Analysis of the Spatiotemporal Variation in Habitat Quality Based on the InVEST Model- A Case Study of Shangri-La City, Northwest Yunnan, China

Xingqi Sun¹, Yuanhe Yu², Jinliang Wang³* and Weidong Liu¹

¹The First Geodetic Surveying Brigade of MNR, Xi'an, Shanxi, 710000, China
²School of Geography, Nanjing Normal University, Nanjing, Jiangsu, 210023, China
³Faculty of Geography, Yunnan Normal University, Kunming, Yunnan 650500, China
* Correspondence author’s e-mail: jlwang@ynnu.edu.cn

Abstract. Habitat quality is an important spatial dynamic factor for evaluating the effectiveness of biodiversity conservation. This study aimed to understand the characteristic variation of habitat quality in Shangri-La City, which can provide a basis for decision-making by relevant departments to protect the biodiversity of the area. The spatiotemporal variation of habitat quality of Shangri-La City in 1989-2015 was estimated based on the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) model. The results showed that: (1) The overall habitat quality presented a decreasing trend from 1989 to 2015, with Jiantang, Naxi, Xiaozhongdian, the northern part of Hutiaoxia and the southern part of Sanba the most significant. (2) The highest value of the average habitat quality of Shangri-La City was located in the middle-elevation regions, while the lowest value was located in the low-elevation areas, and the average habitat quality of the two regions showed a decreasing trend from 1989 to 2015. (3) The average habitat quality of the steep and extremely steep slopes in Shangri-La was higher than that of the slight slopes. This study was useful for biodiversity conservation policy-making for ecological fragile region in China.

1. Introduction

During the rapid development of society and economy, the ecological environment has been severely disturbed by humans, and biodiversity has been severely damaged[1]. Habitat quality refers to the capability of an ecosystem to provide the necessary resources and conditions for all its wildlife or specific populations, which value can reflect the status of biodiversity[2].

The Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) model is based on the “3S” technology (i.e., remote sensing, geographic information system and global position system) to achieve the spatial expression of ecosystem services, which can quantify analyze the distribution characteristics of habitat quality[3]. The habitat quality map can be generated by combining the information of land cover and biodiversity threat factors, which can be supplemented with detailed methods to quickly test the changes of habitat quality and quantity. Shangri-La City, located in the hinterland of Hengduan Mountains in the northwest of Yunnan Province, is rich in animal and plant resources and is the gene bank of organisms.

In recent years, human activities and geological disasters have resulted in serious damage to the ecosystem of Shangri-La City, and biodiversity has been severely damaged resulting from a large amount of vegetation has been cut down. In this study, the InVEST model was used to quantitatively
evaluate the characteristics of habitat quality of Shangri-La City in 1989 and 2015, and the results can provide a basis for decision-making for relevant departments to effectively protect the ecological environment of the region.

2. Study area
Shangri-La City is located in the northwest of Yunnan Province, in the hinterland of the Hengduan Mountains on the southeastern edge of the Qinghai-Tibet Plateau, in the world natural heritage “Three Parallel Rivers” scenic spot. The geographical coordinates are between 26°52'-28°45'N and 99°23'-100°31'E, which is the junction of Yunnan, Sichuan and Tibet. Shangri-La is very rich in biological resources, and forest resources, known as the "forest kingdom". The main forest types are Abies georgei forest, Cangshan fir forest, Lijiang spruce forest, Larix potaninii var.macrocarpa forest, Alpine pine forest, Pinus yunnanensis, Quercus aquifoliodes, Betula albosinensis burkhill forest, Seabuckthorn forest, Betula platyphylla forest, etc.[4-6]. The wildlife resources in Shangri-La are also very rich, including three species of national level I key protected animals: clouded leopard, forest musk deer and snow leopard.

3. Data and methods

3.1. Data sources
Land cover data in 1989 was collected from the Nature Conservancy (TNC) project undertaken by the original project team. The land cover data in 2015 was modified based on the visual interpretation of the number of project acceptances, and the accuracy was verified through field survey data, which accuracy reached 94%. According to the research needs, the land cover data were sorted into urban industrial and mining land, rural residential land, cultivated land, forest land, shrubland, grassland, water body, unutilized land, permanent snow glacier and other types.

The Digital Elevation Model (DEM) data used in this study was jointly completed by National Aeronautics and Space Administration and National Geospatial-Intelligence Agency, which was mainly used for elevation vertical grading and slope grading in Shangri-La City.

3.2. Methods

3.2.1. The InVEST Model. The InVEST-habitat quality model was used in this study, in which the land use type was connected with the threat source. Based on the landscape type data of the study area, the sensitivity of various landscape types and the degree of external threat were analyzed, and the distribution characteristics of the habitat quality in the area were obtained. The model shows that the better the habitat quality, the higher the corresponding biodiversity[7]. The biodiversity of the region was explained through the assessment of the habitat quality of the region, and the process is as follows:

\[ Q_{xj} = H_j \left( 1 - \left( \frac{D_{xj}}{D_{xj} + k^2} \right) \right) \]  (1)

In equation (1), \( Q_{xj} \) represents the habitat quality of the x-th grid in the j-th land use type; \( D_{xj} \) represents the habitat degradation degree of the x-th grid of the j-th land use type; k is half-saturation constant (half of the maximum value of degradation); \( H_j \) represents the habitat attribute of the j-th land use type.

\[ D_{xj} = \sum_{r=1}^{R} \sum_{y=1}^{Y} \left( \frac{w_x}{\sum_{r=1}^{R} w_r} \right) r_y l_{rxy} \beta_x S_{jx} \]  (2)

In equation (2), \( R \) represents a threat factor; \( y \) represents the number of grids of the threat factor r grid layer; \( Y_x \) represents the number of grids accounted for the threat factor; \( w_x \) represents the weight of the threat factor (WEIGHT), with the value between 0 and 1; \( r_y \) represents the threat factor value of the grid (0 or 1); \( l_{rxy} \) represents the threat level of the threat factor value \( r_y \) of the grid \( y \) to the habitat grid \( x \); \( \beta_x \) represents the accessibility level of the grid; \( S_{jx} \) represents the sensitivity
of habitat type $j$ to threat factor $r$.

### 3.2.2. Threat factor parameters.

In the InVEST model, the spatial distance was used to calculate the impact of ecological threat factors on each land use type. Due to the different spatial relationships between different threat factors and land use types, the InVEST model provides two methods for the impact of threat factors on land use types, namely linear recession and exponential recession. The specific implementation process is as follows:

- **If linear:**
  
  $$i_{xy} = 1 - \left( \frac{d_{xy}}{d_{r_{max}}} \right) \quad (3)$$

- **If exponential:**
  
  $$i_{xy} = \exp \left[ - \left( \frac{2.99}{d_{r_{max}}} \right) d_{xy} \right] \quad (4)$$

In equation (3) and equation (4), $d_{xy}$ represents the straight-line distance between grid $x$ and $y$; $d_{r_{max}}$ represents the maximum impact distance of threat factor $r$ (MAX_DIST).

According to the actual situation in Shangri-La, urban industrial and mining land (UIML), rural residential land (RRL), and cultivated land (CL) which are greatly disturbed by human beings were regarded as the source of threats to the Shangri-La ecological environment, and the threat factor layer was extracted by ArcGIS. The threat factor parameters of this study are listed in Table 1.

| MAX_DIST | WEIGHT | THREAT | DECAY    | DESCRIP   | CUR_PATH   |
|----------|--------|--------|----------|-----------|------------|
| 10       | 1      | UIML   | exponential | UIML | urbn_c.tif |
| 6        | 0.5    | RRL    | exponential | RRL    | coun_c.tif |
| 8        | 0.7    | CL     | linear     | CL      | crops_c.tif |

Note: DECAY-- decay types; DESCRIP-- a description of the threat factor; CUR_PATH-- output file name.

### 3.2.3. Habitat suitability score.

The habitat sensitivity factor was set, resulting from land use type has different sensitivity to threat factors. The degree of sensitivity was determined according to the basic principles of protecting biodiversity in landscape ecology, in which natural landscapes are more sensitive to threats, followed by semi-natural landscapes. However, the artificial landscape has a strong anti-interference ability and low sensitivity to the threat source, resulting from the artificial management. In the InVEST model, the sensitivity range was between 0 and 1. The larger the value is, the greater the sensitivity is. The habitat suitability scores are shown in Table 2.

| LULC | NAME | HABITAT | UIML | RRL | CL |
|------|------|---------|------|-----|----|
| 1    | UIML | 0       | 0    | 0   | 0  |
| 2    | RRL  | 0       | 0    | 0   | 0  |
| 3    | CL   | 0.5     | 0.4  | 0.3 | 0.3|
| 4    | FL   | 1       | 0.9  | 0.8 | 0.8|
| 5    | SL   | 0.8     | 0.6  | 0.4 | 0.4|
| 6    | GL   | 0.75    | 0.7  | 0.5 | 0.5|
| 7    | WB   | 0.8     | 0.9  | 0.7 | 0.6|
| 8    | UL   | 0.1     | 0.1  | 0.1 | 0.1|
| 9    | PG   | 0       | 0    | 0   | 0  |

Note: UIML-- urban industrial and mining land; RRL-- rural residential land; CL-- cultivated land; FL-- forest land; SL-- shrubland; GL-- grassland; WB-- water body; UL-- unutilized land; PG-- permanent glacier.

### 4. Results

#### 4.1. Characteristic of spatiotemporal variation in habitat quality

The habitat quality of Shangri-La City in 1989 and 2015 was obtained (Figure 1a and Figure 1b),
indicating that most of the habitat quality in Shangri-La City is relatively high, while the areas with low habitat quality are mainly distributed in Jiantang, Sanba, Xiaozhongdian and Hutiaoxia. The change of habitat quality in Shangri-La City was obtained by subtracting the habitat quality in 2015 from that in 1989 (Figure 1c). The change range of (-0.02-0.02) was regarded as the habitat quality basically no-change, the change range of (-1--0.02) was decreased, and the change range of (0.02-1) was increased. Figure 1c indicates that the areas with decreased habitat quality in Shangri-La City are mainly distributed in Jiantang, Naxi, Xiaozhongdian, the northern part of Hutiaoxia and the southern part of Sanba. However, the areas with increased habitat quality are mainly distributed in the middle of Jiantang Town, the northern of Sanba, the southern of Hutiaoxia and the western of Xiaozhongdian.

![Figure 1. The spatial distribution of habitat quality in Shangri-La City in 1989 (a) and 2015 (b), and the changes in habitat quality during the two periods (c).](image)

The average habitat quality of each area in Shangri-La City was obtained through regional statistical analysis (Figure 2). Figure 2 indicates that the areas with good habitat quality in Shangri-La City include Luoji, Wujing, Shangjiang, Gezhan, and Naxi, whereas the areas with poor habitat quality are Hutiaoxia, Jiantang, Xiaozhongdian, Sanbaxi, among which Sanbaxi has the lowest average habitat quality in all areas. From 1989 to 2015, the areas with improved average habitat quality are Naxi and Luoji, among which average habitat quality of Luoji improved significantly. The average habitat quality of other areas shows a decreasing trend, especially in Jinjiang, Shangjiang, Jiantang, and Xiaozhongdian. The decrease in the first two areas is mainly resulting from the increase in the amount of cultivated land, while the decrease in the latter two areas is resulting from the increase in urban industrial and mining land.
4.2. Characteristics and changes of vertical distribution of habitat quality
According to the vertical distribution of vegetation in Shangri-La[8], the altitude of Shangri-La city was divided into three grades, namely low (altitude \(\leq 2800\)m), middle (2800m < altitude \(\leq 3800\)m), and high (3800m < altitude). The average habitat quality under different altitudes in Shangri-La City is shown in Figure 3, indicating that the average habitat quality of Shangri-La City is the highest under middle altitude and lowest under low altitude. From 1989 to 2015, the average habitat quality under low and middle altitude areas become smaller, and the average habitat quality in high altitude areas improved.

4.3. Characteristics of habitat quality under different slopes
According to the “Comprehensive Control of Soil and Water Conservation-General Rule of Planning (GB/T 15772-2008)”, the slope of Shangri-La was divided into micro-slope (slope \(\leq 5^\circ\)), relatively gentle slope \((5^\circ < \text{slope} \leq 8^\circ)\), and gentle slope \((8^\circ < \text{slope} \leq 15^\circ)\), relatively steep slope \((15^\circ < \text{slope} \leq 25^\circ)\), steep slope \((25^\circ < \text{slope} \leq 35^\circ)\) and extremely steep slope \((35^\circ < \text{slope})\). According to regional statistical analysis, the topographic distribution characteristics of the average habitat quality of Shangri-La City were obtained (Figure 4), indicating the average habitat quality of Shangri-La City is high on steep slope and extremely steep slope, and lower on slight slope. The micro-slope area is subject to more human disturbance resulting from land use, which people are suitable for construction, production and construction under this condition, thereby destroying the quality of the habitat. In areas with steep slope and extremely steep slope, which is difficult for human activities to interfere with the habitat, thereby a good habitat quality can be maintained. From 1989 to 2015, the quality of the habitat of each slope grade has decreased to varying degrees, whereas the decrease is more obvious when the slope is small, resulting from the development of the society, the interference of people to the ecosystem is significantly increased during the small slope.
5. Conclusion and discussion

(1) Generally, the habitat quality of Shangri-La City is high, and the areas with low habitat quality are mainly distributed in Jiantang, Sanba, Xiaozhongdian and Hutiaoxia. From 1989 to 2015, the average habitat quality of Shangri-La changed from 0.86 to 0.84, and the habitat quality of Jiantang, Naxi, Xiaozhongdian, the northern part of Hutiaoxia and the southern part of Sanba is getting worse. The habitat quality has improved in the middle of Jiantang, the northern part of Sanba, the southern part of Hutiaoxia, and the western part of Xiaozhongdian.

(2) The average habitat quality of Shangri-La is highest at middle altitude and lowest at low altitude. From 1989 to 2015, the average habitat quality in low and middle altitude areas decreased, which in high altitude areas increased. The average habitat quality of Shangri-La City is higher under steep and extremely steep slopes, and lower on micro-slopes. From 1989 to 2015, the habitat quality of each grade of slope has decreased to varying degrees.

(3) The areas with good habitat quality in Shangri-La City include Luoji, Wujing, Shangjiang, Gezhan, and Naxi, resulting from people use less land. Therefore, the protection of habitat quality in Shangri-La City can be achieved through measures such as rational planning of urban construction, controlling the scale of cultivated land, and returning farmland to forests.

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