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Application of landscape connectivity in habitat suitability evaluation——case study in Wolong Nature Reserve, Sichuan, China *

Chen Li-ding, Fu Bo-jie

Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijng 100085, China

Abstract—Landscape connectivity is a parameter of landscape function, which measures the processes by which the sub-populations of organisms are interconnected into a functional demographic unit. It is a landscape phenomenon which describes the relationships between landscape subunits. Landscape connectivity can be measured by measuring the degree to which the landscape pattern facilitates or impedes movement of animals among resource patches, particularly for conserved animal species. In this paper, the landscape connectivity for Giant Panda in Wolong Nature Reserve was evaluated by using landscape ecological model on the base of choosing three natural affecting factors on Giant Panda and using geographic information system. The results demonstrate that only about 90.36 km^2(c.a. 4.47%) of total area 2023.31 km^2 is most suitable for Giant Panda survival, the suitable area is about 226.42 km^2(11.19%), the moderately suitable area is 286.09 km^2(14.13%), as much as 1236.51 km^2 is completely unsuitable for Giant Panda living. The result will be helpful for making a decision on improving eco-environment and protecting Giant Panda in Wolong Nature Reserve.

Keywords: landscape connectivity, habitat, suitability evaluation, GIS application.

1 Introduction

Landscape connectivity, as one important parameter to describe the ecological processes and ecological functions in landscape ecology, has been used to study behavior of animals in landscapes (Schreiber, 1988; Forman, 1986; Henein, 1990; Merriam, 1984; 1991). It was particularly used to describe the degree of a landscape element favoring or impeding the movement of animals (Taylor, 1993). Many researches have been carried out to study the relationship between the landscape connectivity and papulation survival, particularly in the strongly human affected region (Fahrig, 1985; Hansson, 1991; Lefkovitch, 1985; Wu, 1993). It has been widely recognized that landscape connectivity is different from landscape connectedness. Landscape connectivity is mainly to describe the relationship of ecological processes and ecological functions between different landscape elements, while landscape connectedness focuses on spatial relationship between different landscape elements with less considering ecological processes and ecological functions (Schreiber, 1988).

Studying landscape connectivity is of very significance on endangered habitat and species protection in fragmented landscape areas (Wu, 1993). Since the ecological process and function are largely dependent on the study objectives and study object, the value of landscape connectivity is particularly related to the following factors (Forman, 1986; Chen, 1996): (1) Landscape pattern: different landscape patterns will determine different ecological processes and functions, such as spatial distribution of landscape elements, patch size, shape, distance between the same type patches, relationship between patch and matrix, patch and corridor, and so on. (2) The ecological process to be studied: due to the mechanism is changeable with different ecological process, for example, animal movement, energy flow, seed transportation, the landscape connectivity for the

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same pattern will be different. (3) Study object: particularly for the endangered animals, since different animals require different environment for survival, thus, landscape connectivity for different animals will be quite different for the same pattern, such as the terrestrial animals and aquatic animals, terrestrial animals and birds, different environment will be required for them to survive.

Generally, landscape connectivity is considered as an abstract concept. Even though landscape pattern has strong impacts on landscape connectivity value, however, it is impossible to define landscape connectivity value only based on the pattern analysis. In most cases, some field surveys and observation on animal's behavior in different environments have to be carried out for determining the landscape connectivity value. Landscape connectivity is usually given a relative value. Its value for certain landscape patterns sometime is very high for certain species while it might be very small for the other species. An example is the river system, many aquatic animals are able to move there freely (i. e. with high landscape connectivity value), however, most terrestrial animals can not live there. It becomes a sink for most terrestrial animals. In general, landscape connectivity with value "1" is considered that the landscape pattern is the most suitable one for the animal's survival, while landscape connectivity with value "0" means that the landscape pattern will be the least suitable for animal's survival. The value of landscape connectivity of the landscape pattern in-between will be fallen in [1,0].

2 Application of landscape connectivity in habitat suitability evaluation of Giant Panda

2.1 The study area

The study area is located in Wenchuan Country of western part of Sichuan Province, China, between 102°52′—103°24′ E and 30°45′—31°20′ N geographically (Fig.1). Wolong Nature Reserve is the largest protected area for Giant Panda in China. The nature reserve was established in 1963 with 20000 hm^2 and enlarged to 200000 hm^2 in 1975. At the beginning, about 140 Giant Pandas were living in this area and reduced to 90 Giant Panda at present due to environmental deterioration and human encroachment. Apart from Giant Pandas, some other national protected species, such as Golden Monkey, Dove Tree and other rare species are also accommodated in this area. The study area is a transitional zone between the Sichuan Basin and Qinghai-Tibet Plateau with an elevation variation from 1120m to 6250m above sea level. It has been moderately dissected and inclines towards southeast direction. A quite steep slope is developed in northwestern aspect of the mountains and a slightly steep slope is developed in the southeastern aspect. Within the study area, five rivers, Pitiao River, Zheng River, Gangda River and Xi Valley are developed. The average rainfall is around 959 mm and the average temperature is about 8.7℃. Most of rainfall is occurred in the summer. Being transitional zone between cold high plateau climate and lower basin warm-humid climate, rich biodiversity is formed. Generally, from the hill top to the foot of the hill, naval (5000—6250m), alpine sparse vegetation (4400—5000m), frigid bush and meadow (3600—4400m), conifer forest (2600—3600m) conifer and broadleaf mixed forest (2000—2600m), evergreen and deciduous broadleaf mixed forest (1600—2600m) and evergreen broadleaf forest (1120—1600m) are grown (Liu, 1997; Ouyang, 1996a).

There about six villages in Wolong Nature Reserve area with 4310 inhabitants in 1995 and about 384 hm^2 has been cultivated as arable land. Apart from agricultural cropping, some other human activities, such as firewood collection, Chinese herb collection, and local mining are also active activities, which have played strong impacts on Giant Panda protection.

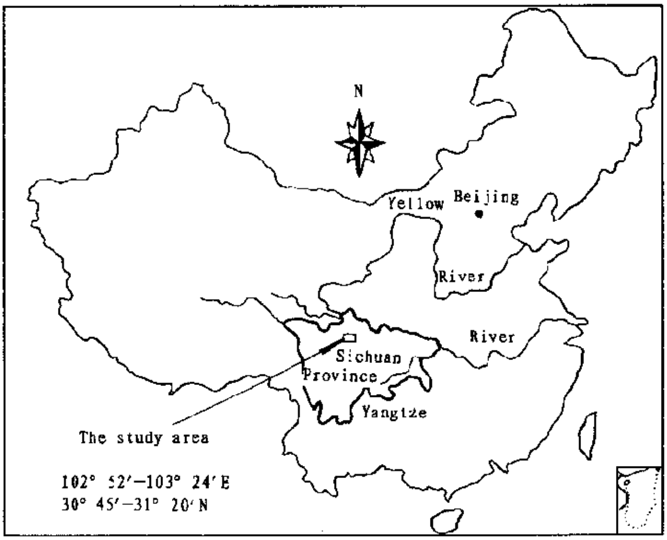

Fig. 1 Location of the study area in China

2.2 Natural factors affecting Giant Panda Habitat suitability

As an old relict large animal in the world, Giant Panda has a corpulent stature with average weight of 75—100 kg. It is one of those animals disliking both hot and cold environment. Giant Panda generally lives at those places having a dense canopy of forest and bamboo within the range of 1600—3000m above sea level on elevation and normally lives in the high hilly area in summer and shift to the lower places during winter time. Since her clumsy body and slow-moving, she is prone to expose herself to the enemy. Due to her own ecological nature, a special environment is usually required for Giant Panda's survival. Apart from the food source, such as bamboo, has strong impacts on Giant Panda's survival, the other natural factors as elevation and slope is also vary important for Giant Panda (Liu, 1997; Ouyang, 1996b). In the case study, a landscape ecological model has been applied by considering the following three natural factors to study landscape connectivity for Giant Panda.

2.2.1 Elevation

With increase of elevation, it is becoming more difficult for Giant Panda to move and to look for food. Some researches have already shown that the frequency of Giant Panda appearance is changeable with elevation, and the range of 1400—3600m above sea level, is the most frequent place for Giant Panda appearance, which means that landscape connectivity for Giant Panda varies with elevation. The most frequent height range of Giant Panda emergence can be considered as the most suitable environment for Giant Panda's survival and the landscape connectivity value to this section will be the highest. Otherwise, the landscape connectivity value to elevation for Giant Panda will be lower. Thus, landscape connectivity value can be given based on the emerging frequency. A relative value is assigned to elevation for Giant Panda (Table 1).

2.2.2 Slope

Since Giant Panda is a large and clumsy animal, she is sensitive to the natural environmental change, particularly to the slope. It becomes more difficult for Giant Panda with slope degree increase. Some surveys demonstrate that those areas with slope gradient less than 20° is most suitable for Giant Panda's moving and looking for food. In Wolong Nature Reserve, 65% of the Giant Pandas are found living in the areas less than 20 degree. About 25% of Giant Panda are observed living in the places within slope form 20—30 degree, and only 12% of Giant Pandas live in the areas above 30 degree (Hu, 1985). Accordingly, the area with less than 20° can be considered as the most suitable areas for Giant Panda living, then 20—30° and 30—40° respectively. When the slope gradient reaches 40° and above, it will be no more suitable for Giant Panda's surviving. Based on these principles, landscape connectivity value for Giant Panda can be assigned as Table 1.

Table 1 Landscape connectivity value for different landscape factors

Elevation	2000—3000m	1150—2000m; 3000—4000m	4000—5000m	>5000m
Slope	Less than 20°	20—30°	30—40°	More than 40°
Food source	*Gelidocalamus fangian*; *Fargesia robusta*	*Yushania chungii*; *Fargesia nitida*; *Phyllostachys nidularia*	*Fargesia angustissima*	No bamboo area
Landscape connectivity value assigned for different affecting factors(u)	1	0.667	0.333	0

2.2.3 Food sources

Apart from the above-mentioned two factors, one of the most important factors affecting Giant Panda's survival is the food source, i.e. bamboo distribution. In most protected nature reserves in China, the coverage of bamboo is shrinking due to deterioration of natural environment with human encroachment. It has become a potential danger for Giant Panda's survival and will result in distinction of Giant Panda's with deteriorating further (Chen, 1993). Normally, the abundance and spatial distribution of bamboo wile be the most important factors to influence Giant Panda surviving. In Wolong Nature Reserve, available bamboos for Giant Panda are *Gelidocalamus fangiana*, *Fargesi robusta*, *Yushania chungii*, *Fargesia nitida*, *Phyllosta chys nidularia*, *Fargesia angustissima*, and so on. Some researches have shown that Giant Panda prefer to eat *Gelidocalamus fangiana* and *Fargesia robusta*, and then the others (Ouyang, 1996b). Thus the value of landscape connectivity to food source can be given based on the preference of Giant Panda to different types of bamboo.

2.3 Setting up of evaluation model

From above-discussed, it has been known that all the three landscape factors are important for Giant Panda survival, however, the spatial combination of these factors will become more important for determining the suitability of environment for Giant Panda. If either of these factors is unsuitable for Giant Panda, the final evaluation will unsuitable for Giant Panda's survival, and only when all the three factors are in the best situation, i.e. the landscape connectivity value is "1", the final evaluation will be most suitable for Giant Panda. In other cases, the environmental suitability for Giant Panda is dependent. Therefore, the following expression could be the best way to describe this process:

$$S = \prod_{i=1}^{n} ui^{wi}. \tag{1}$$

Among them, S represents the landscape connectivity of each cells to Giant Panda. n is the number of affecting factors and is 3 here. ui is the value of landscape connectivity for different classes of different factors to Giant Panda based on their importance to Giant Panda's survival. wi is the weight for the three different landscape factors. From this expression, it is clear that general landscape connectivity S will be zero when landscape connectivity value of either of three affecting factors is zero and only when all three affecting factors' landscape connectivity have a value "1", i. e. being the most suitable situation, S will be 1. In the other cases, S will varies between [0—1].

3 Results and discussion

3.1 Data processing and results

During data processing, a GIS software (ILWIS) developed by International Institute for Aerospace Surveys and Earth Sciences is employed, by which the topomap of scale 1:100000 of the study area has been digitized and a DEM is created. Then an elevation classification map and slope gradient map based on above-mentioned criteria were prepared (Table 1) by use of ILWIS. Meanwhile a vegetation map with scale 1:500000 of the study area is also digitized with ILWIS, which was used for deriving a classification map of food source for Giant Panda and also for overlaying with elevation map and slope map. For overlaying the food source map with the elevation map and the slope gradient map, a common reference map has been used when rasterizing the above three parameter maps. After a landscape connectivity evaluation map to Giant Panda for each factor was produced upon the criteria of Table 1, Equation (1) was then applied for calculating the general landscape connectivity of the study area to Giant Panda and habitat suitability evaluation is indicated in Table 2.

Table 2 General landscape connectivity of Wolong Nature Reserve Combining three landscape factors

Value of landscape connectivity	Number of cells	Area, km^2	Percentage in total area, %	Assessment of habitat suitability	Code for habitat suitability	Total area, km^2	Percentage of total area, %
1	11827	90.36	4.47	Most suitable	S1	90.36	4.47
0.67	29636	226.42	11.19	Suitable	S2	226.42	11.19
0.45	16747	127.95	6.32	Moderately Suitable	S3	286.09	14.13
0.33	19475	148.79	7.35				
0.30	1224	9.35	0.46				
0.22	20222	154.49	7.64	Marginally Suitable	S4	183.93	9.1
0.15	2532	19.34	0.96				
0.11	534	4.08	0.2				
0.07	260	1.99	0.1				
0.04	528	4.03	0.2				
0.00	161849	1236.51	61.11	Unsuitable	S5	1236.51	61.11
Total	264834	2023.31	100				

Based on the above results, a distribution map on habitat evaluation for Giant Panda is derived as Fig.2.

3.2 Discussion

From above evaluation, only about 93.36 km^2 around 4.47% of the study area belongs the most suitable area for Giant Panda, though Wolong Nature Reserve was enlarged in 1970 to 2023.31 km^2 totally. The suitable area is about 226.42 km^2, covering about 11.19% of the entire study area. More than 60% of the study area is completely unsuitable for Giant Panda living. This result is a little different from that research carried out in this area using a qualitative methodology (Ouyang, 1996b). Accordingly, the ecological conservation function of the nature reserve will be more emphasized other than the size when nature reserve area is to be established for some endangered species.

It is also found that the suitable area in the study area is highly fragmented on spatial distribution even though it covers more than 200 km^2, that is extremely unfavorable for Giant Panda's protection and survival. Due to highly fragmentation of the suitable habitat, the protection of the nature reserve for Giant Panda has been greatly decreased, and with the separation of the

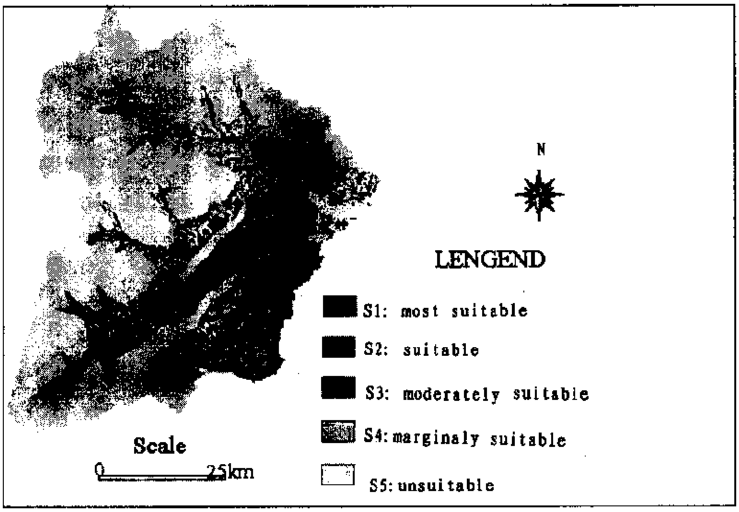

Fig. 2 Habitat suitability assessment for Giant Panda in Wolong Nature Reserve

suitable habitat for a long time, the gene-diversity of Giant Panda will be strongly impacted. For improving landscape connectivity between different habitats and protecting Giant Panda effectively, some corridors to connect the potential habitat are to be established in Wolong Nature Reserve.

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