An Effective Method for Wetland Park Health Assessment: a Case Study of the Guangdong Xinhui National Wetland Park in the Pearl River Delta, China

Xiao-Shan Fang^{1,2} • Shuang Liu¹ • Wei-Zhi Chen¹ • Ren-Zhi Wu¹

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Abstract

The Guangdong Xinhui National Wetland Park (GXNWP) in the Pearl River Delta is an important stopover for migratory birds in China and East Asia. Due to high levels of interference, high sensitivity and fragile environmental constraints, an efficient method to assess the health status of wetland parks such as the GXNWP is urgently needed for sustainable development. In this study, we proposed a habitat-landscape-service (HLS) conceptual model that can be used at the site scale to evaluate health status in terms of habitats, landscapes and services by considering the complex ecosystem of wetland parks. This HLS model included 28 evaluation indicators, and the indicator weights and health-grade divisions were based on expert scores using both the analytic hierarchy process (AHP) and fuzzy comprehension evaluation (FCE) methods. The results showed that the health status of the GXNWP was at the “subhealthy” level, with a membership function of 0.4643. This study found that habitat indicators (0.5715) were the key factors affecting the GXNWP health status, followed by service indicators (0.2856) and landscape indicators (0.1429). The HLS-AHP-FCE method provides a holistic health evaluation indicator system and diagnostic approach for rapidly developing wetland parks in the Pearl River Delta, China.

Keywords Wetland park · Health status evaluation · Habitat-landscape-service conceptual model · Analytic hierarchy process · Fuzzy comprehension evaluation · Pearl River Delta, China

Introduction

Wetlands are among the most productive ecosystems worldwide and are frequently described as the Earth’s kidney due to their ecological benefits. However, as urbanization accelerates, the quality of wetland environments gradually deteriorates, and wetlands dwindle significantly each year (Costanza et al. 1992; Spangenberg and Lorek 2002; García-Álvarez et al. 2016; Asomani-Boateng 2019). The first and second surveys of national wetland resources showed that China’s wetland area decreased by 339.63 million hm^2 in past decades, with overall and annual reduction rates of 8.82% and

0.92%, respectively (Wu et al. 2018). Given this context, as an effective way to protect urban wetland resources without hindering artificial construction, wetland parks are developing rapidly (Mitsch and Day 2006; Hanford et al. 2019). In the Pearl River Delta, located in the central part of Guangdong Province, China (Fig. 1), the number of wetland parks is increasing yearly due to the accessible water sources and abundant biological resources in the area. Wetland parks in the Pearl River Delta are important parts of the ecological corridor for migratory birds in East Asia. Since the Pearl River Delta has become a highly urbanized area in recent years, wetland parks continuously face the environmental constraints of having high levels of interference and being highly sensitivity and fragile (Fang and Wang 2019). Wetland conservation and restoration in the Pearl River Delta have been undertaken and are attracting increasing attention. However, in the absence of assessment methods for wetland park health, managers in the area often lacks scientific and effective guidance for wetland park conservation. Therefore, wetland park managers or designers need an efficient method to assess the health status of wetland parks for sustainable development.

✉ Xiao-Shan Fang
xshfang@scut.edu.cn

¹ School of Architecture, South China University of Technology, Guangzhou 510641, China

² State Key Laboratory of Subtropical Building Science, Guangzhou 510640, China

Fig. 1 Location of the Pearl River Delta in China

A health assessment method can be used to determine the health of wetland parks. The indicator system method is a common wetland health assessment method that measures ecosystem health by establishing a system of multilevel indicators related to wetland health. According to different types of wetland ecosystems and diversified health evaluation objectives, researchers can establish a corresponding evaluation indicator system. The establishment of an indicator system based on the pressure-state-response (PSR) model is currently the most widely used method. A few studies have used PSR and the driving-pressure-state-impact -response (DPSIR) models to evaluate the health of locally constructed wetlands (Mai et al. 2005; Gao et al. 2013; Sun et al. 2016). Australian researchers established a river wetland health diagnostic indicator system that considered environmental status, environmental change trends and the social economy (Walker and Reuter 1996). Song (2016) constructed an evaluation system of reed wetland ecosystems considering the soil, aquatic environment, reed community and enzyme activity. Yin and Liu (2017) combined industry standards to build an evaluation indicator system for specific wetland ecosystems, and the indicators included the aquatic environment, biological residue, habitat and biological status. These studies reflect assessment methods that vary in terms of specific wetland ecosystems. Most of the existing assessment methods are proposed for regional wetland ecosystems (Ardón et al. 2010; Meyer et al. 2015). There are few studies on site-scale wetland park health assessments.

Wetland park is a complex ecosystem that can be impacted by many factors. Wetland health status is influenced by not only habitat degradation but also landscape fragmentation and

poor functionality (Schleyer and Celliers 2005; Marois et al. 2015). The ultimate aim of conserving and managing wetland ecosystems is to improve their contributions to human well-being (Raskin 2005). Based on the quality of habitat conditions, wetland parks provide diversified services and landscape resources. The health statuses of habitats, landscapes and services are related to each other and jointly affect the health status of wetland parks. Therefore, the health assessment indicators (HAIs) proposed in the existing health assessment methods are not appropriate for determining wetland park health status because they do not consider landscape patterns and services. Thus, a scientific method and set of HAIs need to be developed for assessing wetland park health.

Due to the inadequacy of existing methods and assessment indicators used in wetland park health evaluations, this study uses the Guangdong Xinhui National Wetland Park's core area in the Pearl River Delta as a research case and proposes a solution with broad applicability and easy implementation (Fig. 2): develop a system of HAIs for wetland parks in the Pearl River Delta based on the *habitat-landscape-service* (HLS) conceptual model and divide health grades based on *expert judgment* using a combination of *analytic hierarchy process* (AHP) (Saaty and Vargas 2001) and *fuzzy comprehension evaluation* (FCE) methods (Arias et al. 2005). We selected HAIs and calculated the appropriate weight for each indicator by using AHP. Then, the FCE method was adopted to assess the health grades for wetland parks in the Pearl River Delta. Finally, we analyzed the drivers and other potential influencing factors of wetland park health.

The HLS-AHP-FCE method can provide a holistic health evaluation indicator system and diagnostic approach for

Fig. 2 Process of building the HLS-AHP-FCE

rapidly developing wetland parks in the Pearl River Delta and can identify critical factors influencing wetland park health status to help designers and managers to improve wetland parks.

Methodology

Establishment of the HLS Conceptual Model

After reviewing the literature and consulting experts, we proposed the conceptual HLS model, which consisted of three aspects, 10 factors and 28 indicators that were assigned to three levels, namely, aspect, factor and indicator, respectively. These attributes were then assessed using AHP (Fig. 3, Table 1). Based on the HLS model, we established the HAI system according to certain criteria. For example, indicators should (1) be able to be repeatedly measured, (2) correspond to design strategies, (3) be easily understood by nonprofessional people (Kent et al. 1992; Spencer et al. 1998) and (4) be regionally adaptable.

The three overarching aspects of the model are habitats (B1), landscapes (B2) and services (B3). Habitat aspect evaluates the performance of the ecological habitat regarding environmental impacts, including the aquatic environment, soil properties, vegetation conditions and animal diversity. Landscape aspect evaluates the landscape pattern characteristics of the wetland park, including the patch density, corridor features, landscape diversity and landscape evenness. Service aspect evaluates the health status of the services provided to visitors, visitor satisfaction and the financial status of the wetland park, as well as the financial effort (such as the income-to-expenditure ratio) to maintain the services of the infrastructure.

The 10 factors are categorized based on the three upper level categories. Habitats (B1) include four major components of habitat, namely, water (C1), soil (C2), vegetation (C3) and animals (C4); landscapes (B2) include two landscape patterns in the park, namely, patches (C5) and corridors (C6); and services B3 encompass recreation (C7), scientific research (C8), education (C9) and economics (C10).

The health assessment indicator system contains 28 indicators (D1 ~ D28), including 14 habitat indicators, 5 landscape indicators and 9 service indicators. Water is the basic ecological factor of a wetland park (Rastmanesh et al. 2018; Trebitz et al. 2019). D1 ~ D6 were selected to evaluate aquatic health in terms of physical, chemical, biological and other aspects. Water quality (D1), including pH and COD values, is an important aquatic property; water depth (D2) reflects the storage capacity of wetland parks; height of water stage (D3) directly affects the succession and production of wetland plant communities; ecological water demand (D4) evaluates aquatic health by calculating the water consumption of wetland parks, including the water demand of lakes and irrigation; water transparency (D5) shows the level of water pollution, which evaluates the water health by calculating the visible depth of the water; and water velocity (D6) is important in terms of nitrogen and phosphorus contents, chlorophyll a concentrations and dissolved oxygen distribution in water.

Wetland soils mediate chemical reactions and provide storage for most plant chemicals (Bui 2013). Soil nitrogen content (D7) plays a key role in nutrient availability, plant growth and productivity. The soil permeability rate (D8) is the absorption capacity in relation to precipitation and surface runoff, which can reflect the status of the plant habitat.

Wetland vegetation can help reduce water velocity and can contribute to sedimentation of impurities and elimination of toxins (Lopez and Fennessy 2002). Hydrophyte diversity (D9) evaluates the abundance of aquatic plants and wetland habitat

Fig. 3 The *habitat-landscape-service* conceptual model

health by calculating the proportion of hydrophyte species to all plant species in the wetland parks. Native species diversity (D10) can show the self-organization condition of plant communities in wetland parks (Carvalho et al. 2013). The number of invasive species (D11) becomes a problem when the total number of invasive species in a wetland park is high enough to negatively affect plant growth.

Birds, which depend heavily on habitat conditions to thrive, are a useful index group for evaluating wetland park quality (Natuhara and Imai 1999; Mistry et al. 2008; Reeder and Wulker 2017). Bird species diversity (D12) was used to evaluate wetland park health by calculating the proportion of bird species in wetland parks to bird species in the Pearl River Delta. Bird species habitat degradation rate (D13) is defined as the ratio of bird habitat area to wetland park area. The noise caused by human activities in wetland parks has negatively affected bird species and is expressed as the noise decibel around habitats (D14).

Landscape characteristic changes of wetland parks present changes in land uses or covers, affecting the actual service of the entire wetland park. Patches constitute the basic structure and functional unit of wetland landscapes. D15 ~ 17 in the patch factor evaluate the degree of fragmentation and biodiversity of a wetland park landscape. Corridors are important channels connecting animals, plants, water and human beings in wetlands. D18 ~ 19 of the corridor factor is used to judge the fragmentation of the landscape.

To assess whether the visitors are satisfied with the recreation services provided by a wetland park, we selected the indicators of visitor capacity (D20), supporting facilities (D21) and management level satisfaction (D22).

Wetland parks provide science research and education services based on abundant natural resources. We can assess the satisfaction level of the scientific research service by analyzing the number of research facilities (D23) and researchers (D24). The number of cultural activities (D25) and educational facilities (D26) play a vital role in education services.

Economic species diversity (D27) and income-to-expenditure ratio (D28) are important economic properties that indicate the normal operation of wetland parks.

Development of Health Assessment Indicator Weights

The degree of influence of each indicator on the health of wetland parks is different. The present study used AHP and the *expert judgment* method to determine the weight of each indicator. AHP is a structured, traditional technique for integrating and analyzing multiple expert opinions (Saaty and Vargas 2001; Saaty 2007). By establishing a judgment matrix, matrix vector calculation and consistency test, the AHP method can obtain attribute weights of the aspect, factor and indicator levels to evaluate the GXNWP health status (Fogliatto and Albin 2001; Thanh and De Smedt 2012; Sun et al. 2017).

Table 1 Health assessment indicator system for wetland park health evaluation

Aspect layer	Factor layer	Indicator layer
B1 Habitat	C1 Water	D1 Water quality
		D2 Water depth
		D3 Height of water stage
		D4 Ecological water demand
		D5 Water transparency
		D6 Water velocity
	C2 Soil	D7 Soil nitrogen content
		D8 Soil permeability rate
	C3 Vegetation	D9 Hydrophyte diversity
		D10 Native species diversity
	C4 Animal	D11 Number of invasive species
		D12 Bird species diversity
		D13 Bird species habitat degradation rate
		D14 Noise decibel around habitat
B2 Landscape	C5 Patch	D15 Patch density
		D16 Landscape diversity
		D17 Landscape evenness
	C6 Corridor	D18 Corridor width
		D19 Corridor density
		D20 Visitor capacity
B3 Service	C7 Recreation	D21 Supporting facilities satisfaction
		D22 Management satisfaction
	C8 Scientific research	D23 Number of research facilities
		D24 Number of researchers
	C9 Education	D25 Number of cultural activities
		D26 Number of education facilities
	C10 Economics	D27 Economic species diversity
		D28 Income-to-expenditure ratio

The *expert judgment* method can assist in establishing the judgment matrix in the AHP method. It is a combination of qualitative and quantitative evaluation methods that can determine the weight of each indicator by inviting experts to judge the relative importance of any two indicators for comparisons. The relative importance between the two compared indicators is judged by the 1–9 scale method (Saaty and Vargas 2001). For the purpose of the wetland park health evaluation, a total of 20 experts, including 10 with wetland ecology, 4 with animal conservation and 6 with landscape architecture backgrounds, were invited to participate in the process of assigning weights to the indicators in August 2016. A questionnaire survey was conducted among park managers and visitors to the wetland park from August to September 2016 to study the service status of the wetland park. According to the expert evaluation results, judgment matrices for each aspect, factor and indicator level were constructed, and all matrices passed a consistency test on the basis of the calculation formula and evaluation criteria in the AHP method as reported in the literature (Saaty and Begicevic 2010; Li and Cheng 2011).

Grade Division of the Health Assessment Indicators

Based on the appropriate weight of each indicator, we applied the FCE method to assess the health status of respective aspects, factors and indicators. The FCE method is the process of evaluating an attribute utilizing fuzzy set theory, which comprehensively considers the contributions of multiple related indicators according to weights of and decreases in the fuzziness by using membership functions (Cheng-Lin et al. 2015). According to the membership function, there is a corresponding value $S(x) \in [0, 1]$ for each x after evaluating each indicator (x) of the research range U . S is the fuzzy set of U , and $S(x)$ is the membership function of x to S . The membership function $S(x)$ with the value in the interval $[0, 1]$ is used to characterize the degree to which x belongs to S , and the principle of the maximum membership function is followed to judge the belonging state of indicator x in the application process (Jin 2004; Song et al. 2011). The primary feature of this method is that it can quite naturally manage the fuzziness of human thinking (Arias et al. 2005).

Table 2 Range of the reference values for health grade of each indicator

Indicators	Value range of health assessment				Source
	Relatively healthy	Generally healthy	Subhealthy	Generally unhealthy	Seriously unhealthy
D1	PH: 6.0~6.5 COD: 15~20	PH: 6.5~7.0 COD: 20~25	PH: 7.0~7.5 COD: 25~30	PH: 7.5~8.0 COD: 30~35	PH: 8.0~9.0 COD: 35~40
D2	0.5~2.0 m	2.0~2.5 m	2.5~3.0 m	3.0~3.5 m	>3.5 m or <0.5 m
D3	0.1~0.3 m	0.3~0.5 m	0.5~0.7 m	0.7~0.9 m	>0.9 m
D4	66~67.5 ($\times 10^4$ m ³)	64.5~66 ($\times 10^4$ m ³)	63~64.5 ($\times 10^4$ m ³)	61.5~63 ($\times 10^4$ m ³)	60~61.5 ($\times 10^4$ m ³)
D5	Water depth visible 0.9~1.2 m	Water depth visible 0.7~0.9 m	Water depth visible 0.5~0.7 m	Water depth visible 0.2~0.5 m	Water depth visible 0~0.2 m
D6	>0.3 m/s	0.2~0.3 m/s	0.15~0.2 m/s	0.08~0.15 m/s	<0.08 m/s
D7	>3%	2.5%~3%	2%~2.5%	1.5%~2%	<1.5%
D8	>0.35 mm/s	0.225~0.35 mm/s	0.125~0.225 mm/s	0.025~0.125 mm/s	<0.025 mm/s
D9	>40%	30~40%	20~30%	10~20%	<10%
D10	>40%	30~40%	20~30%	10~20%	<10%
D11	Number of invasive species: 0	Number of invasive species: 1~2	Number of invasive species: 3~4	Number of invasive species: 5~6	Number of invasive species: 7~10
D12	Number of bird species: >93	Number of bird species: 83~93	Number of bird species: 56~83	Number of bird species: 29~56	Number of bird species: <29
D13	<2%	2%~5%	5%~8%	8%~12%	>12%
D14	<45 dB	45~50 dB	55~60 dB	60~65 dB	>65 dB
D15	Number of patches: <2	Number of patches: 2~10	Number of patches: 10~20	Number of patches: 20~40	Number of patches: >40
D16	>2	2.0~1.8	1.8~1.6	1.6~1.4	<1.4
D17	>0.8	0.8~0.7	0.7~0.6	0.6~0.5	<0.5
D18	>30 m	20~30 m	10~20 m	5~10 m	<5 m
D19	Number of corridors/park area: 0.038~0.05	Number of corridors/park area: 0.028~0.038	Number of corridors/park area: 0.018~0.028	Number of corridors/park area: 0.010~0.018	Number of corridors/park area: 0.002~0.010
D20	250~330 m ² /person	200~250 m ² /person	150~250 m ² /person	100~150 m ² /person	50~100 m ² /person
D21	Obtained from questionnaire survey	Obtained from questionnaire survey	Obtained from questionnaire survey	Obtained from questionnaire survey	Obtained from questionnaire survey
D22	Obtained from historical data on the park	Obtained from historical data on the park	Obtained from historical data on the park	Obtained from historical data on the park	Obtained from historical data on the park
D23	Obtained from historical data on the park	Obtained from historical data on the park	Obtained from historical data on the park	Obtained from historical data on the park	Obtained from historical data on the park
D24	Obtained from historical data on the park	Obtained from historical data on the park	Obtained from historical data on the park	Obtained from historical data on the park	Obtained from historical data on the park
D25	Obtained from historical data on the park	Obtained from historical data on the park	Obtained from historical data on the park	Obtained from historical data on the park	Obtained from historical data on the park
D26	Obtained from historical data on the park	Obtained from historical data on the park	Obtained from historical data on the park	Obtained from historical data on the park	Obtained from historical data on the park
D27	>20%	15~20%	10~15%	5~10%	<5%
D28	+ 6%	+ 2~+ 6%	-2%~+ 2%	- 6~- 2%	< - 6%

Based on the investigation of 28 evaluation indicators of wetland parks, habitat and landscape indicator data were obtained by instrument measurement and software processing, and service indicator data were obtained by questionnaires and interviews. Based on the summarized data on the current situation of the indicators, the experts were invited to grade each indicator according to their own professional knowledge and relevant standards (Table 2). Finally, we obtained the health grade of each indicator by the formula of the FCE. The workflows of the analytic hierarchy process and fuzzy comprehension evaluation are described in detail in the Supplementary Materials.

Application of Health Assessment to Guangdong Xinhui National Wetland Park

Study Area

The Pearl River Delta has a subtropical maritime monsoon climate with mild temperatures and abundant rainfall. The region has dense river branches and ample wetland resources. Moreover, located on the international bird migration route, the Pearl River Delta wetland resource plays a vital role in global ecological patterns. At the same time, this area is densely populated and highly

urbanized. Problems such as habitat function degradation and habitat fragmentation are becoming prominent, and the number of avian species living in wetlands is markedly decreasing (Fang and Wang 2019).

The Guangdong Xinhui National Wetland Park (hereinafter referred to as GXNWP) is located in Xinhui district, Jiangmen, Guangdong Province. As a well-known ecological wetland park to tourists, it includes a core area, biological feeding ground, and ecological research base (Fig. 4). Because the GXNWP is located near the downtown area and the construction disturbance in surrounding villages increases yearly, its ecological environment is deteriorating. Here, we study the core area of the GXNWP.

Data Collection

We set up 16 sites in the core area of GXNWP in 2016 and collected data on the status of the assessment indicators at the habitat and landscape levels through field sampling, data monitoring and software analysis. The habitat assessment indicators were directly derived from instrumental measurements, except for ecological water demand. For the water factor, the average flow velocity was 0.26 m/s, and the pH value and COD values of the water body were 5.29 and 9 mg/L, respectively. The ecological water demand was $67.5 \times 10^4 \text{ m}^3/\text{a}$, which was

Fig. 4 Location of the Guangdong Xinhui National Wetland Park

calculated by formula (1).

$$W = A \times (E_1 + E_2) + S \times q \times \eta + A \times (H_1 + H_2) \quad (1)$$

where W is the water demand of the optimal ecological environment, A is the water area of the GXNWP, E_1 is the water evaporation and E_2 is the water requirement for evaporation and heat dissipation of aquatic plants. H_1 is the water depth of the biological habitat, and H_2 is the draft depth of the cruise ship. S is the green land area of the GXNWP. q is the irrigation quota of vegetation, and η is the utilization rate of irrigation water.

The soil nitrogen content of the GXNWP was in the range of 10–15 g/kg. The water permeability rate ranged from 0.125 to 0.225 cm/h, which is an intermediate level based on the relevant standards of wetland parks in China. The proportions of native species and invasive species in GXNWP were determined by vegetation field sampling and were 45.76% and 9.33%, respectively. In terms of animals, the species diversity of birds was 61.9%, and the noise decibels around the habitats were 54.6–76.3 dB. The indicator data at the landscape level were calculated using software to obtain the results. The patch density was $7.28 \times 10^4/100 \text{ hm}^2$, which was obtained by formula (2)

$$PDi = Ni/A \times 10000 \times 100 \quad (2)$$

where PDi is the patch density at the landscape level, Ni is the number of patches in the wetland park, and A is the area of GXNWP.

The corridor density was 0.0346 km/km^2 , which was obtained by formula (3)

$$Ti = Li/A \quad (3)$$

where Ti is the corridor density, and Li is the total length of the corridor of GXNWP.

The service indicator scores were obtained through a questionnaire survey of visitors and park managers.

Based on the investigation and monitoring data above, 20 experts familiar with the GXNWP participated in the evaluation, and the expertise areas of these experts are mainly wetland ecology and animal conservation or landscape architecture. The consultation process included two steps: the first step was to let experts compare the relative importance of any two attributes in the aspect, factor, and indicator layers; the second step was to let experts assess the health status of each of the 28 indicators in the GXNWP based on the measurement data of each indicator and the relevant standards of wetland parks in China. The health status was graded as I, II, III, IV, or V, corresponding to levels of “seriously unhealthy”, “generally unhealthy”, “Subhealthy”, “generally healthy”, and “relatively healthy”.

Results

AHP Weight for each Indicator

On the basis of *expert judgment*, the *nine-stage scale method* (Saaty and Vargas 2001) and the AHP method, pairwise comparisons were conducted for 3 indicators at the aspect level, 10 indicators at the factor level and 28 indicators at the indicator level. Then, according to the formula in the AHP method (Saaty and Vargas 2001; Saaty 2007), all matrices passed the consistency test. The matrix comparison results are shown in Tables 3, 4, 5 and 6, where λ_{max} is the maximum eigenvalue of the

Table 3 Pairwise comparison matrix for the aspect level

A	Habitat (B1)	Landscape (B2)	Service (B3)
Habitat (B1)	1	4	2
Landscape (B2)	1/4	1	1/2
Service (B3)	1/2	2	1
$\lambda_{max}=3.0000$ $CI=0.0000$ $CR=0.0000<0.1$			

Table 4 Pairwise comparison matrix for habitats

Habitat (B1)	Water (C1)	Soil (C2)	Vegetation (C3)	Animal (C4)
Water (C1)	1	3	2	2
Soil (C2)	1/3	1	1	1
Vegetation (C3)	1/2	1	1	1
Animal (C4)	1/2	1	1	1
$\lambda_{max}=4.0206$ $CI=0.0069$ $CR=0.0077<0.1$				

Table 5 Pairwise comparison matrix for landscapes

Landscape (B2)	Patch (C5)	Corridor (C6)
Patch (C5)	1	1
Corridor (C6)	1	1
$\lambda_{max}=2.0000$ $CI=0.0000$ $CR=0.0000<0.1$		

Table 6 Pairwise comparison matrix for services

Service (B3)	Recreation (C7)	Scientific research (C8)	Education (C9)	Economics (C10)
Recreation (C7)	1	2	1	2
Scientific research (C8)	1/2	1	1	2
Education (C9)	1	1	1	2
Economics (C10)	1/2	1/2	1/2	1
$\lambda_{max}=4.0606$ $CI=0.0202$ $CR=0.0227<0.1$				

Table 7 Normalized weights of health assessment indicators

Aspect level	Normalized weight	Factor level	Normalized weight	Indicator level	Normalized weight	Rank
B1	0.5715	C1	0.2479	D1	0.0724	1
				D2	0.0277	19
				D3	0.0310	16
				D4	0.0501	6
				D5	0.0528	3
				D6	0.0139	27
		C2	0.1010	D7	0.0505	4
				D8	0.0505	5
		C3	0.1113	D9	0.0431	10
				D10	0.0494	7
				D11	0.0188	24
		C4	0.1113	D12	0.0588	2
				D13	0.0370	13
B2	0.1429	C5	0.0715	D14	0.0155	26
				D15	0.0295	18
				D16	0.0186	25
				D17	0.0234	23
				D18	0.0238	22
B3	0.2856	C6	0.0714	D19	0.0476	9
				D20	0.0243	20
				D21	0.0485	8
				D22	0.0243	21
				D23	0.0341	14
		C7	0.0971	D24	0.0341	15
				D25	0.0401	11
				D26	0.0401	12
		C8	0.0682	D27	0.0100	28
				D28	0.0301	17

matrix and *CI* and *CR* represent the consistency index and the consistency ratio, respectively. The weights of the health assessment indicators are shown in Table 7.

The weights of the habitat, landscape, and service attributes at the aspect level were 0.5715, 0.1429 and 0.2856, respectively. The habitat indicators had a higher impact on wetland park health, followed by the service and landscape indicators. Of all 28 indicators, water quality, bird species diversity, water transparency, soil permeability rate and soil nitrogen content at the habitat level had a greater weight than that of the other indicators, which reflects the importance of water, animals and soil to GXNWP habitat health. The next important indicators were ecological water demand, native species diversity, supporting facility satisfaction, and corridor density, with normalized weights of 0.0501, 0.0494, 0.0485, and 0.0476, respectively. The weights of the other 19 indicators were all smaller than 0.0450, and the economic species diversity indicator of the services accounted for the

smallest proportion of the overall assessment, with a normalized weight of 0.0100.

Within habitats at the factor level (Fig. 5), water had the highest normalized weight (0.2479). The vegetation and animal factors had the same normalized weight of 0.0744, followed by soil. Water quality had the highest normalized weight (0.0724) of all indicators. Water velocity had the lowest weight (0.0139).

For landscapes (Fig. 6), the indicators were divided into two factors: corridor and patch. Of these, the corridor density had the highest weight (0.0476), followed by the patch density (0.0295), corridor width (0.0238), landscape evenness (0.0234), and landscape diversity (0.0186).

For services (Fig. 7), the recreation, education and scientific research factors showed a higher weight, accounting for 0.0971, 0.0802, and 0.0682, while the economics factor had the lowest weight (0.0401) of the services. In comparison to the other indicators, supporting facility satisfaction, the number of cultural activities and the number

Fig. 5 Distribution of the normalized weight of the 14 indicators for habitats determined by the AHP

Fig. 6 Distribution of the normalized weights of the 5 indicators for landscapes determined by the AHP

Fig. 7 Distribution of the normalized weight of the 9 indicators for services determined by the AHP

of educational facilities accounted for a higher proportion of the services.

Health Status Assessment of the Guangdong Xinhui National Wetland Park

The health status of the aspects, factors and indicators are shown in Fig. 8. According to the maximum membership function principle of the FCE method (Song et al. 2011), the membership functions of GXNWP for the five health grades were ranked as follows: 0.4643 (Subhealthy) > 0.4429 (generally unhealthy) > 0.0714 (seriously unhealthy) > 0.0214 (generally healthy) > 0 (relatively healthy). We can see that the health status of the GXNWP was at the level of “subhealthy”, with a membership function of 0.4643. The trend in the GXNWP was toward the “generally unhealthy” state based on the ranking of the membership function degree. Taking $R_{\text{habitat} - \text{landscape} - \text{service}}$

as an example, 2, 11 and 7 experts judged habitat (B1) at the “seriously unhealthy”, “generally unhealthy” and “subhealthy” levels, respectively.

$$\text{Overall Health} = W_i \cdot R_{\text{habitat-landscape-service}}$$

$$= (0.5715, 0.1429, 0.2856) \begin{vmatrix} 2/20 & 11/20 & 7/20 & 0 & 0 \\ 0 & 2/20 & 15/20 & 3/20 & 0 \\ 1/20 & 8/20 & 11/20 & 0 & 0 \end{vmatrix}$$

$$= (0.0714, 0.4429, 0.4643, 0.0214, 0)$$

The FCE results for habitats, landscapes, and services were at the levels of “generally unhealthy” (II), “generally healthy” (IV), and “subhealthy” (III), respectively (Fig. 8a). This result reflected that the GXNWP faces pressures from poor habitat conditions. Habitats negatively impacted the overall health of the wetland park by 57.15%. Water quality, water transparency, water depth and height of water stage are the critical indicators that negatively affect the health of the park. Services worsened the health status of

Fig. 8 The profiles of health status of the aspects, factors and indicators. Values shown on the figures are the membership function of all aspects, factors and indicators

the wetland park by 28.56%, and the main driving factors were the number of cultural activities, number of educational facilities and satisfaction with supporting facilities. Landscapes performed well based on reasonable landscape patterns and ecological corridor planning. The results of the comprehensive evaluation for each aspect are as follows:

$$\begin{aligned} B1Habitat &= W_i \cdot R_{Habitat} \\ &= (0.2479, 0.1010, 0.1113, 0.1113) \begin{vmatrix} 6/20 & 11/20 & 3/20 & 0 & 0 \\ 4/20 & 12/20 & 4/20 & 0 & 0 \\ 2/20 & 6/20 & 12/20 & 0 & 0 \\ 0 & 0 & 7/20 & 13/20 & 0 \end{vmatrix} \\ &= (0.1057, 0.2303, 0.1631, 0.0723, 0) \end{aligned}$$

$$\begin{aligned} B2Landscape &= W_i \cdot R_{Landscape} = (0.0715, 0.0714) \begin{vmatrix} 0 & 3/20 & 5/20 & 12/20 & 0 \\ 0 & 0 & 6/20 & 12/20 & 2/20 \end{vmatrix} \\ &= (0, 0.0107, 0.0393, 0.0857, 0.0071) \end{aligned}$$

$$\begin{aligned} B3Service &= W_i \cdot R_{Service} \\ &= (0.0971, 0.0682, 0.0802, 0.0401) \begin{vmatrix} 0 & 5/20 & 12/20 & 3/20 & 0 \\ 4/20 & 10/20 & 6/20 & 0 & 0 \\ 5/20 & 11/20 & 4/20 & 0 & 0 \\ 0 & 4/20 & 13/20 & 3/20 & 0 \end{vmatrix} \\ &= (0.0337, 0.1105, 0.1208, 0.0206, 0) \end{aligned}$$

At the factor level, the education factor was in relatively vulnerable condition, and the recreation, scientific research, patch and water were the next most vulnerable factors (Fig. 8b). The results of the comprehensive evaluation of each factor are as follows:

$$\begin{aligned} C1Water &= W_i \cdot R_{Water} \\ &= (0.0724, 0.0277, 0.0310, 0.0501, 0.0528, 0.0139) \begin{vmatrix} 5/20 & 5/20 & 10/20 & 0 & 0 \\ 2/20 & 15/20 & 3/20 & 0 & 0 \\ 1/20 & 15/20 & 4/20 & 0 & 0 \\ 0 & 5/20 & 12/20 & 3/20 & 0 \\ 3/20 & 3/20 & 14/20 & 0 & 0 \\ 0 & 2/20 & 16/20 & 2/20 & 0 \end{vmatrix} \\ &= (0.0303, 0.0840, 0.1247, 0.0089, 0) \end{aligned}$$

$$\begin{aligned} C2Soil &= W_i \cdot R_{Soil} \\ &= (0.0505, 0.0505) \begin{vmatrix} 0 & 2/20 & 16/20 & 2/20 & 0 \\ 0 & 5/20 & 12/20 & 3/20 & 0 \end{vmatrix} \\ &= (0, 0.0177, 0.0707, 0.0126, 0) \end{aligned}$$

$$\begin{aligned} C3Vegetation &= W_i \cdot R_{Vegetation} \\ &= (0.0431, 0.0494, 0.0188) \begin{vmatrix} 0 & 8/20 & 10/20 & 2/20 & 0 \\ 0 & 0 & 1/20 & 14/20 & 5/20 \\ 0 & 8/20 & 11/20 & 1/20 & 0 \end{vmatrix} \\ &= (0, 0.0248, 0.0344, 0.0398, 0.0124) \end{aligned}$$

$$\begin{aligned} C4Animal &= W_i \cdot R_{Animal} \\ &= (0.0588, 0.0370, 0.0155) \begin{vmatrix} 0 & 0 & 1/20 & 5/20 & 14/20 \\ 0 & 0 & 6/20 & 11/20 & 3/20 \\ 0 & 12/20 & 8/20 & 0 & 0 \end{vmatrix} \\ &= (0, 0.0093, 0.0202, 0.0350, 0.0467) \end{aligned}$$

$$C5Patch = W_i \cdot R_{Patch}$$

$$\begin{aligned} &= (0.0295, 0.0186, 0.0234) \begin{vmatrix} 5/20 & 9/20 & 6/20 & 0 & 0 \\ 2/20 & 3/20 & 15/20 & 0 & 0 \\ 0 & 5/20 & 13/20 & 2/20 & 0 \end{vmatrix} \\ &= (0.0092, 0.0219, 0.0380, 0.0023, 0) \end{aligned}$$

$$\begin{aligned} C6Corridor &= W_i \cdot R_{Corridor} = (0.0238, 0.0476) \begin{vmatrix} 0 & 0 & 5/20 & 6/20 & 9/20 \\ 0 & 0 & 3/20 & 7/20 & 10/20 \end{vmatrix} \\ &= (0, 0, 0.0131, 0.0238, 0.0345) \end{aligned}$$

$$C7Recreation = W_i \cdot R_{Recreation}$$

$$\begin{aligned} &= (0.0243, 0.0485, 0.0243) \begin{vmatrix} 0 & 3/20 & 16/20 & 1/20 & 0 \\ 2/20 & 6/20 & 12/20 & 0 & 0 \\ 7/20 & 10/20 & 3/20 & 0 & 0 \end{vmatrix} \\ &= (0.0134, 0.0303, 0.0522, 0.0012, 0) \end{aligned}$$

$$\begin{aligned} C8Scientific\ research &= W_i \cdot R_{Scientific\ research} = (0.0341, 0.0341) \begin{vmatrix} 0 & 2/20 & 13/20 & 5/20 & 0 \\ 0 & 4/20 & 11/20 & 5/20 & 0 \end{vmatrix} \\ &= (0, 0.0102, 0.0409, 0.0170, 0) \end{aligned}$$

$$\begin{aligned} C9Education &= W_i \cdot R_{Education} = (0.0401, 0.0401) \begin{vmatrix} 5/20 & 13/20 & 2/20 & 0 & 0 \\ 7/20 & 10/20 & 3/20 & 0 & 0 \end{vmatrix} \\ &= (0.0241, 0.0461, 0.0100, 0, 0) \end{aligned}$$

$$\begin{aligned} C10Economics &= W_i \cdot R_{Economics} = (0.0100, 0.0301) \begin{vmatrix} 0 & 3/20 & 11/20 & 6/20 & 0 \\ 0 & 1/20 & 4/20 & 15/20 & 0 \end{vmatrix} \\ &= (0, 0.0030, 0.0115, 0.0256, 0) \end{aligned}$$

For the specific indicators, as shown in (Fig. 8c), most attributes had a “subhealthy” grade (III) and “generally unhealthy” grade (II). However, healthier grades were found for native tree diversity, bird species diversity, bird species habitat degradation rate, corridor indicators and income-to-expenditure ratio indicators.

Discussion

Health Status of the GXNWP

The health status values of the indicators are interrelated. Specifically, water and soil indicators directly influence hydrophyte and bird diversity. Water transparency is important for the growth of submerged plants as they need a minimum amount of sunlight to survive. Few submerged plants can grow well in a highly turbid environment (Grabas et al. 2012). The GXNWP is frequently affected by human activities, including fishing, agriculture, and industry. Water transparency and the height of the water stage all presented the

“generally unhealthy” (II) status, which can be ascribed to the fruiter farming activities that are prevalent in the GXNWP. In addition, we observed in the field that the noise from boat rides in the park affects bird diversity to some extent. In summary, the presence of external disturbances may change the growing environment for these species and possibly reduce their richness and abundance. The services of the GXNWP were “subhealthy” (III). The economic service performed well, which indicates that the GXNWP can run well. Due to the lack of educational and scientific research facilities, there were fewer cultural activities and visiting researchers in the park, leading the education and scientific research service of the GXNWP to perform relatively poorly.

Optimization Management Strategies in the GXNWP Based on the HLS-AHP-FCE Method

Based on the application of the HLS-AHP-FCE method to the GXNWP, the habitat indicators were the key factors affecting the GXNWP health status, followed by the service and landscape indicators. Habitats and services had negative impacts on the overall health of the GXNWP at 57.15% and 28.56%, respectively. Landscapes had a 14.29% positive effect on the health status of GXNWP. At the factor level, water, vegetation and animals were the critical factors influencing the GXNWP health status. The degree of impact of the factors on the GXNWP health status was ranked as follows: $C1 > C3 = C4 > C2 > C7 > C9 > C5 > C6 > C8 > C10$, which shows that people's entertainment and cultural education needs have gradually become an important factor affecting the health status of wetland parks. Patch and corridor factors also were key factors affecting the health status of wetland parks due to their impact on the habitats of animals and plants. At the indicator level, water quality, bird species diversity, water transparency and soil nitrogen content were the critical indicators that affected the health status of the GXNWP. The indicators of health status for habitats, landscapes and services interact. A healthy habitat status in a wetland park is the foundation for a good landscape status and complete service function. Landscape status indicators are directly related to habitat health because they affect the distribution of biological populations. Among all kinds of services provided by wetland parks, the intensity of visitors' participation directly affects the health of the habitat. Landscape health has a positive impact on service health. Attractive landscapes can attract more tourists and researchers and improve the health level of service.

In summary, the GXNWP tends to be “generally unhealthy” based on its rank of the membership function, and park development is influenced by environmental changes and human activities. According to the evaluation results, measures have been proposed to improve the health status of the GXNWP by protecting habitat, strengthening scientific research and constructing recreation facilities. Specifically,

the core habitat area of the GXNWP should be intensively protected, and zoning should regulate the development of human activities and services. In terms of habitats, hydrological management should be strengthened, soil pollution should be controlled, and habitat status should be continuously monitored. In terms of landscapes, we should optimize the landscape pattern of the GXNWP and adjust the spatial relationship between patches and corridors rationally according to the principle that the development of an ecological landscape is based on a healthy ecological environment. In addition, zoning of the acoustic environment should be strictly controlled, and the boat cruise route should be optimized to reduce the impact of noise caused by artificial activities on the habitat of waterfowl. In terms of services, the intensity of tourism activities should be reasonably limited on the basis of the principle of “ecological priority”. In addition, the GXNWP should focus on the construction of a cultural landscape and be equipped with corresponding basic scientific research and educational facilities to provide visitors with information on wetland science and leisure services.

Effectiveness of the HLS-AHP-FCE Method

Compared to existing assessment methods for wetland parks at the site scale, the HLS-AHP-FCE method combines the commonness of wetland ecosystems and the uniqueness of wetland parks and involves an HLS evaluation model for site-scale wetland parks that focuses on habitats, landscapes and services for the evaluation structure and scale. This method can effectively integrate wetland park health evaluation and wetland park design. Compared to existing ecosystem health assessment methods, the HLS-AHP-FCE method had a more holistic result by integrating landscape characteristics and social services into the wetland park health assessment framework. Wetland parks in the Pearl River Delta, China, are growing rapidly and are numerous (155 total parks are expected by 2020) (Fang and Wang 2019). Thus, the HLS-AHP-FCE method could provide a holistic health evaluation indicator system and diagnostic approach for rapidly developing wetland parks in the Pearl River Delta. The method highlights addressing the issue of making health management decisions for the wetland park based on assessment results. The suite of indicators selected in this study can be described quantitatively and are useful for environmental managers at all levels of government as well as for researchers and the public.

Future Improvement in the HLS-AHP-FCE

In this study, we established a health evaluation indicator system for wetland parks. However, due to the extensive range of professional fields involved in theoretical research and the limited professional knowledge of the authors of the present study, there is room for optimization in the selection of indicators. In

addition, in the application process of HLS-AHP-FCE, there were also some problems that need to be further discussed, such as the difficulty in quantifying some indicators and inaccurate weights of the indicators. In addition, the evaluation criteria were limited by personal ability and the data collected, which may have been slightly less objective. Finally, due to the time scale of the wetland park evaluation, the case study only provides a demonstration of the evaluation process of wetland parks, which cannot truly reflect the health status of the park. An evaluation of wetland park health depends on long-term studies, which needs to be continued into the future.

Conclusion

In this study, taking the site-scale wetland park as the research object, we proposed the HLS-AHP-FCE method to evaluate the health status of a national wetland park (GXNWP) from habitat, landscape and service perspectives. This *habitat-landscape-service* (HLS) conceptual model included 28 evaluation indicators, in which indicator weight and health status grade were calculated based on expert scores using a combination of the analytic hierarchy process (AHP) and fuzzy comprehension evaluation (FCE) methods. The results showed that the health status of the GXNWP was at the “subhealthy” level, with a membership function of 0.4643. The outcome indicated that factors influencing the GXNWP health condition mainly included water quality, bird species diversity, water transparency and soil nitrogen content. This study also found that the habitat indicators (0.5715) were the key factors affecting the GXNWP health status, followed by the service (0.2856) and landscape indicators (0.1429). By focusing on the wetland park’s site-scale health status, the HLS-AHP-FCE method provides a holistic health evaluation indicator system and diagnostic approach for rapidly developing wetland parks in the Pearl River Delta, China, which has a positive influence on wetland park conservation and management for sustainable development.

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Data Availability All data generated or analyzed during this study are included in this article.

Authors’ Contributions XF conceived and designed the research; XF, WC performed the experiments; SL analyzed the data; XF, SL, WC, RW wrote and edited the manuscript. The authors read and approve the final manuscript.

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Code Availability Not applicable.

Compliance with Ethical Standards

Conflicts of Interest/Competing Interests The authors declare that there is no conflict of interests regarding the publication of this article.

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Consent to Participate Not applicable.

Consent for Publication Written informed consent for publication was obtained from all participants.

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References

- Ardón M, Morse JL, Doyle MW, Bernhardt ES (2010) The water quality consequences of restoring wetland hydrology to a large agricultural watershed in the southeastern coastal plain. *Ecosystems* 13:1060–1078. <https://doi.org/10.1007/s10021-010-9374-x>
- Arias SM, Quintana RD, Cagnoni M (2005) Vizcacha’s influence on vegetation and soil in a wetland of Argentina. *Rangel Ecol Manage* 58:51–57. [https://doi.org/10.2111/1551-5028\(2005\)58<51:VIOVAS>2.0.CO;2](https://doi.org/10.2111/1551-5028(2005)58<51:VIOVAS>2.0.CO;2)
- Asomani-Boateng R (2019) Urban wetland planning and management in Ghana: a disappointing implementation. *Wetlands* 39:251–261. <https://doi.org/10.1007/s13157-018-1105-7>
- Bui EN (2013) Soil salinity: a neglected factor in plant ecology and biogeography. *J Arid Environ* 92:14–25. <https://doi.org/10.1016/j.jaridenv.2012.12.014>
- Carvalho P, Thomaz SM, Kobayashi JT, Bini LM (2013) Species richness increases the resilience of wetland plant communities in a tropical floodplain. *Austral Ecol* 38:592–598. <https://doi.org/10.1111/aec.12003>
- Chen WZ (2017) The study of the healthy evaluation and design optimization of the birds paradise national wetland park in Jiangmen, Xinhui Dissertations, South China University of Technology (in chinese)
- Cheng RB (1985) Status of organic matter in soils of Zhujiang Delta. *Acta Pedologica Sinica*:198–202 (in chinese)

- Cheng YN, Zhang YW, Dai DY (2012) Wetland park design. China Architecture and Building Press, Beijing (in chinese)
- Cheng-Lin M, Li-Yan S, Li Y (2015) Evaluation method for coalmining-based cities ecosystem based on attribute mathematical model with Huainan City as an example. *Ecol Indic* 48:17–21. <https://doi.org/10.1016/j.ecolind.2014.07.026>
- Costanza R, Norton BG, Haskell BD (1992) Ecosystem health: new goals for environmental management. Island Press, Washington, DC
- Fang XS, Wang YJ (2019) Thoughts on the habitat creation of wetland parks in the City-dense districts of the Pearl River Delta region. *J Human Settlements Western China* 34:42–52 (in chinese)
- Fogliatto FS, Albin SL (2001) A hierarchical method for evaluating products with quantitative and sensory characteristics. *IIE Trans* 33: 1081–1092. <https://doi.org/10.1023/A:1010970603399>
- Gao X, Wang L, Qi D, Chen J, Wang S, Zhang F (2013) Eco-security evaluation of wetland based on PSR model: taking Dashanbao wetland as an example. *J Nat Sci Hunan Normal Univ* 36:86–90 (in chinese)
- García-Álvarez MT, Moreno B, Soares I (2016) Analyzing the environmental and resource pressures from European energy activity: a comparative study of EU member states. *Energy* 115:1375–1384. <https://doi.org/10.1016/j.energy.2016.01.035>
- Grabas GP, Blukacz-Richards EA, Permanen S (2012) Development of a submerged aquatic vegetation community index of biotic integrity for use in Lake Ontario coastal wetlands. *J Great Lakes Res* 38:243–250. <https://doi.org/10.1016/j.jglr.2012.02.014>
- Hanford JK, Webb CE, Hochuli DF (2019) Habitat traits associated with mosquito risk and aquatic diversity in urban wetlands. *Wetlands* 39: 743–758. <https://doi.org/10.1007/s13157-019-01133-2>
- Huang JS (2010) Landscape ecological analysis and comprehensive evaluation of Ningde Donghu National Wetland Park Dissertations, Fujian Agriculture and Forestry University, Fuzhou, China (in chinese)
- Jiang WQ (2009) Research on the impact of flow velocity on eutrophication in water body Dissertations, Chongqing Jiaotong University (in chinese)
- Jin JL (2004) Fuzzy comprehensive evaluation model based on improved analytic hierarchy process. *J Hydraul Eng*:144–147. <https://doi.org/10.3321/j.issn:0559-9350.2004.03.011> (in chinese)
- Kent DM, Reimold RJ, Kelly JM, Tammi CE (1992) Coupling wetlands structure and function: developing a condition index for wetlands monitoring. In: McKenzie DH, Hyatt DE, McDonald VJ (eds) *Ecological indicators*. Springer, Boston, pp 559–570
- Li S, Cheng J (2011) AHP-FCE method for construction period risk evaluation of long-span bridges. *Struct Eng* 27:159–162 (in chinese)
- Liu HW, Lin ZL, Su HK (2004) Investigation of the present intrusion situation, and the influence of intrusive alien species on ecology in Guangdong. *Ecol Environ*:48–50. <https://doi.org/10.3969/j.issn.1674-5906.2004.02.015>
- Lopez R, Fennessy S (2002) Testing the floristic quality assessment index as an indicator of wetland condition along gradients of human influence. *Ecol Appl* 12:487–497. [https://doi.org/10.1890/1051-0761\(2002\)012\[0487:TTFQAI\]2.0.CO;2](https://doi.org/10.1890/1051-0761(2002)012[0487:TTFQAI]2.0.CO;2)
- Mai S, Xu S, Pan Y (2005) Application of the PSR model to the evaluation of wetland ecosystem health. *Trop Geogr* 4:317–321 (in chinese)
- Marois DE, Mitsch WJ, Song K, Miao S, Zhang L, Nguyen CT (2015) Estimating the importance of aquatic primary productivity for phosphorus retention in Florida everglades mesocosms. *Wetlands* 35: 357–368. <https://doi.org/10.1007/s13157-015-0625-7>
- Meyer MD, Davis CA, Dvoretz D (2015) Response of wetland invertebrate communities to local and landscape factors in north Central Oklahoma. *Wetlands* 35:533–546. <https://doi.org/10.1007/s13157-015-0642-6>
- Mistry J, Berardi A, Simpson M (2008) Birds as indicators of wetland status and change in the north Rupununi, Guyana. *Biodivers Conserv* 17: 2383–2409. <https://doi.org/10.1007/s10531-008-9388-2>
- Mitsch WJ, Day JW (2006) Restoration of wetlands in the Mississippi–Ohio–Missouri (MOM) river basin: experience and needed research. *Ecol Eng* 26:55–69. <https://doi.org/10.1016/j.ecoleng.2005.09.005>
- Natuhara Y, Imai C (1999) Prediction of species richness of breeding birds by landscape-level factors of urban woods in Osaka prefecture, Japan. *Biodivers Conserv* 8:239–253. <https://doi.org/10.1023/A:1008869410668>
- Raskin PD (2005) Global scenarios: background review for the millennium ecosystem assessment. *Ecosystems* 8:133–142. <https://doi.org/10.1007/s10021-004-0074-2>
- Rastmanesh F, Safaie S, Zarasvandi AR, Edraki M (2018) Heavy metal enrichment and ecological risk assessment of surface sediments in Khorramabad River, West Iran. *Environ Monit Assess* 190:273. <https://doi.org/10.1007/s10661-018-6650-2>
- Reeder BC, Wulker BD (2017) Avifauna use of reference and restored bottomland forest wetlands in eastern Kentucky. *Ecol Eng* 108:498–504. <https://doi.org/10.1016/j.ecoleng.2017.06.025>
- Saaty TL (2007) Time dependent decision-making; dynamic priorities in the AHP/ANP: generalizing from points to functions and from real to complex variables. *Mathematical Comput Model* 46:860–891. <https://doi.org/10.1016/j.mcm.2007.03.028>
- Saaty TL, Begicovic N (2010) The scope of human values and human activities in decision making. *Appl Soft Comput* 10:963–974. <https://doi.org/10.1016/j.asoc.2010.04.002>
- Saaty TL, Vargas LG (2001) Models, methods, concepts & applications of the analytic hierarchy process. Kluwer Academic Publishers, Berlin
- Schleyer MH, Celliers L (2005) Modelling reef zonation in the greater St Lucia Wetland Park, South Africa. *Estuar Coast Shelf Sci* 63:373–384. <https://doi.org/10.1016/j.ecss.2004.12.003>
- Song CY (2016) Assessing the health of rehabilitated reed wetland ecosystem in the Yellow River Delta. *Acta Ecol Sin* 36:2705–2714 (in chinese)
- Song GL, Zang SY, Wang XY, Li YB (2011) Ecological security assessment of wetland in Yueqing Bay based on fuzzy comprehensive evaluation. *J Nat Disas* 20:24–31 (in chinese)
- Spangenberg J, Lorek S (2002) Environmentally sustainable household consumption: from aggregate environmental pressures to priority fields of action. *Ecol Econ* 43:127–140. [https://doi.org/10.1016/S0921-8009\(02\)00212-4](https://doi.org/10.1016/S0921-8009(02)00212-4)
- Spencer C, Robertson AI, Curtis A (1998) Development and testing of a rapid appraisal wetland condition index in South-Eastern Australia. *J Environ Manage* 54:143–159. <https://doi.org/10.1006/jema.1998.0212>
- State Environmental Protection Administration GB3096–2008 (2008) Environmental quality standard for noise. Standards, China Standard Press (in chinese)
- State Environmental Protection Administration GB3838–2002 (2002) Surface water environment quality standard. Standards, China Standard Press (in chinese)
- Sun BD, Cui LJ, Li W, Kang XM (2017) Dominant ecosystem services of Shuangtai estuary wetland based on different beneficiaries. *Chin J Ecol* 36:164–171 (in chinese)
- Sun S, Wang Y, Liu J, Cai H, Wu P, Geng Q, Xu L (2016) Sustainability assessment of regional water resources under the DPSIR framework. *J Hydrol* 532:140–148. <https://doi.org/10.1016/j.jhydrol.2015.11.028> (in chinese)
- Thanh LN, De Smedt F (2012) Application of an analytical hierarchical process approach for landslide susceptibility mapping in a Luoi district, Thua Thien Hue Province, Vietnam. *Environ Earth Sci* 66: 1739–1752. <https://doi.org/10.1007/s12665-011-1397-x>
- Trebitz AS, Nestlerode JA, Herlihy AT (2019) USA-scale patterns in wetland water quality as determined from the 2011 national wetland

- condition assessment. *Environ Monit Assess* 191:266. <https://doi.org/10.1007/s10661-019-7321-7>
- Walker J, Reuter DJ (1996) Indicators of catchment health: a technical perspective. CSIRO Publishing, Australia
- Wu C, Chen W, Cao C, Tian R, Liu D, Bao D (2018) Diagnosis of wetland ecosystem health in the zoige wetland, Sichuan of China. *Wetlands* 38:469–484. <https://doi.org/10.1007/s13157-018-0992-y> (in chinese)
- Xu ZG, He Y, Yan BX (2006) Effects of nutrients and water level fluctuation on wetland plants. *Chinese J Ecol* 25:87–92 CNKI:SUN:STXZ.0.2006-01-016 (in chinese)
- Yin JY, Liu SL (2017) Ecosystem health evaluation of mangrove wetlands in Guangxi based on landscape characteristics. *J Safety Environ* 17:1164–1117. <https://doi.org/10.13637/j.issn.1009-6094.2017.03.066> (in chinese)

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