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Research Article

Summer Habitat Selection of Wild Boar *Sus scrofa* Linnaeus, 1758 (Mammalia: Suidae) in mountainous regions in Beijing, China

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Abstract: Based on the sampling of wild boars preferred habitat in north-eastern of Taihang Mountains around Beijing, China, we analysed the factors affecting their habitat selection using resource selection functions (RSFs) and principal component analysis (PCA). The results showed that the number of stumps (2.22 ± 0.62) in used sites was significantly higher (0.95 ± 0.27) ($P < 0.05$) than in the random sample plots, while the ground plant cover was significantly lower (35.26 ± 6.56 %, 61.04 ± 2.92 %, $P < 0.05$). In addition, wild boar preferred the mid-altitude (500–1000 m) habitat with more arbours (81.48 %, 50–100), away from the community (> 1500 m, 51.85 %), weak interference intensity (81.48 %), wet soil moisture (44.44 %), near water dispersion (< 500 m, 66.70 %) and far anthropogenic dispersion (> 1500 m, 51.85 %). The selection and preference of habitat factors reflect the ecological needs for food, water and shelter. In order to reduce the intrusion of wild boars in forest and farmland areas, we propose to change the distribution of water sources and remove nearby key water source sites if necessary, which can also reduce human wildlife conflicts and economic losses.

Key words: *Sus scrofa*, Beijing, Resource selection function, Principal component analysis

Introduction

The wild boar *Sus scrofa* Linnaeus, 1758 (Mammalia: Suidae) is omnivorous with large food intake having cloven-hoof, with high reproduction rate, strong adaptability and exist in diverse habitats (Herrero et al. 2006, Cuevas et al. 2010, Li et al. 2010, Guo et al. 2017, Tang et al. 2019). Wild boars which were once distributed widely in various habitats of China have sharply declined and even extinct regionally due to excessive hunting and habitat degradation. Wild boar population has rebounded significantly in the past 20 years in vast regions of China due to effective implementation of many ecological restoration projects such as "natural forest protection" and "wildlife protection". This has caused economic losses in some agro-forest areas, causing serious human wildlife conflicts.

Several measures such as distribution of compensation due to wildlife damage have been implemented to foster the co-existence of humans and wildlife. However, the efficacy of such measures is largely uncertain due to lack of timely compensation (Cai et al. 2008, Hua et al. 2016). In Yunnan Province, China, for example, the economic losses caused by wild boars amounted to ¥14.933 million in 2009, even resulting in casualties (Cai et al. 2011, Guo et al. 2017). Moreover, wild boars are cause of swine flu,

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trichinellosis and other epidemic disease risks (Meng et al. 2009, Beasley et al. 2018, Linnell et al. 2020), which can have negative impact on native flora and fauna, reducing the level of biodiversity (Engeman et al. 2010, Colino-Rabanal et al. 2012). Therefore, there is need of management of wild boar population and its habitat through in-depth research on the habitat selection and utilization characteristics of this species.

Wild boars prefer to inhabit in forest-type habitats (Acevedo et al. 2006), enjoy oaks forests (*Quercus* spp.) and deciduous broadleaf forest mixed wood with conifers (Abaigar et al. 1994). Kim et al. (2019) reported that wild boars in South Korea feed frequently in Oak forest habitats in sub-frigid zone. In China, the wild boar preferred the habitats with broad leaf forest and shrub, and the key influencing factors include slope, sheltering condition, altitude and the distance from human disturbance (Zhu et al. 2011, Guo et al. 2017, Zhou et al. 2010, Wang et al. 2007). Research by Zhao et al. (2019) showed that wild boars tend to be active during the day and twilight, preferred farmlands close to settlements. Most researches related to wild boar habitat in China are carried out in the protected areas and their surroundings, however, the habitat utilization in a larger area is relatively less.

The North-eastern Taihang Mountain located in North China is one of the key ecological zones in China with an ecological barrier and water sources in Beijing-Tianjin-Hebei region. Since, it is located in the periphery of fast-growing capital economic circle, human activities such as rapid economic development and urbanization in the region can have potential impacts on the habitat utilization of wild boars. There is no relevant research as such. An in-depth understanding of the habitat utilization characteristics of wild boars in north-astern Taihang Mountain is a prerequisite for their conservation and resource management.

Based on the investigation of the habitat suitability of wild boars in mountainous areas around Beijing, this study analysed the characteristics of wild boars' preferred habitats and the selectivity of habitat variables. The results from this research can be references for the protection and management of wild animals in the areas around Beijing.

Materials and Methods

Study area

The mountainous regions surrounding Beijing belongs to the north-eastern part of Taihang Mountain in China, located in the transition zone from the Inner Mongolia Plateau and the Loess Plateau to the North China Plain (38°37'51.6" – 40°57'21.60", 113°50'5.99" – 117°47'9.60"). The region has a warm temperate humid monsoon climate, with the rainy and high temperature during the same period. The rainy season is concentrated in July to August, with an average annual precipitation of 507 mm. The average annual temperature is about 10°C, and the average altitude is 1,200 m.

The region is dominated by temperate deciduous forests such as East Liaoning oak (*Quercus wutaishansea* Mary.), Mongolian oak (*Quercus mongolica* Fisch. ex Ledeb.), Oriental oak (*Quercus variabilis* Bl.), Oviental white oak (*Quercus aliena* Bl.), David poplar (*Populus davidiana* Dode), Asian white birch (*Betula platyphylla* Suk.), Manchurian walnut (*Juglans mandshurica* Maxim.), Prince rupprecht′s larch (*Larix principis-rupprechtii* Mayr.), Tabularformed pine (*Pinus tabuliformis* Carr.), Betula lenta (*Betula dahurica* Pall.), China paper birch (*Betula albosinensis* Burk.) and Seabuckthorn (*Hippophae rhamnoides* L.), etc. Totally, 68 species of mammals, including Siberian Roe Deer (*Capreolus pygargus*), Leopard (*Panthera pardus*), Leopard Cats (*Prionailurus bengalensis*), Yellow weasel (*Mustela sibirica*), Common Hedgehog (*Erinaceus amurensis*), Rhesus Macaque (*Macaca mulatta*), etc. (Bu et al. 2020) are distributed throughout the area.

Field data acquisition

The region was divided into 10 km x 10 km grids after pre-survey, community interviews and literature review. Full coverage of the topography, land use, vegetation type, altitude, and ecosystem types were considered while setting the grids. ArcGIS 10.2 was used for the analysis of the study. A total of 152 line transects each of 6 km long and 50 m single-width were set in the area. The distance between the two line transects was greater than 1 km. The total investigation intensity of the grid was 22.69%, and the investigation intensity of a single grid area dominated by mountain habitats and farmland miscellaneous irrigation both reached 1.2%. Transect survey was conducted between 1st July 2019 and 15th October 2019. Garmin GPSMAP 639sc was used for the field survey to record coordinates of the starting point, midpoint and end point of transect. Three to five investigators walked parallel to the line transects, each responsible for transect with a single side width of 10–20 m, at maintained speed of 1–2 km/h. The signs of wild boar activities (animal entities, faeces, footprints, repose imprint *etc.*), was recorded within 20 m × 20 m sample plot established with the activity traces as the centre (Five 4m×4m small sample plots were set in the centre and four corners of used sample plot) when a sign was located. If no signs were found 100 m ahead, an unused habitat

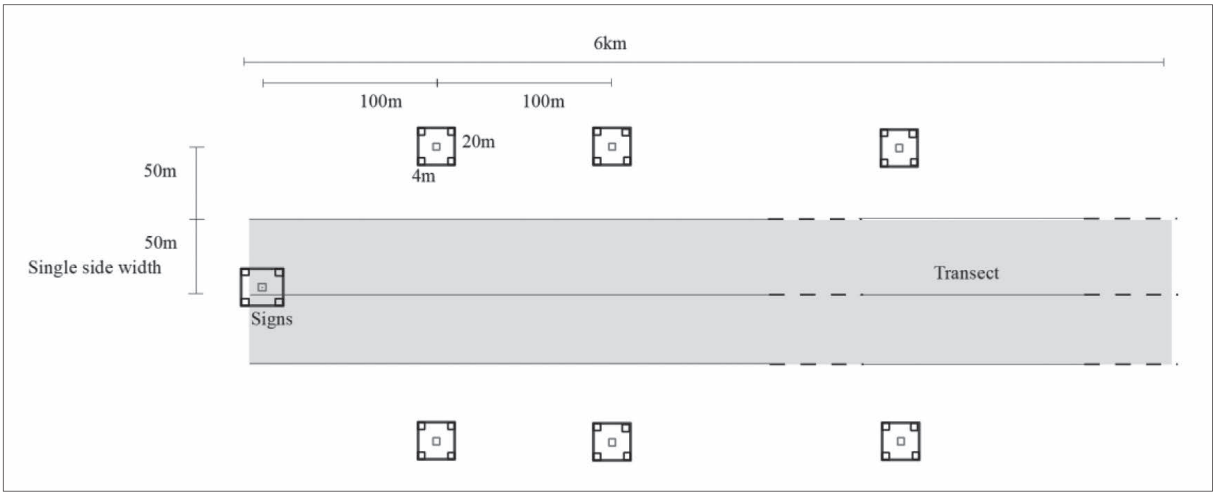

Fig. 1. Schematic diagram of sample plots set in the study area.

Table 1. Definition and description of habitat factors of *Sus scrofa*.

Variables	**Definition and description**
Altitude	Altitude of the centre point of the 20 m × 20 m sample plot.
Arbour canopy coverage	Average coverage percentage of the upper canopy to the ground in the four directions of sample plot centre.
Arbour DBH	Average DBH of the trees closest to the centre point in four directions of the 20 m × 20 m sample plot.
Arbour height	Average height of the nearest tree from the centre point in four directions of the 20 m × 20 m sample plot.
Arbour density	Number of trees in the 20 m × 20 m sample plot.
Shrub height	Average shrub height of five sample plots of 4m ×4 m.
Shrub coverage	Average Shrub coverage of five sample plots of 4m ×4 m.
Ground plant coverage	The ratio of surface vegetation to sample plot area in the 20 m × 20 m sample plot.
Stump quantity	The number of stumps in the 20 m × 20 m sample plot (DBH >10 cm).
Fallen wood quantity	The number of fallen logs in the 20 m × 20 m sample plot (DBH >10 cm).
Withered grass coverage	The average ratio of total coverage of dry plants in the five sample plots of 4m ×4 m.
Slope aspect	The slope direction of the 20 m × 20 m sample plot can be divided into the east slope (45~135°), the south slope (135 ~ 225°), the west slope (225 ~ 315°) and the north slope (315 ~ 45°).
Slope gradient	The slope of the 20 m × 20 m sample plot can be divided into smooth slope (≤30°), gentle slope (30-60°) and steep slope (≥ 60°).
Slope position	The slope position of the 20 m × 20 m sample plot can be divided into lower slope (valley), medium slope (mountainside), and upper slope (ridge).
Vegetation type	Divided into arbour, shrub and grassland.
Hidden degree	At a height of 1 m above the ground, the average visual distance in 4 directions of the sample plot is divided into good (≤10 m), medium (10–20 m) and bad (≥ 20 m).
Sheltered condition	The degree of wind disturbance of the sample plot is divided into four grades: best, good, medium, bad.
Soil moisture degree	Wettest (water can be discharged by hand), wetter (can form a mass when held by hand), moist (can form a mass when held by hand, loose when loosened), and dry.
Water source distance	The vertical distance from sample plot to water source (spring water, rivers and streams, excluding snow) can be divided into near (0–500 m), medium (500–1500 m) and far (>1500 m).
Interference intensity	Divided into strong, medium and weak.
Distance from human disturbance	The distance from sample plot to human disturbance (such as tourism activities, traffic, farming, collection and grazing, etc.) can be divided into near (<500m), medium (500–1500m) and far (>1500m).
Community distance	The vertical distance between the sample plot and the nearest community is divided into near (<500m), middle (500–1500m), and far (>1500m).

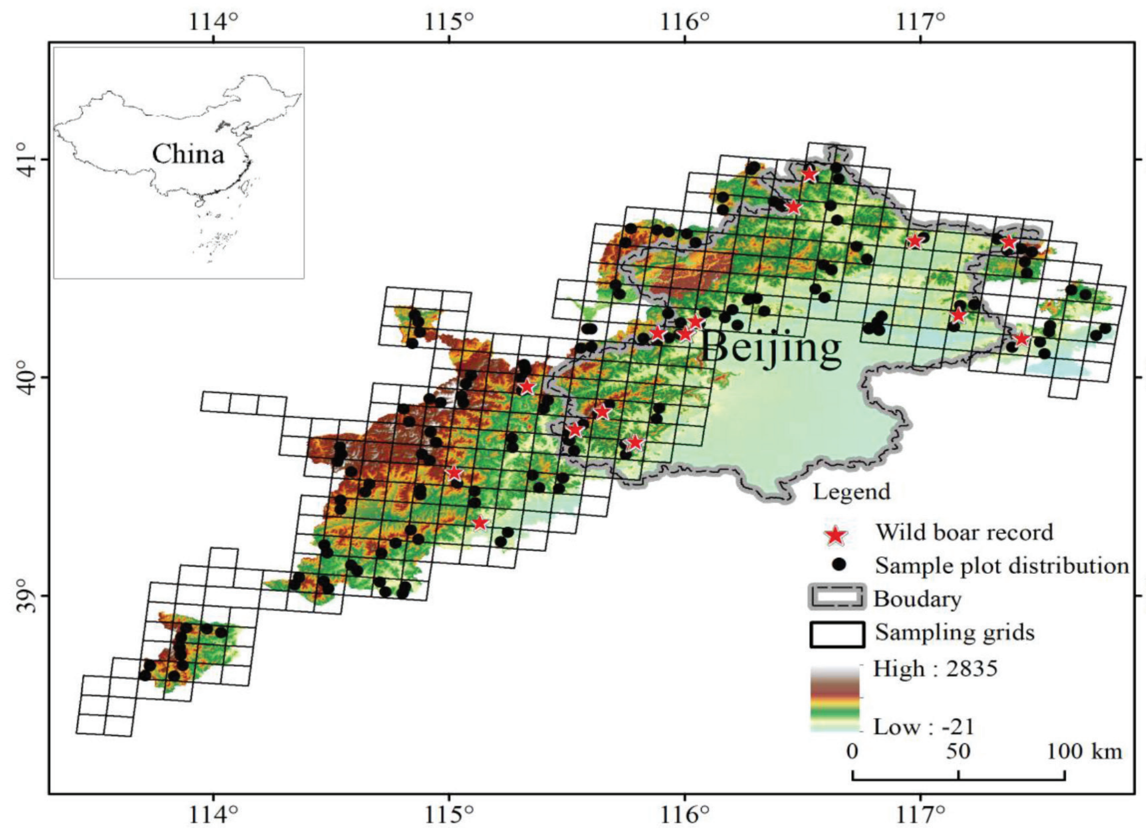

Fig. 2. Location map of the study area around Beijing during summer 2019.

control sample plot of 20 m × 20 m was set at 50 m perpendicular to the line-transect on both sides of the transect (A 4 m × 4 m small sample plot was set in the centre and four corners respectively) (Fig. 1), to ensure sufficient unused habitat data of wild boars. We took 93 unused random quadrats to ensure representativeness and randomness of the control quadrat.

The continuous variables in the sample plots are recorded as Altitude, Arbour canopy coverage, Arbour DBH, Arbour height, Arbour density, Shrub height, Shrub coverage, Ground plant coverage, Stump quantity, Fallen wood quantity, Withered grass coverage. The discrete variables in the sample plots are recorded as Slope aspect, Slope gradient, Slope position, Vegetation type, Hidden degree, Sheltered condition, Soil moisture degree, Water source distance, Community distance, Interference intensity, Distance from human disturbance. The definition and measurement method of habitat variables are modified from Zhou et al. (2013) and Zhu et al. (2011). A detailed explanation of the variables is shown in Table 1.

Data collection and analysis

Mann–Whitney U test was used to compare the difference of continuous variables such as altitude between the used and unused sample plots. Chi-square test was used to compare the difference of discrete variables such as slope.

We used resource selection functions (Boyce & McDonald 1999) to calculate the selection rate of wild boar for each habitat variable (, , o_i represents the utilization rate of resource i, π_i represents the availability of resources, α_i represents the unit that the resource can use, and α_+ represents all available resource units). Spearman correlation analysis was performed on habitat variables to eliminate factors with high correlation to improve their independence. We standardized all ecological variables and removed the influence of variable dimensions to improve the comparability of selection coefficients. We then established a general linear model of resource selection function as , where x is the different independent habitat variables, β is the selection coefficient, *e* is natural numbers. Habitat selection probability of wild boar was calculated as], When the value of τ(x) is 0 or 1, it means select or not select, respectively, the coefficient β can be fitted by logistic regression coefficient (Li et al. 2001), and the dependent variable is whether the wild boar appears (1: appear; 0: not appear). Receiver Operating Characteristic curves was used to evaluate the model, the AUC value between 0.7 and 0.9 is considered

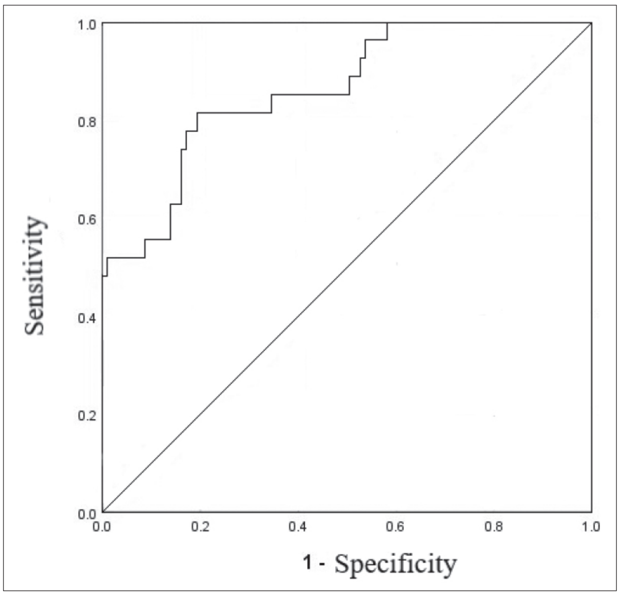

Fig. 3. Receiver Operating Characteristic curve evaluation. The diagonal represents the model has no diagnostic ability (50 % of total area), and the curve above the diagonal represents the diagnostic ability of the model (more than 50 % of total area).

as useful model, and greater than 0.9 is considered as high-precision model (Boyce et al. 2002).

Principal component analysis was used to determine key factors affecting habitat selection of wild boar and compared with habitat preference characteristics based on resource selection function. The significance standard of difference was set as $P = 0.05$. Entire data analysis was performed in the SPSS 25.0 environment.

Results

Used and unused sample plots of wild boar

In all continuous variables of the used and unused sample plot by wild boars, the stump quantity in the used sample plot (2.22 ± 0.62, n = 27) was significantly more than that in the unused sample plot (0.95 ± 0.27, n = 93) ($P < 0.01$), and the ground plant coverage (35.26 ± 6.56%, n = 27) was extremely lower than that of the unused sample plot (61.04 ± 2.92%, n = 93) ($P < 0.01$). There was no significant differences in wild boar's choice of other continuous variables ($P > 0.05$).

Wild boars prefer habitats with arbours (81.48 %), poor sheltered condition (41.67 %), higher soil moisture degree (44.44 %), closer water source (< 500 m, 66.70 %), weak interference intensity (81.48 %), far from community (> 1500 m), and far from human disturbance (> 1500 m, 51.85 %). There were significant differences between above-mentioned variables and unused sample plots ($P < 0.05$), but there were no significant differences in the slope aspect, slope gradient, slope position and hidden degree ($P > 0.05$).

Resource selection function of wild boar sample plot

The correlation analysis between habitat variables showed that only absolute value of correlation coefficient (-0.547) between "slope position" and " community distance" was greater than 0.5. In order to improve the independence and importance of habitat factors, considering that there was no significant difference ($P > 0.05$) in the "slope position" of used and unused sample plots, and the choice of "community distance" has significant differences ($P < 0.05$), "slope position" was eliminated.

The resource selection function of wild boar habitat was constructed as Logit(x) = -2.292–1.206* Altitude +0.269* Arbour canopy coverage -0.481* Arbour DBH +0.72* Arbour height -1.529* Arbour density -0.234* Shrub height +0.638* Shrub coverage -0.94* Ground plant coverage +1.299* Stump quantity -0.325* Fallen wood quantity +0.599* Withered grass coverage -0.276* Slope aspect -1.283* Slope gradient 1.189* Vegetation type +0.035* Hidden degree +0.270* Sheltered condition +0.699* Soil moisture degree +0.524* Water source distance +1.343* Community distance +0.119* Interference intensity +0.623* Distance from human disturbance. The AUC value was 0.862 (Fig. 3), which was between 0.7 and 0.9, indicated that the resource selection function model fitted well (Boyce et al. 2002). Therefore, the selection probability function of wild boar to habitat is constructed as , and the probability of wild boar habitat selection to used sample plot is 81.46 %, while the unused sample plot is 3.27 %.

The selection coefficient of resource selection function is shown in Table 2. Among them, it meets the statistical requirements ($P < 0.05$) and is sorted in descending order of arbour density, community distance, stump quantity, slope gradient, altitude, and vegetation type. Combined with resource selection rate) (Table 3), wild boars prefer arbour forest habitat with more arbours (30–100) and stumps (5–10), far from the community (> 1500m), medium altitude (500–1000), gentle slope (≤ 30°).

Principal component analysis of wild boar habitat factors

The rotated component matrix table of loading coefficients of wild boar's habitat factors in summer is shown in Table 2. The contribution rate of

Table 2. Rotated component matrix showing loading coefficients of habitat factors of *Sus scrofa.*

Factor	Feature vector				
	1	2	3	4	5
Altitude	0.182	0.146	0.037	0.551	0.066
Arbour canopy coverage	0.073	0.254	0.412	0.035	0.482
Arbour DBH	0.344	-0.177	0.103	-0.103	0.041
Arbour height	0.173	-0.078	-0.300	-0.205	0.476
Arbour density	-0.074	0.482	0.092	-0.091	0.176
Shrub height	0.175	-0.052	-0.452	0.053	0.157
Shrub coverage	-0.177	-0.236	0.182	0.162	-0.236
Ground plant coverage	0.001	-0.026	-0.123	0.639	0.097
Stump quantity	0.136	0.379	-0.267	0.000	-0.472
Fallen wood quantity	0.287	0.169	0.132	-0.098	-0.358
Withered grass coverage	0.319	-0.213	0.304	0.026	-0.103
Contribution	19.909	14.382	12.721	11.182	9.589
Cumulative contribution	19.909	34.291	47.012	58.194	67.783

Table 3. Principal components of summer habitat factors in used sample plots of *Sus scrofa.* Abbreviation: PC, Principle component.

PC	Variable	Definition	Value	Rate (%)
1	Arbour DBH	Food factor	15.87±1.09	19.91
	Withered grass coverage		7.13±2.03	
	Fallen wood quantity		1.00±0.26	
2	Arbour density	Arbour factor	42.90±4.11	14.38
	Stump quantity		1.23±0.26	
3	Arbour canopy coverage	Canopy coverage factor	51.57±2.83	12.72
4	Altitude	Altitude factor	812.47±39.32	11.18
5	Shrub height	Shrub factor	2.29±0.78	9.59

the first five principal components reached 67.78 %. The contribution rate of first principal component reached 19.91 %, including arbour diameter at breast height, withered grass coverage and fallen wood quantity, their coefficients are relatively large in absolute value, reflecting food resources of their habitat, and are named "food factors". The contribution rate of second principal component was 14.38 %, among which absolute value of coefficient of arbour density and stump quantity was relatively large, which was defined as "arbour factor". The contribution rate of third principal component was 12.72 %, among which absolute value of coefficient of arbour canopy coverage was larger, which was defined as "canopy coverage factor". The contribution rate of fourth principal component was 11.18 %, and the factor with larger absolute value of the coefficient was altitude, which was defined as "altitude factor". The contribution rate of fifth principal component was 9.59 %, and the coefficient with larger absolute value was average height of shrubs, which was defined as "shrub factor". The names and values of each principal component are shown in Table 3.

Discussion

Habitat selection of wild boar in mountainous area around Beijing

Animal adjustment of relationship between individual and environment by selecting appropriate habitats to maximize their fitness is termed as habitat selection (Yan et al. 1998, Wei et al. 1998). The habitat selection of wild animals is a complex ecological process, in which food conditions (Zeman et al. 2018), space availability, concealment, predation and competition, habitat structure and animal behaviours can all affect the selection and utilization of habitat by animals (Guo et al. 2017, Casula et al. 2017). This study showed that the main factors affecting the summer habitat selection of wild boars in mountainous areas around Beijing were arbours, stumps, water sources, soil moisture, slope, altitude, sheltered condition, community distance, distance from human interference, and interference intensity, which reflected the ecological needs of wild boars for foraging sites, water sources and concealment. This is consistent with the results of Zhao et al. (2019) on the utilization of wild boar habitats in Northeast China.

Wild boars are relatively larger in size, higher in activity and energy demanding, and higher in feed intake and frequency. Therefore, the amount of food resources in habitat is primary factor affecting their habitat selection. Wild boars are omnivorous and have a wide range of diets, in addition to fruit and seeds on ground, young leaves and rhizomes of ground plants, their diet includes soil invertebrates (Wood & Roark 1980, Ballari & Barrios-García 2014). Therefore, evergreen broad-leaved and deciduous broad-leaved mixed forest become the most preferred habitat for wild boars in summer (Abaigar et al. 1994, Meriggi et al. 2001). This study shows that wild boars in mountainous areas around Beijing prefer forest habitats with more arbours (30–100 plants/100 m^2) and stumps (5–10 stumps/100 m^2) in summer.

The mountainous regions around Beijing belongs to the northeast part of Taihang Mountains, north China, mostly temperate broad-leaved forests, coniferous and mixed forests, especially rich in *Quercus* spp. and *Castanea* spp. species with higher maturity, which have higher canopy density, better undergrowth vegetation, more fruits and seeds dropping of the Fagaceae plants that wild boars like to eat. The moist, soft soil and stumps also provide a habitat base for high-energy animal food such as millipedes, insect larvae, snails and earthworms that are fond of eating by wild boars (Keuling et al. 2009, Zhu et al. 2011), ensuring the food abundance of wild boars. In addition, the preference of wild boars for gentle slope habitats (≤ 30°) at medium altitude (500–1000) is related to the vegetation type preferred by wild boars. The north-eastern part of Taihang Mountain is dominated by artificial secondary forests, the coniferous and broad-leaved forests are mainly distributed in the mid-altitude areas, with the highest concentration at 450–900 m (Cheng et al. 2009). There are abundant food resources in this altitude range, and the relatively gentle slope of the habitat is conducive to passage, antipredator behaviour, rooting and breeding of wild boars. Therefore, wild boar prefers lower and middle altitude habitats to higher-altitude habitats with poor food resources and steep slopes.

Water source is the rigid demand of wild animals influencing their distribution pattern (Li et al. 2010). In this study, wild boars preferred the arbours (81.48%, P<0.05) close to the water source (<500 m), indicated that the water source was the key factor to restrict selection and activities of wild boar habitat in summer. The surrounding regions of Beijing has a typical continental climate, with relatively higher daytime temperature in summer, and the habitats close to the water source meets the wild boar's demand for water. Moreover, wild boars cools down by taking mud baths and lying near water sources such as springs, ponds and streams (Henrik et al. 2009). In addition, the soil in areas with abundant water sources is generally moist and soft, which is conducive to the wild boar to rooting the insects and rhizome in the soil. The study of Morelle et al. (2015) and Stillfried et al. (2017) also concluded that the activity route of wild boar is often accompanied by water source distribution, with a significantly higher rate of activity in areas close to water sources.

Human Wildlife Conflict is concerned issue for ecological protection by scholars at home and abroad (Zhu et al. 2011, Rho 2015). This study shows that wild boars in mountainous areas around Beijing prefer habitats that are far from the community (>1500 m, 51.85 %), far from the interference distance (> 1500 m, 51.85 %), and weaker disturbance intensity (81.48 %) in summer, which is consistent with the results of domestic and foreign scholars (Zhu et al. 2011, Rho 2015). Wild boars are alert, timid (Zhang et al. 2012), and sensitive to human activities (Linnell et al. 2020). They can adjust the spatial and temporal patterns of their activities to avoid excessive human interference (Podgorski et al. 2013). Therefore, they usually select to breed their young in habitats far from human interference, to obtain sufficient security and shelter.

This study shows that wild boars are more active in the forest landscape around crops in summer, while the habitat shelter conditions are relatively poor (41.67 %), which is related to the trade-off between feeding and safety. Since summer coincides with the ripening season of corn, potatoes and other crops in the region, the food abundance in farming areas is much higher than that in mountain forest areas (Cai et al. 2008), resulting in the distribution and habitat selection of wild boars strongly dependent on the distribution and maturity of crops (Bueno et al. 2009, Ballari & Barrios-García 2014), thus causing damage to agricultural production and economic loss. According to the "Optimal Ingestion Theory" (Lu et al. 2007), wild boars consider their own safety when ingesting. The safety of habitat and availability of seasonal resources are incorporated into selection strategy at the same time (Kim et al. 2019), which is reflected in balance between foraging sites and low-risk habitats, thus avoiding areas of excessive human interference and reducing excessive energy loss, while facilitating its entry into farmland to feed crops (Ballari & Barrios-García 2014). Therefore, marginal forest habitats far away from human communities and close to agricultural land (crops) became the preferred habitat of wild boar in summer in this study. Compared with habitats with better hidden conditions in high-altitude and deep mountainous areas, the shelter conditions of this kind of habitats are relatively poor, but richer diet can meet the survival needs of wild boars. At the same time, the habitat conditions with large visual range and conducive to escape are particularly important for wild boars, that is, the escape strategy is safer between hiding and escape, and this trend of habitat selection has also been confirmed by Boitani et al. (1994).

Application of RSF and PCA in animal habitat selection

Resource selection function and principal component analysis are commonly used in habitat selection study of wild animals, which are widely used in the analysis of characteristics of preferred habitat for wild animals (Garshelis 2000).

The value of selection coefficient of resource selection function indicates preference degree of animals to habitat variables (Boyce & McDonald 1999). The resource selection function mainly compares difference between the used and unused sample plots of various habitat variables. It has advantages of robustness in judging the effectiveness of factors, and has more applications in studying animal habitat preference (Boyce & McDonald 1999, Manly et al. 2002). However, when there is no significant difference in habitat variables between the used sample plot and the control plot, the model loses its basis of judgment. Since the premise of its use is that the habitats with better ecological conditions correspond to more traces of animal use, and animals are significantly inclined to use better types of habitats (Railsback et al. 2003). This research satisfies its prerequisites well, and therefore obtains better analysis results.

Principal component analysis is to generate comprehensive variables (principal components) by reducing the dimensions of the variables used by animals in the habitat, which contains most of the data information (Zhang 2011), and its essence is to synthesize the distribution frequency of each habitat variable (Legendre & Legendre 1998). The judgment of principal component analysis method is completely based on the data provided by study sample, which only involves distribution of data inside used sample plot, and cannot be distinguished and compared with unused sample plot. Therefore, the principal component analysis is not affected by distribution characteristics of variables in non-used quadrats.

The arbour density is the most important variable in judgment of resource selection function model in this study but this variable only partially contributes to second principal component (arbour factor) in principal component analysis. The resource selection function analysis shows distance to the nearest community, slope gradient and vegetation type are important variables, but they do not contribute to the five principal components; the selection coefficient of stump and altitude has reached a significant level, but it is not particularly important in principal component analysis. In fact, this study found that wild boars have obvious selectivity for arbour density, stump quantity, and altitude in used sample plots. The arbour diameter at breast height contributed the most in principal component analysis, withered grass coverage, fallen wood quantity, arbour canopy coverage, and shrub height also contributed, while results of resource selection function analysis determined that the above factors were not important variables. The results of resource selection function are more consistent with ecological habits and the characteristics for summer habitat utilization of wild boars.

However, the importance of water source distance to wild boars in this study is not well reflected in two methods, but the Chi-square test shows extremely significant differences in selection of water source variables between used and unused sample plots. Field observations in this study similar to many other studies have indicated that water sources are one of the key factor restricting the selection and utilization of summer habitats for wild boar due to rooting and cooling requirements in summer (Stillfried et al. 2017).

In general, when studying the habitat selection and utilization of wildlife, it is necessary to combine animal behaviours and utilization pattern of habitats, distinguish the advantages and disadvantages of resource selection function and the principal component analysis with aid of means test, *etc.*, in order to reveal habitat selection and utilization characteristics of wildlife more scientifically, comprehensively and accurately.

Management and recommendations

Increase population of wild boar force them to use diverse habitats, which not only cause damage to the regional crops, but brings the risk of animal epidemic disease, and aggravate human wildlife conflicts. It can also change soil structure and nutrient circulation through arch-feeding behavior, which has a cascading effect on local flora and fauna communities and ecosystems, reducing the level of regional biodiversity (Ballari & Barrios-García 2014, Don 2019, Boyce 2020).

For improved management of wild boar populations and habitats in the mountainous areas around Beijing, this research recommends firstly to install infrared cameras in key areas to continuously monitor the activities of wild boars in real time, construct a distribution map of their activity intensity, and take measures such as disturbing and driving away the wild boar in key areas, secondly to change the distribution of water sources and remove nearby key water source sites if necessary, to reduce intrusion of wild boars in forest and farmland areas where wild boars favoured and finally, managed quota hunting can be implemented to limit the excessive growth of wild boar population. This can minimize negative impact on agriculture, forestry and community economy in local areas with large wild boar population and over-utilization of habitats.

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References

Abaigar T., Del Barrio G. & Vericad J. R. 1994. Habitat preference of wild boar (*Sus scrofa* L. 1758) in a Mediterranean environment. Indirect evaluation by signs. Mammalia 58(2): 201–210.

Acevedo P., Escudero M. A., Munoz R. & Gortazar C. 2006. Factors affecting wild boar abundance across an environmental gradient in Spain. Acta Theriologica 51(3): 327–336.

Ballari S. A. & Barrios-García M. N. 2014. A review of wild boar *Sus scrofa* diet and factors affecting food selection in native and introduced ranges. Mammal Review 44(2): 124–134.

Beasley J. C., Ditchkoff S. S., Mayer J. J., Smith M. D. & Vercauteren K. C. 2018. Research priorities for managing invasive wild pigs in North America. The Journal of Wildlife Management 82(4): 674–681.

Boitani L., Mattei L., Nonis D. & Corsi F. 1994. Spatial and activity patterns of wild boars in Tuscany, Italy. Journal of Mammalogy 75(3): 600–612.

Boyce C. M., Vercauteren K. C. & Beasley J. C. 2020. Timing and extent of crop damage by wild pigs (*Sus scrofa* Linnaeus) to corn and peanut fields. Crop Protection 133: 105131.

Boyce M. S. & McDonald L. L. 1999. Relating populations to habitats using resource selection functions. Trends in Ecology & Evolution 14(7): 268–272.

Boyce M. S., Vernier P. R., Nielsen S. E. & Schmiegelow F. K. A. 2002. Evaluating resource selection functions. Ecological Modelling 157(2–3): 281–300.

Bu X. L., Wang J., Wu J. Y., Sun T. F., Xiang R. W., Lu Q. B., Hao Y. H., Xiao Z. S., Cui S. P., Sheng Y. & Meng X. X. 2020. Mammal fauna and biodiversity in northeastern Taihang Mountains. Biodiversity Science. DOI: 10.17520/biods.2020081.

Bueno C. G., Alados C. L. D., Gómez-García D., Barrio I. C. & Garcia-Gonzalez R. 2009. Understanding the main factors in the extent and distribution of wild boar rooting on alpine grasslands. Journal of Zoology 279(2): 195-202.

Cai B. C., Li Q. W., Guo L. X., Wang N., Wang X. T. & Zhang L. 2011. A survey on compensation for damage caused by wildlife. Chinese Journal of Wildlife 32(4): 228–232.

Cai J., Jiang Z. G., Zeng Y., Li C. W. & Bravery B. D. 2008. Factors affecting crop damage by wild boar and methods of mitigation in a giant panda reserve. European Journal of Wildlife Research 54(4): 723–728.

Casula P., Luiselli L., Milana G. & Amori G. 2017. Habitat structure and disturbance affect small mammal populations in Mediterranean forests. Basic and Applied Ecology 19: 76–83.

Cheng X. Y. 2009. Analysis of the landscape pattern in Beijing Mountain Area. Master's degree. Beijing Forestry University, China.

Colino-Rabanal V. J., Bosch J., Munoz M. J. & Peris S. J. 2012. Influence of new irrigated croplands on wild boar (*Sus scrofa*) road kills in NW Spain. Animal Biodiversity and Conservation 35(2): 247–252.

Cuevas M. F., Novillo A., Campos C., Dacar M. A. & Ojeda R. A. 2010. Food habits and impact of rooting behaviour of the invasive wild boar, *Sus scrofa*, in a protected area of the Monte Desert, Argentina. Journal of Arid Environments 74(11): 1582–1585.

Don A., Hagen C., Grüneberg E. & Vos C. 2019. Simulated wild boar bioturbation increases the stability of forest soil carbon. Biogeosciences 16(21): 4145–4155.

Engeman R. M., Duffiney A., Braem S., Olsen C., Constantin B., Small P., Dunlap J. & Griffin J. C. 2010. Dramatic and immediate improvements in insular nesting success for threatened sea turtles and shorebirds following predator management. Journal of Experimental Marine Biology and Ecology 395(1–2): 147–152.

Garshelis D. L. 2000. Delusions in habitat evaluation: measuring use, selection, and importance. In: Boitani L. & Fuller T.K. (Eds.): Research Techniques in Animal Ecology: Controversies and Consequences, Columbia University Press, New York, 111–164.

Guo W., Cao G. H. & Quan R. C. 2017. Population dynamics and space use of wild boar in a tropical forest, Southwest China. Global Ecology and Conservation 11(C): 115–124.

Herrero J., García-Serrano A., Couto S., Ortuño V. M. & García-González R. 2006. Diet of wild boar *Sus scrofa* L. and crop damage in an intensive agroecosystem. European Journal of Wildlife Research 52(4): 245–250.

Thurfjell H., Ball J. P., Åhlén P. A., Kornacher P., Dettki H. & Sjöberg K. 2009. Habitat use and spatial patterns of wild boar *Sus scrofa* (L.): agricultural fields and edges. European Journal of Wildlife Research 55(5): 517–523.

Hua X.B., Yan J.Z., Li H.L., He W.F. & Li X.B. 2016. Wildlife damage and cultivated land abandonment: Findings from the mountainous areas of Chongqing, China. Crop Protection 84: 141–149.

Keuling O., Stier N. & Roth M. 2009. Commuting, shifting or remaining? Different spatial utilisation patterns of wild boar *Sus scrofa* L. in forest and field crops during summer. Mammalian Biology 74(2): 145–152.

Kim Y., Cho S. & Choung Y. 2019. Habitat preference of wild boar (*Sus scrofa*) for feeding in cool temperate forests. Journal of Ecology and Environment 43: 30.

Legendre P. & Legendre L. 1998. Numerical Ecology, 2nd ed. Elsevier, Amsterdam. 1–853.

Li L., Liu H., Wan D. M., Ma Q., Zhang S. Q. & Liu Z. L. 2010. Foraging habitat selection of wild boar in Laotudingzi Natural Reserve of Liaoning Province in winter. Chinese Journal of Ecology 29(12): 2408–2413.

Li X. H., Ma Z. J., Li D. M., Ding C. Q., Zhai T. Q. & Lu B. Z. 2001. Using resource selection functions to study nest site selection of Crested Ibis. Biodiversity Science (4): 352–358.

Linnell J. D. C., Cretois B., Nilsen E. B., Rolandsen C. M., Solberg E. J., Veiberg V., Kaczensky P., Van Moorter B., Panzacchi M., Rauset G. R. & Kaltenborn B. 2020. The challenges and opportunities of coexisting with wild ungulates in the human-dominated landscapes of Europe's Anthropocene. Biological Conservation 244.

Lu Q. B., Yu J. A., Gao X., Yang X. Y., Zhou Q., Zhang L. B. & Zhang S. Y. 2007. Winter habitat selection of Reeves's muntjac and wild boars in the Qingliangfeng Mountains. Acta Theriologica Sinica (1): 45–52.

Manly B. F. J., McDonald L. L., Thomas D. L., McDonald T. L. & Erickson W. P. 2002. Resource selection by animals: statistical design and analysis for field studies. Journal of Animal Ecology 63(3): 351–351.

Meng X. J., Lindsay D. S. & Sriranganathan N. 2009. Wild boars as sources for infectious diseases in livestock and humans. Philosophical Transactions of the Royal Society B: Biological Sciences 364(1530): 2697–2707.

Meriggi A. & Sacchi O. 2001. Habitat requirements of wild boars in the northern Apennines (N Italy): A multi-level approach. Italian Journal of Zoology 68(1): 47–55.

Morelle K., Podgorski T., Prevot C., Keuling O., Lehaire F. & Lejeune P. 2015. Towards understanding wild boar *Sus scrofa* movement: a synthetic movement ecology approach. Mammal Review 45(1): 15–29.

Podgorski T., Baś G., Jedrzejewska B., Sonnichsen L., Sniezko S., Jedrzejewski W. & Okarma H. 2013. Spatiotemporal behavioral plasticity of wild boar (*Sus scrofa*) under contrasting conditions of human pressure: primeval forest and metropolitan area. Journal of Mammalogy 94(1): 109–119.

Railsback S. F., Stauffer H. B. & Harvey B. C. 2003. What can habitat preference models tell us? Tests using a virtual trout population. Ecological Applications 13(6): 1580–1594.

Rho P. 2015. Using habitat suitability model for the wild boar (*Sus scrofa* Linnaeus) to select wildlife passage sites in extensively disturbed temperate forests. Journal of ecology and environment 38(2): 163–173.

Stillfried M., Gras P., Börner K., Göritz F., Painer J., Röllig K., Wenzler M., Hofer F., Ortmann S. & Kramer-Schadt S. 2017. Secrets of Success in a Landscape of Fear: Urban Wild Boar Adjust Risk Perception and Tolerate Disturbance. Frontiers in Ecology and Evolution 5: 157.

Tang D. Y., Zhou X. H. & Zhang W. 2019. Management of interactions between wild boar and people. Chinese Journal of Wildlife 40(4): 1043–1049.

Wei F. W., Feng Z. J. & Wang Z. W. 1998. Survey of research on habitat selection by wild animals. Chinese Journal of Zoology (4): 49–53.

Wood G. W. & Roark D. N. 1980. Food habits of feral hogs in coastal South Carolina. Journal of Wildlife Management 44(2): 506–511.

Yan Z. C. & Chen Y. L. 1998. Habitat selection in animals. Chinese Journal of Ecology (2):43–49.

Zeman J., Hrbek J., Drimaj J., Kudlacek T. & Heroldova M. 2018. Habitat and management influence on a seasonal diet composition of wild boar. Biologia 73(3): 259–265.

Zhang D. & Liu B. W. 2012. Survey and control of wild boar *Sus scrofa* damage in Qingyun Forest, Heilongjiang Province. Chinese Journal of Wildlife 33(2): 59–70.

Zhang J. D. 2011. Quantitative ecology. 2nd ed. Science Press. Beijing.

Zhao G. J., Gong Y. N., Yang H. T., Xie B., Wang T. M., Ge J. P. & Feng L. M. 2019. Study on habitat use and activity rhythms of wild boar in eastern region of Northeast Tiger and Leopard National Park. Acta Theriologica Sinica 39(4): 431–441.

Zhou S. C., Zhang M. H., Sun H. Y., Yin Y. X., Huang H. J., Yu H. W., Lu X. D., Ge D. N. & Tian J. L. 2010. Population size and habitat of wild boar (*Sus scrofa*) in the eastern Wanda Mountains. Acta Theriologica Sinica 30(1): 28–34.

Zhou X. Y., Jiao H. W., Douys A. A., Hu J., Hu J. C. & Meng X. X. 2013. The winter habitat selection of Red Panda (*Ailurus fulgens*) in the Meigu Dafengding National Nature Reserve, China. Current Science 105 (10): 1425–1429.

Zhu H. Q., Ge Z. Y., Chang S. H., Liu G., Wu J. C., Shi X. J., Xu J. F. & Mao Z. X. 2011. Winter habitat selection of wild boar (*Sus scrofa ussuricus*) in Huangnihe Nature Reserve. Chinese Journal of Ecology 30(4): 734–738.

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