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A Multi-scale Approach to Investigating the Wintering Habitat Selection of Red-crowned Cranes in the Yancheng Nature Reserve, China

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A B S T R A C T

The red-crowned crane (*Grus japonensis*) is a rare and endangered species that lives in wetland habitats. In this study, we first compared crane habitat selection in December, 2013 and January, 2014 using the Neu method in the Yancheng National Reserve (YNR). We then explored the relative importance of habitats (plot, landscape) and spatial factors on red-crowned crane abundance at multiple scales using regression models and variation partitioning approaches. Our results indicated that seepweed (*Suaeda salsa*) tidal flats and reed ponds were the favored habitats by cranes in December and January, respectively. The variation partitioning results indicated that plot and landscape factors were the determining factors of crane abundance in December, but plot features were more important in January. Furthermore, the pure and total effects of plot factors, and the combined effects of plot, landscape and spatial factors, increased significantly from December to January. At plot scale, vegetation coverage and road distance were the crucial variables that determine crane abundance in both months. At landscape scale, percentage of reed ponds and percentage of seepweed tidal flats showed a positive independent effect on crane abundance in both months. Percentage of paddy fields was also a significant variable in December, whereas percentage of fishponds was in January. Our study indicated that crane habitat selection and the determining factors changed over time due to food availability and human disturbance (*e.g*., reed pond and fishpond harvests). Our results encourage the application of partitioning methods in avian ecology because they provide a more in-depth understanding of the importance of different explanatory variables over traditional regression methods. Efforts should be made to strengthen wetland restoration and improve the mitigation of human disturbance in the YNR.

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Authors' Contributions
MC and YZ conceived and designed the study. All authors conducted field survey. XW and XS performed the satellite image interpretation. XW, MC and YZ wrote the article.

Key words
Red-crowned crane, habitat selection, multiple scales, variation partitioning

INTRODUCTION

Avian habitat selection has been found to be hierarchical, involving a range of organization levels from coarser to finer spatial scales (Johnson, 1980). A single scale may not accurately characterize bird-habitat relationships because species responses to the environment vary with the scale of observation. Instead, comprehensive investigation of these relationships must incorporate environmental variables at multiple spatial scales (Wien, 1989; Cushman and McGarigal, 2002). Furthermore, multicollinearity among explanatory variables across scales may result in the exclusion of more causal ecological variables from traditional multiple regression approaches (MacNally, 2000; Battin and Lawler, 2006). Such exclusion of variables could lead to distorted inferences regarding the relative importance of explanatory variables for bird habitat selection (Heikkinen *et al*., 2005). Variation partitioning methods have been shown to be useful tools to avoid these problems (Cushman and MaGarigal, 2004; Heikkinen *et al*., 2004; Lawler and Edwards, 2006). These methods can examine species–environment relationships by decomposing the variation in response variables into independent components that reflect the relative importance of individual predictors or groups of predictors and their joint effects (Heikkinen *et al*., 2005).

The red-crowned crane (*Grus japonensis*) is one of the most vulnerable migratory waterbird species and has a global wild population of less than 2,750 individuals (BirdLife International, 2012). The species has been listed as "Endangered" on the IUCN Red List of Threatened Species (IUCN, 2014) and has been classified as a national first-grade protected bird in China (Zheng and Wang, 1998). The red-crowned crane is a wetland specialist that prefers reed marsh and intertidal mudflat habitats, both of which have low vegetation cover,

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shallow water, abundant food and low levels of human disturbance (Ma *et al.*, 1999; Shu *et al.*, 2006). However, in recent years, many cranes have been forced to alter their habitat from natural grasslands to artificial wetlands due to the loss and deterioration of natural wetlands in the stopover and wintering areas as a result of increasing human disturbance (Su and Zou, 2012).

The Yancheng Nature Reserve (YNR) is the primary wintering area for the western migratory population of red-crowned cranes (Ma *et al*., 2000; Su and Zou, 2012). Previous studies have indicated that red-crowned cranes prefer tidal grasslands and fishponds, and avoid salt ponds, seepweed marsh and farmlands in the reserve (Ma *et al*., 1999). Moreover, food abundance, soil salinity, distance to roads, and land cover are considered to be the main limiting factors affecting red-crowned crane occurrence (Li *et al*., 1999). However, this reserve has undergone dramatic habitat changes due to natural and human disturbances (*e.g.*, smooth cordgrass invasion, reclamation) over the last two decades, which has likely altered crane habitat selection (Ma *et al*., 2009; Liu *et al*., 2013). Furthermore, no study has been made to consider the issue of cross-scale correlations among predictors or used multiple scale approaches to identify the independent and joint effects of habitat and spatial factors on the red-crowned crane. Therefore, the goals of this study are as follows: (1) analyze the temporal changes (from December to January) of habitat selection by the red-crowned cranes; (2) investigate the relative importance of plot, landscape and spatial factors on habitat selection by the red-crowned cranes.

MATERIALS AND METHODS

Study area

The YNR is located on the east coast of Jiangsu Province, China (32°48′47″—34°29′28″N, 119°53′45″—121°18′12″E) with a total area of 247,260 ha (Fig.1). Mean temperature in winter is about 4° and varies from -8° to 16°. Precipitation is between 70-100mm and small snow occurs occasionally in winter (December to February). The YNR was established in 1983 with the primary goal of protecting red-crowned cranes and their habitats. In 1992, the YNR was approved as an international biosphere reserve under UNESCO’s Man and the Biosphere Programme (MAB); in 2002, it was included on the Ramsar Convention list of Wetlands of International Importance. It is one of the world’s major wintering habitats for red-crowned cranes. However, the number of cranes in the reserve has undergone a serious population decline from over 1,100 in 2000 to less than 500 individual in 2009 (Lv, 2009; Su and Zou, 2012).This decline has been linked to extensive natural wetland loss and degradation due to tidal land reclamation for industrial and agricultural developments as well as the rapid expansion of alien smooth cordgrass (*Spartina alterniflora*) in the Yancheng coastal area (Ma *et al*., 2009; Sun and Liu, 2011; Wang, 2012; Liu *et al*., 2013).

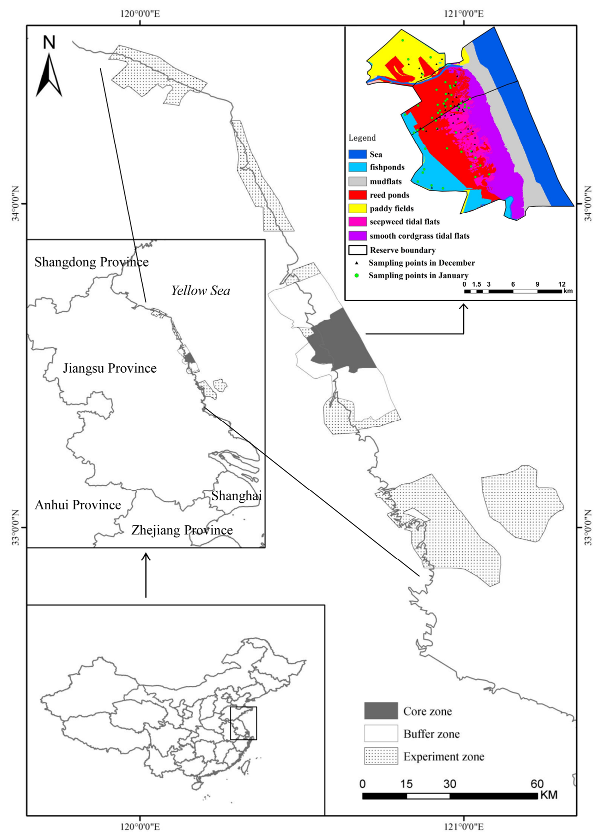

Fig. 1 Locations of Yancheng nature reserve.

Our study was consequently conducted in the core zone and northern part of buffer zones of the Reserve because nearly all population of red-crowned cranes over wintered in these areas in recent years (Lv, 2009). The major habitats include reed ponds, seepweed tidal flats, smooth cordgrass tidal flats, fishponds, paddy fields, and mudflats. Vegetation distribution patterns exhibit a clear gradient from the coast to the inland, and there is a significant difference between the northern and southern parts of the core zone. Mudflat – smooth cordgrass – common reed (*Phragmites communis*) is a dominant vegetation pattern in the northern part of the core zone, whereas mudflat – smooth cordgrass – common seepweed (*Suaeda salsa*) – common reed is typical in the southern core zone (Sun and Liu, 2011). The main habitat types of the northern part of the buffer zone are paddy fields and reed ponds that have been harvested during the cranes' wintering period.

Bird data

Red-crowned cranes migrate from northeastern China to the YNR in October and overwinter in the reserve until early March. However, the cranes' wintering population stabilizes in December and January (Ma *et al.*, 1999). Therefore, the red-crowned crane surveys were performed in December, 2013 and January, 2014. We conducted several regular route surveys by vehicle or on foot between 8:00 A.M. and 4:00 P.M. The survey was cancelled in the case of precipitation or strong winds to avoid the effect of extreme weather conditions (Li *et al.*, 2013). Surveys were not conducted more than once per day to avoid replicated sampling. Each transect was visited at least twice within each month. Binoculars (8×2) were used to detect red-crowned cranes along the transect. When cranes were observed or their calls were heard, provided that no impassable tidal channels or river barriers existed, we approached the birds and used GPS to accurately record their number and location. Based on these techniques, 40 and 51 abundance-sampling points were recorded in December 2013 and January 2014, respectively.

Environmental data

Environmental variables contained plot, landscape and spatial factors. The plot factors indicated the fine-scale features involving vegetation, shelters, water sources and human disturbance surrounding the crane sampling points. At each sampling site, we measured vegetation structure within a 30-m sampling circle from the survey point. We established 1 square area (1×1 m) at the center and 4 square areas (1×1 m) on the border of each sampling circle. In each square, we recorded the maximum vegetation height, vegetation coverage, and average coverage and height for common reed, common seepweed, smooth cordgrass and other plants. Then, we calculated the average values for each vegetation type across the 5 squares. We also estimated the minimum distance to the surrounding shelters, water sources and roads from the center of the crane sampling points.

Landscape factors characterized the landscape composition surrounding the crane sampling points. First, we combined the supervised classification and visual interpretation to generate a habitat map within the study area using a Landsat 8 image from April 11, 2013 (spatial resolution of 15 m). The main habitat types included reed ponds, seepweed tidal flats, smooth cordgrass tidal flats, fishponds, paddy fields, mudflats and residential areas. Next, we used the moving-window function in FRAGSTATS 4.0 to calculate the area percentage of each habitat type surrounding each sample point. Each habitat type was generated at seven spatial scales by shifting the moving-window size (50, 100, 200, 350, 500, 750, and 1,000 ha) (Cao *et al.*, 2011; MaGarigal *et al.*, 2012)

The spatial factors consisted of nine spatial variables constructed from the xy coordinates of each plot site. First, the xy coordinates of the sampling plots were centered on their means (Anderson and Gribble, 1998). Next, five higher and cross-product terms were calculated (x^2, xy, y^2, x^2y, xy^2) on the xy coordinates. Finally, each variable was divided by its standard deviation (Table I).

Statistical analysis

We used the Neu method (Neu *et al.*, 1974) to analyze crane habitat selection in December and January separately. The Neu method is one statistical approach to determine whether animals select or avoid a certain habitat type by comparing the degree of habitat utilization and availability. First, a Chi-square test was used to determine whether the cranes' habitat utilization was in accordance with habitat availability. Then, Bonferroni's Z analysis was used to calculate the confidence interval for the cranes' utilization of each habitat type. The mathematical formula is as follows:

$$\overline{P_i} - Z_{(1-\alpha/2K)} \times \sqrt{\overline{P_i}(1-\overline{P_i})\ /\ n} \le P \le \overline{P_i} + Z_{(1-\alpha/2K)} \times \sqrt{\overline{P_i}(1-\overline{P_i})\ /\ n}$$

Where $\overline{P_i}$ is the utilization of each habitat type; Z is statistics that can be found in a relevant statistical handbook; α is the significance level; K is the number of all comparable habitat types; and n is the sample size (i.e., the total number of cranes in the study area). This formula indicates that the cranes have no selection to one habitat type if its P value is within the confidence interval. This formula also indicates whether the cranes show positive or negative selection of one habitat type depending on whether its P value is on the left or right side of the confidence interval, respectively.

Variance partitioning is a quantitative statistical method by which the variation among dependent variables can be decomposed into independent components reflecting the relative importance of different groups of explanatory variables and their joint effects (Cushman and McGarigal, 2002). In this study, variation partitioning was used to decompose the explained variation in red-crowned crane abundance data among three factors: plot features (P), landscape composition (L) and spatial structure (S).

To avoid multicollinearity, in prior to variance partitioning, we first performed Spearman (two-sided) correlation analyses between any two variables within the plot data sets in two months. If the correlation coefficient between any two variables was >0.7, we retained the variable that explained the greatest deviance for analysis in univariate logistic models, resulting in final plot factors that consisted of eight plot variables (Table I). Second, we performed univariate logistic models for each landscape variable at seven spatial scales to select the scale that explained the greatest deviance in the seven models. The remaining landscape variables were entered into the same screening procedure at the plot scales. we then obtained five landscape variables for each month, respectively (Table I).Third, We use the 'bootStepAIC' package in R 3.1.2 to select the best model with fewer explanatory variables and the lowest AIC value at the plot and landscape scales by a bootstrapping and stepwise algorithm (Rizopoulos, 2009). We also considered adding the quadratic terms for the plot and landscape variables into the best models to account for potential curvilinear relationships between the crane abundance and predictor variables.

The selected plot and landscape variables in the best models, together with the seven spatial variables, were further used to conduct variance decomposition. We performed a series of (partial) multiple regression analyses to calculate the variance decomposition values among plot, spatial and landscape scales using the statistical package R 3.1.2 (R Development Core Team, 2012). The result of variation partitioning was decomposed into eight fractions: (a) the pure effect of plot features; (b) the pure effect of landscape composition; (c) the pure effect of spatial structure; and the combined variation due to joint effects of (d) the plot features and landscape composition; (e) the plot features and spatial structure; (f) the landscape composition and spatial structure; (g) the three groups of variables; and finally, (h) the unexplained variation (Fig. 2) (Heikkinen *et al.*, 2004).

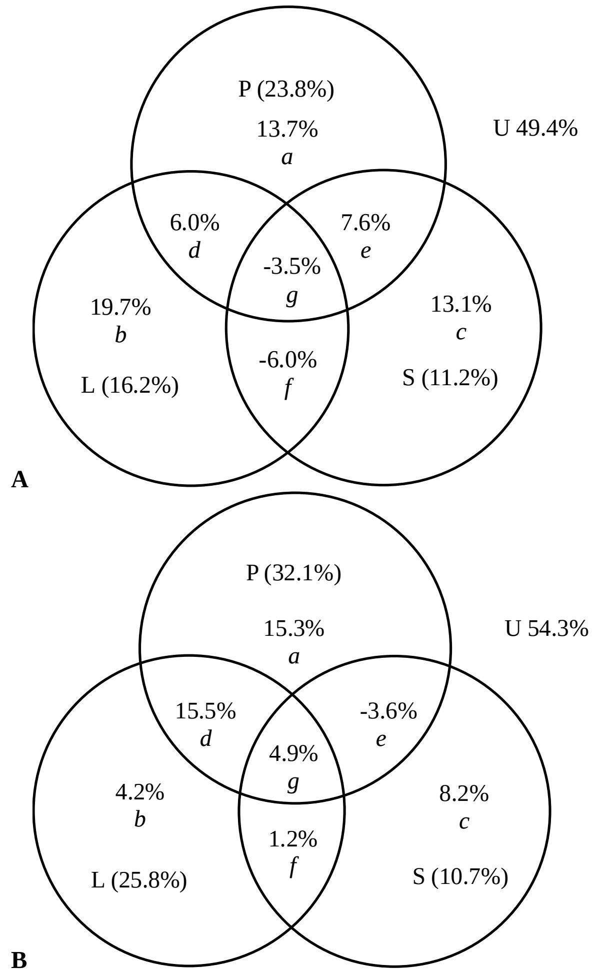

Fig. 2. Results of variation partitioning for the abundance of red-crowned crane for (A) December 2013 and (B) January 2014 in terms of variation explained. Variation of the cranes abundance data is explained by three groups of explanatory variables: P (plot feature), L (landscape composition) and S (spatial structure), and U is the undetermined variation. *a*, *b* and *c* are unique effects of plot feature and landscape composition and spatial structure, respectively, while *d*, *e*, *f* and *g* are fractions indicating their joint effects. Numbers with parentheses indicate the total effects of the three variables groups.

RESULTS

Habitat selection by red-crowned cranes

The total number of red-crowned cranes in the sampling points was 328 in December, 2013 and 298 in January, 2014. Most of cranes were concentrated in the seepweed tidal flats and reed ponds at the core zone and some others were distributed at the paddy fields at the northern part of buffer zone for two months (Table II, Table III). The number of cranes on seepweed tidal flats decreased sharply but increased substantially in reed ponds and fishponds, from December, 2013 to January, 2014 (Table II, Table III).

The cranes exhibited positive selection of seepweed tidal flats, no selection of paddy fields and avoided smooth cordgrass tidal flats and mudflats in the two months of study. Reed ponds were not selected by red-crowned cranes in December but were positively selected in January. Furthermore, red-crowned cranes exhibited negative selection of fishponds in December and no selection in January (Table II, Table III).

Table I. Descriptions of the microhabitat, landscape and spatial variables.

Variable/scale	Code	Description
Plot factors		
Maximum vegetation height	MVH	Maximum height of vegetation in an 30 m×30 m sampling circle
Vegetation coverage	VC	Total coverage of vegetation in an 30 m×30 m sampling circle
Reed coverage	RC	Average coverage of reed in an 30 m×30 m sampling circle
Seepweed coverage	SC	Average coverage of seep weed in an 30 m×30 m sampling circle
Smooth cordgrass coverage	CC	Average coverage of cordgrass in an 30 m×30 m sampling circle
Shelter distance	SD	Distance to the nearest shelters from the center of sampling circle
Water distance	WD	Distance to the nearest water sources from the center of sampling circle
Road distance	RD	Distance to the nearest roads from the center of sampling circle
Landscape factors		
Percentage of reed ponds	RPP	Percentage of reed ponds at a 500 ha scale in December and 750 ha in January
Percentage seepweed tidal flats	STP	Percentage of seepweed tidal flats at a 200 ha scale in December and 50 ha on January
Percentage of smooth cordgrass tidal flats	CTP	Percentage of smooth cordgrass tidal flats at a 1000 ha scale in December and 100 ha on January
Percentage of fishponds	FPP	Percentage of fishponds at a 100 ha scale in December and 100 ha in January
Percentage of paddy fields	PFP	Percentage of paddy fields at a 500 ha scale in December and 50 ha in January
Spatial factors $x, y, x^2, xy, xy^2, x^2y, xy^2$		Geographical coordinates of the sampling points, their quadratic and their cross-product terms

Table II.- Habitat selection of red-crowned crane in December, 2013.

Habitat type	Area /km^2	P_{i0}	Actual abundance of cranes	Mathematical expectation of the crane abundance	$\overline{P_i}$	Confidence interval (p<0.01)	Selectivity
Reed ponds	68.88	0.241	60	79	0.183	0.117, 0.249	No
Seepweed tidal flats	19.75	0.069	199	23	0.607	0.523, 0.691	Positive
Fishponds	26.81	0.094	7	31	0.021	-0.004, 0.046	Negative
Paddy fields	29.34	0.103	62	34	0.189	0.122, 0.214	No
Others	141.28	0.494	0	162	0.000		
Total	286.06	1.000	328	328	1.000		

P_{i0} indicates the availability of each habitat type; $\overline{P_i}$ indicates the utilization of each habitat type.

Variance partitioning

Vegetation coverage (VC) and its quadratic terms (VC^2), road distance (RD) and its quadratic terms (RD^2) were selected into the best plot model for two months. The coefficients of the variables indicated that VC was negatively associated with red-crowned crane abundance while RD was positively associated. Smooth cordgrass coverage (CC) showed a negative independent effect on crane abundance in December, but reed coverage (RC) showed a positive independent effect in January (Table IV).

Percentage of reed ponds (RPP) and the quadratic term of percentage of seepweed tidal flats (STP^2) were selected into the best landscape model and showed a positive independent effect for the two months. Percentage of paddy fields (PFP) and its quadratic term were also significant variables in December, whereas percentage of fishponds (FPP) was in January (Table V).

Plot, landscape, and spatial factors explained 50.6% of the variation in crane abundance data in December. Plot and landscape factors had the largest total effects (23.8%) and pure effects (19.7%), respectively, but spatial variables had the fewest total and pure effects (13.1%, 11.2%). The total pure effects of the three factors (46.5%) were clearly larger than the combined effects (4.1%) (Fig.2A).

Table III.- Habitat selection of red-crowned crane in January, 2014.

Habitat type	Area /km^2	P_{i0}	Actual abundance of cranes	Mathematical expectation of the crane abundance	$\overline{P_i}$	Confidence interval (p<0.01)	Selectivity
Reed ponds	68.88	0.241	151	72	0.507	0.417, 0.597	Positive
Seepweed tidal flats	19.75	0.069	66	21	0.221	0.147, 0.296	Positive
Fishponds	26.81	0.094	41	28	0.138	0.076, 0.200	No
Paddy fields	29.34	0.103	40	31	0.134	0.073, 0.195	No
Others	141.28	0.494	0	147	0.000		
Total	286.06	1.000	298	298	1.000		

P_{i0} indicates the availability of each habitat type; $\overline{P_i}$ indicates the utilization of each habitat type.

Table IV.- Variable parameters for the best plot model in December 2013 and January 2014.

	Variable	Standardized coefficient	t-value	p-value
December	Constant	0	1.104	0.2776
	VC	-0.488	-0.862	0.3946
	VC^2	0.861	1.489	0.1458
	CC	-0.324	-1.981	0.0557**.**
	RD	0.782	1.595	0.1200
	RD^2	-0.888	-1.822	0.0772.
January	Constant	0	1.098	0.27828
	VC	-1.569	-2.800	0.00757**
	VC^2	2.042	3.337	0.00173 **
	RC	1.825	3.176	0.00273**
	RC^2	-1.641	-3.076	0.00360**
	RD	1.095	2.490	0.01661*
	RD^2	-1.135	-2.565	0.01379*

Significant level: ***p< 0.001; **p< 0.01; *p< 0.05; **.**p< 0.1

Table V.- Variable parameters for the best landscape model in December 2013 and January 2014.

	Variable	Standardized coefficient	t-value	p-value
December	Constant	0	-0.599	0.5533
	RPP	0.437	1.661	0.1056
	STP^2	0.635	2.312	0.0268*
	PFP	1.573	2.084	0.0446 *
	PFP^2	-1.206	-1.762	0.0868.
January	Constant	0	3.293	0.00196**
	RPP	1.162	1.607	0.11519
	RPP^2	-1.695	-2.344	0.02367 *
	STP	-1.793	-2.786	0.00784**
	STP^2	1.233	2.129	0.03887 *
	FPP	-1.866	-3.395	0.00146**
	FPP^2	1.519	3.104	0.00333**

Significant level: ***p< 0.001; **p< 0.01; *p< 0.05; **.**p< 0.1

In January, all three factors explained 45.7% of the variation in crane abundance data. Plot factors accounted for the largest pure and total effects (15.3% and 32.1%).and increased compared to December. The pure effects of landscape factors (4.2%) decreased obviously and its total effects (25.8%) increased substantially compared to December. In addition, the total combined effects of the three factors (18.0%) increased in comparison to December (Fig.2B).

DISCUSSION

Avian habitat selection is a central issue in avian ecology (Jones, 2001; Battin and Lawler, 2006; Shao *et al*., 2015). Our habitat selection results indicated that the cranes' favorite habitat shifted from seepweed tidal flats to reed ponds and fishponds during the wintering period at YNR. This shift may have occurred because the seepweed tidal flats can provide better foraging habitat for the cranes because it had lower vegetation cover, more shallow water, and plenty of tender shoots and fruits. However, most artificial reeds and fishponds had not been harvested in December. Their denser vegetation coverage and deeper water areas might have hindered foraging by cranes, thereby reducing their foraging efficiency (Su and Zou, 2012; Cao *et al*., 2015). In January, most seepweeds were dead, while the reed ponds were harvested and fishponds were nearly drained, which would have created a suitable feeding habitat with plenty of reed tubers, fish and invertebrates for the cranes (Lv, 2007).

Our habitat selection results exhibited some differences with the results of Ma *et al.* (1999); they found that red-crowned cranes exhibited positive selection of tidal grasslands and fishponds, no selection of reed ponds, and negative selection of salt works, seepweed tidal flats and wheat fields in the late 20th century. These discrepancies may be explained by the fact that the natural wetlands having undergone significant changes due to tidal land reclamation and the rapid expansion of alien smooth cordgrass in the YNR (Lv, 2009; Liu *et al*., 2013). For example, the tidal grassland is now mainly replaced by reed ponds and cordgrass tidal flats due to an artificial wetland construction project and the invasion by alien smooth cordgrass in recent years. The cranes had to change their habitat selection to adapt to this habitat change (Feng *et al*., 2007).

Identifying the spatial scales at which birds respond most strongly to environmental variables would help to clarify and explain the processes determining bird abundance or occurrence (Wiens, 1989; Pennington and Blair, 2011). Our variance partitioning results revealed that more total variation in crane abundance data could be explained at the plot scale than at the landscape scale. This finding is inconsistent with the results obtained by Cao *et al*. (2011), who collected crane occurrence data in the Yellow River Delta Nature Reserve and found that landscape factors had larger effects on red-crowned cranes than plot factors. This difference may occur because the red-crowned crane is a larger-sized, rare species, a larger-scale landscape pattern (*e.g*., vegetation composition) would be a more important predictor of bird distribution in presence/absence data, whereas fine-scale plot factors (*e.g.*, food abundance) would be more important for determining bird abundance (Cushman and McGarigal, 2004; Heikkinen *et al*., 2004; Fletcher and Hutto, 2008; Thornton *et al*., 2011). Our results also indicated that the pure and total effect of plot factors increased from December to January. This increased effect may be due to the colder weather (lower temperature, fewer Precipitations and frozen ground) and less food in January (Lv and Chen, 2006). The cranes were forced to increase their feeding efficiency to find more available food sources at the plot scale.

Spatial structure should not be overlooked in the habitat selection of red-crowned cranes. A spatial structure in bird abundance/occurrence may actually reflect the distribution of the birds' preferred/avoided habitats or bird aggregation distribution (Siriwardena *et al*., 2000; Heikkinen *et al*., 2004). Our results indicated that the spatial structure in December accounted for larger independent effects on crane abundance than in January. This is not surprising since the cranes seldom feed and rest in the reed ponds and fish ponds due to the harvest of reed ponds and fishponds in December. This intense human disturbance may induce the cranes to find food in a more clustered area of preferred habitat (mostly in seepweed tidal flats) and exhibit a more clustered distribution pattern in December.

Our best plot model indicated that vegetation coverage and road distance were the most important plot factors that determine crane abundance during the wintering period. This was consistent with previous studies indicating that cranes prefer foraging sites with low vegetation cover and small human disturbance (Shu *et al*., 2006). This preference might exist because cranes are large wading birds with body lengths greater than 120 cm, for which denser vegetation coverage might prevent the birds from finding food, thereby reduce their foraging efficiency. Shorter distances from human activity also reduce the species' foraging efficiency due to increased vigilance behavior (Li, 2011). Our best landscape model showed that percentage of reed ponds and percentage of seepweed tidal flats were crucial factors in both months, whereas percentage of paddy fields and percentage of fishponds were also important in December and January, respectively. This confirms the crane habitat selection results; it is also similar to the results from Liu *et al.* (2013), who found that reed ponds, seepweed tidal flats and paddy fields had positive effects on the cranes during wintering periods.

Our results confirmed that a multi-scale approach can provide more comprehensive support than other methods for developing a protection strategy for the red-crowned crane. We propose strengthening the protection of the red-crowned crane and their habitat in the YNR as follows. First, reserve managers should strengthen the restoration and irrigation of degraded seepweed tidal flats in the southern part of core zone, which is an important wintering habitat for red-crowned cranes. Second, we propose the reasonable management of artificial lands (farmlands, reed ponds and fishponds) to supply more available food sources for red-crowned crane during the wintering periods (*e.g*., having an earlier harvest of reed ponds, artificial feeding in paddy fields, and draining off water from fishponds). Third, we propose the strict management of human disturbance and effective measures to minimize the negative effects of harvest of reed ponds, fishponds and paddy fields.

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