Evaluation of the Biodiversity Conservation Function in Liaohe Delta Wetland, Northeastern China

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ABSTRACT

The scientific evaluation of the wetland biodiversity conservation function is the basis of balanced wetland protection and development. Our research sought to provide references for the protection of wetland ecological environments as well as the related planning and management policies. The study established a fitting model for evaluating the biodiversity conservation function in the Liaohe Delta, northeastern China. The new model, the Wetland Biodiversity Conservation Indicator (WBCI), was with four input factors, including the vegetation coverage (VC), habitat suitability index (HI), land use and land cover (LULC) index (LI), and threat factor index (TI) of the LULC type. The values assigned to HI and TI were based on Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) habitat quality models. The weights of all the factors in WBCI were valued with the Principal Component Analysis (PCA). We evaluated the wetland biodiversity conservation function of Panjin, Liaohe Delta, China, by using the WBCI model based on *Gaofen-1* (*GF-1*) satellite data in 2018, and the result was verified with InVEST and other models. It showed that the output map was similar to that of InVEST, with the higher-quality habitat including the wetland, tidal flat, water body, and forest, as well as the lower-quality land use types including the paddy field, crop field, construction land, and land used by traffic. The wetland biodiversity conservation function was better in areas less affected by human disturbance, with very abundant species and good-quality habitat. It was poor in areas impacted by more frequent human activities such as the land cultivation, housing, and traffic, which led to the landscape fragmentation. The WBCI model provided a more accurate reflection of the bird distribution than the InVEST model. The WBCI model was able to reflect the difference in quality of each habitat grade, in contrast to the net primary productivity (NPP) method and species distribution models (SDMs). The new model was, therefore, simpler and suitable in reflecting the quality of wetland biodiversity function in the Liaohe Delta.

Key words: wetland, biodiversity, conservation function, habitat quality, evaluation

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1. Introduction

The biodiversity conservation function is one of the most important functions provided by the ecosystem and plays an important role in maintaining the genetic, species, and ecosystem diversity. Species compositions, biodiversity, and functioning have been impacted worldwide by the global environmental changes, invasion of alien species, and human disturbance (Isbell et al., 2013). The continuous reduction in global biodiversity is another environmental problem that seriously threatens human beings in addition to climate changes. The Convention on Biological Diversity (CBD) emphasized the importance of predicting, preventing, controlling, and erad-

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icating the threat of loss or reduction in biodiversity (Li et al., 2011).

Many research efforts are examining biodiversity and its ecological functions. There are two main assessment methods: field investigation and model method (Zheng et al., 2018). Remote sensing and ecological models are important in evaluating the ecological function of biodiversity over large areas that lack comprehensive field measurement data for biodiversity monitoring. To facilitate assessment, serial global and regional analysis platforms have been established, such as the Global Biodiversity Information Facility (GBIF), Map of Life (MOL), Mapping Asia Plants (MAP), Botanical Information and Ecology Network (BIEN), National Ecological Observatory Network (NEON), and Long Term Ecological Research Network (LTER; Dai and Zhao, 2016; Ma, 2017; Zhang, 2017). The Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) is the most commonly used and mature model, which has been widely used in more than 20 countries and regions for environmental management decisions.

The biodiversity conservation function is one of the most important ecological functions in a wetland ecosystem. Its scientific and accurate evaluation is the basis of wetland protection and development, as well as sustainable development of wetland ecosystems. According to CBD (2014), global wetlands continue to be fragmented, degraded, and lost rapidly. Few studies have examined whether the methods are applicable for assessing the biodiversity conservation function in the Liaohe Delta wetland. In addition, so many parameters must be input that it may not be possible to find an appropriate simplified model that can accommodate complex indicators. The study established a fitting model to evaluate biodiversity conservation function indicators for the Liaohe Delta wetland, and compare the results with InVEST and other models. The objective of this research was to provide references for the protection of wetland ecological environments as well as the related planning and management policies.

2. Data and methods

2.1 *Study site*

The research site, Panjin District, is located in the Liaohe Delta, northeastern China. The delta is situated in the warm temperate zone, with the annual mean temperature of 8.6°C and mean annual precipitation of 630 mm, which happens in July–September (Yu et al., 2017). The Daling, Liaohe, Raoyang, and Daliao rivers all join the Shuangtai and Daliaohe rivers and then flow to the sea; these rivers are the main water source of wetlands. Main soil types there include saline, marsh, meadow, paddy, and sandy (Zhou et al., 2006). The terrain is flat, with an altitude of 1.3–4.0 m (Jiang et al., 2018). Complex mechanisms of the interaction between ocean and land, and of salt and fresh water, have generated a rich wetland (Chen et al., 2017).

The Liaohe Delta wetland is important because of its rich marine as well as terrestrial and aquatic biological resources. The species composition includes more than 120 plant species such as *Phragmites australis (P. australis)*, *Suaeda salsa (S. salsa)*, *Tamarix chinensis*, *Aeluropus sinensis*, *Leymus chinensis*, *Apocynum venetum*, and *Typha orientalis*, as well as more than 200 abundant bird species such as *Grus japonensis*, *Grus leucogeranus*, *Ciconia ciconia,* and *Ciconia nigra* (Zhang and Zhang, 2014; State Forestry Administration, 2015). It has the world's largest *P. australis* wetland and world-famous *S. salsa* beach, and also the world's most extensive breeding grounds for *Saundersilarus saundersi* (Tian et al., 2017). Shuangtai wetland in Panjin, Liaohe Delta has been listed as an International Important Wetland Protectorate in the "Convention on Wetlands of International Importance Especially as Waterfowl Habitat" (Liang et al., 2016).

2.2 *Data processing*

The Chinese *Gaofen-1* (*GF-1*) satellite data used in this paper were from the Land Observation Satellite Data Service Platform of China Center for Resources Satellite Data and Application (http://218.247.138.119:7777/DSSPlatform/index.html). The *GF-1* satellite is equipped with two panchromatic and multispectral (PMS) and four wide field of view (WFV) cameras. A WFV image with a spatial resolution of 16 m and multi-spectral channels in the range of 0.45–0.90 μm, was used in this study. The WFV image used was derived from 1A-level data (a raw digital product that has been processed in the homogenized radiation calibration). The selected image was from 21 June 2018.

The 1A-level data were preprocessed by atmospheric and geometric corrections. The processed data were then segmented and merged, based on an object-oriented method. The image was classified according to, for example, the spectral, shape, and textural features, Normalized Difference Vegetation Index (NDVI), and Normalized Difference Water Index (NDWI).

NDVI is calculated by Eq. (1):

$$\mathrm{NDVI} = \frac{B_{\mathrm{nir}} - B_{\mathrm{red}}}{B_{\mathrm{nir}} + B_{\mathrm{red}}}, \tag{1}$$

where B_{nir} and B_{red} are the reflectivity of near-infrared and of red bands respectively, corresponding to the fourth and third bands of WFV image.

NDWI is calculated by Eq. (2):

$$\mathrm{NDWI} = \frac{B_{\mathrm{green}} - B_{\mathrm{nir}}}{B_{\mathrm{green}} + B_{\mathrm{nir}}}, \quad (2)$$

where B_{green} is the reflectivity of green band, corresponding to the second band of WFV image.

The land use and land cover (LULC) in Panjin, Liaohe Delta was classified into 10 types: *P. australis* wetland, *S. salsa* wetland, tidal flat, water body, forest, other vegetation, paddy field, crop field, construction land, and land used by traffic (Fig. 1).

2.3 *Evaluation of the wetland biodiversity conservation function with InVEST*

Data input for InVEST is more easily obtained than those for other models, making it useful in areas where there is a lack of species distribution. InVEST has smaller input and larger output information than other models, so it can optimize many complex problems and provide visual and spatial maps (Bai et al., 2015). The habitat quality was calculated in Liaohe Delta wetland with the InVEST model, by analyzing maps of LULC in conjunction with threats to species' habitats in this study.

2.3.1 *The habitat quality of InVEST*

As a sub-model of the InVEST model, the InVEST habitat quality model can assess the habitat quality and biodiversity conservation function. The habitat quality is given as below (Sharp et al., 2018):

$$Q_{xj} = H_j\left[1 - \frac{D_{xj}^z}{D_{xj}^z + k^z}\right], \quad (3)$$

where Q_{xj} is the quality of habitat in parcel x of LULC j; and j is habitat type. H_j is the habitat suitability of LULC type j: if LULC j is a habitat, $H_j = 1$; if not, $H_j = 0$. D_{xj} is the total threat level in grid cell x with LULC or habitat type j; and z ($z = 2.5$) and k are scaling parameters (or constants).

D_{xj} is calculated by Eq. (4):

$$D_{xj} = \sum_{r=1}^{R}\sum_{y=1}^{Y_r}\left(\frac{w_r}{\sum_{r=1}^{R} w_r}\right) r_y i_{rxy} \beta_x S_{jr}, \quad (4)$$

where r represents threat factors; R is the number of threat factors; y is all grid cells on threat r's raster map; Y_r is the set of grid cells on r's raster map; w_r is the weight of a degradation source; r_y is the impact of threat r in grid cell y; β_x is the level of accessibility in grid cell x (here $\beta_x = 1$); S_{jr} is the sensitivity of habitat type j to threat r; i_{rxy} is the level of threat r_y in grid cell x, including linear and exponential levels, which are calculated by Eqs. (5) and (6):

$$\text{Linear}: \ i_{rxy} = 1 - \frac{d_{xy}}{d_{r\max}}, \quad (5)$$

$$\text{Exponential}: \ i_{rxy} = \exp\left[-\left(\frac{2.99}{d_{r\max}}\right) d_{xy}\right], \quad (6)$$

where d_{xy} is the linear distance grid cell x and y; and $d_{r\max}$ is the maximum distance of influence of threat factors.

2.3.2 *The habitat threat factor layer, threat source table, and habitat sensitivity table*

The grids of seven habitat threat factor layers were extracted from the LULC map (Fig. 1), including urban, rural, industrial and mining land, cultivated land, and transportation (primary, secondary, and light roads).

The sensitivity of habitat types to threat factors, as well as the maximum distance, weight, and level of the threats, should be valued before the habitat quality is calculated. To obtain the values, we referred to the InVEST user's guide (Sharp et al., 2018), many studies (Bao et al., 2015; Chen et al., 2016; Zhong and Wang, 2017; Chu et al., 2018), and the actual situation in the study area. The values that we set for the maximum distance from threat factors and their weights are shown in Table 1; and our values for the sensitivity of habitat types to threat factors are shown in Table 2.

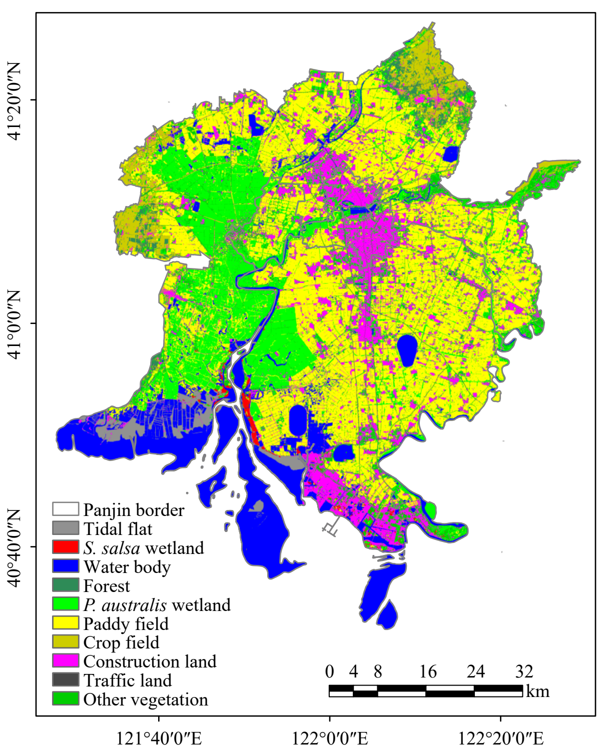

Fig. 1. Land use and land cover (LULC) of the study area.

Table 1. The influence of maximum distance from threat factors on the habitat quality and weight

Threat factor (r)	Maximum distance of influence ($d_{r\max}$; km)	Weight (w_r)	Threat level (i_{rxy})
Cultivated land	8	0.7	Linear
Rural	5	0.7	Exponential
Urban	10	1	Exponential
Industrial land	10	1	Exponential
Primary road	3	1	Linear
Secondary road	1	0.7	Linear
Light road	0.5	0.5	Exponential

2.3.3 *The habitat quality calculation with InVEST*

We calculated the habitat quality of wetland by using InVEST version 3.5.0 (https://naturalcapitalproject.stanford.edu/invest/). The data input included the LULC layer, habitat threat factor layer, threat source table, and habitat sensitivity table. The model input factors, such as cultivated and rural land layers, were then extracted from the classification result of land use types. All images were raster data of the 16-m spatial resolution. To facilitate comparison, the output data of InVEST habitat quality were normalized to values between 0 and 1.

2.4 *Established Wetland Biodiversity Conservation Indicator (WBCI)*

2.4.1 *WBCI model*

We constructed the indicator of wetland biodiversity conservation as in Eq. (7):

$$\mathrm{WBCI} = a \cdot \mathrm{VC} + b \cdot \mathrm{HI} + c \cdot (1 - \mathrm{TI}) + d \cdot \mathrm{LI}, \tag{7}$$

where WBCI is the wetland biodiversity conservation index; VC is the vegetation coverage; HI is the habitat suitability index of LULC type; TI is the threat factor index; LI is the LULC index; and a, b, c, and d are the constant weight of the factors.

HI and TI here were different from those in the InVEST model. Although the meanings were similar, the specific meanings, variables, values, and data types referred to were not exactly the same. After assigning the two factors in the WBCI model, they were directly converted into raster maps. Compared with the InVEST model, the two factors were more simplified, which might greatly reduce the computing time required by the model.

2.4.2 *VC*

VC is calculated by Eq. (8):

$$\mathrm{VC} = \frac{\mathrm{NDVI} - \mathrm{NDVI}_{\min}}{\mathrm{NDVI}_{\max} - \mathrm{NDVI}_{\min}}, \tag{8}$$

where $\mathrm{NDVI}_{\min}$ and $\mathrm{NDVI}_{\max}$ are the NDVI value of pixels with full vegetation cover and pixels without vegetation cover, respectively.

2.4.3 *HI and TI*

Principles used in valuing factors of the wetland biodiversity conservation function are as below:

—LI is assigned a score from 0 to 1 according to each LULC type.

—TI is valued as 0 or 1, where 1 and 0 indicate a threat and no threat, respectively.

—VC only refers to that of the wetland ecosystem.

We assigned HI, TI, and LI the values shown in Table 3, which were suitable for June.

2.4.4 *Weight coefficient of the WBCI model*

Factors in Eq. (7) were processed with the normalized invalid value elimination and unified resolution to obtain raster maps of the 16-m spatial resolution. The weight of normalization data was then determined by using the Principal Component Analysis (PCA) according to the nature of data and contribution of each index. We calculated the weight of each factor by using Matlab4.5 (Mathworks, Natick, Massachusetts, USA) software.

The new model, WBCI, was constructed as shown in Eq. (9):

$$\begin{aligned}\mathrm{WBCI} =& 0.1464 \cdot \mathrm{VC} + 0.5968 \cdot \mathrm{HI} + 0.6146 \\ & \cdot (1 - \mathrm{TI}) + 0.4947 \cdot \mathrm{LI}.\end{aligned} \tag{9}$$

3. Results

3.1 *Evaluation of the wetland habitat quality with InVEST*

Output of the habitat quality in Panjin City is shown in Fig. 2. The value in the coastal tidal flat (including the *S.*

Table 2. The sensitivity of habitat types to threat factors

LULC (j)	Habitat quality score (H_j)	Sensitivity of habitat types to threat factors (S_{jr})						
		Cultivated land	Rural	Urban	Primary road	Secondary road	Light road	Industrial land
Tidal flat	0.6	0.6	0.7	0.8	0.7	0.6	0.5	0.7
S. salsa wetland	0.8	0.6	0.7	0.8	0.7	0.6	0.5	0.7
Water body	0.9	0.7	0.8	0.9	0.7	0.6	0.5	0.8
Forest	1	0.5	0.7	0.8	0.6	0.5	0.4	0.7
P. australis wetland	1	0.8	0.9	1	0.8	0.7	0.6	0.9
Paddy field	0.3	0	0.3	0.5	0.4	0.3	0.2	0.4
Crop field	0	0	0	0	0	0	0	0
Construction land	0	0	0	0	0	0	0	0
Traffic land	0	0	0	0	0	0	0	0
Other vegetation	0.5	0.4	0.5	0.6	0.6	0.5	0.4	0.5

Table 3. Values of the habitat suitability index (HI), threat factor index (TI), as well as land use and land cover index (LI)

LULC	HI	TI	LI
Tidal flat	0.60	0	0.67
S. salsa wetland	0.80	0	0.78
Water body	0.90	0	0.89
Forest	1.00	0	0.56
P. australis wetland	1.00	0	1.00
Paddy field	0.30	1	0.33
Crop field	0	1	0.22
Construction land	0	1	0
Traffic land	0	1	0.11
Other vegetation	0.50	0	0.44

salsa wetland) was generally in the range of 0.6–0.8; the value in the *P. australis* wetland was in the range of 0.4–1.0; the value at the edge of the wetland was considerably lower than that in its interior; the construction land (including urban, rural, industrial land, and roads) was the lowest in the range of 0–0.2; the value of crop fields was approximately from 0 to 0.1; the value of paddy fields was approximately 0.2–0.3; the value of the other vegetation land was around 0.3–0.4; the forest was valued between 0.5 and 0.8; and values of some rivers, reservoirs, and other water bodies were approximately 0.3–0.9.

High-quality habitats were the *P. australis* wetland, *S. salsa* wetland, tidal flat, water body, and forest. Low-quality land use types were the paddy field, crop field, construction land, and land used for traffic. Landscape fragmentation in the wetland was higher where it was near to the construction land and land used for traffic, than where it was far from such land uses.

3.2 *Evaluation of the wetland biodiversity conservation function with WBCI*

Figure 3 shows that the results were similar to those of InVEST, with the higher-quality habitat including the *P. australis* wetland, *S. salsa* wetland, tidal flat, water body, and forest. Lower-quality land use types included the paddy field, crop field, construction land, and land used for traffic. The WBCI output data ranged from 0 to 1.0, where the value in the *P. australis* wetland was generally in the range of 0.8–1.0, which was the highest of all LULCs; the construction land (including urban, rural, industrial land, and roads) was the lowest with a value of 0; the value of crop fields was approximately from 0.1 to 0.2; the value of paddy fields was around 0.2–0.3; the land with other vegetation was valued in the range of 0.3–0.6; the coastal tidal flats and forest were valued between 0.6 and 0.8; and values of some coastal beaches, rivers, reservoirs, and other water bodies were approximately 0.8–0.9.

Areas with the better biodiversity conservation function in Panjin were located in the west, near rivers, and some coastal beaches; the central and eastern areas had poor biodiversity function. We found that areas with fewer disturbances from human activities had rich species and high habitat quality, while the habitat quality was poor

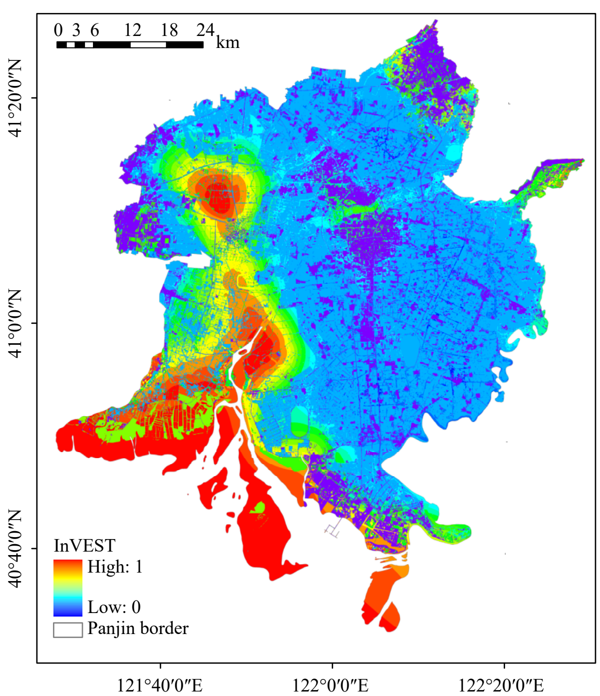

Fig. 2. The wetland habitat quality calculated by the InVEST model.

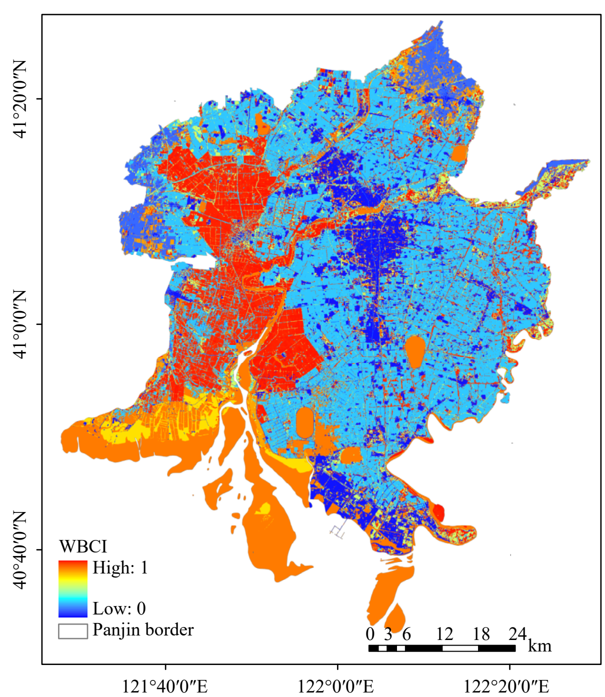

Fig. 3. The wetland biodiversity conservation function evaluation calculated by the WBCI model.

owing to the concentrated urbanization and cultivated land in areas of more frequent human activities. At the same time, residential land and land used for traffic led to fragmentation of the wetland landscape, influencing the surrounding wetland habitat.

4. Discussion

4.1 *Comparison between WBCI and InVEST*

To verify the accuracy of WBCI in evaluating the wetland biodiversity conservation function, spatial correlation analysis was conducted for images valued by InVEST and WBCI models. The correlation coefficient was 0.61, with a good consistency in the two models.

The WBCI result reflected the environment needed for maintaining the wetland species and ecosystem diversity in Liaohe Delta. The bird distribution, as a representation of species diversity, was used to show the reasonability of WBCI model. The actual bird distribution in Panjin (Ma et al., 2019) and a bird survey of the southern Liaohe Delta in spring 2017 (Chen et al., 2019) both showed that many birds gathered in the *P. australis* wetland, coastal tidal flats, rivers, beaches, reservoirs, and ponds (Fig. 4). Values in the bird survey areas were 0.6–1.0 in WBCI and 0.3–1.0 in InVEST (the low values were mainly distributed in rivers, reservoirs, or ponds). The WBCI output map was better able to reflect biodiversity of the bird distribution in a water body than that of InVEST. However, WBCI was unable to reflect sufficient details of inner differences in the *P. australis* wetland compared with InVEST.

Therefore, there were limitations in applying both InVEST and WBCI to evaluate the wetland biodiversity conservation function in Liaohe Delta. In the InVEST model, weights of factors of the habitat suitability, and of sensitivity factors, largely depend on personal assessment, and there were no uniform rules. This made it difficult to make comparisons with studies in different regions (Chen et al., 2016), and the same limitations existed in the WBCI model. The InVEST model assumes that better habitat quality results in higher biodiversity, but the habitat quality does not take the changes caused by seasons or quality of vegetation growth into account. For this reason, the vegetation cover was added to WBCI. In addition, the InVEST model ran for a long time and computation errors easily arose. WBCI was constructed to allow faster computation.

4.2 *Comparison between WBCI and other models*

The "Ecological protection red line delineation guide" (Ministry of Ecology and Environment of the People's Republic of China and National Development and Reform Commission, 2017) was issued to allow the evaluation of importance of biodiversity conservation functions. The guide recommends two models: Net Primary Productivity (NPP) and Species Distribution Models (SDMs).

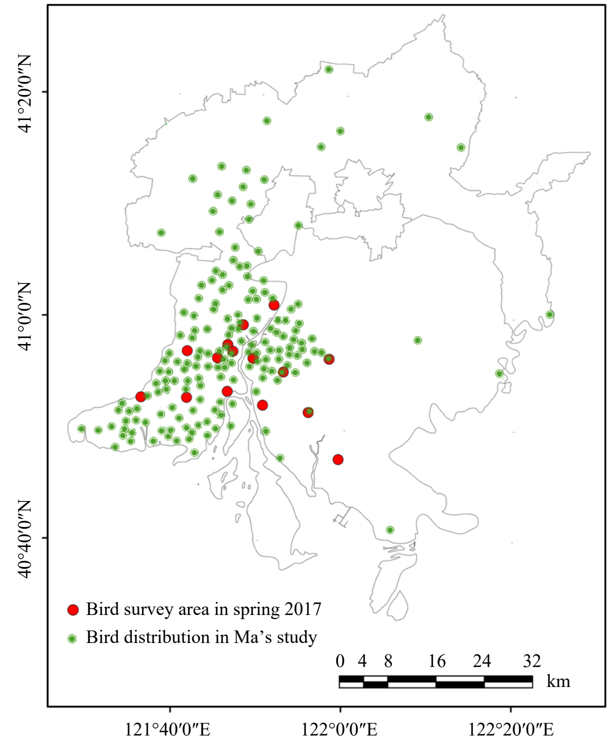

Fig. 4. The bird distribution of Panjin, Liaohe Delta.

Input factors of the NPP model are the average annual NPP, average annual precipitation, average annual temperature, and altitude. Main input factors of SDMs include terrain variables (such as altitude, gradient, and slope direction), land use type variables (such as soil and vegetation types), climate variables (such as precipitation, air temperature, and radiation), ecological indices (such as NPP, NDVI, and carbon content), and cultural indicators [such as Gross Domestic Product (GDP), population, and road density]. In delineating the "Ecological protection red line" in China, the NPP method is widely used because it has fewer factors than SDMs that are less used for this reason (Ma et al., 2019).

Ma et al. (2019) compared NPP and SDMs in evaluating importance of the biodiversity conservation function in Panjin, and found that NPP was unable to cover all important areas of biodiversity, so its results did not match the actual bird distribution because of the high NPP value of crops. The MaxEnt model, one of the SDMs, was consistent with the actual bird distribution. However, the MaxEnt model only determined whether a habitat was present or not but did not reflect the differences in the quality of each habitat grade. Therefore, InVEST and WBCI were more appropriate in evaluating regional differences in the wetland biodiversity conservation function.

This study attempted to add a VC factor in the model to reflect the growth quality of habitat that might affect wetland biodiversity. After adding the VC factor in all land use types, the results were overvalued in the crop land (Fig. 5). Although the internal difference in the *P. australis* wetland showed a better response, the water body and cultivated land did not match the actual biodiversity function. Therefore, we only added the VC factor in the *P. australis* wetland, and the result was close to the actual biodiversity. According to the evaluation results of WBCI, higher biodiversity mainly occurred in the *P. australis* wetland and coastal tidal flat of Liaohe Delta, which was similar to the importance of biodiversity defined in Panjin with the MaxEnt model (Ma et al., 2019).

5. Summary

This study constructed a new model—the WBCI model that includes four factors: VC, TI, HI, and LI. We assigned HI and TI values by referring to the InVEST model and many studies. Weights of the four factors were determined by PCA, which were processed with the normalized invalid value elimination and unified resolution to obtain raster maps of the 16-m spatial resolution. The WBCI model was simpler than InVEST, which might greatly help reduce the computing time that it required.

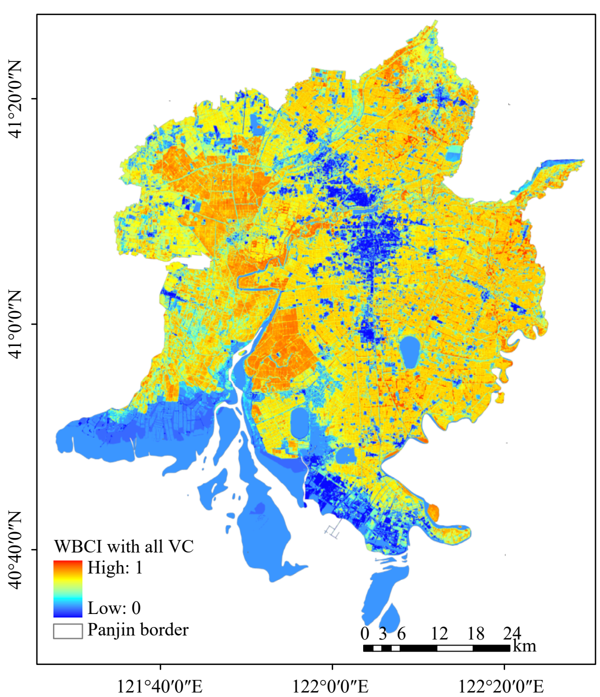

Fig. 5. The results after adding the vegetation coverage (VC) factor in all LULCs.

The WBCI model was used to evaluate the wetland biodiversity conservation function in Liaohe Delta wetland in 2018. The WBCI output data ranged from 0 to 1.0, where values in the *P. australis* wetland, coastal tidal flats, rivers, reservoirs, and other water bodies were in the range 0.6–1.0; values of the crop, paddy, and other vegetation were in the range 0.1–0.6; and value of the construction land (including urban, rural and industrial land, and roads) was 0. The results of this study showed that the wetland biodiversity conservation function was better in areas less disturbed by humans, which were abundant in species and showed good habitat quality. The function was poor where more frequent human activities were found, owing to the land cultivation as well as presence of residents and traffic that led to the landscape fragmentation.

We found that the application of WBCI better reflected the wetland biodiversity conservation function in Liaohe Delta than InVEST and other models. Our aim was to find an accurate and simple habitat quality assessment method; scientifically and accurately evaluate the ecological quality of a wetland; identify threat factors; and propose reasonable protection and restoration suggestions. Because the relationship between the response and independent variables (habitat factor) of the PCA method is unclear (Yi and Zhang, 2019), further research into the model construction is needed. Furthermore, the evaluation in Liaohe Delta wetland in the past years may identify the reasons for changes in wetland biodiversity, allowing us to research key problems and provide suggestions for the management and protection of these habitats.

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