Scientific solutions for the functional zoning of nature reserves in China

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A B S T R A C T

Reasonable zoning of the nature reserve (NR) is the key to maintain the reserve’s ecological functions for sustainable development. Many zoning designs in the past years were too subjective and lack of scientific contents. The aim of this paper is to find the new approaches for NRs’ functional zoning. We firstly analyzed the practical problems occurred in the functional zoning of giant panda NRs in China. Secondly, a reasonable index system to guide zoning was established for the case study area—Laoxiancheng NR. Finally two new zoning approaches were developed, which were all automatic realization methods based on spatial analysis using GIS.

The habitat suitability assessment (HSA)-based approach considered both natural landscape factors and human disturbing factors. It integrated the outputs of landscape suitability assessment and human disturbance assessment with overlaying the trail density of giant pandas. The HSA zoning showed that (1) 72.2% trail locations of giant panda lied within the core zone, while all human settlements were sited inside the experimental zone; (2) the core zone contained 82.3% suitable habitat patches, while the experimental zone defined 82% human disturbed areas. The least-cost distance calculation (LCDC)-based approach described the degrees of species conservation and of landscape resistance on species. The animal’s selective movement process could be reflected by the spatial variation of the least-cost distance. We classified the least-cost distance using the standard deviation and obtained three thresholds for the core, buffer and experimental zones of Laoxiancheng NR. The LCDC zoning showed that (1) the selection of three thresholds for functional zoning was the key step of this approach; (2) the different safety-level zonings can be designed by utilizing the classification of standard deviation; and the used medium safety-level zoning produced the core, buffer and experimental zones with the areas of 77.37, 22.51 and 25.25 km2, respectively.

Two zoning results demonstrated that two approaches will be useful for species conservation and NR management and can be applied and extended to the relevant nature reserves which aim at the preservation of the endangered species and their habitats. They make it possible to avoid the subjective and non-scientific zoning.

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1. Introduction

The nature reserve’s functional zoning in China means to define every established reserve into three zones, e.g., core zone, buffer zone and experimental zone (SFA, 1994) (Fig. 1). The functional zoning must be based on various types of natural resource and ecosystem as well as their roles, and is a priority issue which needs to be addressed when any nature reserve being established. Many people have studied the methods of functional zoning, including landscape suitability assessment (Chen et al., 2000), habitat distribution model (Li et al., 1999), clustering analysis model (Zhou, 1997) and constellation mapping model (Ouyang et al., 2004). The reasonable functional zoning will be helpful not only to maintain biodiversity in the nature reserve but also to protect its rare or endangered species and typical ecosystems, and also play an important role on keeping the long-term development of the entire nature reserve.

Concerning the nature reserve’s functional zoning in China, many researches are concentrating on those wildlife-protecting reserves. The problems are typical in these reserves’ functional zoning. Therefore, our research took Laoxiancheng NR as the case study area, which is a nature reserve for protecting giant pandas and their habitat. We aimed to demonstrate the GIS-based scientific approaches to implement the functional zoning, and to provide the guidance with scientific contents and methods for those nature reserves which either has no or a problematic zoning system.

2. Problems in the functional zoning of nature reserves in China

There still exist some problems listed below on theory, method and application of NR’s functional zoning, which is calling solutions for management.

The application of nature reserve theories on functional zoning is still not complete and perfect. For instance, island biogeography used as the foundation of reserves’ design only provides the principles for designing. Some other theories are still full of arguing, such as the famous debating on SLOSS (Li and Li, 1994) which has no final correct judgment yet. Although the population viability has been widely applied, it is a new developing theory with targeting on the complicate problems. It is still imperfect on its experience, experiment and theory (BFNRR, 2001). The landscape ecology theory lacks of maneuverability on its application into reserve’s functional zoning (Li, 1997).

There are difficulties on high integration of multidisciplines. Nature reserve’s functional zoning needs to consider not only the ecological factors but also the reserve’s social, economic and humanity factors. That how to successfully integrate these all-aspects factors to design a reasonable functional zoning is a key project on reserves’ designing and management.

The unreasonable internal functional zoning within the nature reserve is also the problems. This includes the boundary blurriness of core and buffer zones, the difficulty on defining the boundary of functional zones, the conflicting between conservation and development, the cutting down of the nature reserve’s size which limits the functional zoning, etc. Here we took the giant panda nature reserves as the case to analyze the reasonableness and unreasonableness of internal functional zoning.

(1) The nature reserve’s reasonable functional zoning can be represented by the clear core, buffer and experimental zones with the protected species and typical ecosystem inside the core zone. The buffer zone locates in-between the core zone and experimental zone with a certain width in order to keep away the human impacts on the core zone, which makes an effective conservation (Fig. 2a) (BTNNR, 2001; BZNNR, 2001).

(2) Some nature reserves have unreasonable functional zonings represented by three situations: (i) the zoning has considered only core and experimental zones, for example, Zhouzhi NR in Shaanxi (BZNNR, 2001; BFNRR, 2001) (Fig. 2b). This two-zone approach has been proved not to fit to the reserves in China where people are living inside the reserves, and have brought great difficulties on reserve management and consequently low down the effectiveness of practical conservation. (ii) The zoning sets up the buffer zone in the wrong location, such as Fengtongzai NR in Sichuan (Fig. 2c). This situation has no way to keep away the negative impacts on the core zone from outside. (iii) Although no people live inside the nature reserve, the zoning still puts the experimental zone inside the nature reserve, such as Changqing Nature Reserve in Shaanxi (Fig. 2d). This situation definitely reduces the conservation efficiency.

(3) Some new reserves have no functional zoning yet. They are just circled with a certain area based on the concentration of the protected species, and not given the core, buffer and experimental zones.

Although the above three represent the problems for giant panda NRs, other types of reserves have the similar situation. Therefore, some researches have been carried out the habitat assessment for the protected areas (Zhou, 1997) and made reevaluation on reserves’ functional zoning. Some zoning methods have been proposed (Li, 1997; Xu, 2000). However, the functional zoning is subjective and lack of scientific contents and practical methods. The objective of the functional zoning is to apply the scientific contents and methods to design the nature reserve (Kingsland, 2000), and at the same time take the internal mechanism of nature reserve and ecosystem services into account (Chave et al., 2002). The current research hotspots on functional zoning lie on the delineation of bound-

![Experimental zone](image-url)
Fig. 2 – The different schemes of functional zoning from giant panda nature reserves (a) an effective functional zone in Baishuihe NR, Sichuan; (b) two zone schemes in Zhouzhi NR, Shaanxi; (c) wrongly locating of buffer zone in Fengtongzai NR, Sichuan; (d) zoning with experimental zone inside the nature reserve but with no people living inside Changqing NR, Shaanxi.

Fig. 3 – Location of Laoxiancheng Nature Reserve, the area with slash lines.

3. Case study area—Laoxiancheng Nature Reserve

Laoxiancheng NR is located on the southern slope of the middle Qinling Mountains in Shaanxi Province with a geo-location of 107°40′E to 107°49′E and 33°43′N to 33°50′N. It is a connection region neighbored by five nature reserves of Foping, Zhouzhi, Changqing, Taibaishan and Huangbaiyuan (Fig. 3). It has an area of 126 km² and the topography with higher elevation in the southeast and lower elevation in the northwest with a difference from 1524 to 2904 m. The reserve has a population of 156 persons. There are 25 giant pandas. Its establishment made a connection of several isolated panda habitats which can play an important role for giant pandas’ gene exchange as well as population rejuvenation.

4. Methods

Two approaches were explored for nature reserve’s functional zoning. One is the HSA-based approach. The other is the LCDC-based approach.

4.1. HSA-based functional zoning

This approach included four steps: (1) to identify and select the key factors which influence the protected species and habitats, (2) to quantify the selected factors for functional zoning, (3) to carry out the HSA and (4) to design the core, buffer and experiment zones according to the HSA results and designing rules.

4.1.1. Identifying and quantifying the key factors

Based on Pan et al. (2001), Liu et al. (2002, 2005) and SFA (2006), the integrated analysis on the factors affecting the giant panda habitat in Laoxiancheng NR was implemented and the results showed that these factors can be grouped into two namely that landscape factors and human disturbing factors. The landscape factors include elevation, slope, edible bamboos’ distribution and richness, vegetation types, etc. The human disturbing factors are mainly firewood cutting, tourism, agri-
Table 1 – Classifying and quantifying of landscape indices for Laoxiancheng Nature Reserve’s zoning

<table>
<thead>
<tr>
<th>Indices</th>
<th>Highly suitable</th>
<th>Moderately suitable</th>
<th>Marginally suitable</th>
<th>Unsuitable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elevation (m)</td>
<td>2200–2900</td>
<td>2000–2200</td>
<td>1800–2000</td>
<td>1500–1800</td>
</tr>
<tr>
<td>Slope (°)</td>
<td>0–20</td>
<td>20–30</td>
<td>30–40</td>
<td>&gt;40</td>
</tr>
<tr>
<td>Bamboo type</td>
<td>Fq</td>
<td>Fn</td>
<td>Fd</td>
<td>No bamboo</td>
</tr>
<tr>
<td>Vegetation type</td>
<td>CF, MCBF</td>
<td>DBF</td>
<td>Shrub</td>
<td>Grass, farmland, forest plantation</td>
</tr>
<tr>
<td>Score of suitability</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

Fq, Fargesia qinlingensis; Fn, Fargesia nitida; Fd, Fargesia dracocephala; CF, conifer forest; MCBF, mixed conifer and broadleaf forest; DBF, deciduous broadleaf forest.

Table 2 – Classifying and quantifying of human impact indices for Laoxiancheng Nature Reserve’s zoning

<table>
<thead>
<tr>
<th>Indices</th>
<th>Strongly disturbed</th>
<th>Moderately disturbed</th>
<th>Slightly disturbed</th>
<th>Not disturbed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential density (households/km²)</td>
<td>2–4</td>
<td>1–2</td>
<td>0–1</td>
<td>0</td>
</tr>
<tr>
<td>Distance to farmlands (m)</td>
<td>0–100</td>
<td>500–200</td>
<td>200–750</td>
<td>&gt;750</td>
</tr>
<tr>
<td>Distance to touring sites (m)</td>
<td>0–500</td>
<td>500–200</td>
<td>1000–1500</td>
<td>&gt;1500</td>
</tr>
<tr>
<td>Distance to road (m)</td>
<td>0–50</td>
<td>50–200</td>
<td>200–1000</td>
<td>&gt;1000</td>
</tr>
<tr>
<td>Distance to firewood area (m)</td>
<td>0–100</td>
<td>100–200</td>
<td>200–1000</td>
<td>&gt;1000</td>
</tr>
<tr>
<td>Score of disturbance</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

4.1.2. Habitat suitability assessment

This is a key step in NR’s functional zoning. Based on the selected indices and their quantification, the individual assessment for each index was implemented and produced reclassification maps with consideration of assigned scores. By using Formulas (1) and (2), we obtained the indices for assessing landscape suitability and human impacts and listed them in Tables 3 and 4.

The index of landscape suitability was calculated through Formula (1):

\[ L = \sum_{i=1}^{m} w_i \]  

where \( L \) represents the index of landscape suitability to giant pandas resulted from four indices (see Table 1). Here \( m \) is the number of landscape suitability index with a value of 4 representing elevation, slope, bamboo species and vegetation type. The \( w_i \) is the scores of suitability shown in Table 1. The range of \( L \) calculated through Formula (1) is from 0 to 12. We then classified the \( L \) into four classes shown in Table 3.

The index of human impact was calculated through Formula (2):

\[ H = \text{MAX}(s_i) \quad i = 1, 2, \ldots, n \]  

where \( H \) represents the index of human impact to giant pandas resulted from five indices (see Table 2). Here \( n \) is the number of human impact index with a value of 5 representing residential density, distance to farmlands, distance to touring sites, distance to road, distance to firewood areas. The \( s_i \) is the score of disturbance shown in Table 2. The range of \( H \) calculated through Formula (2) is from 0 to 3. We then classified the \( H \) into four classes also shown in Table 4.

4.1.3. Functional zoning based on HSA

Firstly, we designed the core zone followed three principles: (i) the cone zone should have higher landscape suitability, (ii) the
area of core zone patch should be big enough for pandas to live and (iii) the density of animal trail sites should be considered. The designing steps are listed below:

- Use the landscape suitability index map and take the pixels with landscape suitability values of $L \geq 6$. Two classes of “highly suitable” with a value of 12 and of “moderately suitable” with values from 6 to 11 were regrouped together into the “core zone” as the initial core zone patch.
- Create the density map of giant panda trail sites with the field survey records and produce eight density classes from no panda trail to 7 trails/km². We overlaid this trail density map with the produced initial core zone patch map. We determined the overlaid area which belonged to both the initial core zone patches and also the dense panda area with densities from 4 to 7 trails/km².
- Delete the small patches using the threshold value of 7 km² which can support giant pandas to survive (Li et al., 1999; Xu, 2000).
- Merge the remaining big patches as a whole core zone with including those non-core zone patches, which are surrounded by these big core zone patches through GIS.
- Obtain the core zone.

Secondly, the designing of the experimental zone was implemented and followed two principles: (i) the area should be located in the human living and disturbing region with allowing people to have more intense activities and (ii) a certain distance should be taken into account between the experimental zone and the core zone in order to have an effective protection. Two steps are listed below:

- Use the human impact index map and classify the area based on the degree of human disturbance. The pixels with a disturbing value of $H \geq 1$ were all grouped together as the initial experimental zone patches. It means that the areas with “strongly disturbed”, “moderately disturbed” and “slightly disturbed” all were determined as the initial experimental zone.
- Adjust the boundary of experimental zone based on the buffer zone discussed below.

Lastly, the designing of the buffer zone was implemented. The width of buffer zone was obtained based on the initial boundaries of the core zone and experimental zone:

- Take the boundary of core zone as the inner boundary of the buffer zone.
- Since the activity range of giant pandas was documented as 7 km² with the activity radius of 1500 m, the distance of 1500 m from the inner boundary of the buffer zone was adopted as its initial outer boundary.
- Update the boundary of the experimental zone based on the distance of 1500 m. The area with distance less than 1500 m from the inner boundary of the buffer zone was extended to 1500 m, and the area with distance further than 1500 m was accepted as the buffer zone.
- Obtain the final functional zones after ascertaining the outer boundary of the buffer zone.

### 4.2. Least-cost distance calculation-based functional zoning

#### 4.2.1. Calculating the least-cost distance

Calculating the least-cost distance is the base in this second approach. Three important elements are sources, resistance layers and resistance values. Based on the spatial separation through using Spatial Analyst in Arc/Info (ESRI, 1991), the least-cost distance to the source was calculated for every pixel (Adriaensen et al., 2003).

#### 4.2.2. Defining source

The source, representing the starting point of the animal’s movement, needs to be defined firstly for LCDC-based functional zoning. The locations of the protected species can be defined as the source of cost, for example, the sites of giant pandas in this study. Due to that giant pandas’ mobility and in order to make the source of cost more representative, we used all kinds of giant panda trail sites, such as corpse sites, sleeping sites, feeding sites, foot print sites and living panda sites, as the sources of cost for analyzing and modeling.

#### 4.2.3. Defining resistance

The movement process of giant pandas needs to overcome the resistance from various landscape factors, like elevation, slope, vegetation and bamboo food which are also consistent with the used landscape factors in HSA-based approach. These factors were selected as the resistance layers for calculating the cost distance (Yu, 1998). The resistance from various landscape factors to giant pandas’ movement is different, and

<table>
<thead>
<tr>
<th>Elevation ranges</th>
<th>The 1st resistance</th>
<th>The 2nd resistance</th>
<th>The 3rd resistance</th>
<th>The 4th resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Relative resistance value</td>
<td>Slope range</td>
<td>Relative resistance value</td>
<td>Vegetation type</td>
</tr>
<tr>
<td>2200–2900</td>
<td>1</td>
<td>0–6</td>
<td>1</td>
<td>CF</td>
</tr>
<tr>
<td>2000–2200</td>
<td>10</td>
<td>6–10</td>
<td>2</td>
<td>MCBF</td>
</tr>
<tr>
<td>1800–2000</td>
<td>50</td>
<td>10–20</td>
<td>5</td>
<td>DBF</td>
</tr>
<tr>
<td>1500–1800</td>
<td>100</td>
<td>20–30</td>
<td>10</td>
<td>Shrub</td>
</tr>
<tr>
<td></td>
<td></td>
<td>30–40</td>
<td>50</td>
<td>Grass, farmland</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt;40</td>
<td>100</td>
<td>Forest plantation</td>
</tr>
</tbody>
</table>

CF, conifer forest; MCBF, mixed conifer and broadleaf forest; DBF, deciduous broadleaf forest; Fq, Fargesia qinlingensis; Fn, Fargesia nitida; Fd, Fargesia dracocephala.
Table 6 – The classification based on 1/2 S.D. interval for least-cost distance calculation zoning approach of Laoxiancheng Nature Reserve

<table>
<thead>
<tr>
<th>Least-cost distance classes</th>
<th>Mean ± S.D.</th>
<th>Range of least-cost distance values (LCD)</th>
<th>The covered total pixels</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>&lt;Mean – 0.75 S.D.</td>
<td>0–3,442</td>
<td>10,321</td>
</tr>
<tr>
<td>C2</td>
<td>Mean – 0.75 S.D.–mean – 0.25 S.D.</td>
<td>3,443–27,681</td>
<td>75,644</td>
</tr>
<tr>
<td>C3</td>
<td>Mean – 0.25 S.D.–mean + 0.25 S.D.</td>
<td>27,682–51,921</td>
<td>15,629</td>
</tr>
<tr>
<td>C4</td>
<td>Mean + 0.25 S.D.–mean + 0.75 S.D.</td>
<td>51,922–76,160</td>
<td>9,385</td>
</tr>
<tr>
<td>C5</td>
<td>Mean + 0.75 S.D.–mean + 1.25 S.D.</td>
<td>76,161–100,399</td>
<td>7,120</td>
</tr>
<tr>
<td>C6</td>
<td>Mean + 1.25 S.D.–mean + 1.75 S.D.</td>
<td>100,400–124,639</td>
<td>5,763</td>
</tr>
<tr>
<td>C7</td>
<td>Mean + 1.75 S.D.–mean + 2.25 S.D.</td>
<td>124,640–148,878</td>
<td>4,668</td>
</tr>
<tr>
<td>C8</td>
<td>&gt;Mean + 2.25 S.D.</td>
<td>148,879–221,006</td>
<td>7,670</td>
</tr>
</tbody>
</table>

4.2.4. Functional zoning based on LCDC

The thresholds were set for creating functional zones based on the produced resistance map. Due to that the least-cost distance reflects the animal’s selective movement process according to the surrounding environment, the difference of the least-cost distance in spatial can represent the habitat stability and sharp changing. Therefore, we classified the least-cost distance map through using mean values and their standard deviations (1/2 S.D. interval) (Table 6).

Then Fig. 4 was created through showing total pixels for each least-cost distance class. The thresholds for the core zone used C1 and C2 with LCD equaling to 27,681, which reflects the large change of standard deviation. The buffer zone can be set up based on two different safety levels. Thresholds of medium safety level for buffer zone were taken from C3 to C4 with LCD equaling to 76,160 and thresholds of higher safety level for buffer zone were taken from C3 to C6 with LCD equaling to 124,639. In this paper, we only show the zoning result from medium safety level for buffer zone which can meet the requirement of nature reserve management.

5. Results

5.1. HSA-based functional zoning

Fig. 5 shows the maps of landscape suitability assessment (Fig. 5A) and the human impact evaluation (Fig. 5B) in Laoxiancheng NR. The landscape suitable area for giant pandas is about 114.1 km² with the highly suitable area of 31.9 km², the moderately suitable area of 35.5 km² and marginally suitable area of 46.7 km². The unsuitable area only occupies 11.1 km². The total landscape suitable area is occupying 91.2% of the whole nature reserve, and 71.8% of NR has no human disturbing. The most serious disturbed area is 6.3 km². The slightly disturbed area is about 29.4 km². Therefore, the assessment showed better landscape suitability in Laoxiancheng NR.

The zoning result based on HSA was shown in Fig. 5C. The core zone has an area of 53.9 km² and occupies 43.0% of Laoxiancheng NR. The area of buffer zone ranks second and is 40.5 km² occupying 32.2% of NR. The experimental zone has the area of 31.2 km² and is 24.8% of NR.

5.2. LCDC-based functional zoning

Fig. 6 shows the obtained least-cost distance map (Fig. 6A) and classified least-cost distance map with eight classes using 1/2 S.D. interval as classification rule (Fig. 6B). Fig. 6C is the output of medium level safety zoning scheme of Laoxiancheng NR. We can see that the core zone represents the patches where the giant pandas move with less resistance and is the key area for conservation. This zoning output produced the core,
buffer and experimental zones with the areas of 77.37, 22.51 and 25.25 km², respectively.

6. Discussion

6.1. Reasonability and advantage of HSA-based functional zoning scheme

HSA model can reflect the various extent of species suitability to the different landscape elements. Therefore, this model can directly influence the design of core zone. Similarly, the human disturbing assessment can be applied directly in designing of the experimental zone. The functional zoning for nature reserves, which focuses on species and ecosystem conservation, needs to consider multi-factors. However, the existing zoning system of Laoxiancheng NR only considered one factor (i.e., elevation) and consequently has not effectively protected the giant panda. Our new developed HSA-based zoning scheme took more factors into account including the panda trail sites, the important species-relevant information. From conservation perspective, this HSA zoning scheme is more scientific and practical. The designed core zone almost covers all suitable habitats for giant pandas, and the designed experimental zone enclosed all human disturbed area. The designed buffer zone with a width of 1500 m can not only mitigate the influence from outside environment but also result in the habitat recover in the buffer zone which can be taken as the potential habitat. Such a zoning output directly harmonizes the conservation and developing management.

The scoring system for landscape suitability and human impact assessments in this paper was used in the HSA in Wolong Nature Reserve (Liu, 1997; Liu et al., 1998), from which the good assessing results were obtained. Although the scoring system is subjective to some extend, it will result in the reasonable if the scoring is assigned based on the real experience and the trends of the real situation. This is why the results we obtained in this study looks also reasonable.

6.2. Safety consideration in LCDC-based functional zoning scheme

Yu (1999) and Xu (2000) proposed that the nature reserves’ entire planning and functional zoning should contain the safety concept. Our research was just building our base from the safety perspective in conservation, giving our consideration of animals’ moving process in the various landscape types, and then combining the biological and other landscape factors into LCDC approach. We proposed, as a result, the LCDC zoning methodology with a medium safety level. This zoning approach further enriched the functional zoning methods.

The correct assigning of the resistance values to LCDC approach is the precondition of getting reasonable functional zoning. The different landscape types produce various resistances influencing the animals’ moving process and habitat selection, which to some extends reflects that giant pandas...
moving along the route with a minimum resistance. Many scholars have made some analysis and discussion on the resistance values (Ferreras, 2001). Although more exploring is necessary for assigning the exact real resistance, the relative value can be assigned to reflect the integrated resistance of various landscape types, which can quantify the resistance of animal movement (Villalba et al., 1998). Therefore, the assigned relative resistance values can meet the requirement of functional zoning.

Since the least-cost distance is gradually increasing from the source to target which represents the increasing resistance from various landscape types on the moving animals, zoning scheme with core, buffer and experimental zones can fulfill the species conservation purpose. The resistance the species encounter in their moving in the core zone is the smallest, the strongest in the experimental zone, and the medium in buffer zone. Therefore, the important step in this LCDC study is how to decide the thresholds for three zones and then how to run automatically the zoning process. We defined three thresholds based on the obvious statistic difference expressed by the calculated least-cost distance, which indicates the landscape resistance on animal and the animal selection on the landscape.

6.3. Similarity and differentiation between HSA and LCDC

The explored HSA and LCDC zoning approaches in this study have their similarity and difference. The HSA zoning approach reflects the suitability of landscape on the species, while the LCDC approach reflects the resistance of landscape on the species movement. Both do have similar conservation concepts. Their difference lies on the zoning procedures. The HSA approach was based on assessing the habitat suitability and providing each zone a judging rule for final defining three boundaries of core, buffer and experimental zones. However, The LCDC approach was based on calculating the resistance variance and defining three zones boundaries according to the change of resistance and pixel numbers. Both all produced the reasonable results. LCDC produced larger area of
core zone but smaller and narrow buffer zone comparing with HSA approach.

6.4. **Automatic realization of NR’s functional zoning**

The biggest advantage of these two zoning schemes is to have used GIS for implementing all design process. The spatial analysis and modeling of GIS were well applied in this study, which made all zoning process automatically completed. This automatic zoning process through GIS can avoid the subjectivity from human in terms of defining boundaries of core, buffer and experimental zones, and consequently can avoid the conflicts between conservation and local development. GIS played a very important role in spatial analysis of multi-factors concerning feasibility and effectiveness.

7. **Conclusion**

The study developed two approaches for NR’s functional zoning, namely that the HSA-based and the LCDC-based approaches. Both HSA and LCDC can be used in automatically zoning. The landscape suitability assessing in HSA is a proper step for core zone design and its output can strongly support selection of the core zone patches. The human disturbing assessment can control human activities within the designed experimental zone. The certain width of buffer zone can mitigate the impacts from outside disturbing and even destroy on the habitat.

The LCDC approach is new in application in NR’s functional zoning. Our study set up the detailed steps and methods, including defining the “sources” for LCDC, assigning the resistance of landscape, ascertaining the thresholds of functional zones. These methods and steps can be applied in other nature reserves’ zoning tasks. Various safety levels in zoning proposed in this study can produce the different zoning outputs according to the practical situation. It is generally known that the NR’s functional zoning is complicated. Therefore, the research of functional zoning has not reached the phase which can directly provide proper information for right decision making for nature reserve management. Our developed HSA and LCDC strongly show the extent of controlling and managing on biological conservation, and their zoning outputs certainly need more testing concerning their validity on sustainable development in nature reserves.

**REFERENCES**


State Forestry Administration (SFA), 1994. PRC. Byelaw of nature reserve of PRC.


