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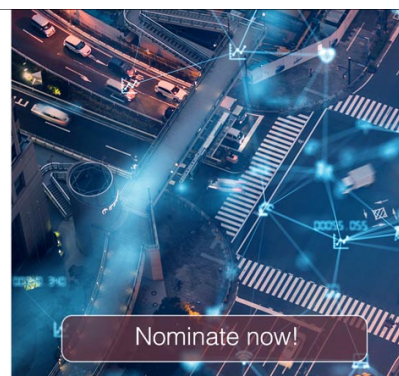


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Assessing the spatial pattern of wilderness in central Yunnan: a case study from Chuxiong county, Yunnan

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Abstract: Wilderness plays a key role in mankind's response to combat climate change and slow down the rapid loss of biodiversity. Wilderness protection is the basis and key to preserving biodiversity, and wilderness identification is the basis for wilderness protection. This paper identified the wilderness areas (WAs) and analyzed the spatial pattern of wilderness level using the data of terrain, vegetation types, land use types, roads, and night lights, and classified the wilderness level into levels 1 to 10, with level 1 indicating the highest level of wilderness and level 10 indicating the lowest. Only patches characterized by wilderness level 1 and a patch area of $\geq 1.0\text{km}^2$ are identified as wilderness areas in this study. The results showed that (1) the low wilderness (level 8-10), middle wilderness (level 4-7), and high wilderness levels (level 1-3) in the region were in mosaic distribution, which accounted for 52.98%, 14.81%, and 32.21% of the region land area, respectively. Low wilderness areas were mainly distributed in the eastern part of the region, the middle wilderness areas were in the west part of the region, and the high wilderness areas were mainly distributed in the southwest and southeast of the region. (2) The wilderness areas accounted for 12.74% of the total land area of the region with presenting scattered distribution. Moreover, wilderness area which exceeded 10% of the total wilderness area had 5 towns such as Lucheng, Ziwu, and Xincun, Xishelu, and Dadi, and the range of wilderness covered 7 vegetation types, of which 97.46% of the wilderness areas was in pure forests, with 55.2% of the wilderness distributed in the range of 1800-2200 m. (3) The wilderness areas in the region were almost unprotected. The number and area of wilderness patches that were covered by nature reserves only accounted for 13.24% and 13.19% of patch numbers and areas of the total wilderness. Consequently, this might make it difficult to achieve animal and plant migration and gene exchange between different wilderness patches, and it was also difficult to implement effective protection measures.

1. Introduction

Wilderness areas (WAs) with no or minimal human disturbances, are considered the “last refuges” for a complete natural ecosystem on the earth. WAs have important ecological, economic and social functions and play an important role in helping the human mediate climate change and reduce the rapid



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loss of biodiversity[1-4]showed that 44% of the earth's land had met the conditions being classified as wilderness. However, Wilson[5] indicated that of the world's wilderness had been lost in the past 20 years, of which Amazon and Central Africa had suffered the most. At the same time, Venter et al.[6] also proved that the global wilderness area had shrunk significantly and the issue of biodiversity lost had been more serious. As a result, reducing the rate of global biodiversity loss was an important challenge faced by all humanity[7].

To slow down the rate of global biodiversity loss, wilderness protection is the foundation and key. For the global terrestrial ecosystem, the average risk of species extinction in the wilderness is half of the relative risk of non-wilderness, as wilderness areas are the "last refuges" for a large number of rare and endangered wild animals and plants. The wilderness areas also play significant roles in acting as a buffer for species loss and preserving biodiversity[8]. In addition, wilderness protection has always been a core issue of national parks and nature reserves. The International Union for Conservation of Nature (IUCN) and the World Wilderness Congress (WWC) has been committed to global wilderness protection. By 2016, the United States has included 48 countries and regions which have identified wilderness reserves through laws[9]. There were also 23 countries and regions which have established wilderness areas or wilderness functional areas in nature reserves through administrative means [9]. In China, although various types of nature reserves have been established, such as national parks, nature reserves, and scenic spots, there is still no content associated with wilderness protection in the nature reserve system [10]. All wilderness areas have inherent values to be protected [11, 12]. Therefore, the identification of wilderness areas is the basis of wilderness area protection and biodiversity conservation. On a global scale, Macro et al.[8] have identified wilderness areas on various continents. Yang et al.[13] identified the priority expansion areas of global terrestrial nature reserves with high efficiency and low cost based on spatial analysis and superimposed 7 global biodiversity conservation priority areas. At the regional scale, Lin et al.[14] identified the wilderness in northwestern Yunnan and analyzed its spatial pattern, Zuo et al.[15] analyzed the spatial pattern of wilderness from the perspective of landscape architecture in Dali.

Central Yunnan is located in the upstream region of Yangtze River and Red River, where located the plateau lakes such as Dian Lake and Fuxian Lake. Central Yunnan is also the center of social and economic development in Yunnan Province, the maintenance and improvement of ecological functions of this region are the foundation for its sustainable social and economic development, and biodiversity conservation is the basis for ensuring regional ecological functions. Chuxiong county is located in the hinterland of the Central Yunnan Plateau, and the zonal vegetation is an evergreen broad-leaved forest of the northern subtropical plateau with a high and uneven distribution biodiversity[16]. Due to historical reasons, the native vegetation is distributed sporadically within the county scale. The biodiversity protected areas mainly include the Ailao Mountain National Nature Reserve and the Zixi Mountain Provincial Nature Reserve, and many terrestrial areas are currently still not covered by any type of protected areas due to lack of quantitative study on whether these areas have conservation value. Protecting wilderness areas is a crucial proactive approach to ensure the long-term persistence of biodiversity. Analyzing the spatial distribution pattern of wilderness areas in Chuxiong was of great significance for biodiversity protection. This study would analyze the spatial distribution of the wilderness areas in Chuxiong combining data of topography (DEM), vegetation, roads, night lights, and land use/cover types. Moreover, the study is expected to provide an evidence for the formulation of more scientific and reasonable management measures for biodiversity conservation.

2. Materials and methods

2.1. Study area

Chuxiong includes 15 towns, located in the central Yunnan province, neighboring Lufeng county to the east, Shuangbai county to the south, Nanhua county, and Jingdong county to the west, and Mouding county to the north. The city is also the political, cultural, economic center of Yi Autonomous Municipality of Chuxiong. Chuxiong is located in the watershed of the Jinsha River and Yuanjiang

River basin, and the terrain of this region slopes from northwest to southeast, high in the northwest and low in the southeast, with the highest point is an elevation of 2916 m and the lowest point is 691 m (Figure 1). The climate of Chuxiong belongs to the northern subtropics monsoon, with long spring and autumn, short winter and summer, the temperature varies greatly between day and night, while the variation of temperature throughout the whole year is small. Moreover, 90% of the annual precipitation is concentrated in May to October. The soil of this region is mostly red loam and paddy soil, the typical vegetation mainly includes evergreen broad-leaved forest and coniferous forest, and the vegetation composition is quite complex. In 2019, the forest coverage of Chuxiong reached 76.93%. In this region, common families of plants include pinaceae plants, firaceae plants, cupressaceae plants, camellia plants, fagaceae plants, and euphorbiaceae plants, but the original vegetation has only fragmented distribution, with most of the current vegetation types being Yunnan pine forests.

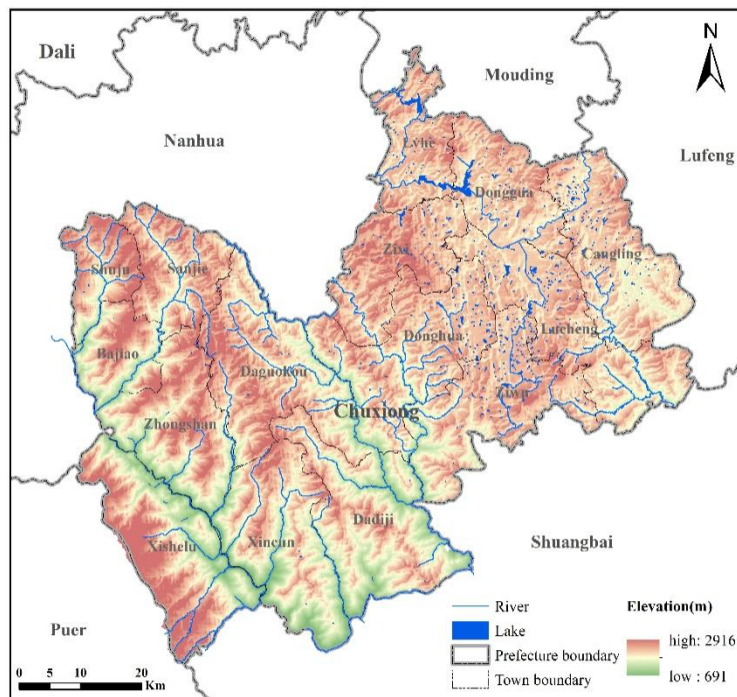


Figure 1. Location of the study area.

2.2. Methods

We evaluated the degree of wilderness and identified the wilderness areas (WAs) in Chuxiong using five proxy indicators such as the human activities, remoteness, naturalness, ecological integrity and ruggedness based on DEM data (30m×30m), vegetation distribution data (2016), land cover/use data (30m×30m, 2016), road network data (2016), night light data (1km×1km, 2016), administrative divisions and nature reserve data (2016). The night light data was downloaded from NASA Earth Observatory (<https://www.earthobservatory.nasa.gov/>), and the land cover/use data was visually interpreted based on Landsat 8 OLI and verified according to the 2016 Google earth image. Additionally, the other data were provided by Chuxiong Forestry and Grass Bureau.

Population density was usually used to measure the impact of human activities on natural ecosystems[2, 17], whereas the population density is generally limited by time and space. The night lights data could better reflect the distribution of population density[18-20], we used the night light data (1km×1km) instead of population density data to reflect the degree of disturbance and threat of human activities to the ecosystem. The night light data were resample to 30m×30m considering the distribution of town settlements in this study, were standardized 0-1 using Equation 1, and then were divided into 10 categories from 0-9 by natural breakpoint method. The larger the light value represented the greater impact of human activities on the natural ecosystem.

Ecological integrity could measure the degree of habitat fragmentation under a condition of certain land use in a region[21], and the effective mesh size (MESH) was usually used as an index to measure the degree of habitat fragmentation[22]. In this study, the vegetation distribution data (excluding cultivated land and construction land) is divided with a road layer by spatial overlaying analysis and converted into raster data (30m×30m), and then we calculated the effective mesh size of the study area used by using Fragstats4.2 moving window function (window size is 300m×300m).

Wilderness areas (WAs) were usually distributed in remote areas that were inconvenient and difficult to reach[11, 23]. We calculated the terrain ruggedness[24] based on DEM data and calculated the remoteness[25] using the path analysis according to the DEM data and land use data, respectively.

Naturalness reflects the degree to which the human-influenced ecosystem deviates from its original state, and its value depends on people's understanding of nature in a specific time and space background[21]. Therefore, naturalness usually relies on different land cover types or expert knowledge to set[26, 27]. Based on the natural and socio-economic conditions of Chuxiong and its vegetation distribution data (1:100,000), we divided the vegetation types of Chuxiong into 18 categories including mixed forests, pure forests, shrubs, bamboo forests, sparse forests, logging sites, nurseries, and auxiliary vegetation to make the natural setting of the county's ecosystem (Table 1). Then, the vector layer was converted to a 30m×30m raster data layer.

In this study, the results of the wilderness classification were obtained according to the method of Lin et al.[14]. First, the raster pixel value of the layer of the five index maps of naturalness, ecological integrity, remoteness, topographic ruggedness, and human activities was standardized[28] (Equation 1). Second, the principal component analysis is performed. According to the result of principal component analysis (the first three principal components in this study can explain 99.40% of the characteristic root), the unsupervised classification tool of cluster analysis in ArcGIS was used to perform cluster analysis to obtain a wilderness classification layer, which could represent the integrated condition of the ecological system distribution, terrain, roads and other natural and socio-economic conditions of Chuxiong. The degree of wilderness was divided into 10 levels, with 1 indicating the highest degree of wildness and 10 indicating the lowest degree of wildness.

$$NI_i = \lg(a_i) / \lg(a_{imax}) \text{ (equation 1)}$$

In equation 1, NI_i is the standardized value, a_i is the pixel value of index layer i , and a_{imax} is the maximum value of the pixel of index layer i .

Table1. Naturalness of vegetation types in Chuxiong

Vegetation types	Naturalness	Vegetation types	Naturalness
Mixed forest (MF)	5	Auxiliary production forest (APF)	2
Pure forest (PF)	4	Barren hills and land suitable for forest (BHLSF)	3
Shrub forest (SF)	4	Other suitable forest land (OSFL)	2
Bamboo forest (BF)	4	Artificial immature forest land (AIFL)	3
Arbor economic forest (AEF)	3	Non-standing trees woodland (NTW)	3
Shrub economic forest (SEF)	3	Other non-forest land (ONL)	1
Sparse woodland (SW)	3	Arable land (AL)	2
Logging site (LS)	3	Construction land (CL)	1
Nursery	2	Waters	3

3. Results

3.1. Spatial patterns of wilderness levels

The wilderness level of the study area was classified into high wilderness level (level 1-3), middle wilderness level (level 4-7), and low wilderness level (level 8-10), which accounted for 32.21% and

14.81% and 52.98% of the study area respectively (Figure 2). In general, various wilderness areas present mosaic distribution. The southwest and southeast of the region showed significantly higher level of wilderness compared to other parts. Low wilderness areas were concentrated in the east of the region, and medium wilderness areas were mainly distributed in the middle of the region, scattered between low and high wilderness areas (Figure 2).

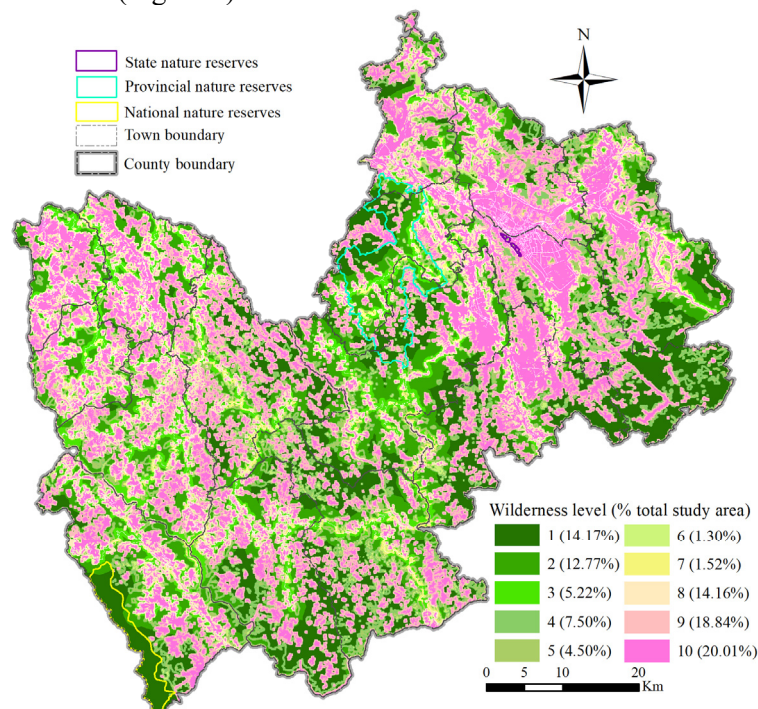


Figure2. The spatial distribution of wilderness levels in Chuxiong County.

However, the proportions of wilderness areas in different towns varied greatly. Only in Zixi Town and Donghua Town, high wilderness areas (44.64% and 44.54% respectively) are slightly higher than their low wilderness areas (44.48% and 41.59% respectively). However, for the other towns, low wilderness areas occupied the largest area, followed by high wilderness areas, and medium wilderness areas with the smallest area (Figure 3a).

Wilderness levels of various vegetation types in the region also varied greatly (Figure 3b). The mean coverage of low wilderness level in the 20 vegetation types was 64.95%+31.97% (variation range is 0-100%), the mean coverage ratio of the middle wilderness level is 29.90%+30.22% (variation range is 0-81.29%), and the mean ratio of high wilderness areas was 5.14%+11.76% (variation range is 0-47.05%). In particular, for the high wilderness level, when comparing the vegetation types, pure forest (47.05%) > shrub forest (19.44%) > mixed forest (13.65%) > sparse forest land (6.35%) > artificial forest land (2.16%) > Water area (1.27%) > shrub economic forest (0.63%) > arbor economic forest (0.59%) > barren hills and wasteland suitable for afforestation (0.54%) > logging area (0.52%) > bamboo forest (0.36%), the area of the remaining 9 vegetation types at high wilderness levels was 0.

The relationship between wilderness levels and altitudinal gradients in the region was nonlinear. In the range of 1000m to 2600m, the proportion of high wilderness area (22.60%-78.42%) increased first and then decreased with the increasing of elevation when the elevation is lower than 2000m, while wilderness levels significantly increased with the increasing of elevation when the elevation is higher than 2000m. Accordingly, the area ratio (9.31%-41.85%) of the middle wilderness changed more complicatedly with the increase in elevation. When the elevation is lower than 1800m and higher than 2400m, it decreased as the elevation increases, and then the ratio of middle wilderness increased with increasing of elevation when the elevation is between 1800m to 2400m. When it comes to the low wilderness area(level 8-10), the proportion (12.27%-63.80%) of the area first increased with the

increasing of the elevation and then decreased as the elevation increases, and then reaches its maximum proportion in the elevation of 1600m to 1800m (Figure 3c).

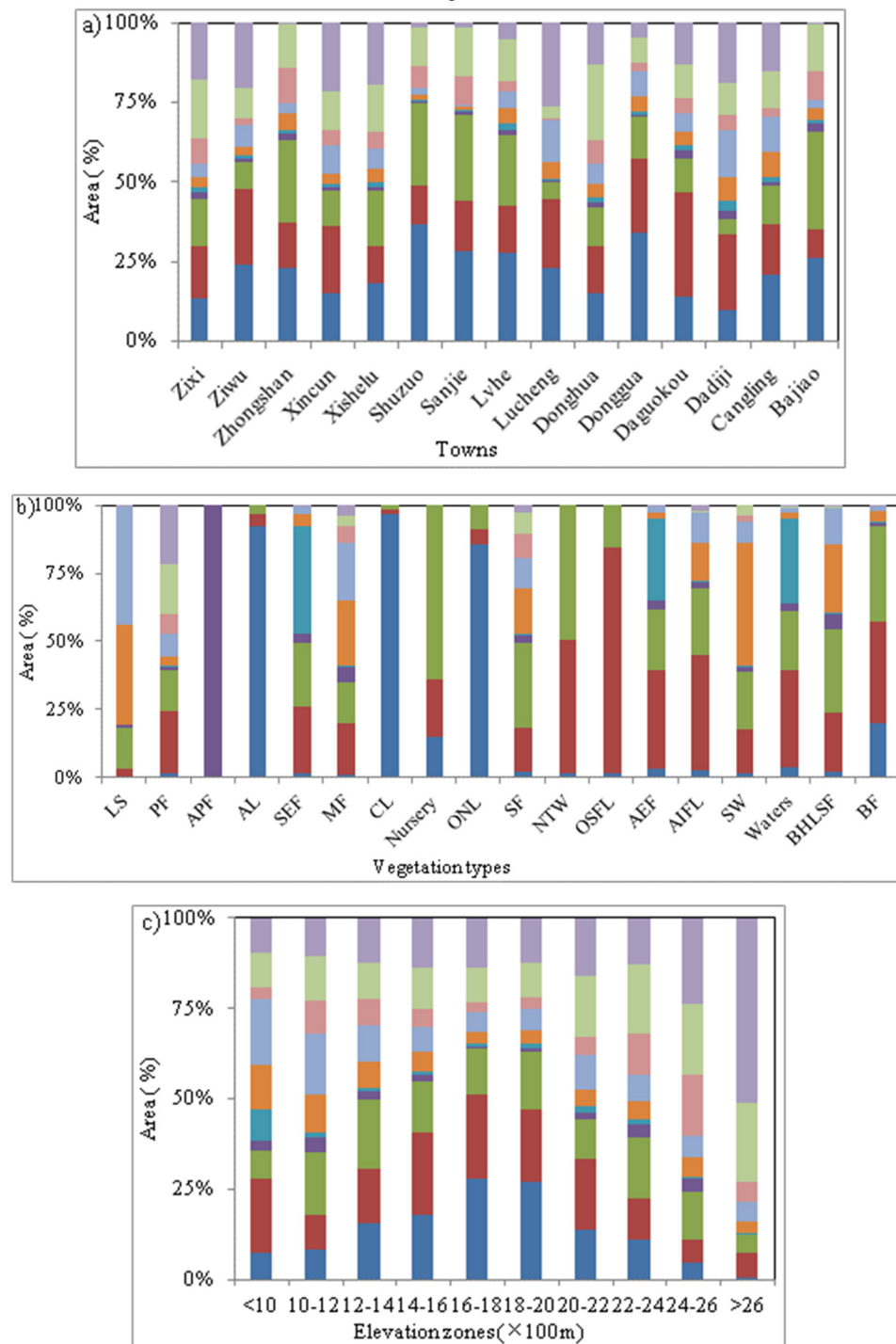


Figure 3. Area percentages of wilderness levels within different (a) towns, (b) vegetation types (see Table.1 for the full names of vegetation types), and (c) elevation zones.

3.2. Spatial patterns of wilderness areas

The study area consisted of 68 wilderness patches, accounting for 12.74% of the county's total area, and the largest patch area was 120.09 km² (Figure 4).

There were 3 nature reserves above the municipal level, Ailao Mountain National Nature Reserve, Zixi Mountain Provincial Nature Reserve, and Xi Mountain Municipal Nature Reserve, with a total area accounted for 4.65% of the county's land area. The overlap between the area of the nature reserve in the county and the area of the wilderness was 73.30km², and the number and area of the protected wilderness only accounted for 13.24% and 13.19% of the wilderness respectively (Figure 4). The Ailao Mountain National Nature Reserve located in a high wilderness area in the southwest of the county, was overlapped with the wilderness area of more than 91.21%. The Zixi Mountain Provincial Nature Reserve located in Zixi Town, was with an overlap area of 45.88%. While the Xi Mountain Municipal Nature Reserve located in the center of the municipal administrative area and had no wilderness in its area. In contrast with the southeast area, the wilderness area in the northeast of Chuxiong was relatively large and concentrated, but was mostly made up of planted forests and not covered by protected areas. The wilderness areas in other regions were mostly distributed in small fragmented patches.

There are a large number of small patches in the wilderness, while the areas of 3 patches distributed in southwest of Xishelu Town and northeast of Lucheng Town were over 50 km² (Figure 5a). The number of patches that were smaller 2km² was 29 accounted for 7.31% of the total area of the wilderness. 17 patches had an area of 2-5 km², accounting for 10.63% of the total area of the wilderness. Followed by that, 10 patches with various sizes from 5 km² to 10 km² accounted for 10.42% of the total wilderness area, and 9 patches with an area of 10 km² to 50 km² accounted for 29.61% of the total wilderness area. Two patches had areas of 50km² to 100km² accounted for 20.41% of the total wilderness area, and only 1 patch was larger than 100 km² accounted for 21.61% of the wilderness area (Figure 5a).

Simultaneously, there was a big difference in the proportion of wilderness areas in 15 towns within the county (Figure 5b). Lucheng Town occupied the largest proportion of wilderness area, accounting for 15.46% of the rural area. Followed by that, the proportion of wilderness areas of Xincun Town, Dadiji Town, Xishelu Town, Ziwu Town, Donghua Town, Cangling Town, Daguokou Town, and Zixi Town was accounted for 12.46%, 11.98%, 11.84%, 11.77%, 9.69%, 8.49%, 7.14%, and 6.95% of the rural area respectively. However, the proportion of the wilderness area in the rest of towns is less than 2%, especially in the four towns of Zhongshan Town, Shuju Town, Sanjie Town, and Bajiao Town, all of which are less than 0.50%. In this region, the vegetation types in the wilderness area are mostly pure forests (97.46%), that most of them were Yunnan pine forests, followed by mixed forests (1.43%) and other shrubs (1.05%), and the proportion of the other 15 types of vegetation were less than 0.02% (Figure 5c). More than 70% of the wilderness in the county was located at an elevation of 1800m to 2000 m (number and area are 35.51% and 31.14% respectively), 2000m to 2200m (number and area are 22.25% and 24.08% respectively), and 1600m to 1800m (number and area were within the range of 14.59% and 14.43% respectively). The number of patches and area of other wilderness at other altitudinal gradients were all less than 10% (Figure 5d).

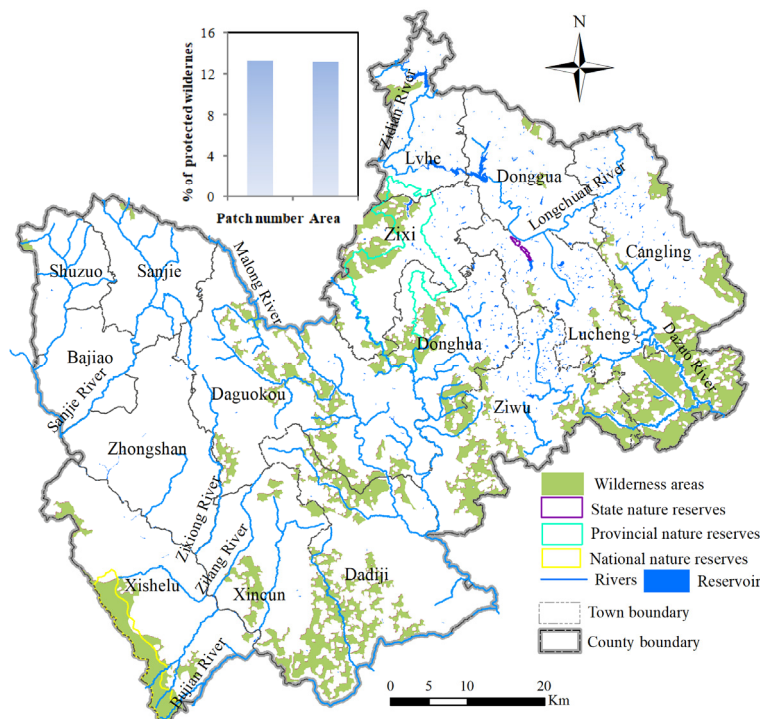
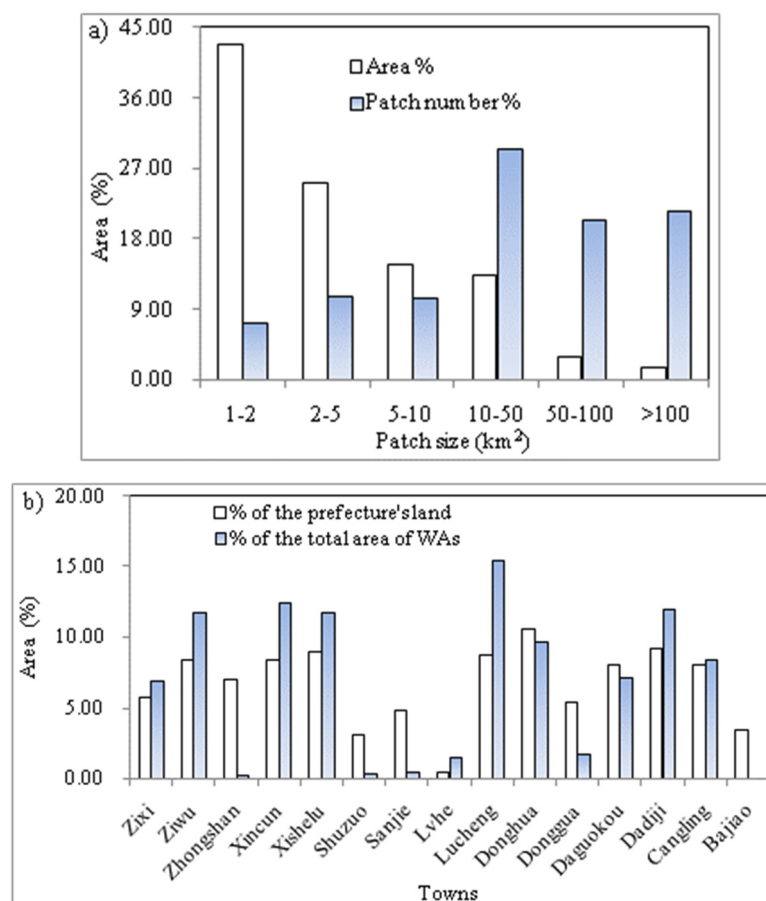


Figure 4. The spatial pattern of wilderness areas (WAs) and the comparison of distributions between WAs and natural reserves.



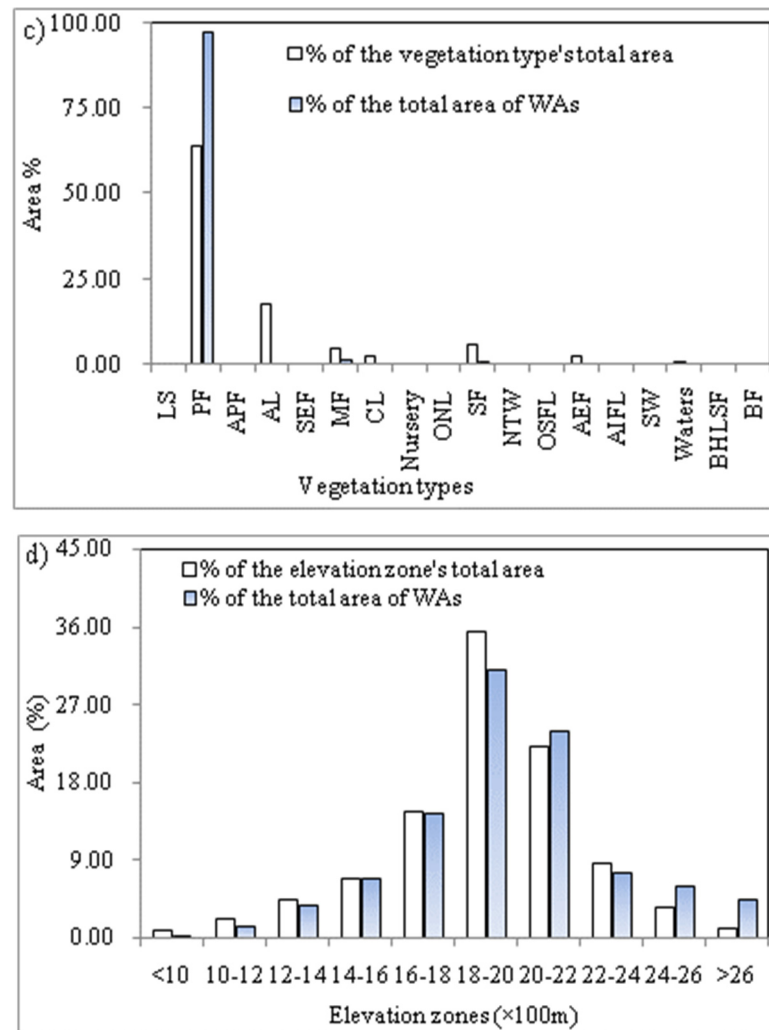


Figure 5. Area percentages of wilderness with patch size, towns, vegetation types, and elevations. (a) The area%(and patch number%) of different WAs patch size classes accounted of the total WAs area(and total patch number), and the distribution of WAs on different (b)towns, (c) vegetation types(see Table 1 for the full names of vegetation types) and (d) elevation zones.

4. Discussion

Chuxiong county has been developed long ago and there were only a few primitive forests present fragmented distribution with mostly pure artificial forests. The distribution of wilderness in this region was almost consistent with the spatial distribution of NDVI in Chuxiong[29]. The southwest and northeast areas of the region were characterized by large patches of wilderness, and the southwestern wilderness area was located in the hinterland of Ailao Mountain, which was an area with rich biodiversity. The wilderness areas in the northeast were pure forests, most of which were located in the scope of natural forest protection projects and had important ecological functions. Except for the Zixi Mountain, most of the wilderness in the central area was distributed along the river. The northeast and northwest areas were more conducive to human survival due to their relatively flat terrain, warm climate, and fertile soil. However, the northeast and northwest areas had also been the center of regional economic development for a long time, the distribution of wilderness areas was fragmented. The terrain in the central and south eastern regions is extremely steep and rugged, which also made it difficult for many human exploitation activities such as land development and natural resource extraction. Therefore, the interference intensity of human activities on the natural ecosystems in the southwest, central, and

southeast of the county was significantly lower than in the northeast and northwest dam areas and mid-levels. Moreover, the natural degree of the southwest, central and southeast of the county was much higher than it of the northwest and northeast.

Night light data covers information about traffic roads, residential areas, and others closely related to population distribution, which could comprehensively reflect population distribution. Moreover, the night light data based on pixels could better describe population distribution[18, 30]. Because the population density data was limited by time and other factors, this study used night light data instead of population density. According to the population census of Chuxiong in 2010, the rural population density of Chuxiong was divided into high-density areas (450-600people/km², Lucheng (594.83) > Donggua (450.17)) and medium-density areas ((100-150 people /km²), Lvhe (140.26) > Shuju (137.28) > Bajiao (111.54) > Sanjie (108.85)) and low-density areas ((0-80 people/km², Zixi (54.90) > Xishelu (48.34) > Daguokou (45.19) > Xincun (39.84) > Dadiji (31.97)). At the same time, the characteristics of the vertical distribution of population density indicate that the population of Chuxiong was mainly concentrated in the range of 1700-1800m. The vertical distribution of Chuxiong's population had obvious stratification characteristics, with most of them living in the dam area and the mid-levels. There were only a small number of residents living in mountainous and alpine mountainous areas, which was almost consistent with the distribution characteristics of night light data [31].

5. Conclusion

The wilderness areas in Chuxiong County had fragmented distribution. There were a large number of wilderness patches, but the area of patches was small. The patches with large areas were concentrated in the Ailao Mountain National Nature Reserve in Xishelu Town and the northeast corner of Lucheng Town. However, only part of Xishelu Town was a natural forest and under protection. Therefore, the systemic protection of these areas should be strengthened and their spatial connectivity should be enhanced to avoid the formation of ecological islands. Pearson et al.[32] confirmed the negative influence of copper and nickel sulfide mining around the wilderness on the environment and human health and pointed to the positive significance of the existence of wilderness. However, the production of food, the emergence of agriculture, and the expansion of cultivated land continue to erode biodiversity[33].

The future ecological environment would be mainly composed of human-dominated ecosystems, regardless of intentional management or unintentional impact[34]. Therefore, different wilderness areas had their different ecological, social, and economic values. Specifically, relatively strict reserves and targeted protection measures should be established for wilderness areas with high values and different wilderness levels should have corresponding protective measures. Meanwhile for the public, it is also important to improve their awareness of ecological protection and guide them to actively protect nature, forming a benign interaction model between the people and the natural environment to decrease further damage to wilderness areas.

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