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Identification of Key Patches for Biodiversity Conservation Based on Possibility of Connectivity Method

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Abstract: The optimization of landscape structure will benefit for biodiversity conservation by analysing the best landscape layout as the habitat patches have been rapidly lost. Based on the possibility of connectivity (PC) method have been proposed for the assessment of biodiversity value that considered both habitat size and spatial connectivity, which regards the index of PC as its primary parameter. Miyun County, Beijing is studied as a case area to evaluate the biodiversity value by both the popular method and the proposed method. It is concluded that the total biodiversity value of each concerned land use types based on 2010 data are: grazing land 3.69×10^6 Yuan•ha^{-1}•year^{-1}, forest land 132.39×10^6 Yuan•ha^{-1}•year^{-1}, cropland 5.65×10^6 Yuan•ha^{-1}•year^{-1}, water area 18.94×10^6 Yuan•ha^{-1}•year^{-1}, built-up land 0, and unused land 0.11×10^6 Yuan•ha^{-1}•year^{-1}. Secondly, for the identification of key patches, there are three kinds of key patches: (1) the patches with larger habitat size; (2) the satellite patches around the large patches as the undertaken area for biological migration; (3) the stepping stone patches. It is found that biodiversity value is not evenly distributed with patch area because of the difference of connectivity. Larger patches and the patches locate in the connecting position are important for maintaining connectivity. The results of this paper will provide technology and data references for environmental protection in the near future.

1. Introduction

Ecosystem service (ES) is the benefit that human obtained from natural system (MA, 2005), which is the cornerstone of the survival of mankind and the modern civilization (Feng et al., 2009). The loss of ES will severely affect the sustainable development. Biodiversity, as an important kind of ES, is the regulator of ecological process (Mace et al., 2012). Biodiversity and habitats have been degraded and fragmentized due to human activities and disturbance, which is the main cause of biodiversity recession. For example, global biodiversity has declined about 12% (WWF, 2011; UNEP, 2015). By 2020, at the current rate of biodiversity loss, the world could have witnessed a two-thirds decline in global wildlife populations in only half a century (WWF, 2015).

The protection of biodiversity should be proceeded with the maintaining of biodiversity conservation (Lazarus et al., 2015) and identified the area of high value density. The current assessments of biodiversity value mainly follow the conventional method which is represented by Costanza (1997). The conventional method considers patch area as the only factor that related to biodiversity value. The ability and products that ecosystem had provided are usually not evenly distributed. Landscape pattern is also another important factor that affected ES value, which was not fully reflected in recent studies (Frank et al., 2012). Landscape features, such as patch size, edge effect, proximity, and corridor, could affect the ES provision and be integrated to assess ES (Kreuter et al., 2001). Landscape connectivity, one of the representative indicators that reflected landscape patterns, was closely related to animal migration, species reproduction, population growth, ecological functions maintaining and so on (Mitchell et al., 2013). Landscape connectivity can reflect landscape structure and function. There are a variety of definitions for connectivity, which can be divided into two categories: 1) one referred to the spatial continuity of landscape patches, corridors and matrix (Pelorossoa et al., 2016) which tended to reflect the structure of landscape; 2) the other meaning was the smooth degree of ecological processes between patches (Taylor et al., 1993), which was

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defined from the perspective of landscape functions. In this article, we primarily referred the connectivity to landscape functions. Functional landscape connectivity can be measured with the combination of landscape structure and ecological processes (animal migration, pollination, etc.). Many ES are affected by animal migration and material transportation, and animal migration and material transportation are closely related to landscape connectivity, therefore landscape connectivity will affect ES to some extent.

Biodiversity that underpins most ES, is also an important ES (With et al., 1997). In the classification of ES conducted by different ecological researchers, ESB are important types of ES (Mace et al., 2012). In this study, biodiversity is regarded as ES. Biodiversity refers to a kind of ES that provided by habitats about conservation of species diversity, genetic diversity and ecosystem diversity. ESB that relate to animal migration and the spread of pollen are more vulnerable to landscape structure, therefore ESB are selected as representative ES in this article.

We used both conventional method and a PC-based method (Ng et al., 2013) to evaluate ESB value of Miyun, and we also corrected ESB value unit area in Miyun County. Then we made further efforts to integrate three kinds of ES value into two categories. According to the ESB value of each patch of two categories, we identified key patches for biodiversity conservation. The results can provide reference to ecological restoration and urban planning in regional management.

2. Methods and study area

2.1 Landscape connectivity index

When evaluating the biodiversity value that based on landscape patterns, appropriate biological indices will be the key component that affects the accuracy of the results. Some of the studies have proposed various indices to assess the landscape connectivity (Bunn et al., 2000). After qualitative and quantitative comparison by some analysis (Saura & Pascual-Hortal, 2007), index of probability of connectivity (PC) has been chosen to analyze the landscape connectivity of ecosystem, which is an area-based functional connectivity approach that can incorporate two important elements in habitat size and connectivity in a single measure (Ng et al., 2013). Both landscape connectivity and important value of key patches can be reflected in PC index (Pascual-Hortal & Saura, 2006).

The range of PC index is from 0 to 1, 0 indicates no connectivity, and 1 indicates the patches are completely connective or they are the same patch. The equation is as follows (Saura & Pascual-Hortal, 2007):

$$PC = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} a_i \times a_j \times p_{ij}^{*}}{A_L^2} \tag{1}$$

Where n is the total number of habitat nodes in a landscape, a_i and a_j are areas of the habitat patches i and j, respectively, and A_L is the total area of the landscape. P^*_{ij} indicates the maximum product probability of all possible paths between patches i and j.

Based on the concept of PC index, the method that considered both habitat size and spatial connectivity are used to calculate the biodiversity value, as follows (Ng et al., 2013).

$$ESVB(PC) = \sum_k ESVB_k \tag{2}$$

$$ESVB(PC)_k = \sum_i [VC_k \times (\frac{A_{k_{max}}}{dPC_{k-max}}) \times dPC_{k_i}] \tag{3}$$

$$dPC_{k_i} = \frac{PC_{k_i} - PC'_{k_i}}{PC_{k_i}} \times 100 \tag{4}$$

Where ESVB(PC) is the estimated biodiversity value of all land use types, $ESVB(PC)_k$ is the estimated biodiversity value of land use k, and VC_k is the value of coefficient for land use k. $A_{k\text{-}max}$ refers to the largest patches among the land use k. dPC indicates the importance of each patch in terms of its contribution to the maintenance of overall connectivity by comparing the overall connectivity difference before and after moving the patch. dPC_{ki} indicates the connectivity importance of patch i in land use k. It is able to identify the important patches of landscape structure. $dPC_{k\text{-}max}$ indicates the maximum value of dPC among land use k.

$$VC_k = VC'_k \times \frac{A_k}{A} \tag{5}$$

Where VC_k is the value of coefficient we've used for land use k, A_k is the size of land use k of a habitat, A is total area of the habitat. As for VC_k', the values of coefficient of Tang et al. (2010) for Beijing have been adopted in our case study, which is highlighted in **Errore. L'origine riferimento non è stata trovata.**.

I represents cropland, II represents forest land, III represents grazing land, IV represents water area, V represents unused land, VI represents built-up land. The unit of Area is 10^4 hm^2, the unit of VC_k is Yuan/ hm^2.

Table 1: Value of coefficient of Beijing

Land use	Sub-type	VC_k'	Area	$VC_{'k}$
I	dry	628.2	38.15	621.4
	paddy	314.1	0.84	
II	woodland	2884.6	19.81	2271.2
	shrubland	2307.7	35.38	
	open forest	1730.8	14.40	
	others	1442.3	6.83	
III	High coverage	964.5	0.90	768.1
	Medium coverage	771.6	10.86	
	Low coverage	482.3	0.75	
IV		2203.3	6.49	2203.3
V		300.8	0.18	300.8
VI		0	29.24	0

In conventional method, the biodiversity value is to be evaluated as follows (Costanza et al., 1997):

$$ESVB = \sum_k \sum_i VC_k \times A_{k-i} \tag{6}$$

Where *ESVB* is biodiversity value, VC_k is the value of the coefficient for land use category k, and $A_{k\text{-}i}$ is the area size of patch *i* of land use *k*.

2.2 Identification of key patches

The identification of the key patches has been divided into two procedures: the reclassification of the key patches and the identification of the key patches.

Key patches are patches with higher biodiversity value in our study. In general, because of agglomeration effect, larger patches have higher value of unit area. In addition, patches located in the critical connectivity position are also more important. Therefore, we would start from the importance of connectivity of certain patch to identify the key patches. Usually, there are three kinds of values of one patch: (1) internal value; (2) value of the patch which acts as a starting or ending patch in the migration path; (3) value of the patch that acts as stepping stone in the path with maximum product probability. It will be illustrated as follows:

Where VC_k is the value of the coefficient for land use category k, and $A_{k\text{-}i}$ is the area of patch i of land use k.

$$dPC_{k_i} = dPCintra_{k_i} + dPCflux_{k_i} + dPCconnector_{k_i} \tag{7}$$

$$ESVB(PC)_{k_i} = ESVB(PC)\ intra_{k_i} + ESVB(PC)\ flux\ _{k_i} + ESVB(PC)\ connector_{k_i} \tag{8}$$

Where $dPCintra_{ki}$ indicates the contribution of the internal area of patch i to the overall connectivity of land use category k. $dPCflux_{ki}$ indicates the contribution of patch i that act as a starting or ending patch to the overall connectivity. $dPCconnector_{ki}$ indicates the contribution of patch i that act as stepping stone in the path with maximum product probability to the overall connectivity. $dPCintra_{ki}$ $dPCflux_{ki}$, $dPCconnector_{ki}$ can be calculated by software Confor2.6. $ESVB(PC)_{ki}$ is the ESB value of patch i of land use k. $ESVB(PC)intra_{ki}$ is the ESB value that provide by the internal area of patch i. $ESVB(PC)flux_{ki}$ is the ESB value of patch i which act as a starting or ending patch in the migration path. $ESVB(PC)connector_{ki}$ is the ESB value of patch i that act as stepping stone in the path with maximum product probability.

In order to explore the internal and external effects that a patch has contributed, we will reclassify the biodiversity value to provide reference for identification of key patches. In the reclassification of biodiversity value, we've divided $ESVB(PC)flux_{ki}$ into two parts as it has been calculated twice which is regarded as the starting and ending point of a patch. A patch will have internal value when it is regarded as the ending point of migration. At the meantime, a patch will have the external as it has the affected the rest of the patches for its biodiversity output. Therefore, $ESVB(PC)flux_{ki}$ is divided into two parts: half of $ESVB(PC)flux_{ki}$ is the internal value that it contributed to itself; the other half of it is the external value that the patch contributed to the rest of the patches. The formula will be seen as follows:

$$ESVB(PC)_{k_i} = ESVB(PC)1_{k_i} + ESVB(PC)2_{k_i} \tag{9}$$

$$ESVB(PC)1_{k_i} = ESVB(PC)\ intra_{k_i} + ESVB(PC)\ flux\ _{k_i}/2 \tag{10}$$

$$ESVB(PC)2_{k_i} = ESVB(PC)\ flux\ _{k_i}/2 + ESVB(PC)connector_{k_i} \tag{11}$$

Where $ESVB(PC)1_{ki}$ represents the ecosystem value that patch *i* contribute to itself, $ESVB(PC)2_{ki}$ represents the ES value that provided by patch *i* to other patches.After the reclassification, we will identify the key patches according to the value of $ESVB(PC)1_{ki}$ and $ESVB(PC)2_{ki}$. Higher value of $ESVB(PC)1_{ki}$ and $ESVB(PC)2_{ki}$ are regarded as key patches. In this article, we defined the key patches are those whose unit value of $ESVB(PC)1_{ki}$ and $ESVB(PC)2_{ki}$ are thrice or more than thrice than the average unit value of $ESVB(PC)1_{ki}$ and $ESVB(PC)2_{ki}$ are key patches, which is seen as follows:

$$\frac{ESVB(PC)1_{k_i}}{A_{ki}} \geq 3 * \frac{\sum_1^n \frac{ESVB(PC)1_{k_i}}{A_{ki}}}{n} \tag{12}$$

$$\frac{ESVB(PC)2_{k_i}}{A_{ki}} \geq 3 * \frac{\sum_1^n \frac{ESVB(PC)2_{k_i}}{A_{ki}}}{n} \tag{13}$$

However, for further study, the standard for the identification of key patches will be adjusted to a more appropriate value if necessary, such as twice or five times than the average unit value. The change of the standard will not change our identification system.

3. Results and discussions

3.1 The estimation results of ES value

Conventional method and new method were both used to calculate the ESB value in Miyun County, the result of conventional method was 174.13×10^6 yuan, while the result of new method was 160.77×10^6 yuan, the calculation results of five types of land use were shown in Table 2.

Table 2: The ES values from two methods (10^{6}Yuan·ha^{-1}·year^{-1})

Land use	ESVB(PC)	ESVB	ESVB(PC)/ESVB
Water	18.94	18.43	1.03
Forest	132.39	140.02	0.95
Unused	0.11	0.12	0.91
Grazing	3.69	5.36	0.69
Cropland	5.65	10.19	0.55

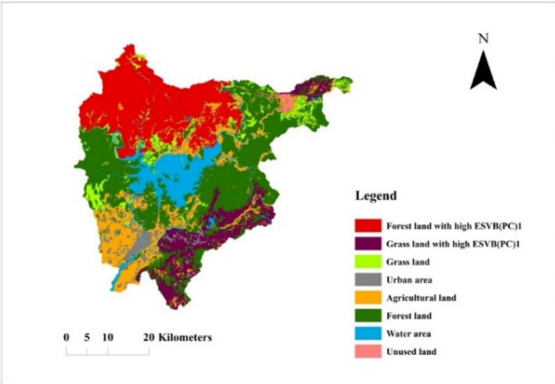
Largely because of the different measurement of the area, those two results that showed in table 2 were different. The conventional method used the real area of the land use types, while the new method used the equivalent area, namely, $\frac{A_{k-max}}{dPC_{k-max}} \times dPC_{k_i}$, where $\frac{A_{k-max}}{dPC_{k-max}}$ represents area unit *dPC* of the patch largest sizes and the patch with largest *dPC*. The product of $\frac{A_{k-max}}{dPC_{k-max}}$ and $dPC_{k\text{-}i}$ means the equivalent area. *ESVB(PC)* is higher than *ESVB* when equivalent area higher than the real area.

Water area was the only land use type that ESVB(PC) higher than ESVB. The descending order of ESVB(PC)/ESVB of 5 land use types is water area, forest land, unused land, grass land and agricultural land. The reason for those results was that patches with the same ratio of area have different ratio of importance in maintaining landscape connectivity. We took water area and agricultural land as representative land use to illustrate the results. Water area occupied 92% of the total water area sizes provided 90% connectivity (Represented by dPC%, which is the normalization of dPC), while the remaining 10% connectivity was provided by 8% area, connectivity was evenly distributed with area. Whereas, in agricultural land, 59% agricultural land provided 90% connectivity, the remaining 10% connectivity was provided by 41% area. Most of the patch area had hardly played a role in maintaining the connectivity. Those patches had low ES values and had even pulled down the total value of agricultural land. Therefore, the degree of uniformity in the distribution of connectivity determined the different results of two methods. The more evenly the connectivity had been distributed with area, the larger the ratio of ESVB(PC) and ESVB would be. It can be fully reflected by the new method.

3.2 Identification of key patches

In our study, the factor of landscape pattern was included to evaluate the value of biodiversity of Miyun to attempt to provide scientific basis for payments for ecosystem services of biodiversity, which could avoid the inappropriate policy guidance that caused by only paying attention to the habitat size. If the factors of landscape pattern were missing, it would have negative influence for urban planning of China. Based on conventional method, the improvement of PC-based method is to add landscape pattern into evaluation of biodiversity value.

In the identification of key patches, we had reclassified the biodiversity value. We found that key patches were not only the patches with larger size, but also the patches located in the dominant position or located in the connectivity position. The loss of those key patches may lower down the landscape connectivity, which meant the biodiversity value were not evenly distributed caused by the difference of connectivity. Sometimes smaller patches would have higher value if they were in the connective position. After the identification of the patches with higher value or in the stepping stone position, we are able to provide reference for the important reserve to protect the biodiversity.



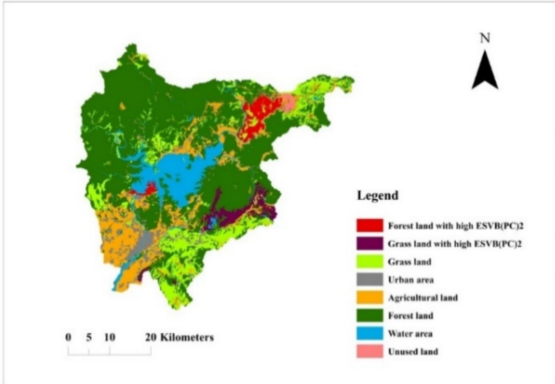


Figure 1: Patches with high ESVB(PC)1 of land (grazing land) and forest land

Figure 2: The patches with high ESVB(PC)2 grass in grazing land and forest land

In Fig.1, forest land with high ESVB(PC)1 is located from east bank of Chao River to the west bank of Bai River in northern Miyun, which accounted for 44.6% of the total forest land, but provided 53.9% ESVB(PC)1. Grass land with high ESVB(PC)1 is located in southern Miyun, which accounted for 64.8% of the total grass land, but provided 95.4% ESVB(PC)1. That region of forest land with high ESVB(PC)1 mainly developes tourism and ecological agriculture, but grass land with high ESVB(PC)1 is mainly industry and tourism. We should prevent the reduction of grassland area caused by the expansion of industrial zone and tourism sector.
In Fig.2, forest land, which is located in the east bank of Chao River, has high ESVB(PC)2 area that accounted for 4.3% of the total forest land, but provided 15.1% ESVB(PC)2. Grass land with high ESVB(PC)2 accounted for 17.5% of the total grass land ,but provided 34.4% ESVB(PC)2. Those area belong to the Chao River Industrial Belt where mainly focused on leisure tourism and modern agriculture. We should prevent fragmentation of forest land and further expansion of grass land. We should delimit protected areas to prevent the expansion of the industrial zone from occupying the grass land.

4. Conclusions

Index of probability of connectivity has been used with the habitat size to assess the biodiversity value of Miyun County of 2010. The land use were divided into six types: forest land, grazing land, cropland, built-up land, water area, and unused land. After the calculation of biodiversity value by PC-based method and conventional method, we got different results which were 160.78×106 Yuan·ha-1·year-1 and 174.12×106 Yuan·ha-1·year-1 respectively. The reason for the difference of the results was the difference of the habitat size in the calculation. If the equivalence area was larger than the actual area, the results of PC-based method would higher than that of the conventional method, and vice versa. Except water area, all of the other land use types of Miyun had lower landscape connectivity because of the change of landscape pattern.
In addition, we found that the key patches that with higher values were divided into three types: 1) patches with larger size; 2) satellite patches that surrounded a larger patch; 3) patches located in connective position. According to the reclassification of the biodiversity value, we have identified the key patches. Different from the conventional classification, we reclassified the biodiversity value into two parts: the internal value and the external value.

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