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Scale Differences in the Dependence of Seasonal Bird Diversity on Landscape Structure: A Case Study in Northeastern China

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Authors' Contribution
ML, JW and SH designed the experiments and collected the data. GJ conceived the study and helped in designing the experiments. ML, JW and SH wrote the manuscript with the help of HB, HL, PS and DC. BL and LL helped in field survey.

Key words
Scale dependence, Bird diversity, Landscape structure, Wetland.

ABSTRACT

Wildlife interact with environmental variables at different spatial scales. We undertook point counts of birds in the Xianghai wetland reserve of northeastern China from 2000 to 2009, and used remote sensing and GIS technologies to map land cover types. We linked cover types to avian species richness, evenness, and Shannon's diversity using a stepwise linear regression model and regressions of proportions of cover types at different spatial scales. We recorded 109,026 sightings comprising 94 species, and found that avian diversity indices were positively influenced by the presence of open water, farmland, and alkaline marsh, and negatively by human settlement; and in addition, these relationships were only apparent when scale was considered. We detected the dependence of the avian assemblage on alkaline marshes and open water, which in turn might depend on incoming flows of water. We also found negative relationship between human settlements and bird diversity which extended to a distance of 3 km. Consequently, we provide evidence of significant scale dependence on landscape structure of wetland bird diversity. Therefore, scalar effects of different habitat variables need to be taken into account when managing wetland bird populations with the aim of conserving avian biodiversity.

INTRODUCTION

Scale is a key concept in ecology studies (Cunningham *et al*., 2014). Consideration of scale takes into account the spatial extent of ecological processes and enables interpretation of spatial data at different levels of granularity (Levin, 1992; Chave, 2013). Because species interact with environmental variations at different scales (Allen and Starr, 1982; Urban *et al*., 1987; Wu, 1999; Turner, 1989), spatial scaling is fundamental to all ecological research (Wiens, 1989). Most of our knowledge of habitat use by birds comes from studies carried out at single, small spatial scales (Buler *et al*., 2007), but differences in body size, nesting, home range and foraging requirements among different species suggest that different taxa are likely to respond to the environment at different spatial scales (Carignan and Villard, 2002; Chave, 2013; Cunningham *et al*., 2014). General rules of the effects of changing scale on landscape metrics were sought by Wu *et al*. (2002) who investigated how a suite of commonly used landscape metrics responded to changing grain size, extent, and the direction of analysis in several different landscapes in North America. In a more specific study of the effects of scale, the impact of urban developments on the avian assemblages of adjacent coastal marshes was examined by DeLuca *et al*. (2004), which identified negative effects on marsh bird community integrity of differing densities of urban development at different scales, and in largely rural

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areas. Road density has been shown to influence wetland bird assemblages at a finer scale (Whited *et al.*, 2000), but in that study connectness between wetland areas was more important at a coarser scale. In attempting to understand natural mechanisms influencing biodiversity, failures to take account of human activities are fraught, because human impacts are now often integral components of ecosystem processes, and may have different influences at different levels of scale (Fletcher and Hutto, 2008).

Such wetlands are among the world's most threatened and fragile ecosystems and more than half of the world's wetlands have disappeared during the past century (IPCC, 2001). Most natural wetlands are under intense pressure from encroaching human activities (Froneman *et al.*, 2001; Turner *et al.*, 2000), from land cover changes to climate change (Liu *et al.*, 2011), or both. Birds are highly mobile, and for this reason, they can be used as monitors to provide objective biological indices of the qualities of wetland environments. Their mobility also means that a landscape perspective including consideration of the effects of scale is pertinent to the derivation of effective conservation measures for wetlands.

China is rich in wetland bird species. Of 57 species of endangered birds in Asia, 31 species inhabit wetlands in China (Liu, 2005). Questions about habitat quality are particularly relevant in the far northeast of China where wetland degradation on the Songnen (Han *et al.*, 2007; Wang *et al.*, 2009a) and Sanjiang Plains (Liu *et al.*, 2004; Zhang *et al.*, 2009), the largest concentrated area of freshwater wetlands in China, affects habitat availability for endangered waterbird species (Wang *et al.*, 2006). Wetlands in Northeastern China are known to be stopover or breeding sites for migrating cranes (Higuchi *et al.*, 2004) and other waterbirds such as curlews (Ueta *et al.*, 2002) and storks (Shimazaki *et al.*, 2004). Despite the fact that natural wetland landscapes are the main habitats for wetland bird species, farmland is amongst the favorite foraging habitats for some avian species (Amano, 2009; Lee *et al.*, 2007). Consequently, our hypothesis is that different land cover factors will play different roles in maintaining waterbird biodiversity at different scalar extents, providing heterogeneous conditions for selective exploitation by different species. In this study, we addressed the following questions: 1) Does wetland bird species diversity depend on types and extent of land-use? 2) Are there scale-dependent effects based on landscape composition? 3) What management measures would maintain habitat quality for waterbirds in wetlands?

MATERIALS AND METHODS

Study area

This study focused on the Xianghai National Nature Reserve (XHNR), a c. 1000 km^2 area of Ramsar Convention wetlands on the Songnen Plain, ranging from 44°50' N to 45°19' N, from 122°05' E to 122°35' E, located in Baicheng Prefecture, Jilin Province of China (Fig. 1). Temperatures range from −32 ^{O}C to +37 ^{O}C, and given that the annual precipitation is c. 338 mm, the region is semiarid. However, the reserve is an inland delta for the Huolin River which enters the XHNR in its southwestern corner. Because it is located in a semiarid area, XHNR plays an important role in harbouring local wetland bird species. In addition, there are many kinds of wetland landscapes in XHNR that provide a diversity of habitats and therefore attract a diversity of bird species. The reserve was designated as a national nature reserve in 1981 with the aim of protecting an important breeding site for red-crowned crane (*Grus japonensis*) (Xu *et al.*, 2005). It also supports other rare birds such as white-naped (*Grus vipio*), and demoiselle (*G. virgo*) cranes, the Oriental white stork (*Ciconia boyciana*), and great bustard (*Otis tarda*). In addition, it is one of the most important stopover sites for the Siberian (*G. leucogeranus*), hooded (*G. monacha*), and common (*G. grus*) cranes (Fan *et al.*, 1994). However, between the years 2000 and 2009, the number of breeding pairs of red-crowned cranes, the flagship species for the XHNR, decreased from c. 20 to none and the one stork that used to nest disappeared, indicating that conservation and recovery of the XHNR wetland landscape is a challenge that must be faced if obligations to conserve water bird biodiversity under the Ramsar Convention are to be met.

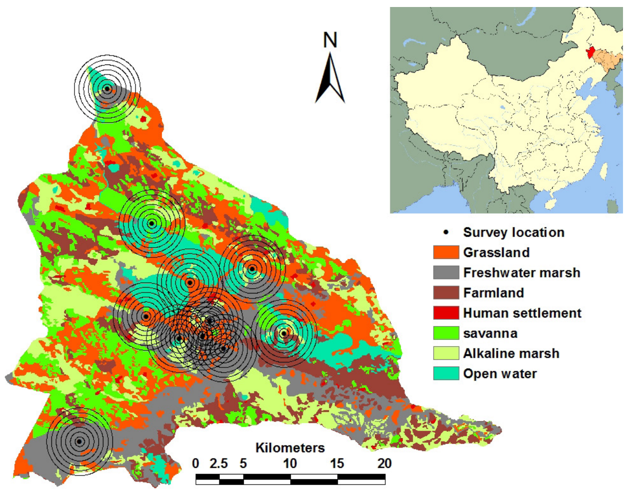

Fig. 1. Land cover types, locations of the bird count points (circle centres) and concentric disc-shaped land cover assessment areas in Xianghai National Nature Reserve.

Bird species and land cover survey

In 2000, we established eleven point count stations for the purpose of monitoring the birds using the wetland areas of the reserve, covering the areas typically used by aquatic birds in the XHNR. At each station, counts of numbers of each visible bird species were taken by two experienced observers at each survey event using binoculars, overflying birds being included. In the years 2000, 2001 (spring), 2005 to 2007, 2008 (autumn) and 2009 (spring), counts were conducted at most stations between sunrise and 4 h after sunrise and between May and June, and also September and October. In most years, four counts were regularly spaced within a season except that planned counts were cancelled during rain or winds exceeding 20 km hr^{-1}. The total number of counts was 330. The duration of each visual count was ten minutes (Fuller and Langslow, 1984), and immediately after that, the calls of secretive species were broadcasted and responses counted. We recorded all bird species however detected. Richness was defined as the number of bird species detected at the time of the survey (Spellerberg and Fedor, 2003), and diversity was measured using the Shannon's diversity (Krebs, 1989). Evenness was measured according to Molinari (1989).

We used Landsat Thematic Mapper (TM) datasets in May 2000 and July 2009 with 30 m resolution for the study area (http://datamirror.csdb.cn/index.jsp). Then, we interpreted the TM remote sensing images with Etdas, and through field validation, six categories of land cover were classified, namely grassland, farmland, savanna, marshland, open water, and human settlement. Marshland was then further partitioned into freshwater marsh and alkaline marsh. Human settlement included both villages and the reserve's tourism and management centers; savanna mainly included natural Mongolian yellow elm (*Ulmus macrocarpa* var. *mongolica, Ulmus pumila*) forest, the dominant plant species of the reserve's grasslands include *Leymus chinensis, Artemisia anethifolia* and *Setaria viridis*; the main crops grown on the farmlands are sunflowers and watermelons, with some maize and mung beans. Cattle are grazed on the harvested farmlands, and illegally on the grasslands and in the Mongolian yellow elm forest. Wetland reeds are harvested for sale to a paper mill. ArcGIS 9.3 was used for the landscape spatial analysis.

Statistics and analysis

To establish extraction buffers, a layer of concentric disc-shaped survey areas centred on each bird survey point and with the radii of the bounding circles increasing at 500 m intervals up to 3500 m was incorporated into the map. The proportion (%) of each land cover type within each circle was calculated as habitat variables. Subsequently, we focused specifically on the responses of bird species diversity to landscape structure by even partitioning each habitat type to "low", "middle", or "high" level based on the proportion of the total area at each scale represented by that habitat type (Table I), with the upper limit of the "high" range set at the maximum proportion of that habitat type within any of the survey areas at the nominated scale.

We used Mann–Whitney U-test statistics and bootstrap 95% Confidence Interval (CI) methods to compare measures of bird diversity between seasons (spring versus autumn).We calculated the indices of the year through the combined spring and autumn data. We undertook analyses of stepwise linear regression model to explore whether there were significant effects of specific scalar land cover variables on bird diversity, and how the biodiversity response to the increasing of scale at the different proportions of land cover type area within the areas of the buffer circles, then, we selected the models of statistical significance and biological significance as the best model. To avoid spatial auto-correlation, we randomly selected 25% of the primary data for analysis.

Table I.- Ranges of proportions used to assign each land cover type as high, middle, or low. The highest value for each habitat at each scale was the maximum proportion of that habitat at any site at any scale.

	Scale (m)	Low (%)	Middle (%)	High (%)
Open water				
	500	0 - 15	15 - 31	31 - 46
	1000	0 - 15	15 - 30	30 - 45
	1500	0 - 13	13 - 27	27 - 40
	2000	0 - 16	16 - 33	33 - 48
	2500	0 - 18	18 - 35	35 - 53
	3000	0 - 18	18 - 37	37 - 55
	3500	0 - 18	18 - 37	37 - 55
Farmland				
	500	0 - 5	5 - 10	10 - 15
	1000	0 - 10	10 - 19	19 - 29
	1500	0 - 8	8 - 15	15 - 23
	2000	0 - 7	7 - 13	13 - 20
	2500	0 - 7	7 - 15	15 - 22
	3000	0 - 8	8 - 16	16 - 24
	3500	0 - 8	8 - 17	17 - 25
Alkaline marsh				
	500	0 - 25	25 - 49	49 - 74
	1000	0 - 12	12 - 25	25 - 37
	1500	0 - 9	9 - 18	18 - 27
	2000	0 - 6	6 - 13	13 - 19
	2500	0 - 7	7 - 13	13 - 20
	3000	0 - 7	7 - 13	13 - 20
	3500	0 - 6	6 -13	13 - 19

RESULTS

Bird species and diversity index

The total number of individual sightings was 109,026 comprising 94 species (Supplementary Table I) from 22 families. The assemblage was dominated by taiga bean (*Anser fabalis*), greater white-fronted (*A. albifrons*), and swan geese (*A. cygnoides*), mallard (*Anas platyrhynchos*), northern lapwing (*Vanellus vanellus*), and common pochard (*Aythya ferina*), together representing 60% of all sightings. One critically endangered species: Siberian crane; three endangered species: oriental stork, Baer's pochard (*Aythya baeri*), and red-crowned crane; and six vulnerable species: lesser white-fronted (*Anser erythropus*) and swan geese, white-naped and hooded cranes, great bustard, and eastern imperial eagle (*Aquila heliaca*), were sighted. Mean number of sightings was higher in autumn (12,836 ± 10,403) than in spring (7475 ± 4095), but the difference was not significant (paired sample t-test, $P > 0.05$). We calculated the bird species diversity indices of each count station in spring and autumn. Mean richness was much higher in spring than in autumn, but no significant difference between seasons in either mean evenness or Shannon's diversity was detected (Table II).

Table II.- Seasonal comparison of mean bird biodiversity measures (mean ± SE) in the Xianghai National Nature Reserve from the year 2000 to 2009.

	Evenness	Richness	Shannon index
Spring (n=48)	0.647±0.03	0.083±0.018	2.142±0.16
Autumn(n=33)	0.651±0.06	0.023±0.005	2.045±0.19
Mann-Whitney U	636	422	741
P	0.486	<0.001	0.637

Table III.- Land cover composition in the Xianghai National Nature Reserve.

Land cover	Total area (ha)	Number of patches	Mean patch area (ha)	Median patch area (ha)
Open water	10629.6	37	287.3	21.1
Freshwater marsh	20627.9	44	468.8	28.4
Alkaline marsh	18518.2	137	135.2	23.9
Grassland	25782.0	203	127.0	20.1
Savanna	17198.0	250	68.8	15.3
Farmland	15701.6	115	136.5	17.5
Human settlement	788.9	39	20.2	16.7

Effects of multiple scalar land cover types

All of the land cover types in the study site, except human settlements, were represented by a small number of very large patches among many small patches, which were more even in size. With an area of 25,782 ha, grassland (23.60%) represented the largest proportion of land cover, and then in sequence were freshwater marsh, alkaline marsh, savanna, farmland and open water. Human settlement proportion made up less than 1%, covering an area of 788.9 ha (Table III).

Table IV.- Significant linear relationships between measures of bird diversity (Evenness, Richness and Shannon index) and land cover area variables with a scale (500, 2500, 3000 and 3500m) and season (year, spring and auttumn) in the Xianghai National Nature Reserve.

Model effects	Slope ± SE	F	t	P
Evenness				
Year (f =1,74)				
Farmland-3500	1.202 ± 0.478	6.32	2.51	0.014
Spring (f =1, 42)				
Alkaline marsh-es-500	0.343 ± 0.156	4.85	2.20	0.03
Richness				
Year (f = 1, 79)				
Alkaline marsh-es-3500	0.659 ± 0.247	7.13	2.67	0.009
Spring (f = 1,46)				
Alkaline marsh-es-3500	1.131 ± 0.391	8.36	2.89	0.006
Autumn (f = 1,31)				
Farmland-2500	0.385 ± 0.101	7.55	3.83	0.001
Open water-500	0.071 ± 0.026	8.10	2.67	0.01
Shannon index				
Year (f=1, 79)				
Farmland-3500	4.969 ± 1.727	8.27	2.87	0.005
Spring (f=1, 46)				
Farmland-3500	5.228 ± 2.216	5.56	2.35	0.02
Autumn (f=1, 31)				
Settlement-3000	-44.781 ± 19.895	5.05	-2.24	0.03

The stepwise linear regression model indicated that the presence of farmland was significantly positive associated with yearly evenness, autumn richness and yearly/spring Shannon's diversity at the broader scales of 2500 and 3500 m, whereas the presence of alkaline marshes was positively associated only with spring evenness at the smaller scale of 500 m and yearly/spring richness at the broader scale of 3500 m. There was a negative relationship between Shannon's diversity in autumn and human settlement at the scale of 3000 m. Significant associations between farmland and the bird diversity only occurred at broader scales (2500 and 3500 m), but the significant association between open water and autumn richness only occurred at the 500 m scale (Table IV).

Effects of increasing spatial scales

We demonstrated that significant correlations between scale and all three biodiversity indices occurred if the landscape comprised a high proportion (13% ~ 55%) of open water (Fig. 2). Spring evenness and Shannon's diversity increased with an increase in scale (Fig. 2c). However, autumn evenness (Fig. 2c), richness (Fig. 2f), and yearly/autumn Shannon's diversity (Fig. 2i) decreased with increasing scale.

When farmland represented a low (0 ~ 8%) proportion of landscape cover, significant negative relationships between scale and both evenness and Shannon's diversity were evident in all seasons (Figs. 3a, g). Furthermore, autumn richness significantly decreased with increasing scale at both low and middle proportions of farmland (Figs. 3d, e).

Our results indicated a significant positive relationships between scale and both yearly/spring evenness and Shannon's diversity when there were middle proportions of alkaline marsh (6% ~ 25%) in the landscape (Figs. 4b, h), but there were negative relationships when there were high proportions (6% ~ 74%) (Figs. 4c, i). Similarly, a significant negative relationship between scale and yearly/spring richness occurred if there were low proportions of alkaline marsh (0% ~ 25%) in the landscape; however, the reverse was found if there were high proportions of alkaline marsh (6% ~ 74%). Conversely, a significant negative relationship between scale and autumn richness was evident if there were high proportions of alkaline marshes in the landscape (Fig. 4f).

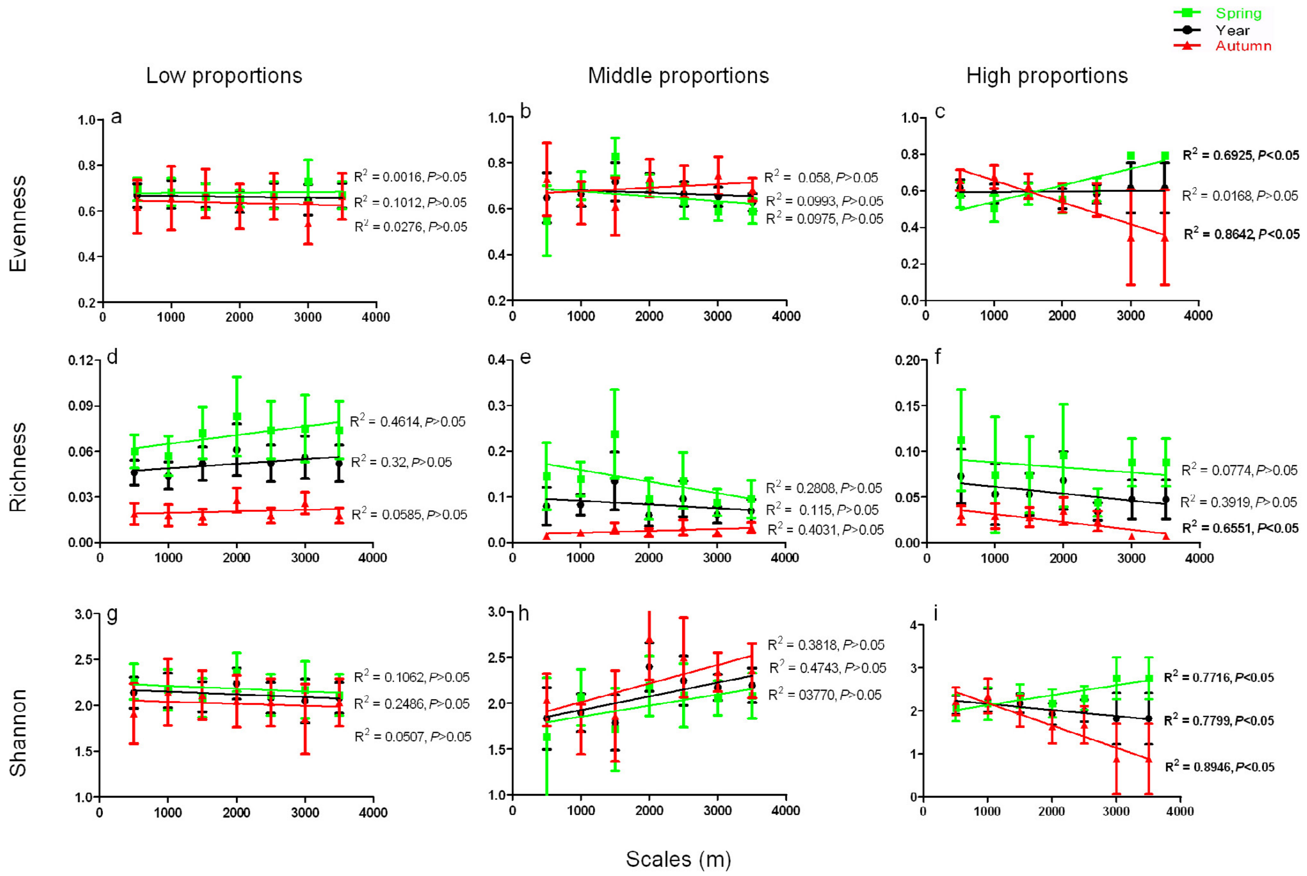

Fig. 2. Response of seasonal bird species diversity to increasing spatial scales with proportion gradient of open water area in Xianghai National Nature Reserve.

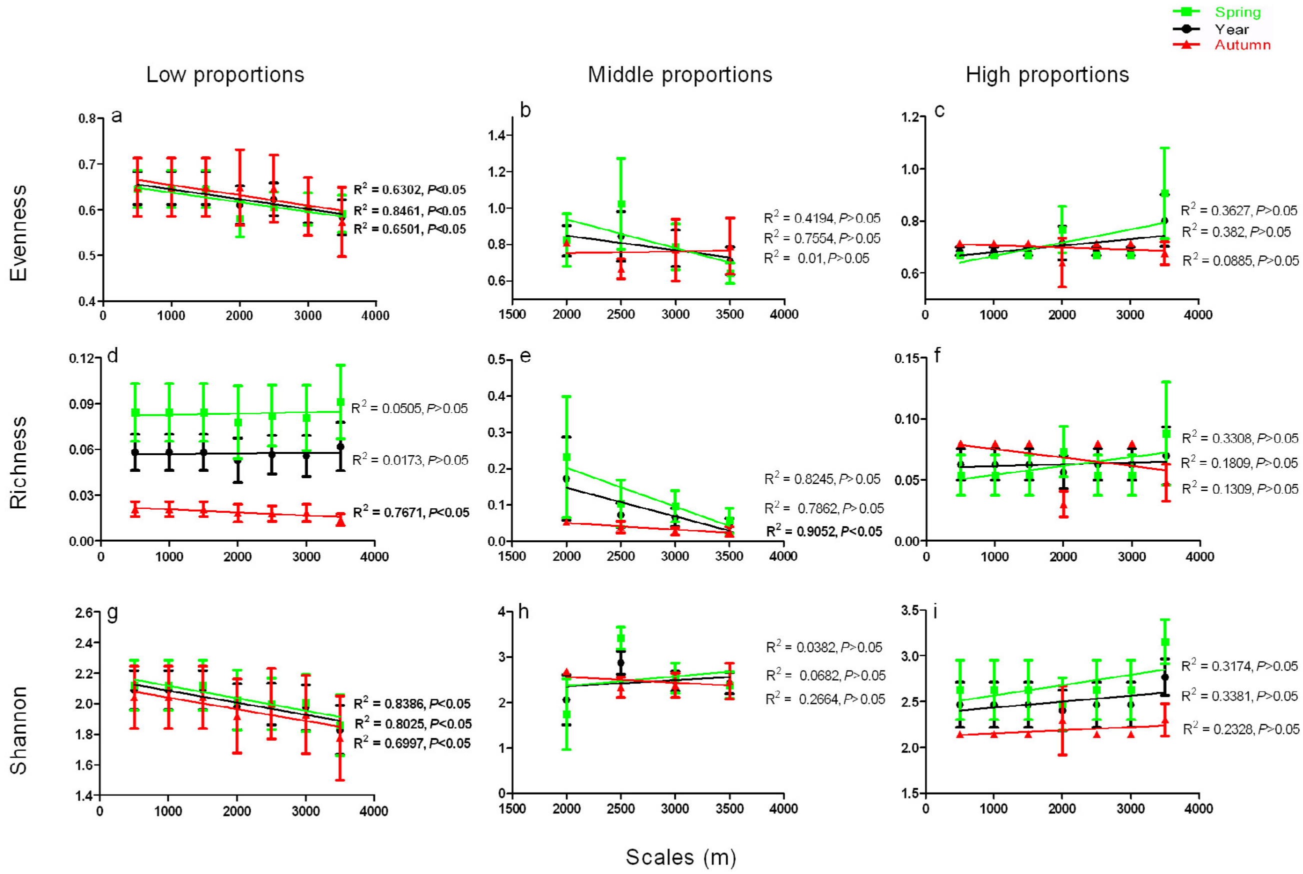

Fig. 3. Response of seasonal bird species diversity to increasing spatial scales with proportion gradient of farmland area in Xianghai National Nature Reserve.

DISCUSSION

Effect of open water

At most spatial scales, no the proportion of open water in the landscape did not influence the diversity of the bird assemblage. However, the significant positive relationship between open water within 500 m of the count stations and evenness occurred because of the presence of the more highly aquatic species, which were more likely to be encompassed in the counts. Buffer circles containing high proportions of water were unrepresentative of the XHNR, and in spring a high proportion of open water in the landscape resulted in species that were less disparate in numbers, although it did not attract a greater range of species. Conversely, in autumn, high proportions of open water in the landscape diminished the number of species at a time when the species were more disparate in numbers of individuals and diversity was lower. Firstly, we attributed the seasonal difference in evenness to the habitat preference of the species and a skew between their abundances and their degree of dependence on open water. For example, the mallard was the third most abundant bird in our counts the mallard have large broods (Lu, 2011), and a high proportion of open water in the landscape is important for mallard brood survival (Dzus and Clark, 1998), whereas crane species are more terrestrial, and mean clutch sizes for the cranes are typically under 2 (e.g., *Grus leucogeranus*, Degtyarev and Labutin, 1999). The two most abundant species at our site also had brood sizes higher than those of the cranes (e.g., *Anser fabalis,* Degtyarev *et al*., 2008; *Anser albifrons*, Ely *et al*., 2007). Secondly, seasonal differences between migratory routes, the number of stopovers en route, and the arrival and departure times from particular stopovers have been demonstrated for many species of migratory birds (Battley and Piersma, 2005; Gill *et al*., 2006; Ma *et al*., 2002), together with age differences (Ge *et al*., 2006). For example, Siberian cranes use multiple wetland sites around XHNR in the Qiqihar-Baicheng region as stopover points (Kanai *et al*., 2002). Consequently, life history strategy and migration

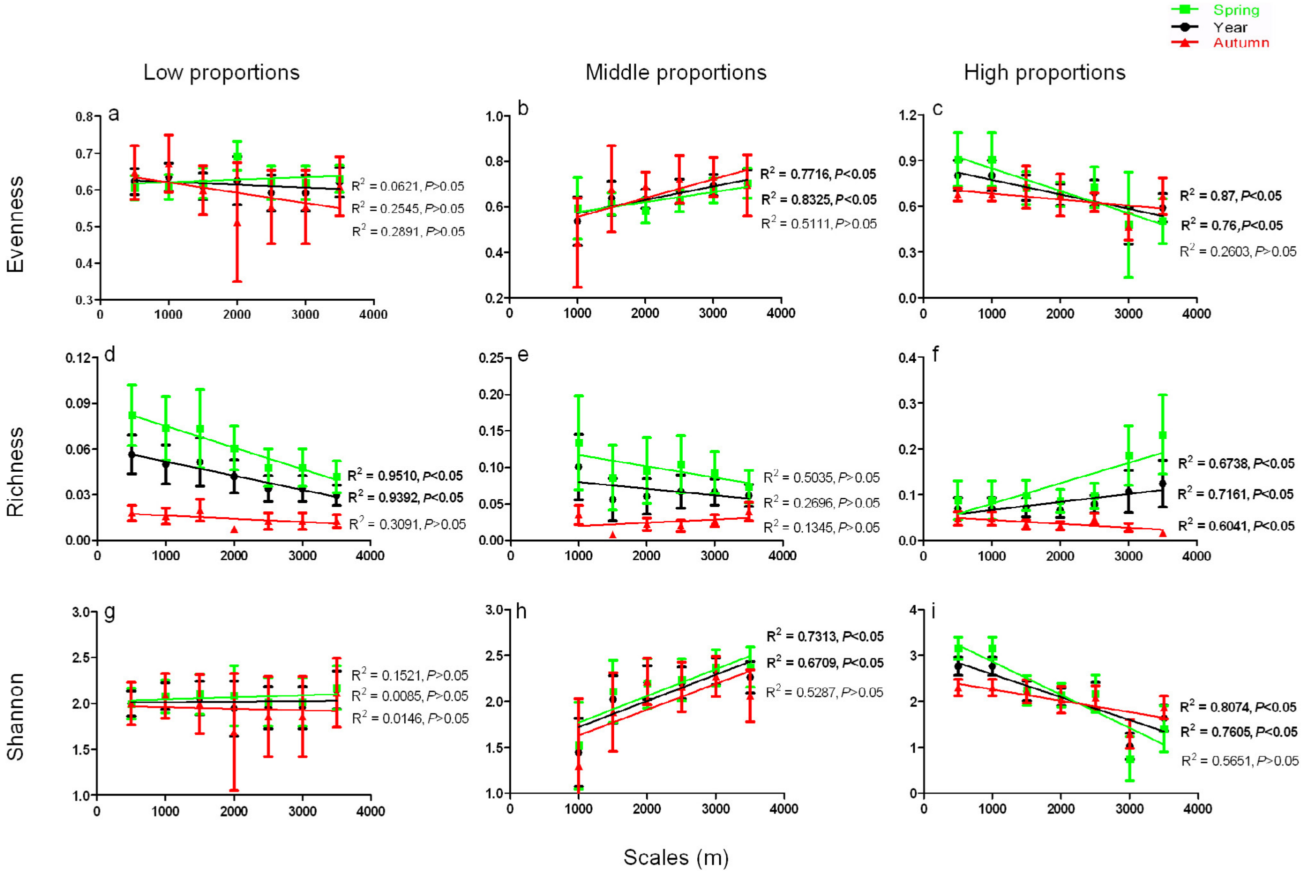

Fig. 4. Response of seasonal bird species diversity to increasing spatial scales with proportion gradient of alkaline marsh area in Xianghai National Nature Reserve.

adaptation may explain the seasonal differences in mean richness in XHNR, and positive relationship between open water and both evenness and Shannon's diversity at the landscape scale in spring, but negative relationship in autumn (Fig. 2 c, i).

Effects of farmland and settlements

Our results revealed that the presence of farmland was significantly positively associated with yearly evenness, autumn richness and yearly/spring Shannon's diversity at the broader scales of 2500 and 3500 m. Many species referred to as "waterbirds" roost in water but obtaining a substantial proportion of their food from terrestrial habitats (Hahn *et al*., 2008), which in the XHNR were represented by grassland, savanna, and farmland. The association between the composition of the avian assemblage and XHNR grassland may have been lacking because the grassland has been degraded due to overgrazing, a widespread problem in this region (Wang *et al*., 2011). The close association with farmland may be due to general factors such as an increase in the availability of earthworms for northern lapwings *Vanellus vanellus* (Gillings and Sutherland, 2007) or to specific factors such as sunflower and mung bean cropping making foraging for seeds on farmland more efficient than foraging for seeds in native grasslands (Moreno *et al*., 2011; Wiryawan *et al*., 1997). Geese and cranes, in particular, have been shown to depend on high-energy food sources available on farmland such as recently-sown seed corn (Aviles *et al*., 2002) and residues of corn (Anteau *et al*., 2011) left on the ground because of the inefficiencies associated with harvesting. The importance of the farmland to the avian assemblage would also depend on the stage of the cropping cycle (i.e., season) (Gillings *et al*., 2007; Lee *et al*., 2007). It is also likely that seasonal heterogeneity within the farmland would be associated with higher richness, just as the case in France (Devictor and Jiguet, 2007).

In this study, we also found that significant negative relationship between scale and both evenness and Shannon's diversity were shown with 0~8% of farmland cover. The value of the farmland would also depend on its distance from roosting or nesting sites. For example, research demonstrated that golden plover (*Pluvialis apricaria*) foraged on farmland 1.1-3.7 km away from nesting sites and was highly selective of the foraging sites (Whittingham *et al*., 2000), suggesting that resources on farmland were patchily distributed, that the efficiency of foraging was important, and that longer foraging distances were energetically too expensive. Hence, the value of farmlands to avian diversity in XHNR was likely not only a function of the food resources provided by the farmlands, but also the proportion of farmlands in the landscape and the proximity of the farmlands to roosting sites.

Effects of alkaline marshes

The presence of alkaline marshes in the landscape, such as the presence of farmland, attracted birds to the XHNR in spring. Alkaline bodies of water are good foraging environments for aquatic birds because they contain abundant food in the form of small crustaceans, hemipterans, coleopterans (Hancock and Timms, 2002) or larval dipterids (Alcocer *et al*., 2001; Cartier *et al*., 2011), particularly in the absence of fish as competitors (Boros *et al*., 2006), and the adult diet of a number of avian species present at XHNR comprises high proportions of small halophilic invertebrates (Vest and Conover, 2011; Ueng *et al*., 2009). A wider range of species depend on small halophilic invertebrates to provide high protein foods for hatchlings (Aguilera *et al*., 1996; Szalay *et al*., 2003; Dessborn *et al*., 2011).

Geese graze in saltmarsh environments (Rozenfeld *et al*., 2010; Fox and Kahlert, 2003; Dormann and Bakker, 2000). In spring, greater white-fronted geese consume new plant growth of high protein content (Ely and Raveling, 2011) to meet requirements for reproduction (Schmutz *et al*., 2006), but in autumn, they need to accumulate the energy reserves required to fuel migration, and as a consequence, the diet comprises mostly seeds (Ely and Raveling, 2011), most sources of which are found away from alkaline marshes. *Phragmites australis* is grazed by geese (Markkola *et al*., 2003), but there was a negative association between pH and cover of *P. australis* and a positive association between *P. australis* cover and wetland bird species richness (Cui, 2009), which indicated that avian diversity is vulnerable to the ongoing process of increasing alkalinisation in the Songnen Plain (Wang *et al*., 2009b).

Flocking behaviour will influence measures of bird diversity, and flock sizes in some species e.g. mallards (Randler, 2004) vary greatly. In the region, a significant increase in avian species richness in spring coincided with a slight decrease in the Shannon's diversity, suggesting a relationship between the flock size and the presence of alkaline marshes. Mixed species aggregations have been observed in waders (Ogden *et al*., 2008), implying mutual attraction, which would also influence measures of bird diversity (Stolen *et al*., 2007). Such flocking behaviour from a minor species in an assemblage will be detected in measures of avian diversity as an increase in both richness and the Shannon's diversity, which assigns more weight to rare or less abundant species (Krebs, 1989).

Effect of scale

We were well aware that spatial heterogeneity is scale-dependent and hanging grain size or extent often affect landscape metrics. King (1991) propounded four methods of upscaling: lumping, direct extrapolation, extrapolation by expected value, and explicit integration. Wu (1999) presented a hierarchical scaling strategy of hierarchical patch dynamics paradigm. But the most effective method of scaling was combined with field survey, experiment and model for many complex problems (Wu, 2006). The mobility of birds enabled them to exploit resources at landscape scale. The presence of diverse bodies of open water, multiple alkaline marsh and farmland areas in the landscape would foster differences in composition and abundance of the species of invertebrates, grass and crop seeds making up the communities of the different habitat types, which in turn would benefit the avian assemblage by accommodating bird species with different dietary preferences and by providing a mosaic of many habitats that peak in their food supply at different times (Sanchez *et al*., 2006). In the case of open water, topography would also have been a factor, because flooded wetlands with average depths of 10-20 cm would have provided a range of suitable foraging habitats for wading and dabbling species, and could accommodate more species than deeper waters (Colwell and Taft, 2000). We found that only at the 500 m scale open water was a significant variable for autumn richness, indicating the importance at that time of year of a mosaic of small, shallow patches of open water for water bird survival. The negative relationship during autumn of open water at the landscape scale on evenness and on the Shannon's diversity, whereas the positive relationship during spring indicates that open water was limiting in that season and hence, our results suggest that mangers should restrict the input of water during autumn and strengthen it during spring. There are no major water storages on the Huolin River, but water is potentially available from the Nenjiang River to Baicheng City water diversion project.

Both farmland and alkaline marsh had important positive relationships with water bird diversity in the landscape (Table IV). However, the effects were obviously dependent on scale (Fig. 2-4). The negative relationship of scale on evenness and the Shannon's diversity were evident at low proportions of farmland in the landscape, which demonstrated that there was a threshold proportion (c. 8%) below which the avian assemblage would be adversely impacted. With alkaline marshes, two scalar dependence domains in spring/year evenness and the Shannon's diversity were evident, with negative domains at middle proportions, and positive domains at high proportions in the landscape, respectively. These result indicated that both high and low proportions of alkaline marshes decreased the heterogeneity of the habitat required for water bird survival, and middle proportions should be maintained to sustain avian biodiversity. The soils of the Songnen Plain are naturally prone to alkalinisation (Wang *et al*., 2009b), but the availability of alkaline marshes and also open waters to the avian assemblage would inevitably diminish if the rate of increase of upstream water off-take from the Huolin River continues (He *et al*., 2009). Off-take from the River comprises many small-scale diversions rather than diversions as part of large-scale irrigation schemes and as a consequence are less amenable to government control; hence, managers should reach out to upstream farmers through community education projects to encourage them to change their business model.

CONSERVATION IMPLICATIONS

Recently, habitat loss from human disturbance has been a critical factor driving some endangered species towards extinction (Mehmood *et al*., 2018). In 2003, the International Union for Conservation of Nature and Natural Resources (IUCN) recorded that 762 species have become extinct globally as a result of human activities in the past few hundred years. Initially, XHNR was established to rescue Red-crowned Crane populations in Northeastern China. As the most eye-catching flagship species for waterbird conservation, the red-crowned crane was one member of the avian assemblage, and specific conservation efforts were implemented to recover the Red-crowned Crane, including the establishment of breeding farms in XHNR. However, in this study, we focused on the effects of habitat variables on avian assemblages at different spatial scales to examine the response of bird community to habitat changes, which might inform adjustments to the conservation strategy for the wetland birds in XHNR. In addition, the limited population size of Red-crowned Crane made it difficult to study its habitat selection at the nature reserve level. Thus, the study of the avian assemblage, especially species with similar habitat requirements, could provide insights into conservation and recovery work in XHNR in the future. Considering the positive effects of crop farms on the avian assemblage and the fact that farming would exist for a long term in the XHNR, we proposed an avian community friendly crop farming model, including 1) encouraging local farmers plant more crops of the types that birds prefer to feed on, such as sunflowers and maize, and providing compensation to farmers for crop losses; 2) prohibiting the use of deleterious pesticides and chemical fertilizers in the nature reserve; 3) strict prohibiting fencing or netting around the farms to reduce possible harm to birds; 4) requiring farmers to continue to live in settlements rather than allowing new farmhouses to be distributed around the farmlands.

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Supplementary material

There is supplementary material associated with this article. Access the material online at: https://dx.doi.org/10.17582/journal.pjz/2020.52.1.23.35

Statement of conflict of interest

Authors have declares that there is no conflict.

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