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RESEARCH ARTICLE

Residential green zones as additional habitats for mammals in a mountainous area around Beijing, China

Jing Wang[1,2], Robert B. Weladji[3], Xiuxiang Meng[2]

[1]*School of Customs and Public Administration, Shanghai Customs College. Shanghai 201204, China.*
[2]*School of Environment and Natural Resources, Renmin University of China. Beijing 100872, China.*
[3]*Department of Biology, Concordia University. Montreal, Quebec H4B 1R6, Canada.*
Corresponding author: Xiuxiang Meng (meng2014@ruc.edu.cn)

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ABSTRACT. Habitat loss and land use changes resulting from urbanization in residential communities are among the greatest threats to wild mammals. Identifying anthropogenic factors determining mammal diversity and composition can help coordinate socio-economic development with ecological conservation. In this study, we used transect surveys to compare the mammal assemblages near human-disturbed communities with those in the natural off-community area around Beijing, a major metropolis. We assessed the variables affecting the mammals' presence using 19 environmental indicators. Of the twelve mammal species detected in the area, three vulnerable species have obtained legislative protection. In 58% of the observations, mammals were discovered around communities closer to croplands and located at slightly higher elevations with less vegetation, and these are the main environmental variables contributing to more mammals' presences in the disturbed near-community area. The selection of croplands for the mammals in the suburb should be a trade-off between feeding benefits and predation risks, and with the rise of protection willingness, green zones near residential communities can serve as additional habitats for mammals facing the expansion of urbanization.

KEY WORDS. Croplands, habitat selection, mammal assemblage, metropolis, urbanization.

INTRODUCTION

Over half of the human population lives in suburban and urban areas, and as the proportion is expected to rise continuously, ecological sustainability is significant in implementing the 2030 Agenda for Sustainable Development and nature conservation (UN 2015, Ikeda et al. 2022). Urbanization and suburbanization, along with habitat loss and overexploitation, have threatened biodiversity, including mammals that are particularly vulnerable and sensitive to these disturbances, with some even facing extinction (Gilbert 2008, Wilcove et al. 2013, Zungu et al. 2019). As a result of the higher temperature, dryness in the transitional area between disturbed anthropogenic remnants and intact natural habitats, mammals are particularly sensitive in the densely populated communities of suburbs that are subject to high levels of human disturbance (Brodie et al. 2015, Gentile et al. 2018). An essential question is whether such disturbed remnants, including pastoral lands, croplands, and orchards, can support sustainable urbanization and human-wildlife coexistence. This may be helped by understanding the response of mammal assemblage to environmental changes under anthropogenic influences.

Habitat preferences can be regarded as a fine-grained theory of optimizing ecological needs for animals and the communities (Orians and Wittenberg 1991), and it is affected by trophic resources, shelters, intra- and inter- specific relations, and other environmental constraints (Rosenzweig 1991). The most threatened species are those specialists subjected the most to fragmentation and have small distributions and low proportions of suitable habitat within their ranges (Crooks et al. 2017). Wu et al. (2020) reported that the leopard cat, *Prionailurus bengalensis* (Kerr, 1792), a threatened carnivore with rising attention in Beijing, preferred northern, flat slope habitats with less fallen-wood and shrub-dominated coverage to satisfy the need for food and shelters. Generalist mammals, most of which are not listed as protected species in laws and regulations, are supposed to have strong ecological adaptability, and temporal-spatial variability (Tilman 2004, Nordberg and Lin 2019). For instance, Asian badgers, *Meles leucurus* (Hodgson, 1847), one of the most common mammals in northern China, preferred to use gentle upper slopes with moist soil and good lee conditions, as an adaptation strategy to maximize their fitness in summer (Wang et al. 2021). Generally, most previous studies analyzed the habitat preferences of a single species, and human disturbance was far less concerned (Goulart et al. 2009).

The mammal assemblage and habitats are undoubtedly impacted in the suburban region that is characterized by various anthropogenic activities, such as infrastructure development (e.g., roads, fences, tubes and ditches, electric towers), vehicle and traffic, irrigation, and plantation (de Lima et al. 2018). Despite the negative consequences caused by road killers, movement barriers, traps, and hunting, the alterations in suburban ecosystem may benefit mammals, especially the generalist synanthropic species (Coffin 2007). Road surfaces can provide substrate for visual and olfactory marking, as supported by wolves, *Canis lupus* Linnaeus, 1758 depositing scats more often along roads (Barja et al. 2004). Plant communities along roads and cultivated land can produce higher quality foraging for mammals due to more sunlight exposure and fertilization (Rea 2003). Besides, ditches, tubes, or abandoned barns have been reported as temporary or seasonal shelters for mammals to avoid extreme climatic conditions or predators (Hill et al. 2021). Van Helden et al. (2020) reported a potential value of residential gardens supporting mammal assemblages, which supported that species diversity may be higher through increased habitat heterogeneity at the intermediate levels of urbanization (Corrado and Giuliano 2018, Moi et al. 2020). Therefore, identifying factors affecting mammals' assemblage and habitat preferences under human disturbance can help reconcile wildlife conservation facing continuous land use change.

As China's capital city, a notable feature of Beijing was its rapid expansion of human land use. Bu et al. (2021) reported that the mammal diversity in the mountainous area around Beijing has been decreasing, and no wild population of Siberian musk deer, *Moschus moschiferus* Linnaeus, 1758 has been found since 2006. With the urbanization extrapolation of a capital-centered metropolis, the presence of mammals with various habitat preferences and resource requirements made the mountainous suburb area around Beijing an ideal area to test the relationship between mammal assemblage and environmental variables. In this study, we first assumed that environmental variables, as well as the mammal assemblage, changed with the intensity of anthropogenic activities. We, therefore, expected that there would be differences in the diversity and richness of mammals in green zones that are near and away from residential communities, which are noted for intense and widespread human activity. We tested it by assessing the mammal assemblage compositions both in green zones that are near and away from residential communities in the mountainous suburb around Beijing. We also hypothesized that a few key environmental variables, especially those related to human activities, dominated the habitat selection for both generalist and specialist mammals. To test it, we established an environmental evaluation index system consisting of biotic and abiotic variables, compared their variances in the two types of green zones, and then analyzed the determinants of mammal presence. Given that the suitable biotope for mammals may be shrinking, our results can not only deepen the understanding of the potential role of suburban residential communities in wildlife conservation and management, also help to find ways of mitigating the loss of mammals in sustainable urbanization and nature conservation.

MATERIAL AND METHODS

Study area

This study was conducted in the suburb area around Beijing, the capital city of China (36°0"N ~ 42°37"N; 113°04"E ~ 119°53"E). The 18,909 km^2 region is contiguous with Hebei province and Tianjin city, and is a core part of the Coordinated Development of the Beijing-Tianjin-Hebei Region, one of China's national development strategies.

The study region has a diverse topography, with lowlands in the southeast and highlands in the northwest (Fig. 1A). The Taihang and Yanshan Mountains are the major mountain ranges in this region, acting as natural barriers and having a significant impact on the climate and geography. There are also plateaus and plains, particularly the North China Plain, making the region suitable for agriculture and urban development, and the region is also dotted with rivers and lakes. Fruit trees and crops are planted on gully and alluvial platforms (Fig. 1B). The elevation ranges from about 5 m to 2000 m above sea level (a.s.l.). Affected by a temperate monsoon climate, this region is characterized by hot and humid summers, and cold and dry winters. The

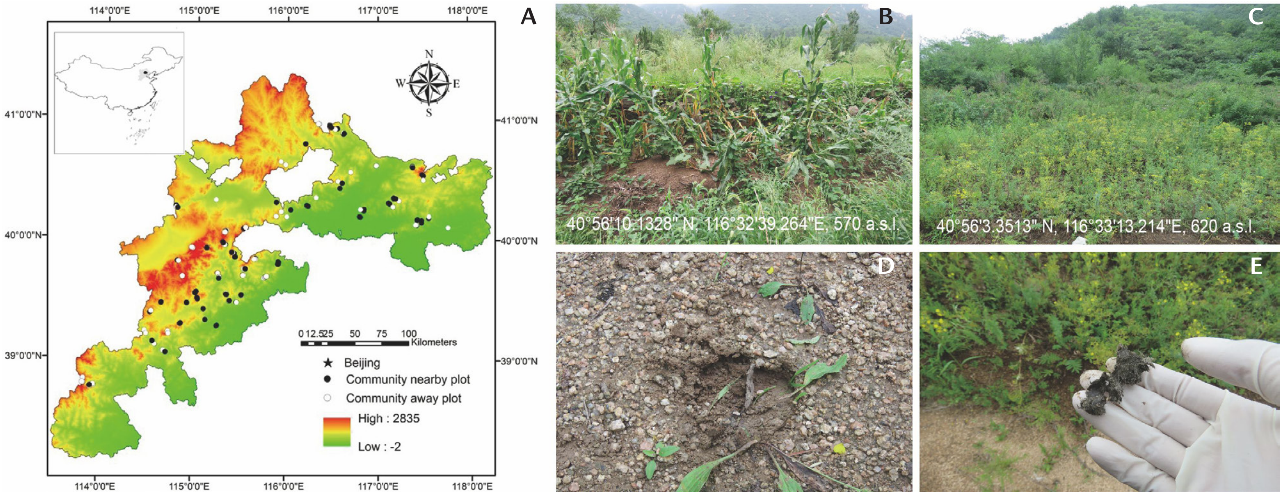

Figure 1. Map of investigation locations within the suburb area surrounding Beijing between July and August 2019; (A) geographical location of the study area in China is shown in the sketch at the top left. The star represents the capital city of China, Beijing, and the grey shadow is the study area. Filled dots represent disturbed plots near human communities (≤1500 m), and blank dots are non-disturbed plots distant from human communities (>1500 m). 115 near-communities and 114 off-community plots were investigated. The elevation gradient change from high to low is represented by red-green colorbar; (B) a sample of the near-community plots; (C) a sample of the off-community plots; (D) a footprint of wild boar (*Sus scrofa*) was detected in a cornfield of (B); (E) faeces of leopard cat (*Prionailurus bengalensis*) were detected in a deciduous forest of (C).

average temperature in summer ranges from 25–31 *°C,* while in winter it can drop to as low as -18 *°C* (National Bureau of Statistics of China 2019). Lying at an average elevation of 600 m a.s.l., this area is characterized by distinct vegetation vertical band. Evergreen broad-leaved forests and mild grasslands dominate the low-altitude regions, mixed broad-leaved forests and deciduous broad-leaved forests make up the intermediate altitude region, and cold temperate broad-leaved, deciduous, and coniferous forests make up the high-altitude regions (Fig. 1C).

Situated within a mountainous landscape, the study area supports a population of approximately 10 million people in over 2000 communities belonging to 21 counties and has a population density of around five persons per ha (National Bureau of Statistics of China 2019). Affected by nomadic culture in the north and farming culture in the central plains, ethnic minorities like the Manchu, Mongolian, and Hui have a long-dwelling history here, who have demonstrated a deep connection to nature and have protected it through traditional ecological knowledge (Huang 2011). Despite intensive urbanization, community-led conservation initiatives like forest management and sustainable farming have led to the existence of numerous green patches with varying topography, vegetation coverage, species composition, and anthropogenic disturbances in the region (Wang et al. 2021). Within these green zones, mammals such as Asian badgers, *M. leucurus*; wild boars, *Sus scrofa* Linnaeus, 1758; toli hares, *Lepus tolai* Pallas, 1778; and gorals, *Naemorhedus griseus* (Milne-Edwards, 1871) have been documented (Bu et al. 2021).

Field investigation

We used 1500 m to the nearest household as a benchmark for green zones that are near- and off-community to better identify the impacts of human residential communities on mammals. Given that anthropogenic activities, such as cropping, farming, logging, are typically next to settlements with a short distance (1000 m, 15 minutes walk), it seemed acceptable to infer that plots over 1500 m distant from the households should be natural green remnant with rare human activities.

To identify the richness and distribution of terrestrial mammals in the green zones, we investigated the mountainous area around Beijing by transect survey method in sunny days between July and August in 2019, given that the species' detectability is higher in summertime with more food and water accessibility (Burt et al. 2021). Because of the homogenized development in the urban circle, the residential size and socioeconomic situation among communities were similar, and we assumed no differences in the detectability of mammals distributed in the area. To avoid human accidentally injures in residential communities by traps, we did not set traps for rodents or shrews which cannot be readily identified by transect survey due to their behavior or size, so small mammals were not included in this survey. In consideration of the flourish vegetation in summer, each investigator surveyed the signs of mammals, such as direct observation, feces, setts, and footprints, within a 3 m visibility on the left and right. From 8:00 am to 16:00 pm, three investigators, trained for standardized measurement and investigation, walked side-by-side from a randomly selected household cultivated land, and perpendicular to the nearest mountain ridge for 3 km in length, so that various green zones along with the vertical gradient change can be equally thoroughly surveyed. The selected households were involved in 21 mountainous communities, and each transect was mutually separated by a minimum distance of 1500 m to avoid repeated recording or interaction effects (i.e., trans-lines movements of mammals) during the investigation. Furthermore, Higuchi (1996) suggested that the width of the activity area for animals was the diameter of the home range circle, and by studying the activity area of the documented species, the home range of mammals reported in the area varies between 5 and 225 ha (Bu et al. 2021), approximately a circle with a diameter of 200~1500 m. By defining a minimum interval of 1500 m, the mammals were unlikely to move between the transects in a short time, so the pseudo-variance due to mammals' activities can be avoided. As a result, ninety-two 18 m-wide transects with an elevation from 300 to 1500 m a.s.l. were investigated.

Once mammals traces were found, the investigator would identify the species from the list of all documented mammals in the region. All documented mammals were classified into generalist or specialist species from the perspectives of diet, habitat, behavior, reproduction, or competition (Pardini et al. 2009, Michálek et al. 2017), and the generalist species can survive and thrive in a wide range of habitats with broad diets and tolerate changes in their surroundings, while the specialist species can only thrive in a very specific set of conditions with a narrow diet and tend to be threatened by the changes. To describe the environmental characteristics, based on the previous studies of habitat selection of the mammals in that area, nineteen environmental variables were identified (Bu et al. 2021, Wang et al. 2021). Wherever mammal traces were found, a 20 m × 20 m plot centered on the sign was set, and the same plots were also set at the start, middle and end of each transect, from which we collect environmental variables as described in Table 1. Five 4 m × 4 m small samples were set in the center and four corners of each plot to obtain the average (Wu et al. 2020). Finally, 229 plots were described by the environmental variables in Table 1.

Thus, the investigated plots were divided into two groups, those situated near the household (≤1500 m, referred to as the "near-community" area), and those located at a distance from the household (>1500 m, referred to as the "off-community" area). Totally, we surveyed 115 near-communities plots and 114 off-community ones in the mountainous area surrounding Beijing for the presences of mammal species (Fig. 1).

Data analysis

We compared the assemblage composition and richness of mammals between disturbed near-community plots and natural off-community remnants using R 3.6.1. Mann-Whitney U Test was used to test the variances of traces' records and the number of species, including specialist and generalist species, between near-community and off-community plots. Because the study contains geographical structure in the data, we consider the existence of spatial autocorrelation at p-value less than 0.05 (Pita et al. 2020), Morans' I index was used to assess the plots spatial autocorrelation. The environmental variances between plots were analyzed according to data category, in which discrete variables were compared by χ^2 test, while Mann-Whitney U Test was also adopted for continuous variables. The Spearman's correlation was used to test to relationships among environmental variables, and partial correlations were used to select the necessary predictors into the regression model. Continuous data was standardized as a distribution with a mean of zero and a standard deviation of 1 by Z-score method, and step-wised binomial generalized linear models with logit-link were built to test how ecological factors influenced mammals' presences. We used the "in" and "out" probabilities to select variables, and the significant fit goodness change indicated that the newly introduced variable could be an independent explanatory parameter (Hegyi and Garamszegi 2010). All p-value less than 0.05 were considered statistically significant.

RESULTS

Detected mammals

Throughout the summer, 12 mammal species were found in the Beijing suburbs, and no significant spatial autocorrelation was found among plots in mammal presences

Table 1. Definition and description of summer habitat factors for mammals' presence in mountainous area around Beijing.

	Ecological variable	Definition and description
Biotic factors	Tree canopy density	Estimate the upper canopy of vegetation cover on the ground percentage averaged in the center and four-corner samples (4 × 4 m, the same below).
	Tree DBH (diameter at breast height, cm)	Average DBH of trees closest to the center point (up to 1.3 m high) in plots
	Tree height (m)	Average height of trees closest to the center point (DBH > 10 cm) in plots
	Stumps	Number of stumps in the plots
	Fallings	Number of falling trees in the plots
	Tree amount	Number of trees (DBH > 10 cm) in the plot
	Shrub height (m)	Average height of shrub in the center and four-corner samples
	Shrub canopy	Average shrub canopy shadowed on the ground in the center and four-corner samples
	Ground plant coverage	Average percentage of ground vegetation coverage in the center and four-corner samples
	Concealment	At the height of 1 m, the visual distance of the plot in four directions, and classified into three categories: good (≥ 20 m), moderate (10~20 m) and bad (≤ 10 m)
Abiotic factors	Elevation (m)	Elevation at the center point of the plot
	Slope aspect (°)	East slope (45~135°), south slope (135~225°), west slope (225~315°) and north slope (315~45°)
	Slope inclination (°)	Gentle slope (≤25°), moderate slope (25~50°) and steep slope (≥50°)
	Slope position	Lower slope (valley included), medium slope (mountainside included) and upper slope (ridge included)
	Lee condition	Potential space against severe weather, and classified into good, moderate, and bad
	Soil moisture degree	Moisture (grip will make dough), moderate (grip will make dough, scattered if loosen the grip), and dry (cannot form a lump)
	Distance to water	Linear distance to visible water supply, including far (≥ 900m), medium (600~900m) and near (≤300m)
	Distance to cropland	Linear distance to cultivated land, including far (≥ 900m), medium (600~900m) and near (≤300m)
	Distance to road	Linear distance to traffic parkway, including far (≥ 900m), medium (600~900m) and near (≤300m)

(Morans' I index = -0.0024, z = 1.05, p = 0.29). These comprises three threatened species under national protection (the long-tailed goral, *N. griseus*; leopard cat, *P. bengalensis*; and rhesus monkey, *Macaca mulatta* (Zimmermann, 1780), and nine common species that are not listed in the national protection law (Fig. 1D; Table 2). The only record of rhesus monkey was in the off-community site and the only record of raccoon dog was in the near-community site. The most often detected generalist species was the northern hog badger, with 59.7% of its detections were in the near-community area. Twenty-seven traces of the endangered leopard cat were also found during the survey (Fig. 1E), and slightly more signs (52%) were found in the near-community area.

Fifty-eight percent of the records were detected in the near-community area. Significant differences were found between near-community plots and off-community ones regarding the number of mammal species (z = -2.641, p = 0.016) and generalist species (z = -2.362, p = 0.028), and the number of species were higher in near-community area. Though the detected records of mammals in the near-community area were also more than those in the off-community area, the difference was not significant (p = 0.11), neither was the number of specialist species (p = 0.11, Fig. 2).

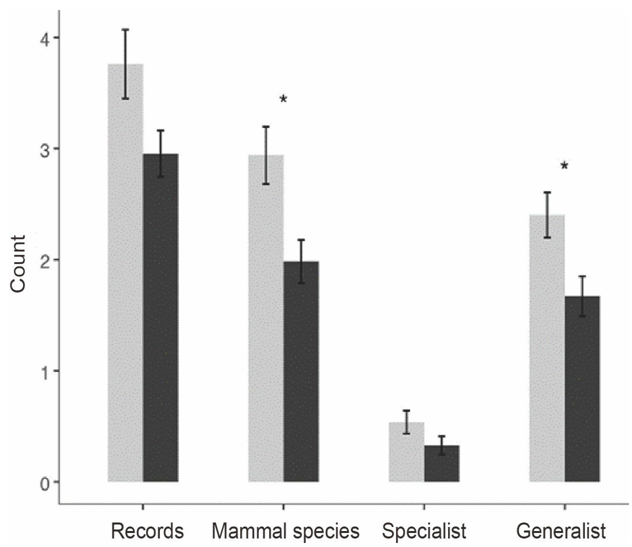

Figure 2. Mean counts of detected trace records, mammal species, specialist species, and generalist species in disturbed near-community (grey) and non-disturbed off-community (black) area between July and August 2019 in the mountainous suburb area around Beijing. Significant differences (p < 0.05) are denoted by *. The bars represent standard error.

Table 2. Records of mammal traces detected in the near-community area and off-community area in the mountainous suburb around Beijing.

Group	Scientific name	Common name	Records	
			Near-community	Off-community
Generalist species	*Sciurotamias davidianus*	Rock squirrel	30	26
	Meles leucurus	Asian badger	24	23
	Arctonyx albogularis	Northern hog badger	40	27
	Sus scrofa	Wild boar	39	20
	Capreolus pygargus	Siberian roe deer	24	12
	Lepus tolai	Tolai Hare	21	18
	Erinaceus amurensis	Amur Hedgehog	2	1
	Mustela sibirica	Siberian weasel	4	3
	Nyctereutes procyonoides	Raccoon dog	1	0
Specialist species	*Naemorhedus griseus*	Long-tailed goral	11	8
	Prionailurus bengalensis	Leopard cat	14	13
	Macaca mulatta	Rhesus monkey	0	1

Environmental variances

The ecological variances between the human-disturbed near-community area and natural off-community area were mainly represented in six indicators, namely elevation ($p < 0.001$), fallings ($p = 0.017$), slope position ($p = 0.001$), concealment ($p = 0.019$), lee condition ($p = 0.030$) and distance to cropland ($p < 0.001$), a marginally significant difference was also found in the tree canopy ($p = 0.051$). In the survey, the near-community plots were characterized by significantly lower elevation, fewer fallings, upper slope position, non-ideal concealment, or lee condition, and closer to the cropland. Although insignificant at the 0.05 cut-off, the tree canopy in the off-community plots tended to be higher than in near-community plots (Table 3).

Ecological and anthropogenic factors influencing mammal presences

Mammals' presences were directly correlated with elevation ($r = 0.270$, $p < 0.001$), tree amount ($r = -0.226$, $p = 0.001$), distance to cropland ($r = -0.143$, $p = 0.03$), slope aspect ($r = 0.145$, $p = 0.03$), and concealment ($r = 0.183$, $p = 0.006$), which were also affected by other environmental variables. Significant correlations were found in latitude with slope inclination ($p = 0.01$), slop aspect ($p = 0.037$), concealment ($p = 0.046$); in four tree-related variables (tree canopy density, tree height, stumps and fallings, all $p < 0.05$); in distance to cropland with tree canopy density ($p = 0.021$), fallings ($p = 0.005$), soil moisture degree ($p < 0.001$); in slope aspect with soil moisture degree ($p = 0.04$); in concealment with lee condition ($p < 0.001$). When controlling the correlated variables, slope aspect ($p = 0.086$), concealment ($p = 0.18$) were removed from the regression model. Thus, elevation, tree amount, ground plant coverage, and the distance to cropland were the four main determinants of mammal presences in the mountainous area around Beijing (Table 4). Mammal presences were positively influenced by elevation ($\beta_{elevation} = 0.633$, $p < 0.001$) but negatively influenced by tree amount ($\beta_{tree\_amount} = -0.541$, $p = 0.007$) and ground plant coverage ($\beta_{ground\_plant\_coverage} = -0.348$, $p = 0.028$). Compared with the plots distant from croplands, mammals were more likely to use those near the cropland ($\beta_{distance\_to\_cropland\_near} = 1.426$, $p = 0.003$, Table 4).

In terms of generalist species, their presences were positively influenced by the elevation ($\beta_{elevation} = 0.394$, $p = 0.015$) and the distance to cropland ($\beta_{distance\_to\_cropland\_near} = 1.250$, $p = 0.016$), and negatively by ground plant coverage ($\beta_{ground\_plant\_coverage} = -0.332$, $p = 0.039$). Specialist species were more likely to use the habitats with higher shrub canopy ($\beta_{shrub\_canopy} = 0.900$, $p = 0.006$) with thick, sturdy trees ($\beta_{tree\_DBH} = 0.664$, $p = 0.001$), and other factors negligibly influenced their presences (Table 4).

DISCUSSION

The assemblage of mammals near communities has been assumed to be characterized with less richness or diversity by changing landscape patterns resulting from anthropogenic activities (Mckinney 2006, McCollister and van Manen 2010), but there is a growing body of evidence demonstrating that communities in suburban areas may also serve as potential vegetation habitats, and provide more accessible resources for wildlife (Lerman et al. 2012, van Helden et al. 2020). During the survey, we totally found 12 mammal species,

Table 3. Environmental variances (Mean ± S.E.) between near-community and off-community plots in the mountainous area around Beijing.

Data category	Factor		Near-community	Off-community	Significance
Continuous	Elevation (m a.s.l.)		580.21 ± 40.57	882.38 ± 40.22	z = -4.753, p < 0.001
	Tree canopy density		0.50 ± 0.03	0.54 ± 0.03	z = -1.950, p = 0.051
	Tree DBH (cm)		18.73 ± 1.47	20.41 ± 1.67	z = -0.044, p = 0.965
	Tree height (m)		8.81 ± 0.53	9.75 ± 0.71	z = -0.898, p = 0.369
	Tree amount		39.44 ± 4.19	40.47 ± 4.81	z = -0.846, p = 0.398
	Stumps		0.55 ± 0.15	1.32 ± 0.31	z = -1.480, p = 0.139
	Fallings		0.78 ± 0.29	1.63 ± 0.41	z = -2.389, p = 0.017
	Shrub height (m)		1.26 ± 0.53	2.68 ± 0.99	z = -0.591, p = 0.554
	Shrub canopy		0.47 ± 0.02	0.48 ± 0.03	z = -0.369, p = 0.712
	Ground plant coverage		0.51 ± 0.03	0.57 ± 0.03	z = -0.142, p = 0.887
Discrete	Slope aspect	North	30	38	χ^2 = 4.143, df = 3, p = 0.246
		West	30	26	
		South	22	28	
		East	33	22	
	Slope inclination	Gentle	71	56	χ^2 = 4.179, df = 2, p = 0.124
		Moderate	31	37	
		Steep	13	21	
	Slope position	Upper	42	21	χ^2 = 14.344, df = 2, p = 0.001
		Medium	46	43	
		Lower	25	48	
	Conceal-ment	Bad	53	42	χ^2 = 7.890, df = 2, p = 0.019
		Medium	40	30	
		Good	22	40	
	Lee condition	Bad	52	38	χ^2 = 6.983, df = 2, p = 0.030
		Medium	54	55	
		Good	9	21	
	Soil moisture degree	Dry	21	11	χ^2 = 3.592, df = 2, p = 0.166
		Moderate	60	64	
		Moisture	34	39	
	Distance to water	Near	74	67	χ^2 = 0.811, df = 2, p = 0.667
		Medium	22	24	
		Far	19	23	
	Distance to road	Near	48	64	χ^2 = 4.785, df = 2, p = 0.091
		Medium	40	29	
		Far	27	21	
	Distance to cropland	Near	87	54	χ^2 = 26.205, df = 2, p < 0.001
		Medium	24	33	
		Far	4	27	

including three threatened species, in the mountainous area around Beijing, and they all have been reported in previous studies (Wang et al. 2007, Jiang et al. 2015, Liu et al. 2018). Our investigation result accounts for a half of the mammal species in the whole Taihang mountain reported by Bu et al. (2021). Though affected by the urbanization extrapolation of this capital-centered metropolis, the near-community area was clearly different from the natural remnants in off-community area in elevation, fallings, slope position, concealment, lee condition, and distance to cropland. Mammals were more likely to be recorded in the disturbed near-community habitats, especially for the generalist species, which verified our first expectation that mammal assemblage varied with the distances to residential communities.

Although no significant difference was found in the number of specialist species between near-community and off-community area, more traces of the endangered leopard cat were found in near-community area than those in

Table 4. Regression coefficient of selected ecological variables in the final model to predict mammal presences in the mountainous area around Beijing.

Model			B	S.E.	95% Wald CI		Hypothesis Test		
Response	Predictor				Lower	Upper	Wald χ^2	df	p
Mammal presences	(Intercept)		-1.783	0.428	-2.622	-0.943	17.315	1	<0.001
	Distance to cropland	Near	1.426	0.472	0.500	2.353	9.112	1	0.003
		Medium	1.478	0.499	0.500	2.457	8.765	1	0.003
		Far	–						
	Ground plant coverage		-0.348	0.158	-0.659	-0.037	4.816	1	0.028
	Elevation		0.633	0.164	0.312	0.954	14.926	1	<0.001
	Tree amount		-0.541	0.201	-0.935	-0.146	7.225	1	0.007
Presences of generalist species	(Intercept)		-2.110	0.476	-3.043	-1.178	19.661	1	<0.001
	Distance to cropland	Near	1.250	0.520	0.231	2.269	5.781	1	0.016
		Medium	1.302	0.549	0.225	2.378	5.617	1	0.018
		Far	–						
	Ground plant coverage		-0.332	0.161	-0.647	-0.017	4.278	1	0.039
	Elevation		0.394	0.163	0.075	0.713	5.863	1	0.015
Presences of specialist species	(Intercept)		-2.740	0.347	-3.420	-2.060	62.316	1	<0.001
	Tree DBH		0.664	0.207	0.258	1.070	10.265	1	0.001
	Shrub canopy		0.900	0.324	0.264	1.535	7.704	1	0.006

off-community area. Consistent with our results, Wu et al. (2020) reported that leopard cats had a strong tendency to use habitats near human disturbance area with moderate levels of disturbance intensity. Generally, the higher mammal diversity of the near-community area in our study provided new evidence that an intermediate disturbance benefits local species diversity and maximizing coexistence (Moi et al. 2020), and it was not mutually exclusive with the intermediate disturbance hypothesis, which predicts that few species are able to compete successfully in habitats that experience little or no disturbance (Connell 1978, Corrado and Giuliano 2018).

Ecological demands such as food, suitable climate, shelter, and security influenced habitat selection, which in turn altered the existence, abundance, and assemblage of species (Orians and Wittenberg 1991, Shilereyo et al. 2021). As we secondly hypothesized, the number of animals and the ways in which mammals partitioned natural resources to secure their existences in the mountainous area around Beijing were determined by factors including elevation, tree amount, ground plant coverage, and distance to croplands. Mammals use microhabitats with different characteristics. More precisely, the presences of generalist and specialist species have different driving factors. For generalist species in mountainous area around Beijing, the determinants of presences were lower ground plant coverage, higher elevation, and the closer to cropland, which can be explained by their ability to thrive well in disturbed habitats and the ability to tolerate a wide range of habitats in the suburban ecosystem being often generalist feeders (Saeki et al. 2007, Shilereyo et al. 2021, Wang et al. 2021). As for the specialist species, the determining factors were higher tree DBH and shrub canopy. Sturdy trees can provide tree shelters for rhesus monkey (Xie et al. 2009), and provide shade for leopard cat (Wu et al. 2020) and long-tailed goral (Park and Hong 2021). Besides, as attractive food resources, rodents and berries are more abundant in the area with high shrub canopy, providing hiding and fleeing conditions when they encounter predators (Shilereyo et al. 2021, Wang et al. 2021).

Affected by the sub-humid continental monsoon in the temperate region, the summer time in the mountainous area around Beijing is also the season with the highest food availability, including earthworms, insects, and berries for small omnivorous species such as Asian badger, Northern hog badger, and rock squirrel (Kaneko et al. 2006, Liu et al. 2012), herbs and leaves for herbivorous species such as long-tailed goral (Cho et al. 2016), and rodents for carnivores such as leopard cat (Wu et al. 2020). The lower canopy and more solar radiation in the selected habitats with fewer trees provide more space for shrubs and higher productivity of berries, further attracting small rodents and their predators. This may also be a safety strategy of having an open-area view and escaping predation in advance, which is not mutually exclusive with hinder species using the dense forest to conceal their movements (Goulart et al. 2009). In the near-community area, though opposite with natural remnants distant from communities, the traits of upper slope position, less satisfied concealment, lee condition, or tree canopy also support this "lookout" safety strategy.

High temperature is one of the significant environmental constraints for mammals in summer. The higher elevation preference of mammals in our study portrays a strategy to adapt to temperature during the season and hence an adaptation to summer climatic conditions, which accords with previous studies on seasonal habitat utilization of mammals (Novillo et al. 2017, Diriba et al. 2020). Likewise, mammals in the mountainous area around Beijing have been reported to select the higher elevation microhabitats to cope with summer heat (Wang et al. 2021). Driven by the gradual temperature decline in higher-altitude habitats, mammals were less exposed to solar radiation. They benefited from the cooler climatic conditions to avoid the heat, which reduces energy consumption for body temperature maintenance to maximize climatic suitability.

Most species in the study area are ground dwellers, who spend a considerable amount of time on ground activities, including digging, scraping, trampling, and others, which can easily destroy topsoil nearby, and these harm the growth of ground plants and lead to a lower ground plant coverage. Though mammal urine and feces are important nutrients and vehicles for seed dispersion when looking at a longer-term context, they may etch ground plants directly (Wang et al. 2021). On the other hand, the habitat preferences on green zones with less ground plant coverage may also be an approach to shelters. Lower ground plant coverage contributes to rock erosion, creating natural setts, caves, and crevices. The smaller of these geographical structures can collect precipitation and store excess water for use as water sources during the summer monsoon, explaining the unexpected nonsignificant role of distance to water to some extent. While the larger ones provide opportunities for mammals to conceal and rest, which have been reported in mammals (Hadjisterkotis and Reese 2008, de Pinho et al. 2017).

Contrary to studies reporting that many species apparently avoid the pastoral or agricultural lands, especially the habitat specialists preferring intact and less disturbed habitats (McPeek 1996), our results showed that mammals in the mountainous area around Beijing tended to use croplands close to residential community, especially for the generalist species. The cultivated land surface covered with soft and moist ground is ideal habitat for insects and worms, which enrich the food sources for mammals (Seaki et al. 2007, Ramesh and Downs 2015). Besides, policy development, public awareness and community involvement benefit building local support to conserve mammal diversity (Jiang et al. 2015). With the enforcement of wildlife conservation law in China since 2017, and improvement of ecological compensation system (Du et al. 2023), as well as the widespread of traditional ecological knowledge in minority cultures (i.e., Asian badgers called "huan" in Chinese with the meaning of happiness, and hunting "huan" can be regarded as destroying happiness in the traditional culture), the rising protection awareness of residents furtherly decreased the risks of using croplands for mammals.

Survey attempts and typical flaws impacted the species observed outcome, making it difficult to detect the existence of some species (Chao et al. 2014). Although a half of the mammal species documented (Bu et al. 2021) were detected during our two-months summer line-transects survey, the limited survey time and visibility resulted in imperfect observations, like rodents and nocturnal species were not considered in the investigation. Besides, thorough data collected from residential communities using a well-crafted questionnaire enhances analysis and comprehension of the protection awareness of residents in mountainous area around Beijing, which was not performed in our study. Thus, we recommend that further seasonal long-time research by other approaches like infrared camera and community interviews, incorporating other variables such as intraspecies relationship, climatic adaptation, mammals' activity pattern, need to be assessed.

Final remarks

Mammal assemblage in the near-community area had a higher diversity and richness than in the off-community area in the mountainous area around Beijing, reflecting a tradeoff between animals' physiological benefits (e.g., food accessibility) and the predation risks (e.g., hunting mortality) to maximize the individuals' fitness. With increasing protection awareness, more suitable environmental conditions in food and shelter accessibility, and limiting development activities at higher elevations, the green zones near residential communities can be managed in a manner that enhances wildlife population and serves as additional temporary refuges and remnants for mammals.

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