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Application of weight method based on canonical correspondence analysis for assessment of Anatidae habitat suitability: A case study in East Dongting Lake, Middle China

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ABSTRACT

Habitat suitability assessment is one of the essential steps in habitat conservation and restoration. A weight method, which used the length of arrow in the result of canonical correspondence analysis (CCA) to determine the weight of the environmental variables, was developed to evaluate the Anatidae habitat suitability in East Dongting Lake. Based on descriptive waterfowl statistics from field observation data, Anatidae were selected as the representative waterfowl by the dominance. And then five environmental variables were identified by the correlation analysis as having important effects on the presence/absence of Anatidae habitat suitability. The Anatidae habitat suitability was evaluated by the new weight method. The results showed that the area of highly suitable habitat and moderately suitable habitat were 21.8% and 48.5%, respectively. Only small area was unsuitable habitat (9.3%). The survey data of Anatidae from 2006 to 2011 in East Dongting Lake were used to test the validity of the assessment results. It was concluded that the five environmental variables could well explain the results of Anatidae habitat suitability. The weight method based on CCA was feasible in assessment of Anatidae habitat suitability.

1. Introduction

As human population and resource consumption augment, the pressure on endangered species increases accordingly (Millar and Blouin-Demers, 2012). The importance of habitat suitability assessment to explain species distribution has been recognized (Olsson and Rogers, 2009; Zeng et al., 2013). Habitat suitability assessment is one of the essential steps in habitat conservation and restoration (Fernandez and Gurrutxaga, 2010). Through the analysis of habitat suitability assessment, the spatial distribution of habitat can be predicted. It can help to make the conservation and restoration of species habitat more effective and scientific (Fredriksson and Nijman, 2004; Andrew and Ustin, 2009; Andrew et al., 2012).

Wetland is the main habitat for endangered waterfowl (Vougioukalou et al., 2011). As an important component of wetland (Hua et al., 2012), wetland waterfowl play a decisive role in the energy flow of a wetland ecological system and in maintaining its stability (Monfils and Prince, 2009; McKinney et al., 2011). Conserving and restoring the critical habitat of endangered waterfowl are ones of the most important objectives in wetland ecosystem (Baattrup-Pedersen et al., 2012). Waterfowl are so sensitive to environmental variables that the assessment of waterfowl habitat suitability is usually used to evaluate whether or not a place is suitable for living (Lant et al., 2005). The key to waterfowl conservation is to protect the waterfowl survival habitat (Long et al., 2008). To achieve this goal, the distribution of habitat suitability must be known first (Knudby et al., 2010). Therefore, it is essential to evaluate the waterfowl habitat.

For habitat suitability assessment, several studies have been undertaken and models developed, such as Habitat Suitability Index (HSI) (Dussault et al., 2006; Cho et al., 2012), generalized linear models (GLM) (Hirzel et al., 2006) and ecological niche variable analysis (ENFA) (Basille et al., 2008; Galparsoro et al., 2009). All of them have been widely used as tools in habitat suitability assessment of species to model management and

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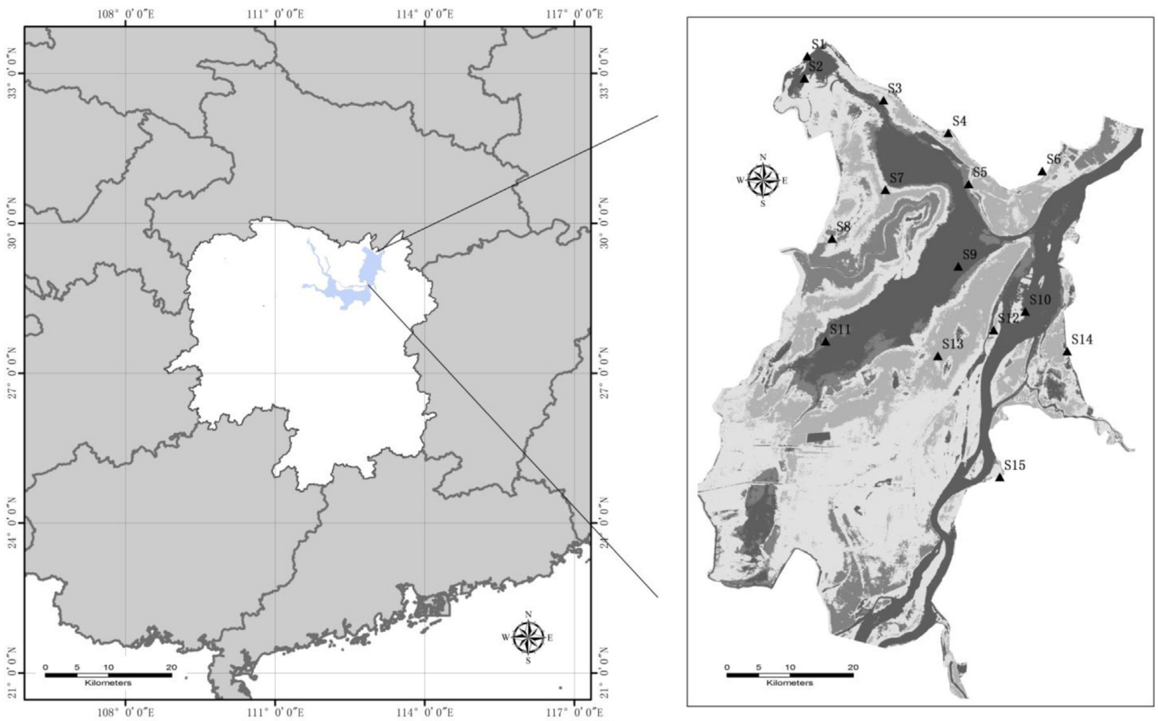

Fig. 1. Sample sites of waterfowl survey in East Dongting Lake. S1 – Caisang Lake; S2 – Small West Lake; S3 – Siba Beach; S4 – Dingzi Dyke; S5 – Junshan Lake; S6 – The outside; S7 – Tuanzhou Beach; S8 – Zhuzi Estuary; S9 – Baihu Lake; S10 – Laoshuwei; S11 – Xingfu Beach; S12 – Meitan Bay; S13 – Hongqi Lake; S14 – Chunfeng Lake; S15 – Baota Lake.

conservation (Lu et al., 2012). Numerous efforts have been made to predict or pattern the spatial distribution of waterfowl habitat suitability.

In the assessment of waterfowl habitat suitability, the weight of variables may affect the accuracy and the validity of the results directly. Therefore, the determination of weight of variables is a key and difficult point in the assessment. Weight method is the method that is used to determine the weight of variables in the process of assessment (Lehong and Baochen, 2006). In the existing assessment methods, the commonly used weight methods are weights of evidence (WE) and analytic hierarchy process method (AHP) (Fang and Qu, 2007; Zhang and Zeng, 2012). In addition, Delphi method (DE) (Luan and Sun, 2009) and principal component analysis method (PCA) (Liu, 2007) are commonly utilized to determine the weight of variables (Suter and Cormier, 2011). However, although these methods can evaluate the waterfowl habitat suitability to some extent, there are some limitations. WE and DE are depended more on the subjective factors. AHP method and PCA rely on the objective data excessively and neglect the significance of the expert in the weight determination. Hence, the need for a suitable method, which is more accurate and uncomplicated to evaluate the waterfowl habitat suitability, is apparent but has yet to be established.

The aim of this research is to predict waterfowl habitat suitability distribution in East Dongting Lake. Canonical correspondence analysis (CCA) was used to determine the weight of environmental variables. CCA is the method that extracts the best synthetic gradients from field data on biological communities and environmental features. It forms a linear combination of environmental variables that maximally separates the niches of the species (Klami et al., 2013). Historically, the length of an environmental arrow which was in the CCA ordination diagram was used to explain the qualitative importance of variables (Arandjelović, 2014; Yuan et al., 2014). In this research, it was used to predict the quantitative importance of variables. Then a new model was established, which used the weight method to evaluate the Anatidae habitat suitability based on CCA to determine the weight of environmental variables. Some assumptions/conclusions on the basis of the hypothesis remained to be proved, in particular, to: (1) identify the major environmental variables in East Dongting Lake; (2) verify the feasibility of the new weight method based on CCA; (3) show the spatial distribution of habitat suitability and

Table 1
Dominance of Anatidae in East Dongting Lake.

Species	Count	Dominance
Anser fabalis	21329	0.1471
Anser albifrons	9000	0.0420
Anser erythropus	16529	0.1100
Tadornaferruginea	1377	0.0128
Anasfalcata	11831	0.0987
Anascrecca	2593	0.0374
Anasplatyrhynchos	4389	0.0524
Anaszonorhyncha	1523	0.0339
Anasacuta	4508	0.0357

count the area of suitable habitat of East Dongting Lake; and (4) verify the precision of suitable map which was obtained based on five variables.

2. Materials and methods

2.1. Study site

The study was conducted in East Dongting Lake (Fig. 1), which is located in the middle of the Yangtze River, Hunan Province, Middle China (approximately 28°59′–29°38′N, 112°43′–113°15′E) (Li et al., 2013). The climate of East Dongting Lake is subtropical monsoon, with an annual rainfall of 1.2–1.33 m per annum and mean temperature of 17 °C, with frequent sub-zero temperatures in winter (Li et al., 2011; Wu et al., 2013). East Dongting Lake National Nature Reserve was designated as a wetland of international importance by the Chinese Government in the Ramsar Convention in 1992, and the wetlands as well as surrounding areas were designated as a National Nature Reserve in December 1984.

Because of its special geographical position, unique climate conditions and topography, East Dongting Lake provides appropriate eco-environment for a wide variety of flora and fauna. Tens of thousands of migratory waterfowl arrive at East Dongting Lake wetland from Siberia, Mongolia in every autumn. The abundant waterfowl in East Dongting Lake wetland have made the wetland a critical habitat and over-wintering area for East Asian migratory waterfowl.

2.2. Waterfowl survey

According to the characteristics of distribution and habitat assessment principles of waterfowl in East Dongting Lake, waterfowl species were surveyed from 15 sites (Fig. 1) throughout East Dongting Lake. Each site was investigated from 2006 to 2012 based on point counting (Rooney and Bayley, 2012). Samplings were conducted from November to February to record wintering species, and each site was sampled once or twice a year. In this research, the same sampling sites were recorded by same method from 2006 to 2012. The location of each site was also recorded with a handheld global positioning system. Waterfowl surveys were carried out within a radius of 2 km of the sampling site each year on fine weather without rain or significant wind.

2.3. Species data

In this research, Anatidae, which account for about 70% individuals of the total population in East Dongting Lake, were chosen as the representative waterfowl. The names of 9 species of Anatidae and the dominance index of each species are shown in Table 1.

2.4. Environmental variables

According to the living conditions of Anatidae as well as the previous studies, 7 environmental variables were used to model the Anatidae habitat suitability. Three physical variables included in the study were patch density (PD), distance to residents (DRE), distance to road (DR) (Yuan et al., 2014). And four biological variables were: water area (WA), reed area (RA), sedge area (SA) (Rinnan et al., 2009; Bernhardt-Römermann et al., 2011; Blok et al., 2011).

The variables in each study site were derived from Landsat 4–5 TM images in 2012. The study area was divided into 20 × 20 units, each unit 2 km × 2 km grid. The environmental variables were extracted from every grid by ArcGIS9.3, and the calculations of environmental variables were executed using Fragstats 3.3.

2.5. Date analysis

To define dominant species, the dominance index was calculated by Eq. (1)

$$Y = \frac{n_i f_i}{N} \tag{1}$$

where Y is the dominance index of each species; f_i is occurrence frequency of species i; and N is the total population. When $Y \geq 0.02$, the species would denote dominant ones.

Firstly, the number of the 9 species (Table 1) obtained at 15 sampling sites in 2012 were counted. Then the data were calibrated by Eq. (2) to ensure the range of value from 0 to 1. All the statistical analysis was carried out based on the calibrated data.

$$z = \frac{(X - \mu)}{\sigma} \tag{2}$$

where Z is the standard score, X is the value of the element, μ is the population mean, and σ is the standard deviation.

Secondly, the data of the environmental variables were also calibrated by Eq. (1). Then, the calibrated data of variables were divided into four ranges, namely 0–0.25, 0.25–0.5, 0.5–0.75 and 0.75–1.0. The variable scores were 1, 3, 5 and 7, respectively (Kneib et al., 2008; Martinuzzi et al., 2009), representing unsuitable, generally suitable, moderately suitable, and highly suitable, correspondingly. (Ortigosa et al., 2000). Lastly, correlation analysis, specifically Spearman rank correlation, was used to identify the main environmental variables in the habitat suitability assessment in SPSS (Li et al., 2006; Akhtar et al., 2007).

2.6. Weight of environmental variables

In this research, CCA was proposed to determine the weight based on the characteristics of CCA. CCA is a multivariate extension of weighted averaging ordination, which is a simple method for

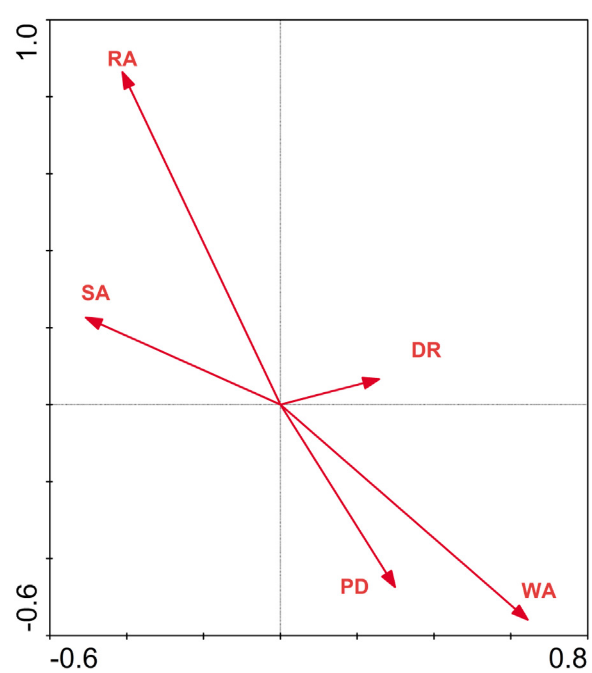

Fig. 2. CCA ordination diagram of environmental variables in the East Dongting Lake (DR = distant to road; RA = reed area; PD = patch destiny; SA = sedge area; WA = water area).

Table 2
Correlation analysis[a] of the environmental variables.

	LSI	WA	SA	RA	DRA	DR	PD	Anatidae
LSI	1.0000							
WA	0.0637	1.0000						
SA	−.0266	−.6963	1.0000					
RA	−.2096	−.6395	−.0305	1.0000				
DRA	0.7553	0.2433	0.0714	−.4570	1.0000			
DR	−.2054	−.6620	0.3112	0.5609	−.2875	1.0000		
PD	0.4821	−.3705	0.4851	−.0295	0.2857	−.0772	1.0000	
Anatidae	−.1093	0.6057	−.3870	0.3843	−.1027	−.5479	0.4332	1.0000

[a] Correlation at the 5% significant level.

arranging Anatidae along environmental variables. It can elucidate the relationship between species and their environmental variables, and is widely used in biological quality assessment (Ter Braak, 1987). In this research, it is of interest to rank environmental variables in their importance for determining the Anatidae habitat suitability. CCA chooses the optimal weight for the environmental variables in the Anatidae habitat suitability assessment (Gauch and Wentworth, 1976).

The ordination diagram generated by CCA visualizes the main features of the distribution of Anatidae along the environmental variables as well as the importance of the variables (Ter Braak and Verdonschot, 1995). The CCA ordination diagram is constructed and interpreted as follows (Fig. 2): the arrows represent the environmental variables; the coordinates of the arrows are the values of the arrows on the two best synthetic gradients (axes 1 and 2 in Fig. 2); the direction of the arrows represent the maximum change of the associated variables; the length of an arrow representing an environmental variable is equal to the rate of change in the weighted averaging ordination, and is a measure of how much the Anatidae distribution differ along the environmental variables. Important environmental variables tend to be represented by longer arrows than less important environmental variables (Ter Braak, 1989). The importance of environmental variables was determined by the coefficients, and the weight was determined by the length of the arrow in the process of Anatidae habitat suitability assessment.

2.7. Habitat suitability assessment

According to the weight which was determined by the results of CCA, this assessment model applied the weighted summation method to calculate Anatidae habitat suitability. The habitat suitability was calculated by Eq. (3)

$$M_i = \sum_{j=1}^{n} w_j \times x_{ij} \tag{3}$$

where, M_i is the overall score of habitat suitability for ith gird cell; w_j is the weight of jth variable, and x_{ij} is the value of ith gird cell for jth variable.

3. Results

3.1. Correlation analysis and the value of the variables

The correlation coefficient between environmental variables and Anatidae are shown in Table 2. The environmental variables of WA, SA, RA, DR and PD were selected to evaluate the Anatidae habitat suitability. Anatidae was positively correlated with RA, WA

Table 3
The score of environmental variables.

Variable	Range	Suitable types	Score
RA	0–0.25	Unsuitable	1
	0.25–0.5	Generally suitable	3
	0.5–0.75	Moderately suitable	5
	0.75–1.0	Highly suitable	7
SA	0–0.25	Unsuitable	7
	0.25–0.5	Generally suitable	5
	0.5–0.75	Moderately suitable	3
	0.75–1.0	Highly suitable	1
WA	0–0.25	Unsuitable	1
	0.25–0.5	Generally suitable	3
	0.5–0.75	Moderately suitable t	5
	0.75–1.0	Highly suitable	7
DR	0–0.25	Unsuitable	1
	0.25–0.5	Generally suitable	3
	0.5–0.75	Moderately suitable	5
	0.75–1.0	Highly suitable	7
PD	0–0.25	Unsuitable	1
	0.25–0.5	Generally suitable	3
	0.5–0.75	Moderately suitable	5
	0.75–1.0	Highly suitable	7

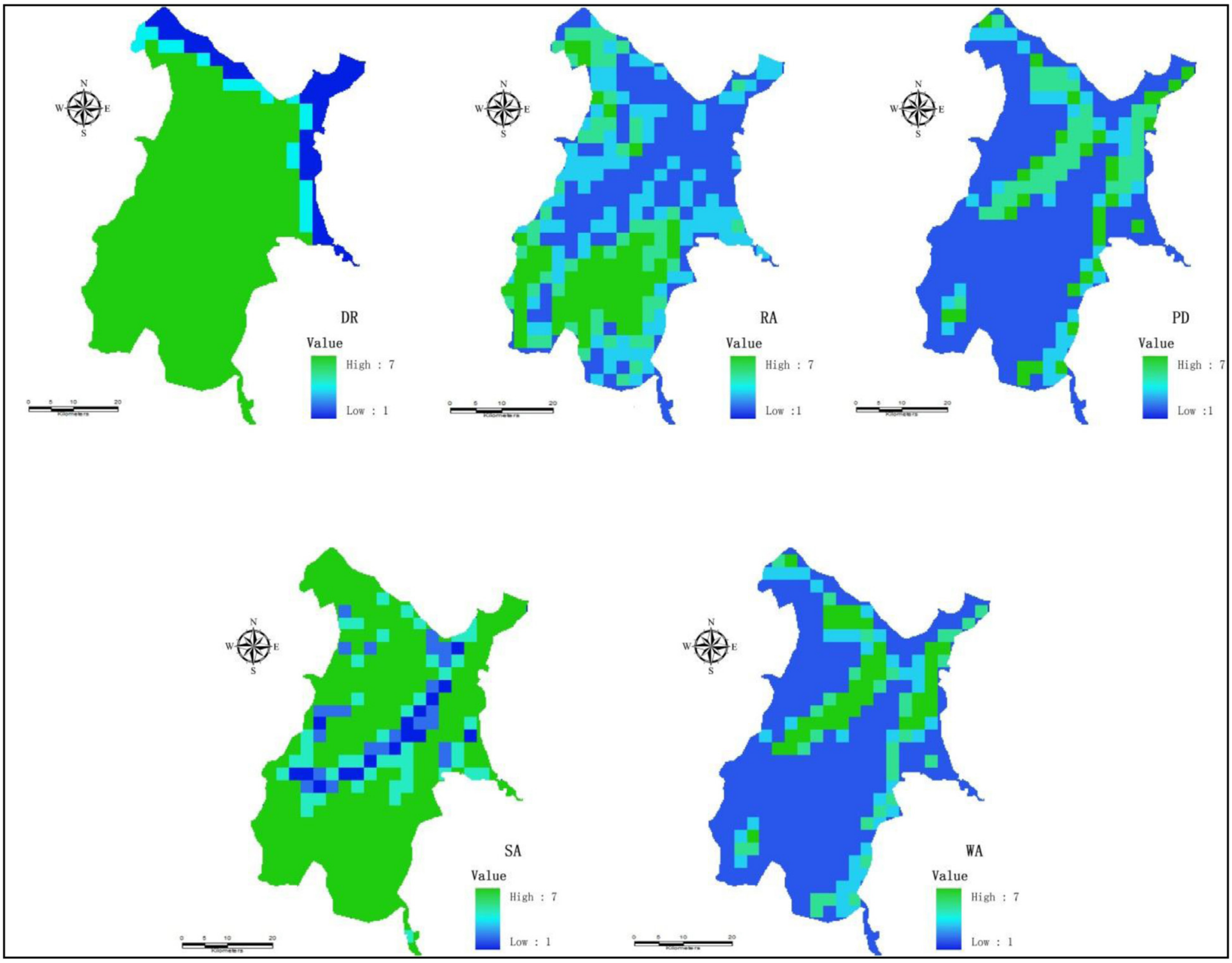

Fig. 3. Suitability of five variables (the 1 value indicated unsuitable, 7 indicated the highly suitable. DR = distant to road; RA = reed area; PD = patch destiny; SA r = sedge area; WA = water area).

and PD at 5% significant level and negatively correlated with SA and DR, and the correlation coefficients were 0.3843, 0.6057, 0.4332, −0.3870 and −0.5479, respectively. LSI and DRA could be ignored for their correlation coefficients were −0.1093 and −0.1027 at 5% significant level.

In order to simplify the analysis and assessment, score was assigned to selected environmental variables, which is shown in Table 3. The suitability distribution of five variables are shown in Fig. 3

3.2. Anatidae habitat suitability assessment

The result of CCA has been applied to calculate the weight of all the variables. The weights are shown in Table 4. Based on the weights, the final comprehensive habitat suitability of East Dongting Lake is shown in Fig. 4. The score of the results showed that habitat suitability index values were ranged from 1 to 7. Suitability index values were divided by equal interval. Then the Anatidae habitat suitability was divided into four grades: highly suitable, moderately suitable, generally suitable and unsuitable habitat. For highly suitable habitat, suitability index values were higher than 5.5. For moderately suitable habitat, suitability index values were from 4 to 5.5. For generally suitable habitat, suitability index values lay between 2.5 and 4. And for unsuitable habitat, suitability index values were less than 2.5. The areas of four grades are shown in Table 5. Table 5 shows that moderately suitable habitat (48.5%) and highly suitable habitat (21.8%) accounted for 70.3% of the entire Anatidae habitat of the total area.

3.3. The validation of the evaluation result

Fig. 5 shows the total number and species number of Anatidae in all 15 sample sites from 2006 to 2011. Comparing sample site diagram (Fig. 1) with the grade graph of habitat (Fig. 4), it could be concluded that: (1) five sample sites, S1, S2, S9, S10 and S11, with relatively great number of Anatidae and species, were evaluated to be located in highly suitable habitat; (2) the four sample sites, S5, S7, S8 and S15,with great number of Anatidae and species, were evaluated to be located in moderately suitable habitat; and (3) the rest six sampling sites, which had relatively small number of Anatidae and species, were evaluated to be located in generally suitable habitat or unsuitable habitat. Thus, it is clear that the new method is effective to explain the Anatidae habitat suitability.

4. Discussion

4.1. Environmental variables and distribution of habitat

From the result of validation, it can be verified that the evaluation results can reflect the habitat suitability grade in East

Table 4
Weights of the main environmental variables.

Variable	Weight (%)	Variable	Weight (%)
Water area (WA)	30	Reed area (RA)	27
Distance to road (DR)	8	Patch density (PD)	18
Sedge area (SA)	17		

Dongting Lake. It was found that CCA could be used to determine the weight of environmental variables and the habitat suitability could be predicted by the method of weight summation. The results of assessment showed that: (1) highly suitability habitat was closely tied to water areas; (2) moderately suitable habitat was comparatively concentrate on reed area; (3) the habitat close to the road or the sedge area were mainly generally suitable or unsuitable habitat; and (4) the habitat with fewer PD mainly has better suitability

From the weight of the environmental variables to habitat suitability assessment (Table 4), it could be seen that the weight of WA and RA were 30% and 27%, respectively. Therefore, it could be inferred that these two environmental variables play important roles in the Anatidae habitat suitability. From the grade graph of habitat, it could be seen that highly suitable habitat was mostly located in the water area and the moderately suitable habitat was mostly located in reed area. The reason is that the Anatidae prey mainly on shrimp, fish, benthic aquatic animals in the water as well as the benthic animals on the root portion of the tender reed. The grade graph of habitat was obtained based on the Anatidae survey data in winter as well as remote sensing data in January 2012. During this time, a majority of the reed were dead or artificially harvested, most of the Anatidae put water as the main habitat, and the assessment results also reflected this regularity (Schmidt et al., 2005). The PD in moderately suitable habitat and highly suitable habitat was low. It indicated that the size of the fragment would influence the number of species. Through the theoretical analysis

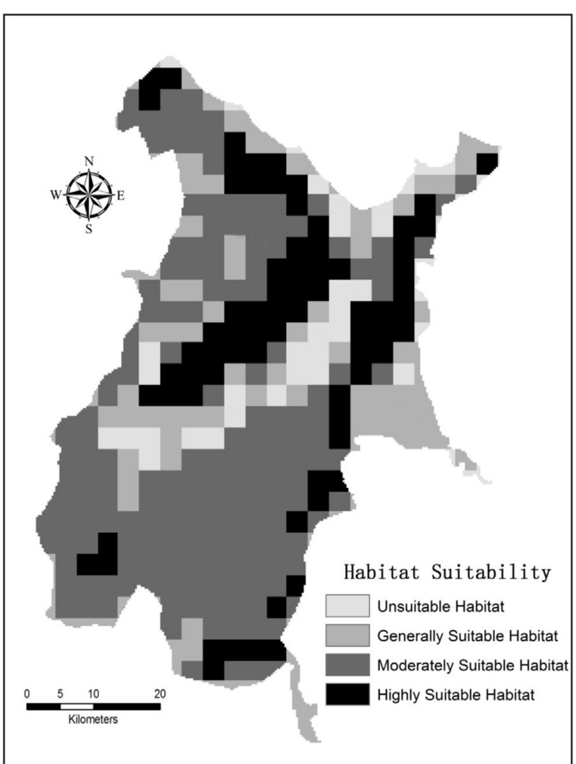

Fig. 4. The distribution of the Anatidae habitat suitability.

and sample sites data validation, it was found that the assessment results were objectively and accurately reflect habitat suitability assessment grades of Anatidae in East Dongting Lake. Therefore, the five variables are major variables in the assessment of the Anatidae habitat suitability. Our results (Table 5) also showed that moderately suitable habitat (48.5%) and highly suitable habitat (21.8%) accounted for 70.3% of the entire Anatidae habitat suitability of the total area, which indicated a satisfying quality of habitat in East Dongting Lake.

4.2. Advantages of the new method

In the habitat suitability assessment, the weight of variables may affect the accuracy and the validity of the results directly. Moreover, the correct determination of weight should be the reflections of both the objective information of variable and the experts' subjective judgment (including both aspects of quantitative and qualitative). Considering the deficiencies of the indexes weight method in present assessment, a new method, which used the result of CCA to determine the weight of variables, was proposed. This new method is able to rapidly identify the possible causal relationship between species distribution and environmental variables. Without the need of any specific habitat requirement, this approach provided a qualitative and quantitative method to determine the importance of environmental variables. Moreover, the objective and subjective aspects of weight are taken into account in this method, and a relatively reasonable weight value is obtained by combining the species and the environmental variables. The use of the direct ordination diagram enabled us to determine the variability of species distribution explained by observed environmental variables.

In this research, CCA was used to determine the weights of the environmental variables which were influence the distribution of Anatidae habitat suitability. According to the weights of variables and the observation data of Anatidae, it can certify that the CCA can reflect both the objective information of variable and the experts' subjective judgment. In addition, weighted summation method is an objective approach to evaluate the habitat suitability. Therefore, the model which was proposed can evaluate the habitat suitability objectively and determine the weight of variables reasonable. In the condition of lacking sufficient expert knowledge or conventional established definitions, this method can evaluate the habitat suitability based on data, and determine the weight of environmental variables.

4.3. The application of the method to ecological modeling

The method proposed in this paper provides a quantitative and qualitative approach to determine the weight of each environmental variable which had influence on the species habitat suitability. It can help to evaluate species habitat suitability and geographic distribution. It represents a tractable modeling method when more knowledge about habitat requirements of some species is insufficient. This method can determine suitable range of each variable for species. With this information, biological managers can conserve and restore wildlife habitat more

Table 5
The area percentage of different grade habitat.

Grade	Percent (%)	Grade	Percent (%)
Unsuitable habitat	9.3	Moderately suitable habitat	48.5
Generally suitable habitat	20.4	Highly suitable habitat	21.8

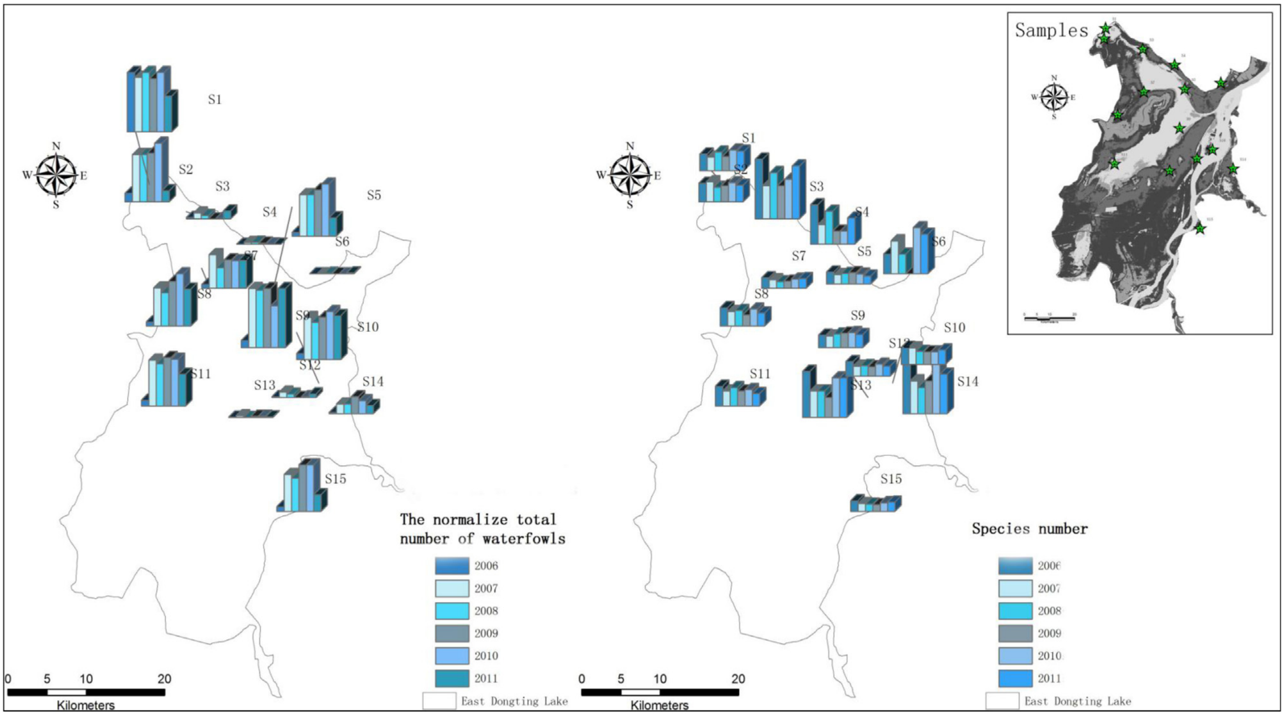

Fig. 5. The total number of Anatidae and species number of Anatidae in all fifteen sample points from 2006 to 2011.

efficiently and effectively. Clearly, objective modeling of geographic distribution as well as suitable condition of a species is important for ecological and biological conservation. In the future, this method can be explored to evaluate other species habitat suitability. Moreover, in order to make the modeling more accurate and universal, future research about the application of this method should continue to be conducted to make up for the possible deficiencies.

4.4. Habitat conservation and restoration

Reasonable understanding of the results of assessment and the main environmental variables not only contribute to the conservation and restoration of habitat (Hernando et al., 2010), but also help to improve and maintaining existing habitat suitability grade (Osgathorpe et al., 2012). In order to achieve more scientific and accurate strategies for habitat protection and restoration, a detailed understanding of habitat conditions is required. In this research, on the basis of the results of habitat and distribution of suitable conditions, the government should give great importance to restoring and reconstructing waterfowl habitats. The following recommendations for biodiversity conservation and habitat restoration are given.

Firstly, for highly suitable habitat, the local water conservancy departments should strengthen the protection of the water resources in East Dongting Lake to ensure Anatidae feeding, benthic animals in particular (Yen et al., 2004; Hammersmark et al., 2010). For moderately suitable habitat, humans should act in compliance with national policy of returning farmland to forests to restore the habitat. Managers and protectors should encourage farmers to protect the reed resources. Harvesting reeds or other vegetation was not allowed during lush reed or Anatidae wintering. Lastly, for generally suitable and unsuitable habitat, more efforts and investments should be made to restore the habitat to make them suitable for survival of species. Furthermore, it must avoid too much human disturbs which determine the size of PD. Roads or residential areas should be constructed far away from wetland (Randrianandrianina et al., 2006; Seino and Uda, 2007; Lloyd and Marsden, 2008).

5. Conclusion

In summary, canonical correspondence analysis (CCA) can be used to determine the weight of the environmental variables, which is applied to evaluate the suitability of waterfowl. From the results of the assessment and the validation, it could be concluded that the new method could accurately simulate the distribution of Anatidae habitat suitability. Moreover, based on the weight of the variables, the study clearly revealed that habitat suitability was significantly associated with land use and the disturbance of human. This approach will enable forest and wildlife management officials to determine the importance of the variables and the distribution of suitable habitat, and help them make various strategies for future habitat conservation and restoration.

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