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ABSTRACT

For decision making in terms of environmental economics for wetland construction, restoration and preservation, net ecosystem services values of constructed, human-interfered and natural wetlands are explored in the present work as a comparative study. The ecosystem services values of a pilot constructed wetland in Beijing, China in different discount rates and time horizons are accounted and compared with those of the natural wetlands all over the world as a mean and of a typical human-interfered wetland in Wenzhou, China. Results show that in both finite and infinite time horizons considered, the constructed wetland has the largest net services value in a reasonable discount rate.

1. Introduction

Ecosystem services are the profits people obtain from ecosystem functions as some intrinsic characteristics of the structure and processes of an ecosystem to satisfy their need. When accounted as part of human welfare [1], ecosystem services value (ESV) is actually considered as the specific price of ecosystem services.

Owing to the rising concern on ecosystem degradation and the increasing need for decision making to conserve and restore ecosystem, comprehensive evaluations on ESV have been emerged [2], since the problem of market failure for "free services" was put forward by Krutilla [3]. In particularly, wetland as one kind of the most important ecosystems in the world has attracted many studies on ESV evaluation in the past decades [4–12]. As the syntheses of above studies, meta-analyses have also been carried out by Brouwer et al. [13], Woodward and Wui [14], Brander et al. [15] and Ghermandi et al. [16].

In decision making of an ecological engineering, what matters is not the ESV itself but the net value of ecosystem services (NVES) as the difference between ESV and ecosystem services cost (ESC), i.e.

$$\mathrm{NVES} = \mathrm{ESV} - \mathrm{ESC},$$

where

$$\mathrm{ESC} = C_c + C_o + C_v$$

with C_c standing for the construction cost, C_o the operation and maintenance cost, and C_v the virtual cost. As an initial investment, C_c is needed when people want to construct a new ecosystem or modify an original ecosystem for certain use. The adequate input of C_o is crucial to maintain stable ecosystem services from some artificial ecosystems. The concept of virtual cost is brought forward to represent the costs which do not happen in practical process but should be accounted because of the exis-

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tences of uncharged cost and externality. Uncharged rent for covered land and payments for absorbed solar energy and underground water are some of the most important virtual costs. A constructed ecosystem has positive input of C_c and C_o, while a natural ecosystem with no human interventions is with zero C_c and C_o. Between the extreme cases as transitional is the human-interfered with positive C_o and zero C_c. Actually, many ecosystems essential to our daily lives, e.g. the suburban forest, the coastal mangrove, and even the so-called nature reserve with human management, are human-interfered ecosystems.

For an ecological economy, policy making is for the maximization of long term NVES. Since the accounting of long term NVES necessitates a comparison between ESV and ESC varying in the lifetime of an ecosystem, dynamic analysis is required to deal with the temporal horizon [17]. In this circumstance, ESV and ESC should be discounted. Discounting is commonly used to express future gain or cost in term of present value by the use of a discount rate. To make the decision procedure simple and visible, the dynamic performances of benefit and cost are usually transformed into present value by using discount rate in many studies by, among others, Costanza et al. [4], Gren et al. [6], Kosz [18], Leschine et al. [19], Turner et al. [20], Gutrich and Hitzhusen [21] and Ko et al. [22]. The discounted NVES is referred to as the net present value of ecosystem services (NPVES).

Presented in this paper is an environmental economic cost–benefit analysis for a constructed wetland in Beijing (Beijing wetland). Based on Tong et al. [12] and Costanza et al. [1], valuations for a typical human-interfered wetland in Sanyang, Wenzhou, China (Sanyang wetland) and for the natural wetlands all over the world as a mean (mean wetland) are provided for a comparison.

2. Typical wetlands

2.1. Beijing wetland

The Longdao River with a daily discharge of 16,000 m^3 flows across the countryside of Beijing. The river water was heavily polluted by the sewage received from the upstream residential area and the river ecosystem was severely destroyed by the pollution. The wastewater has average loading rate of about 47, 23 and 5.0 mg/l for BOD_5, NH_3-N and total-P. Nearby residents suffer the smelly odor let off from the river every summer and complain a lot. To restore the river ecosystem and treat the polluted water, we built a vertical subsurface-flow constructed wetland, the Beijing wetland near the estuary of the Longdao River in 2004 as a demonstrative ecological engineering. The constructed wetland is at a latitude of 40°04′N and a longitude of 116°34′E in the North Temperate Zone with climate type of semi-humid temperate continental monsoon climate. The average daily temperature and precipitation in Beijing were 11.8 °C and 578 mm in 2004 [23].

As a vertical subsurface-flow constructed treatment wetland near the Longdao River, the Beijing wetland [24–26] has a vegetated bed area of 602 m^2 with a length and width of 28 m and 21.5 m respectively. With a daily treatment capacity of 200 m^3, the effluent water fits the criterion for the fourth grade of ground water based on GB/T18921-2002 [27]. The construction cost of this engineering is 23,983 $ and the annual operation and maintenance expenditure is about 834 $/yr. The lifetime is supposed to be 20 years.

2.2. Sanyang wetland

As a typical human-interfered ecosystem, the Sanyang wetland [12] with an area of about 1141 hectares situates in Wenzhou, China, at a latitude of 28°00′N and a longitude of 120°38′E in the North Temperate Zone. The climate type in Wenzhou are subtropical monsoon climate and the average daily temperature and precipitation were 19.3 °C and 15,124 mm in 2004 [28]. The Sanyang wetland is a permanent river wetland or a riverine perennial marsh, according to the Ramsar wetland classification system or the US Fish and Wildlife System separately [2,12]. Various plants, at least 11 species, grow in the Sanyang wetland and orange grove is the dominant vegetative cover on the land area. Part of the wetland area is currently used as residential area and the rest is mainly managed for agriculture production. Tong et al. [12] aim to evaluate the difference of essential ESV and possible ESV to reflect the degree of degradation of the wetland ecosystem. Potential ESV in their work represents the largest amount of ESV can be obtained from a certain wetland when it is restored.

2.3. Mean wetland

According to Costanza et al. [1], the wetland all over the world occupying only 6.5% of the earth's surface area contributes about 14.7% of the world's ecosystem services values. Based on their results, the wetland ecosystem services can be classified into six categories as (1) waste treatment, (2) food and material production, (3) water supply, (4) gas regulation, (5) disturbance and water regulations, and (6) habitat and refugia provision. The wetland in its average status as a representative of the natural wetland is referred to as the mean wetland.

3. Account method

3.1. Ecosystem services value

To price the ecosystem services, a variety of methods associated with voided cost, contingent valuation, hedonic pricing, market pricing, production approach, replacement cost and travel cost have been implemented. In the present study, ESV account is largely based upon Costanza et al. [1] and Tong et al. [12], with references to de Groot et al. [9], Turner et al. [20], MA [10] and Farber et al. [29], associated with the six kinds of ecosystem services presented in Section 2.3.

3.1.1. Waste treatment

The value from waste treatment service, V_w, is estimated as

$$V_w = V_p - V_a$$

where V_p is the value gained from waste purification and V_a is the value lost from waste accumulation. Negative value may occur when waste accumulation exceeds the purify capacity of the ecosystem.

For the Beijing wetland, V_a is assumed to be zero according to the effluent quality [24] and V_p is evaluated by the replacement cost method as

$$V_p = P_p \times C_t$$

where C_t is the treating capacity of the constructed wetland and P_p is the average wastewater treating cost per unit volume, equal to 0.11 $/m^3 as available in the governmental website (http://www.chinaprice.gov.cn/fgw/ProxyServlet?server=e450&urls_count=1&url=sev/jiage_jiance/F_A1_H1_ws_0.html in Chinese). The main technique for waste water treatment in Beijing is the activated sludge (AS) process, and a new technique of cyclic activated sludge system (CASS) for wastewater treatment in Beijing is introduced by Liu [30]. The costs to treat wastewater by AS and CASS are about 0.067 and 0.051 $/m^3, respectively. However, these costs do not include the charges for wastewater collection and pipes system construction and are actually much lower than the real treatment cost. Also, the AS and CASS techniques correspond to lower effluent water quality, compared with the Beijing wetland. Then the Beijing wetland is considered to be a good choice to treat the wastewater in the Longdao River.

3.1.2. Food and material production

Food and material production value V_f is estimated by the market price method as

$$V_f = \sum P_i \times M_i$$

where P_i is the price of the ith production and M_i is the net increase of biomass of the ith production.

For the Beijing wetland, common reed (*Phrugmites australis*) all over the vegetated bed is taken to represent the plants when calculating the food and material production service value. Fresh leaves from common reed (*P. australis*) are harvested every year and the output is about 51.2 g/m^2 according to field investigation. The harvest cost is included in the wage of about 240 $/yr for a part-time maintenance worker. The market price of fresh common reed (*P. australis*) for paper industry is about 51 $/t [31].

3.1.3. Water supply

The value from water supply service V_s is estimate as

$$V_s = V_e - V_i$$

where V_e is the value of the effluent water and V_i is the cost of influent water. Negative value may be resulted in the case of the cost of influent water exceeding the value of effluent water.

For the Beijing wetland, the market price method gives

$$V_e = P_s \times O \times A$$
$$V_i = P_s \times I \times A$$

where P_s is the price of qualified water for agricultural use, O and I are the average amount of effluent and influent water qualified for agricultural use per unit area of wetland, and A is the wetland area. The effluent water is qualified for agricultural use according to Chen et al. [24] and P_s is 0.072 $/m^3 in Beijing as available in governmental website (http://www.bjwater.gov.cn/tabid/110/Default.aspx in Chinese). According to the current status that water resource for agriculture use is in serious shortage in the Beijing area, all the effluent water is assumed to be used. Farmers gain the water from rivers by existing facilities. The cost of supplying water from the wetland to agriculture is omitted since treated water flows into the river and no new pipes and facilities are needed. The influent wastewater does not qualify for agricultural use due to high pollutant concentrations, thus the only qualified input water is the collected participation. With consideration of evaporation, the average effluent water quantity is about 1.2×10^6 m^3/ha/yr.

3.1.4. Gas regulation

The value from gas regulation services due to the greenhouse gas storage/emission and oxygen production, V_g, is evaluated by market price method as

$$V_g = P_c \times M_{st} - P_c \times M_{em} + P_{ox} \times M_{ox}$$

where P_c and P_{ox} are the trade prices for greenhouse gas and oxygen, respectively; M_{st} and M_e are the amounts of the greenhouse gas storage and emission, respectively; and M_{ox} is the oxygen production.

For the Beijing wetland, we have

$$M_{st} = \sum M_i \times \eta_i \times W_{co_2} \div W_c$$
$$M_{ox} = M_{st} \times W_{o_2} \div W_{co_2}$$

Where η_i is the carbon concentration in the ith production of M_i, and W_{co_2}, W_c and W_{o_2} are the molecular weights of carbon dioxide, carbon and gaseous oxygen, respectively.

The average price for carbon dioxide in the international greenhouse gas exchange in 2006 is taken for P_c as 22 \$/t.[3]. The trade price of oxygen P_{ox} is taken as the industrial oxygen price [32] of 88 \$/t. The mean M_{em} value of a vertical subsurface-flow constructed wetland from Teiter and Mander [33] is adopted for the Beijing wetland due to the same wetland type and similar pollutant concentrations. For simplicity, it is assumed that there exits only common reed (*P. australis*) in the constructed wetland and the average carbon concentration in common reed is estimated as 39%, the same as the carbon concentration in straw [34].

3.1.5. Disturbance and water regulations

The disturbance and water regulations service provides flood control ability and water recover from drought period. Dam, lake and river course are the main disturbance and water regulations facilities in the Beijing area, most of which are artificial. The value from this service, V_d, depends on the water storage capacity of the ecosystem and is estimated in replacement cost method as

$$V_d = C_d \times S$$

where C_d is the construction cost for local disturbance and water regulations facility per unit storage volume and S is the water storage capacity of the ecosystem.

The construction of the Beijing wetland reduces the marginal demand to construct new disturbance and water regulations facilities. C_d is adopted from Guo et al. [35] as 0.081 \$/m^3 and S is equal to 3080 m^3/ha based on engineering design.

3.1.6. Habitat and refugia provision

The habitat and refugia provision service represents the environment provided to biodiversity by the ecosystem. However, since there is no generally accepted and precise evaluation method for this service, we adopt the result from Tong et al. [12] and make a calculation by vegetation species ratio, assuming that habitat and refugia provision service value per area is in proportion to the specie numbers of vegetations. Thus we have

$$V_h = V'_h \times N/N'$$

where V_h and V'_h are the habitat and refugia provision service values of the Beijing wetland and the Sanyang wetland, respectively; N and N' are the corresponding vegetation species numbers. The minimum number of 11 is taken to represent the vegetation species number in the Sanyang wetland. Only three species, i.e. common reed (*P. australis*), water bamboo (*Zizania aquatica*) and cattail (*Typha latifolia*) are planted in the Beijing wetland.

3.2. Discount

Different discount rates are used in the accounting to reflect the people's time preference in decision making. Since the Beijing wetland was designed to have a lifetime of 20 years, the total NPVESs of the three wetlands in a time horizon of 20 years have been discounted into the baseline year of 2004 to reflect the relative results in this period. The total NPVESs in an infinite time horizon are also presented, assuming the Beijing wetland is to be destroyed (no fee will be needed for the destruction) and reconstructed after its lifetime.

3.3. Other simplifications and assumptions

For simplification, the virtual cost for all the three wetlands under consideration is taken as the average land rent of about 272 \$/ha/yr estimated by Yang [36].

For the Beijing wetland, construction cost involves material cost for the infrastructure and labor cost for constructing; operation and maintenance cost contains material cost for fixing, electricity fee for operating and labor cost for managing; virtual cost is equal to the rent of the covered land.

4. Results and discussion

Listed in Table 1 are the accounted ESV results for the Beijing wetland, in comparison with those for the mean wetland by Costanza et al. [1] and for the Sanyang wetland by Tong et al. [12]. The Beijing wetland provides an ESV of 2,06,740 \$/ha/yr, which is about 13 times of that from the mean wetland (15,643 \$/ha/yr) and 294 times of that from the Sanyang wetland

Table 1
ESV and its composition of the Beijing wetland, the mean wetland and the Sanyang wetland

Item	Beijing wetland		Mean wetland		Sanyang wetland	
	ESV ($/ha/yr)	Proportion (%)	ESV ($/ha/yr)	Proportion (%)	ESV ($/ha/yr)	Proportion (%)
Waste treatment	1,31,948	63.82	4902	31.34	−854	−121.58
Food and material production	40	0.02	425	2.72	895	127.47
Water supply	74,706	36.14	4460	28.51	207	29.50
Gas regulation	−238	−0.11	156	1.00	48	6.88
Disturbance and water regulations	249	0.12	5344	34.16	278	39.52
Habitat and refugia	35	0.02	357	2.28	128	18.21
Total	2,06,740	100.00	15,643	100.00	702	100.00

(702 $/ha/yr). The average ESV of about 2800 $/ha/yr by Brander et al. [15] for various wetland types is remarkable. For the Beijing wetland, the ecosystem service of waste treatment is dominant, with a fraction of 63.82% corresponding to the amount of 1,31,948 $/ha/yr. The ESVs of the same service from the mean wetland and the Sanyang wetland are 4902 $/ha/yr and −854 $/ha/yr, respectively. The negative value of the Sanyang wetland is due to the accumulation of pollutants such as heavy metals. The ESV of food and material production service from the Beijing wetland is 40 $/ha/yr, remarkably less than those from the other two wetlands (425 $/ha/yr and 895 $/ha/yr, respectively), especially from the Sanyang wetland which is managed as a human-interfered ecosystem with the main purpose to gain agricultural product. The water supply service contributes comparable fractions of about 36.14%, 28.51% and 29.50% by the Beijing wetland, the mean wetland and the Sanyang wetland, respectively. But the first one gains a net services value of 74,706 $/ha/yr, which is greater in order of magnitude than those of 4460 $/ha/yr and 207 $/ha/yr respectively for the mean wetland and Sanyang wetland. The negative ESV of −238 $/ha/yr of gas regulation from the Beijing wetland is due to the vast greenhouse gas emission into the atmosphere from the treated wastewater, in contrast to the positive values associated with the other two wetlands. The disturbance and water regulations service from the Beijing wetland contributes only 0.12% in the total ESV because of the small water storage capacity in the wetland. With obviously less species compared with the other wetlands, the Beijing wetland has a correspondingly low ESV of 35 $/ha/yr for habitat and regugia provision.

As shown in Table 2, unlike the mean wetland and the Sanyang wetland with constant ESV and ESC, the Beijing wetland has stable ESV while the ESC in its constructing year is dramatically higher than that in the operating years. The high construction cost brings this artificial ecosystem a NVES deficit in the first year. But positive NVES will be obtained in later years because ESV exceeds ESC after the constructing year.

As shown in Table 3, under any reasonable discount rate the constructed wetland has the highest NPVES, in both 20 years and infinite time horizons. The NPVES of the Beijing wetland is equal to that from the mean wetland in a discount rate up to

Table 2
ESV, ESC and NVES of the Beijing wetland, the mean wetland and the Sanyang wetland

Item	ESV ($/ha/yr)	ESC ($/ha/yr)				NVES ($/ha/yr)
	Total	Total	C_c	C_o	C_v	Total
Beijing wetland (constructing year)	2,06,740	4,12,504	3,98,384	13,848	272	−2,05,763
Beijing wetland (operating year)	2,06,740	14,120	0	13,848	272	1,92,620
Mean wetland	15,643	272	0	0	272	15,372
Sanyang wetland	702	2678	0	2406	272	−1976

Table 3
NPVES discounted into 2004 in different discount rates and different time scales of the Beijing wetland, the mean wetland and the Sanyang wetland

Discount rate (%)	Discount factor	Beijing wetland ($/ha)		Mean wetland ($/ha)		Sanyang wetland ($/ha)	
		20 years	Infinite horizon	20 years	Infinite horizon	20 years	Infinite horizon
0.00	1.0000	3,454,025		307,433		−39,520	
5.00	0.9524	2,122,117	3,405,683	201,143	3,22,804	−25,857	−41,496
10.00	0.9091	1,405,491	1,650,885	1,43,954	1,69,088	−18,505	−21,736
20.00	0.8333	7,27,193	7,46,669	89,824	92,230	−11,547	−11,856
30.00	0.7692	4,31,913	4,34,198	66,260	66,610	−8518	−8563
40.00	0.7143	2,74,982	2,75,311	53,736	53,801	−6908	−6916
50.00	0.6667	1,79,304	1,79,358	46,101	46,115	−5926	−5928
100.00	0.5000	−13,143	−13,143	30,743	30,743	−3952	−3952
80.15	0.5551	34,549	34,549	34,549	34,549	−4441	−4441
80.15	0.5551	34,549	34,549	34,549	34,549	−4441	−4441
93.61	0.5165	0	0	31,792	31,792	−4087	−4087
93.61	0.5165	0	0	31,792	31,792	−4087	−4087
95.49	0.5115	−4045	−4045	31,469	31,469	−4045	−4045
95.49	0.5115	−4045	−4045	31,469	31,469	−4045	−4045

80.15%, and is equal to that from the Sanyang wetland in a discount rate up to 95.49%. The persistent positive NPVES from the mean wetland means that we should conserve the natural wetland since the cost will always be less than the ESV people acquires from it, while the persistent negative ESB from the Sanyang wetland suggests that this wetland needs restoration [12]. Meanwhile, the Beijing wetland is expected to gain a balanced NPVES in a discount rate up to 93.61%. Though no specific discount rate is generally accepted in previous studies since discount rate is not a static value, varying not only across cultures in the same times but also within a culture over time [37], a reasonable discount rate is believed less than 10% [4,6,18–22], thence the construction of the Beijing wetland is considered highly profitable in general circumstances.

5. Concluding remarks

An environmental economic accounting scheme for net ecosystem services value, as difference between ecosystem services value and relevant ecological engineering or maintenance cost, is illustrated in this paper. For wetland construction, restoration and preservation, net ecosystem services values of constructed, human-interfered and natural wetlands are explored in the present work as a comparative study. The ecosystem services values of a pilot constructed treatment wetland in Beijing, China in different discount rates and time horizons are accounted and compared with those of the natural wetlands all over the world as a mean and of a typical human-interfered wetland in Wenzhou, China. This work represents a preliminary effort towards a general framework for cost–benefit analysis in terms of ecological economics for wetland engineering and management.

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