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RESEARCH PAPER

# Application of ecological-niche factor analysis in habitat assessment of giant pandas

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**Abstract:** Ecological-niche factor analysis (ENFA) is a multivariate approach to study geographic distribution of species on a large scale with only “presence” data. It has been widely applied in many fields including wildlife management, habitat assessment and habitat prediction. In this paper, this approach was applied in habitat suitability assessment for giant pandas in Pingwu County, Sichuan Province, China. With “presence” data of giant pandas and remote sensing data, habitat suitability of pandas in this county was evaluated based on ENFA model, and spatial distribution pattern of nature reserves and conservation gaps were then evaluated. The results show that giant pandas in this county prefer high-elevation zones (> 2128 m) dominated by coniferous forest, and mixed coniferous and deciduous broadleaf forest, and avoid deciduous broadleaf forest and shrubs. Pandas avoid staying at habitats with human disturbances. Farmland is a major factor threatening panda habitat. Panda habitat is mainly distributed in north and west of Pingwu with a total area of 234033 $hm^2$, 106345$hm^2$ for suitable habitat and 127688 $hm^2$ for marginally suitable habitat). 3 nature reserves were located in Pingwu, covering over 49.2% of total suitable habitat and 45.6% of total marginally suitable habitat. Although 47.2% of panda habitat was in reserves under protection, connectivity between reserves was weak and a conservation gap existed in the north part of Pingwu. Thus, a new nature reserve in Baima and Mupi should be established to link the isolated habitats.

**Key Words:** giant panda (*Ailuropoda melanoleuca*); ecological-niche factor analysis; habitat suitability; habitat assessment

Increasing human disturbance has caused the habitat fragmentation and the population descent of giant pandas (*Ailuropoda melanoleuca*), which has aroused many researchers’ attention. Studying habitat selection and fragmentation is one of the research hotspots of giant panda conservation. Many researches on habitat selection and habitat restoration for giant pandas have been conducted based on field survey since 1970[1–5].

With the development of 3S technology (*i.e.*, GIS, RS and GPS) in recent years, studying giant panda habitat at large scale has become a new research hotspot[6–11]. Many studies have been carried on habitat assessment[6–9], habitat design[10] and habitat protection[11] based on habitat models. Among these models, ecological-niche factor analysis (ENFA) was recently established, but it has been widely applied in many fields, such as habitat assessment and habitat prediction[12–16]. Different from the regression model and the conception model, ENFA requires only species presence data[12,13]. Study based on this model can interpret the relation between species habitat utilization and niche factors[12].

Many studies on giant pandas’ habitat evaluation were conducted in Qingling[9,10], Qionglai[6,7,11] and Minshan[8] based on the conception model, which provided scientific basis for the protection of panda habitat in these places. The habitat suitability map of giant pandas on the basis of the model can reflect neither the extent of habitat utilization nor the relations between habitat utilization and niche factors. But illuminating these relations is the key step to understand the reason of habitat degrade of giant pandas, and then to process habitat designation and conservation. Therefore, in order to fully un-

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derstand the relations between habitat utilization and niche factors, ENFA model was introduced in the panda habitat evaluation. This model was further used to assess the habitat status and conservation gaps in the case study area (*i.e.*, Pingwu County).

## 1 Materials and methods

### 1.1 Study area

Pingwu County, with an area of 5959 km$^2$, is located in Mianyang, Sichuan Province, China (31°59′31″–33°02′41″N, 103°40′31″–104°59′13″E), northwest of the Sichuan basin, east edge of the Qinghai-Tibetan Plateau and east slope of Minshan Mountains. About 94% of the area is in mountains with elevation over 1000 m, higher in the north-west and lower in the south-north. The peak of the mountains, namely Xuebaoding in the north-west, has an elevation of 5588 m above sea level. It is nearly 5000 m higher than the lowest valley in the south-east. The climate in this area belongs to the northern sub-tropical monsoon, and the forest coverage of Pingwu is over 51%.

Pingwu has the largest wild giant panda population in China on the county level. According to the result of the Third National Giant Panda Survey in 1998, Pingwu had more than 230 wild panda individuals[17]. This number could be higher according to the recent research, which showed that the population in Wanglang Nature Reserve of this county doubled in 2003 than in 1998[18]. Two national reserves (*i.e.*, Wanglang and Xuebaoding) and one provincial reserve (Xiaohegou) are located in Pingwu, covering 21% of the total area of the whole county.

### 1.2 Model introduction

ENFA is a multivariate approach to study specific geographic distribution on a large scale. This model only requires “presence” data but not “absence” data during calculation. Built on the conception of ecological niche, the model compares, in the multidimensional space of ecological variables, the distribution of the localities where the focal species has been observed to a reference set describing the whole study area. Like the principal component analysis, ENFA summarizes all predictors from Ecogeographical Variables (EGVs) into a few uncorrelated factors, and then build habitat suitability map based on eigenvectors and eigenvalues[12,13]. In this case, the combination factors, which retain most of the information of EGVs, have ecological meaning. ENFA possesses 3 conceptions[13]:

Marginality, $$M=\frac{|m_G-m_S|}{1.96\sigma_G}$$

Specialisation, $$S=\frac{\sigma_G}{\sigma_S}$$

Tolerance, $$T=\frac{1}{S}$$

where $m_G$ is the mean of the EGV in the whole research areas, $\sigma_G$ is the standard deviation of the global distribution, $m_S$ is the mean of the EGV of the focal species distribution, and $\sigma_S$ is the standard deviation of the focal species distribution.

Marginality was defined as the ecological distance between the species optimum and the mean habitat in the whole area. The positive value of marginality indicates that the focal species prefers the values that are high than the mean in the whole areas, while the negative value indicates the preference of lower-than-mean values. The higher the absolute value of marginality is, the farther the species depart from the mean available habitat. Specialisation was defined as the ratio of the ecological variance in the mean habitat to that of the focal species. The specialisation coefficient varies from one to infinite. More tractable, however, is the tolerance value–inverse of the specialisation which varies from 0 to 1. The value of $T$ closing to 0 means that the species are distributed in a narrow space, while $T$ closing to 1 means that the distribution area of the species is wide.

### 1.3 Data sources

The data sources of ENFA include panda presence points, bio-geographical factors and human disturbance factors. Panda presence data mainly contain the evidence of panda feeding and movement (including fecal droppings, feeding remnants and footprints), in the case that live individuals were very difficult to find. Bio-geographical factors include elevation, slope, aspect, vegetation, bamboo distribution and water source, which affect selection of giant panda habitat. The human disturbance factors include roads, residential area and farmlands. But some human disturbances (such as herding, herb collecting and mining) were not considered in this study because they existed seasonally in some local area and could not be interpreted in large scale habitat model.

A total number of 687 panda presence points were used in the model. These points were acquired from the wild population survey at Pingwu, which was conducted across the whole county with transect line sampling method in 1998. The bamboo distribution map was from the Third National Giant Panda Survey[17], and the elevation, slope and aspect were derived from the digital elevation map (DEM, 1:50000). The vegetation types and farmlands were from the supervised classification of TM images (acquired in June 2001) by using Erdas Imagine 8.6 with a resolution of 30×30 m$^2$/pixel. The classification contains 7 types, *i.e.*, bare land, alpine grassland, coniferous forest, mixed coniferous and deciduous broadleaf forest, deciduous broadleaf forest, shrubs and farmlands.

### 1.4 Data process

Topographical data (altitude, slope and aspect) were quantitative, and were used directly. But land-coverage and human disturbance factors were qualitative, and were transformed into frequency and distance variables before the calculation[13].

Frequency variables described a proportion of cells from a given category within a circle of 1410 m (47 pixels) radius around the focal cell. This radius reflects the home range of giant pandas which varies from 3 to 6 $km^2$ depending on seasons[19]. The home range in summer is the largest, so we choose ~6 $km^2$ as the area of the circle. Distance variables express the distance between the focal cell and the closest cell belonging to a given category. The distance of each variable was calculated in ArcView 3.2.

A total number of 25 variable factors (Table 1) and giant panda presence points were converted to raster grid (30 m × 30 m), and then standardized with Box-Cox transformation for further modeling[20].

### 1.5 Analysis methods

All ENFA calculations were performed in Biomapper 3.1[20] and ArcView 3.2. The first 5 factors from eigenvalues were selected for mapping habitat suitability. Values of the habitat suitability index (HSI) ranged from 0 to 1, in which 0 means the most unsuitable habitat, and 1 means the most suitable habitat. These values were then reclassified into 3 classes: unsuitable, marginally suitable and suitable.

### 1.6 Model validation

Model validation was achieved through a Jake-Knife Cross-Validation process[21]. The presence points were partitioned into 10 subsets of equal size. 9 of them were used to calibrate the habitat suitability map and the last one was used to evaluate the result. Absolute Validation Index (AVI) was introduced into the model validation, and defined as the percentage of predicted suitability exceeding 0.5 of the validation cells. By replicating this process 10 times, each subset was used in turn for the validation purpose. The mean and the standard deviation of the accuracy assessment were calculated for modal validation.

## 2 Results and analysis

### 2.1 Relation between pandas' distribution and habitat factors

Table 1 showed that giant pandas were mainly distributed in the areas with high elevation (higher than the average eleva-

Table 1 List of EGVs included in the ENFA and ratio of contribution for the first 5 (of 25) ecological factors

| EGV | Factor 1 (48%) | Factor 2 (10%) | Factor 3 (8%) | Factor 4 (5%) | Factor 5 (4%) |
|---|---|---|---|---|---|
| Frequency of mixed coniferous and deciduous broadleaf | 0.32 | 0.11 | 0.48 | –0.09 | –0.25 |
| Distance to mixed coniferous and deciduous broadleaf | –0.32 | 0.19 | –0.03 | –0.24 | 0.14 |
| Coniferous frequency | 0.30 | –0.07 | –0.05 | 0.05 | 0.05 |
| Shrub frequency | –0.29 | –0.22 | –0.17 | 0.57 | –0.55 |
| Distance to farmlands | 0.29 | 0.13 | –0.07 | 0.26 | 0.26 |
| Bamboo frequency | 0.28 | 0.05 | –0.80 | –0.08 | 0.13 |
| Distance to coniferous | –0.27 | 0.33 | –0.19 | –0.19 | 0.21 |
| Distance to shrubs | 0.23 | –0.22 | –0.07 | 0.43 | –0.08 |
| Distance to rock | –0.22 | 0.07 | 0.07 | 0.17 | 0.12 |
| Distance to towns | 0.22 | –0.05 | 0.07 | –0.11 | –0.05 |
| Distance to villages | 0.21 | 0.08 | 0.05 | 0 | 0.29 |
| Frequency of deciduous broadleaf | –0.20 | 0.09 | 0.07 | 0.22 | 0.07 |
| Distance to secondary roads | 0.20 | –0.05 | –0.04 | –0.05 | –0.05 |
| Distance to grass | –0.19 | 0.03 | –0.07 | 0.02 | 0.56 |
| Elevation | 0.16 | 0.80 | 0.13 | 0.33 | 0.01 |
| Distance to small rivers | –0.13 | –0.08 | –0.03 | 0 | –0.01 |
| Distance to deciduous broadleaf | 0.13 | 0.05 | –0.01 | –0.28 | 0.10 |
| Distance to major roads | 0.08 | –0.11 | –0.06 | –0.01 | –0.05 |
| Rock frequency | –0.07 | 0.19 | –0.02 | –0.06 | –0.13 |
| Cosine of aspect | –0.04 | 0.03 | 0 | 0.01 | 0.01 |
| Sine of aspect | –0.04 | 0.02 | 0.03 | –0.02 | –0.02 |
| Grass frequency | 0.03 | –0.02 | –0.04 | 0.01 | 0.09 |
| Aspect | 0.02 | 0.01 | 0 | –0.02 | 0.01 |
| Distance to large rivers (width ⩾ 2 m) | –0.02 | 0.04 | 0.02 | 0.13 | –0.17 |
| Slope | 0.01 | 0.03 | 0.02 | 0.01 | –0.03 |

Notes: Factor 1 is marginality factor and the others are specialisation factors. The amount of specialisation accounted for is given in parentheses in each column heading.

tion of 2128 m; Coefficient = 0.16) and low slope (close to the average 31; Coefficient = 0.01). The distribution of bamboo to some extent determines the habitat distribution (Frequency = 0.28). Giant pandas like small rivers (less than an average distance of 362 m; Distance = –0.13) and avoid large rivers (close to an average distance of 5840 m; Distance = –0.02). Giant pandas prefer coniferous forest (Frequency = 0.3; Distance = –0.27) and mixed coniferous and deciduous broadleaf forest (Frequency = 0.32; Distance = –0.32), and avoid deciduous broadleaf forest (Frequency = –0.2; Distance = 0.13), shrubs (Frequency = –0.28; Distance = 0.23), grass (Frequency = 0.03) and bare land (Frequency = –0.07).

Giant pandas avoid staying at habitats with human disturbance (all distance > 0). Among all these factors, farmland is the biggest one in Pingwu (Distance = 0.29).

### 2.2 Habitat distribution map

The first 5 factors (Table 1) of eigenvalues were selected for mapping the habitat suitability, and their accumulative contribution reached 75.1%, accounting for 100% of marginality and 75.1% of the total specialisation. The AVI Index from Jake-Knife Cross-Validation is 0.703 ± 0.07, showing the good performance of the modeling results.

A criterion was established as follows for habitat classes by overlapping the habitat suitability map with the vegetation map and human factor maps: (1) HSI<0.15: these areas mostly occurred in roads, human settlements, farmlands and bare land, and they were not suitable for giant pandas. (2) 0.15 ⩽ HSI < 0.5: these areas were mainly located in grassland or zones with low elevation (less than 2000 m) dominated by shrubs or deciduous broadleaf forests. They were not very suitable for giant pandas, but giant pandas could seasonally occur in these areas. (3) HSI > 0.5: the areas were distributed in coniferous forests, and mixed coniferous and deciduous broadleaf forests, and they were suitable for giant pandas. By this criterion, the habitat suitability map was reclassified into 3 classes: 0–0.15 for unsuitable, 0.15–0.5 for marginally suitable and 0.5–1 for suitable (Fig. 1).

### 2.3 Habitat suitability analysis

Giant panda habitats were mainly distributed in the west and north of Pingwu (Fig. 1) with a total area of 234033 $hm^2$ (106345 $hm^2$ for suitable and 127688 $hm^2$ for marginally suitable), accounting for 39.3% of the whole area of the county. 3 nature reserves (Wanglang, Xuebaoding and Xiaohegou) were located in Pingwu, covering over 49.2% of the total suitable habitat and 45.6% of the total marginally suitable habitat. Baima and Mupi, located in the north of Pingwu with a total area of 72006 $hm^2$ (34538 $hm^2$ for suitable and 37468 $hm^2$ for marginally suitable), are two of the main panda distribution areas outside the reserves in Pingwu. The human disturbance here is intensive, and most of local residents are Tibetans. It is urgent to establish a nature reserve to fill the conservation gap existing in this area with Jiuzhai ring roads cross.

## 3 Discussion

Habitat models can be classified into regression models[22–24],

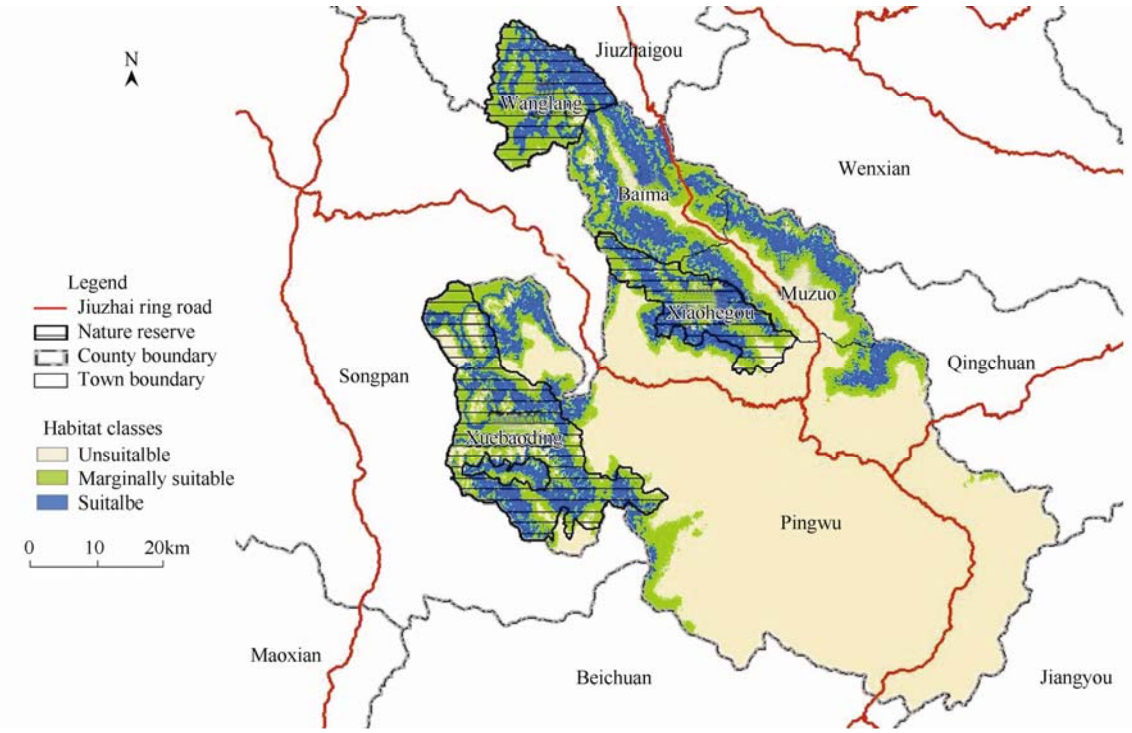


Fig. 1 Habitat distribution map for giant pandas in Pingwu, China

Niche models (ENFA[4–16], Entropy[25], etc.) and conception models[6–11]. Both "presence" data and "absence" data are required in habitat suitability evaluation by using regression models. With these models, good prediction results can be achieved when the "absence" data are reliable[12]. Considerable prediction results can also be achieved by using ENFA models with only "presence" points[12,15]. This model is particularly useful in modeling habitats for mammals like giant pandas. For them, the reliability of "absence" points is not guaranteed[12] because they may not always leave evidences. Or even if evidences (such as footprints) were left in the wild, they could not be detectable after some time. For the conception models, "presence" data as well as "absence" data are not necessary in modeling. Suitable habitats can be predicted by simulating the relative suitability of distribution areas of species with the relations between the habitat selection and niche factors[8]. But conception models can not interpret the extent of habitat utilization of species. Therefore, ENFA model was applied in assessing the habitat suitability in Pingwu.

In this study, the relationship between panda habitat selection and niche factors were analyzed on a large scale by using ENFA, and then habitat suitability was mapped based on this relationship. The marginality coefficients of ENFA interpret this relation, and the absolute values of coefficients reflect the extent of the preferences for niche factors. Giant pandas in Pingwu prefer coniferous forests, and mixed coniferous and deciduous broadleaf forests, but avoid deciduous broadleaf forests, shrubs and bare land. These results are consistent in essential with the research results conducted at the Wanglang nature reserve[3]. Pandas need to drink clean water directly every day[19], so they trend to stay around small rivers. In contrast, they avoid staying near large rivers because large rivers are mostly influenced by human settlements and roads.

The distributions of bamboos determine the habitat of giant pandas to a great extent because bamboos comprise about 99% of the panda diet[19]. The dominant bamboo species in Pingwu are *Fargesia denudate Yi*, *Fargesia nitida Mitford Keng f. ex Yi* and *Fargesia rufa Yi*[12], which are scattered or mottled understory species. Owing to the data availability, bamboo distribution map derived from the Third National Panda Survey was used in this study. This map may overestimate bamboo distribution since only field sample points and limit elevation of each bamboo were considered during the map making[17,26]. The accuracy of bamboo distribution map can be improved by combining detailed bamboo information through extensive field survey, but it is infeasible in reality owing to the high cost and labor expenditure. Using artificial neural networks to map the distribution of understory bamboo has been developed[27], but further studies are necessary to proceed, and there are still some difficulties for wild application in evaluation on giant panda habitats now.

Giant pandas avoid staying at circumstances with human disturbances. In this study, disturbance from farmlands is regarded as the most severe human factor. Farmlands are mainly located around low elevation hills near human settlements, which results in the reduction of the panda habitats directly. This is different from the previous research results indicating that grazing was the main human disturbance in Wanglang[3]. This difference might be caused by different research scales. Human settlements and secondary roads are mostly located at low altitude areas in the south-east, so they have nearly the same impacts on selection of panda habitats. Jiuzhai ring road is the minimum impact factor comparing to other human factors. It crosses over the habitat distribution area from south to north, but leads to the isolation and fragmentation. Some seasonally and locally existed human disturbances, such as grazing and mining[3,4], could not be included in this model, though these have some negative effect on habitat selection for giant pandas.

Pingwu is located at the center of the giant panda distribution areas of Minshan Mountains, and it is the county with the largest wild giant panda population in China. Although the 3 existing reserves cover 47.2% of the total habitat in Pingwu, the connectivity between reserves is still weak. Some panda distribution areas with intensive human impacts are not efficiently protected, especially Baima and Muzuo that are the two areas most suitable for giant pandas. These two areas are located at the core region of Minshan reserve group, and are the connection areas to link the major habitats of Minshan and the habitats of Wenxian and Qingchuan. But they are influenced by the Jiuzhai ring road with high vehicle flux, and by the increasingly intensive production activities from Tibetan residents around, which will cause the isolation of panda population. So an effective way such as establishing new reserves needs to be taken to reduce these human disturbances so that most habitats can be effectively protected. In addition, some effective measures, such as improving local residents' livelihood, and controlling the number of vehicles passing per day, should be taken immediately to improve the qualities of giant panda habitat.

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