem, lying at the converging point of terrestrial ecosystem, wetland ecosystem and marine ecosystem.



Note: Labeled numbers on the map is after column "No." in Table 1

Fig. 1 Distribution of wetlands in Shanghai

2.2 Data Collection and Preparation

The data used here were extracted from cloud-free Landsat Thematic Mapper (TM) imagery in February 1997. The imagery was geo-rectified and registered to a Universal Transverse Mercator (UTM) coordinate system, by using road intersections and other prominent visible features on the existing topographic map of Shanghai at the scale of 1:100 000 (provided by Shanghai Municipal Institute of Surveying and Mapping in IDRISI Release 2 (http://www.clarklabs.org/)). Other data layers included a topographic map of Shanghai at the scale of 1:50 000 (provided by Shanghai Municipal Institute of Surveying and Mapping). Three reports were used here to help us classify and calculate the areas of different wetland types (Shanghai Agriculture and Forestry Bureau, 1998, 2001; Shanghai Teachers University, 1999). Statistical data for calculating the areas of open ocean, forest and cropland were extracted from the *Statistical Yearbook of Shanghai* (Shanghai Municipal Statistics Bureau, 2001).

2.3 Estimate of Ecosystem Service Values

Because our major aim was to determine the significance of wetlands in Shanghai, we did not intend to obtain specific area value coefficients. On the other hand, in order to make this study comparable with other similar studies (SEIDL and MORAES, 2000; CHEN and ZHANG, 2000; KREUTER *et al*., 2001; ZHAO *et al*., 2004), we used the classification system of ecosystem services proposed by COSTANZA *et al*. (1997). Following his study, the total service value for each biome was obtained through multiplying unit area value for the ecosystem services (in US$/(ha·a)) by the total area of the biome. An ecosystem service value (ESV) can be calculated respectively using the following equation:

$$ESV=\sum(A_k \times VC_k) \quad (1)$$

where A_k is the area (ha) and VC_k the value coefficient (US$/(ha·a)) for land use type k.

3 RESULTS

3.1 Wetland Types and Their Values of Ecosystem Services

According to the definition of wetland in Ramsar Convention on Wetlands (http://www.ramsar.org/), the wetlands in Shanghai include coastal, riverine, lacustrine, and reservoir and pond. Twenty-nine tracts of wetlands with a total area of 319 714ha were identified in this study, including 305 421ha of coastal wetlands, 7191ha of river wetlands, 6803ha of lake wetlands, and 299ha of reservoir and pond wetlands. Five important wetlands were identified by the municipal government as 1) Chongming East Beach (*Dongtan* in Chinese), 2) Three Jinshan Island wetlands, 3) Jiuduansha Island, 4) Nanhui coast, and 5) Huangpu River wetland, with a total area of 176 893ha (Table 1).

Table 1 Types (Ramsar Classification System) and areas of wetlands in Shanghai

No.	Wetland name or location	Area (ha)
	Type 1 Marine and Coastal	
	Rocky marine shores	2501.85
1	Three Jinshan Islands	2501.85
	Estuarine waters	289424.57
2	Chongming East Beach	71896.77
3	Chongming Coast	41188.24
4	Changxing Coast	15483.91
5	Hengsha Coast	50549.87
6	Wusongkou-North Baoshan	5654.07
7	Pudong New Area Coast	5954.70
8	Nanhui Coast	58086.13
9	Jiuduansha Island	40610.88
	Intertidal mud, sand or saltflats	13494.97
10	Jinshan Coast	5703.15
11	Fengxian Coast	5954.70
12	Nanhui County Coast	1837.12
	Type 2 Inland Wetlands	
	Permanent rivers/streams/creeks	7190.58
13	Huangpu River	3797.97
14	Suzhou River	243.00
15	Yunzhaobang	142.27
16	Dianpu River	207.27
17	Lanlugang-Shuliaojing	954.02
18	Dazhengkuang-Yuanxiejing	193.77
19	Taipu River	255.30
20	Damaogang-Xupukuang	196.98
21	Jishuigang	1200.00
	Permanent freshwater/lakes (>8ha)	6803.11
22	Dianshan Lake	4760.00
23	Yuandang Lake	324.75
24	Xueluodang Lake	129.20
25	Wangyangdang Lake	21.30
26	Dalian Lake	147.40
27	Dafengyang Lake	1420.46
	Type 3 Man-made Wetlands	
	Water storage areas	299.00
28	Baogang Reservoir	164.00
29	Chenxing Reservoir	135.00
	Total	319714.08

While the global ecosystems were divided into 16 biomes according to COSTANZA *et al*.(1997)'s system, only 6 biomes were identified in Shanghai, including open ocean, coastal estuary, forest, lakes/river, cropland and urban. According to the definition of wetland in the Ramsar Classification System for Wetland Type (http://www.ramsar.org/key_ris_types.htm), wetland (broad sense) includes coastal estuary, wetland (swamp and marsh), lakes/river and cropland come under wetland of broad sense. In conformity with the method of COSTANZA *et al*. (1997), we divided the wetland in Shanghai into 2 types: coastal estuaries and lakes/rivers. Additionally, the temperate/boreal forests represented by COSTANZA *et al*. (1997) did not match the forest biome for our study areas; however, in order to calculate the ecosystem services, we used the value coefficient of temperate/boreal forests to replace that of forest biome in this study. The areas of 6 biomes (Table 2) and the corresponding value of each ecosystem service were then obtained by multiplying area of each type of ecosystem by its service value per unit area.

Table 2 Estimated values of ecosystem services in Shanghai

Ecosystem	Unit area value (US$/ha·a)	Area (ha)	Total value ($\times10^6$US$/a)	Percentage (%)
Wetland (Coastal estuaries)	22832	305421	6973.37	95.43
Wetland (Lakes/rivers)	8498	14293	121.46	1.66
Forest	302	11290	3.41	0.05
Open ocean	252	722600	182.10	2.50
Cropland	92	290862	26.76	0.36
Urban	0	12234	0	0
Total	–	1356700	7307.10	100.00

3.2 Total Value of Ecosystem Services

The estimated service values of 6 biomes in Shanghai are listed in Table 2. It clearly shows that the total value of ecosystem services was 7.3×10^9US$/a for the total area of 1 356 700ha in Shanghai, among which more than 97% was provided by wetlands (estuaries and lakes/rivers). The total area of natural wetlands accounts for 23.5% of the total area (including marine area) of Shanghai, whereas the value for China is only 2.6%. Therefore Shanghai could be envisaged as a wetland city. Specifically, the estuarine wetlands played the most important role in the ecosystem services, which made a contribution of 96% towards the total value. It is therefore concluded that Shanghai is a coastal urban ecosystem that is dominated by estuarine wetlands.

Using the method of COSTANZA *et al*.(1997), CHEN and ZHANG (2000) similarly estimated the ecosystem values of different provinces in China. The total value of Shanghai was found to be only 5.2×10^7 US$/a, which was quite different from the estimation made in this study. One reason is that CHEN and ZHANG (2000) used a vegetation map of China (1∶4 000 000), in which the wetlands in Shanghai were ignored. Obviously the ecosystem service value of Shanghai was greatly underestimated in the study of CHEN and ZHANG (2000). It can be seen from our estimation that the ecological value of forests made a minor contribution to the total ecosystem service value in Shanghai (less than 1%).

3.3 Ecological Functions of Wetlands in Shanghai

To understand the value of wetlands, it is necessary to distinguish the systems' ecological functions from the associated services that are directly valued by humans (COSTANZA *et al*., 1997). LARSON *et al*. (1989) listed 17 services and functions provided by the world's ecosystems. WOODWARD and WUI (2001) grouped the functions of the wetland ecosystems into 10 categories, which may not be exhaustive. In actuality, ecosystem function depends greatly on where the wetlands are distributed (Table 3).

Table 3 Estimated service values of wetlands in Shanghai

Function	Coastal estuaries (US$/ha·a)	Lakes/rivers (US$/ha·a)	Total ($\times10^6$ US$/ha·a)	Percentage (%)
Disturbance regulation	567	–	173.17	2.44
Water regulation	–	5445	77.83	1.10
Water supply	–	2117	30.26	0.43
Nutrient cycling	21100	–	6444.38	90.83
Waster treatment	–	665	9.50	0.13
Pollination	–	–	4.07	0.06
Biological control	78	–	23.82	0.34
Habitat /refuge	131	–	40.01	0.56
Food production	521	41	159.71	2.25
Raw materials	25	–	7.64	0.11
Recreation	381	230	119.65	1.69
Cultural	29	–	8.86	0.12
Total	–	–	7094.83	100.00

Wetland ecosystems are associated with a diverse and complex array of direct and indirect uses (ACHARYA, 2000). Generally, the ecological service of the wetlands can be divided into 3 types (UNEP, 1993): ecological value, direct economic value (including foods and raw materials) and social value (i.e. the cultural value here). It is clear that the ecological service in Shanghai is the most important of the three, whose value amounts to about 6.89×10^9 US\$/a, or equivalently 96.69% of the total value. In contrast, the direct economic value of the wetlands is about 183.05×10^6 US\$/a, i.e. 2.57% of the total value. The social value is the lowest, about 8.86×10^9 US\$/a, or 0.12% of the total value. Obviously, the ecological value of the wetland ecosystem in Shanghai reflects the major component of the total value, is 37.61 times of economic value, playing a key role in the maintenance of ecological security of Shanghai.

The estimation made here is a cursory range of wetlands' ecosystem service value in Shanghai. A more detailed estimation system is still needed in the future. With such measurements, the ecosystem service value of Shanghai can be calculated accurately, which can offer suggestions to execute the sustainable development strategy of Shanghai scientifically and efficiently.

4 DISCUSSION

4.1 Wetland Degradation and Its Ecosystem Service Discount

Urban wetlands have suffered from many abuses, including destruction of vegetation by off-road vehicles and use as dumps; they are also highly susceptible to invasion by horticultural escapees, pets, and feral animals (ZEDLER and LEACH, 1998; GRAYSON *et al*., 1999). Shanghai's wetlands are being degraded due to intensive human disturbance. Consequently wetland ecosystem services are greatly discounted. The main reasons are over-reclamation, water pollution, over-fishing, rapid urbanization and degradation of ecosystems.

4.2 Limitations of the Current Estimation Method

COSTANZA *et al*. (1997) has made a significant contribution to the understanding of the natural capital value of biodiversity. It also provides us with a new insight into conservation, and sustainable utilization of biodiversity. However COSTANZA *et al*.'s estimation method may have some limitations when analysis is focusing on a specific region. First, wetlands at different geographic locations may vary in structure and function, and hence the values per unit area might be quite different. Taking no account of the variation may lead to unrealistic estimation of the service value. Services can be available on the local or global scale according to the scope of the problem they are connected to and the possibility of transferring the service from which it is produced to the city where humans benefit from it. Such a transfer can take place both by man-made transport and by natural means (BOLUND and HUNHAMMAR, 1999). Second, almost all types of ecosystems in the world are to a varying degree disturbed, thus the service value per unit area of degraded ecosystems should be discounted according to the degree of the ecosystem's degradation. Third, because detailed information for different functions of ecosystems are scarce, COSTANZA *et al*.'s estimation of natural capital values may be subject to errors. Fourth, some ecological potential functions of ecosystem have not been identified yet. A number of these ecological services are not consumed by humans directly, but are needed to sustain the ecosystems themselves. Such indirect services include pollination of plants and nutrient cycling, but the classification is not obvious (BOLUND and HUNHAMMAR, 1999).

In addition, mean ecosystem service value assigned to each land cover category may be problematic because the biomes used as proxies for the land cover categories are clearly not perfect matches in every case (KREUTER *et al*., 2001). Some types of ecosystems may not well be represented by COSTANZA *et al*.'s system. Therefore, at the regional scale, if the absolute ecosystem values are of primary interest, the service values should be assigned to each land cover category according to the actual categories of services provided. Additionally, accessibility of ecosystem services might also be taken into account. Nevertheless, if one is more interested in relative importance of different land cover categories to the urban environment (as in this study) than in the absolute ecosystem service value, this estimation method is still valid.

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