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The Landscape Patterns of the Giant Panda Protection Area in Sichuan Province and Their Impact on Giant Pandas

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Abstract: As the flagship species of biodiversity conservation in China, the giant panda has significant ecological protection value and plays an important demonstrative role for conservation. Sichuan Province has the largest area of giant panda habitat, making its protected areas the most important for the conservation of this species. However, the habitats of the giant panda are shrinking due to human disturbance through land encroachment for agriculture and other forms of resource exploitation. Reducing these pressures requires assessing current land use and the causes of fragmenting giant panda habitats. This paper reports on changes in land-use patterns and socio-economic development in typical counties with giant panda habitats in Sichuan in 2003 and 2015, with a focus on giant panda protection areas and human pressures in the surrounding lands. We found that road construction, industrial infrastructure, and other forms of economic development have led to increases in human populations and fragmentation of the giant panda habitats, such that that the population of this species has been significantly reduced in some counties. Improving the protection of giant panda requires designing regional economic development activities based on scientific principles to provide benefits to both the local people and the giant pandas. For example, when making land use plans, the local government should consider the impact of the development of the communities surrounding the giant panda areas on the giant pandas' habitat.

Keywords: giant panda; land use and cover change (LUCC); landscape pattern; development; protected area

1. Introduction

Giant panda habitats are located in the middle and upper reaches of the Yangtze River, which is an important, yet fragile, ecological area of China. The ecological security of this vast area is directly related to territorial and ecological security. The protection of giant pandas and their habitats has great scientific value. Giant panda habitats are rich in forest and species resources, and the development of surrounding areas is highly dependent on the natural resources of the habitat [1]. Due to the disturbance of human economic activities, such as resource exploitation, land occupation, and urbanization, the habitat of giant pandas is currently shrinking and degenerating, and the balance of the ecosystem has been seriously damaged. In 2017, the State Council of China issued the Giant Panda National Park System pilot scheme, aiming at increasing the connectivity and integrity of the giant panda's habitat. In 2018, the Giant Panda National Park Authority was officially listed. In 2019, China encouraged the integration of important natural ecosystems that were representative of the nation into the national park system and the implementation of a natural protection site system. China will establish a natural reserve system with national parks as the main body. The construction of this protected-land management system, the inclusion of more protected areas, and the strengthening of ecological protection are all important measures that China has implemented to effectively protect giant pandas and their habitats, as well as being strategic measures to maintain regional ecological balance. Maintenance of the ecological balance and coordination of the relationship between protection and development is the key, yet difficult, issue regarding the national ecological protection strategy alongside China's rapid social and ecological development, thus providing a hot spot of academic research.

Human social and economic development activities have had an impact on the ecological environment and species' protection [2]. Land resources are scarce and irreplaceable, so are important resources and assets for the production and life of human society [3]. Human beings purposefully develop and utilize land resources, through the development of arable land, roads, and other infrastructure, thereby changing the surrounding environment of giant panda protection sites [4]. Land use is the main cause of land cover change. The land use and cover change (LUCC) index objectively records the changes of human social and economic development on the surface of the earth [5,6]. The severe disturbance of human economic activities results in changes in land use and cover [7]. Transforming land use patterns can change ecosystem types, patterns, and ecological processes, which directly affect ecosystem services [8]. To illustrate, a land use change in Satchari National Park in Bangladesh has had an impact on the ecosystem's support function, supply function, regulation function, and cultural function [9]. Additionally, the large-scale agricultural expansion in Minnesota's land use evolution can be seen to have resulted in a loss of carbon storage, a decline in water quality, and a decline in biodiversity value, alongside increased economic return [10]. The water quality of Australia's Great Barrier Reef directly affects fishery productivity in the area [11].

Scholars use different methods to research the impact of land use changes on the ecosystem. These research scales are different, and the research objects are different. Scholars mainly use the land use transfer matrix [12], the landscape pattern index [13], the dynamic change model, and gradient analysis [14] to study land use and cover changes. Research results using these methods show mainly landscape pattern changes [12], ecological environment effects [14], the driving mechanisms of urbanization processes [15], changes and predictions in land use type [16], and so on. The objects of these research efforts are mostly concentrated in one city [17], one region [18], one urban agglomeration [19], etc. However, there are few studies on protected areas, especially for distinct species.

Because of the needs associated with human population growth and economic development, the intensities of various economic activities, such as land use, infrastructure construction, and population migration, has increased, and their scopes of impact have also been expanding [20]. Social and economic development disturbs the habitat of giant pandas more than natural factors. Changes of land cover affect ecological environments and biodiversity, as well as the environments lived in by human beings. [21,22]. Analysis of land use and cover changes in giant panda protection areas can help us to understand the impact of regional economic development on the landscape patterns of giant panda habitats and the process of change. This is of great significance to provide a reliable theoretical basis for the implementation of giant panda protection and management policies.

Sichuan province has the largest habitat for giant pandas and the largest number of wild giant pandas, thus it is an important giant panda protection area [23]. At the same time, giant panda habitats contain abundant natural resources, which are utilized for regional economic development. As a result, the ecosystem conservation and habitat distribution have changed accordingly. With the acceleration of economic development, this leads to the question to be asked about what changes have taken place regarding the landscape patterns of protected areas, and what impacts these changes have had on the distributions of giant pandas and habitats? In order to study this problem, we selected 20 typical counties where giant panda protection areas were distributed. Firstly, the land use changes of giant panda protection areas in 2003 and 2015 were evaluated. Then, the landscape characteristics of the giant panda protection areas were analyzed. Finally, through correlation analysis, the impact of regional development on landscape pattern characteristics was illustrated and the distribution characteristics of giant pandas and habitats under that influence were investigated, so as to reveal the main factors affecting the disturbance of regional economic development on giant pandas and their habitats.

2. Study Area

There are 1378 wild giant pandas in the Sichuan province, with a habitat area of 2.02 million hm^2 and a potential habitat area of 0.41 million hm^2 [23]. The giant panda protection area is rich in resources, and most of the counties in Sichuan province rank in the middle and lower levels of the economy. The total number of wild giant pandas in the 20 counties that were selected for this study is 1220, accounting for 87.96% of the total number in Sichuan province, and the giant panda habitat area of the counties is 1.62 hm^2, accounting for 66.38% of the total habitat area of Sichuan province. It is a typical area where giant pandas are densely distributed [24]. At the same time, the economy of these counties is relatively backward, including 12 poverty-stricken counties at the national level [25]. In recent years, as the population has grown, the motive force of economic development has strengthened. However, due to the complex terrain, diverse geology, and frequent natural disasters, among other reasons, once the ecological environment is damaged, it will be difficult to renovate it. Therefore, not only biodiversity, such as giant pandas, are threatened; the living conditions of human beings in this area have also been destroyed.

3. Data and Methods

3.1. Data Collection

Land use and cover change data of 20 typical counties with high-density distributions of giant pandas in 2003 and 2015 were collected from the monitoring platform of geographical conditions. The evaluation accuracy of the first-level classification results was 92.5% and the comprehensive accuracy of the second-level classification results was 90.7%. Giant panda population and habitat area data were derived from data resulting from the third and fourth panda surveys in China. The economic data were derived from the Sichuan Statistical Yearbook and the Sichuan Rural Yearbook. ArcGIS 10.2 was used for spatial data calculations and spatial analysis. The study area was divided into 30 m x 30 m grids. The proportion of area made up of different land types in 2003 and 2015 was calculated, and the changes in land types of the giant panda protection area between 2003 and 2015 were analyzed. Fragstats 4.2 was used to calculate the landscape pattern index of the 20 counties in the giant panda reserve in 2015, and the landscape pattern characteristics of different counties were compared. The socio-economic driving forces of the landscape pattern changes in the giant panda protection areas and their effects on the number of giant pandas and their habitat areas were studied using correlation analysis.

3.2. Methods

3.2.1. Classification Criteria

According to the national land resources classification system and the national ecological ten-year dynamic monitoring technical requirements, combined with regional characteristics and research needs, the land use and cover types in the study area were classified. In order to compare and analyze the land use types and changes in giant panda protection areas in 2003–2015, the land use and cover types were divided into eight categories; namely, non-forest land, artificial shrubbery(AS), artificial broad-leaved forest(ABF), artificial coniferous forest(ACF), natural shrubbery(NS), natural mixed forest(NMF), natural broad-leaved forest(NBF), and natural coniferous forest(NCF). Among these categories, non-forest land included construction land, farmland, water bodies, meadows, and so on. The changes in woodland and non-woodland at the two time points were compared to illustrate the general state and change in regional land use and cover under the pressure of economic development over the past ten years. In order to analyze the landscape pattern characteristics of counties in 2015 in more detail, the land use types, especially non-forest land, in 2015, were further classified into eight categories, i.e., farmland, construction land, water bodies, meadows, plantations, natural forest, artificial shrubbery, and natural shrubbery, in order to reveal the impact of economic development on the landscape patterns of protected areas and the fragmentation of giant panda habitats.

3.2.2. Index

This study used an evaluation index and a method of ecological pattern change for the investigation and assessment; i.e., remote sensing to analyze the change in China's ecological environment over ten years (2000–2010). The evaluation index system relating to patterns of the regional ecosystem was constructed, as shown in Table 1.

Table 1. Evaluation index of ecosystem structure and change in Study areas.

Content	Index
Characteristics and change of land type	(1) Area of each land type (2) Proportion of land types (3) Variation rate of land area of different land types (4) Direction of Land Type Change (Transfer Matrix)
Characteristics of landscape pattern	(5) plaque index (Number of plaques (NP), patch density (PD), Largest patch index (LPI)) (6) Contagion index (CON) (7) Shannon's diversity index (SHDI) (8) Landscape connectivity index (LCI)

3.2.3. Data Analyses

This study used descriptive statistics and a transfer matrix to compare and analyze land use types and prove the dynamic change of land use and land cover status in the study area. Based on the statistical data and field survey data, the changes in giant panda habitats and their current status were analyzed by the spatial method.

(1) This study analyzed the distribution, change, and conversion characteristics of non-forest land and seven areas of forest land in 2003 and 2015.
(2) This paper only calculated the landscape pattern index and analyzed the landscape pattern characteristics in 2015, because the land type data of several counties in 2003 could only be determined to be woodland or non-woodland.
(3) Based on the above analysis, this study analyzed the correlation between economic development and landscape pattern characteristics, and the correlation between landscape pattern characteristics and the distribution of giant pandas and their habitat in 2015. It should be pointed out that direct analysis of the correlation between the socio-economic data and giant pandas and their habitats resulted in many errors and unsatisfactory results. In theory, giant pandas and their habitats are directly affected by landscape pattern characteristics. Therefore, this paper adopted the logical analysis thinking of A→B, B→C. Firstly, the correlation between giant pandas and their habitat and landscape pattern characteristics was analyzed. Secondly, the correlation between

socio-economic development and landscape pattern characteristics was analyzed to illustrate the impact of regional economic development on giant panda habitats.

4. Results

4.1. Characteristics and Changes of Land Use and Cover

With the rapid increase in social and economic development and the acceleration of urbanization in the study area, great changes have taken place among different land types in the giant panda distribution area. Firstly, distribution characteristics and changes in land use according to area in the protected areas were calculated. On this basis, this study analyzed and evaluated the conversion of land use types, analyzed the characteristics of the conversion between land use types in protected areas, and revealed the changes in landscape patterns in protected areas.

4.1.1. Constitutive Characteristics

In order to analyze the composition characteristics of land types in the research area, according to the classification criteria of land types, this study calculated the land cover data in 2003 and 2015 by two indicators; namely, "land type area" and "land type area ratio." The area and proportion of each type were obtained, and the state values and changes of each type of land in 2003 and 2015 were analyzed.

Overall Characteristics

The different types of land area in 2003 and 2015 are shown in Table 2. In 2003, the largest area of land was non-woodland, consisting of 33,328.11 hm^2, followed by 12,089.92 hm^2 of natural shrubbery. The area consisting of artificial shrubbery was the smallest at only 484.89 hm^2. In 2015, the largest area was still non-woodland, consisting of 17,374.97 hm^2, followed by 15,177.88 hm^2 of natural shrubbery, and 1051.69 hm^2 of artificial shrubbery.

Table 2. Distribution of land types in 2003 and 2015.

Classification		2003		2015	
		Area (hm^2)	Proportion (%)	Area (hm^2)	Proportion (%)
Non-woodland		33328.11	51.55	17374.97	26.89
Woodland	AS	484.89	0.75	1051.69	1.63
	ABF	724.10	1.12	3166.58	4.90
	ACF	3329.58	5.15	6525.21	10.10
	NS	12089.92	18.70	15177.88	23.49
	NMF	3064.50	4.74	4422.84	6.84
	NBF	4803.64	7.43	9256.64	14.32
	NCF	6827.25	10.56	7650.06	11.84

NW: non-woodland includes construction land, farmland, water bodies, and meadows. AS: artificial shrubbery; ABF: artificial broad-leaved forest; ACF: artificial coniferous forest; NS: natural shrubbery, NMF: natural mixed forest; NBF: natural broad-leaved forest; NCF: natural coniferous forest.

The highest proportion of land type in 2003 was non-woodland land, which made up about 51.55% of the total area, followed by natural shrubbery making up about 18.70%, natural coniferous forests with about 10.56%, and artificial shrubbery with about 0.75%. In 2015, the highest proportion was still non-forest land, accounting for 26.89%, followed by natural shrubbery, which accounted for 23.49%, and finally, artificial shrubbery, which accounted for about 1.63%. Because bamboo belongs to Gramineae, this study classified it as shrubbery for convenience. Due to the implementation of the Natural Forest Protection Project, the growth of natural shrubbery has been restored. Because of the project involving returning farmland to forest, the forest coverage rate has increased. Because of the above reasons, the habitat of giant panda has also been restored.

Regional Characteristics

In 2003, Wenchuan, Lixian, Baoxing, Shimian, and Mianning counties all had large forest areas. In 2015, Jiuzhaigou, Pingwu, Qingchuan, Li, Wenchuan, Baoxing, Tianquan, Asbestos, Mabian, and Ebian all had large forest areas. Counties with relatively small areas of forest included an, Dujiangyan, Leibo, Meigu, Mianning, etc. Among these, southeast Mianning had a large area of natural forest in 2003, but as of 2015, one third of that had become non-forest land. This showed that the destruction of vegetation via economic construction in China is very serious. Combined with the previous analysis, results showed a large area of mining and highway construction in this region, and the degree of landscape fragmentation was relatively high. From 2003 to 2015, the area of natural forest in central and eastern Minshan increased rapidly, while forest land in Daxiangling increased but remained grim. The natural forest area in Liangshan became planted forest in 2003. This may have been due to degradation by deforestation, among other reasons. Because the government has invested more protection funds, the effect of ecological engineering has been remarkable.

4.1.2. Change Characteristics

Many studies showed that the development of urbanization, agriculture, forestry, and grassland induce changes, such as a reduction in arable land area, a conversion of land cover to other land types, a fragmentation of forest land and grassland, a dramatic change in land cover, and a decrease in carbon fixation and oxygen release from vegetation [26]. With population growth and the expansion of cities into surrounding areas, artificial land, such as cities and transportation, is likely to grow rapidly. At the same time, exploitation of mineral resources is expected to increase, and arable land, woodland, and grassland land types are expected to decrease. These changes may have a negative impact on the ecosystem of giant panda's conservation sites [27].

The Areas and Change Rates of Different Types of Land

On the basis of the statistical results relating to the area composition of each land type in 2003 and 2015, the area changes of each land type in the study area were calculated respectively. The following conclusions can be seen from Figure 1.

(1) From 2003 to 2015, the absolute extent of the non-forest land area in the study area decreased by 15,953 hm^2, including farmland, water area, construction land, and meadows. The absolute extent of the forest land area increased, obviously, with the natural broad-leaved forest increasing the most (4453 hm^2), followed by artificial coniferous forest (3195.63 hm^2). Artificial shrubbery increased by 566.80 hm^2, and natural coniferous forests increased by 822.81 hm^2.
(2) Non-forest land changed dramatically from 2003 to 2015, reducing by 47.87%. At the same time, the area of forest increased substantially, and almost all types of forest land increased, to varying degrees. The largest increase was in artificial broad-leaved forest, which increased about 3.37 times, followed by artificial shrub, which increased about 1.16 times, and artificial coniferous forest, which increased about 95.98%. The smallest increase was in natural coniferous forest (12.05%), followed by natural shrub (25.54%).

These results show that the ecosystem of the giant panda tends to improve in general, because the Natural Forest Protection Project and the project of returning farmland to forest have achieved remarkable results in the past decade. On the other hand, Table 3 and Figure 2 show that natural broad-leaved forest increased by 92.70% and natural mixed forest increased by 44.32%. Studies have shown that the common formation groups for giant panda survival are in broad-leaved mixed forest, evergreen shrubbery, and so on [28]. Therefore, the expansion of these vegetation areas also plays an important role in the protection of giant panda's habitat.

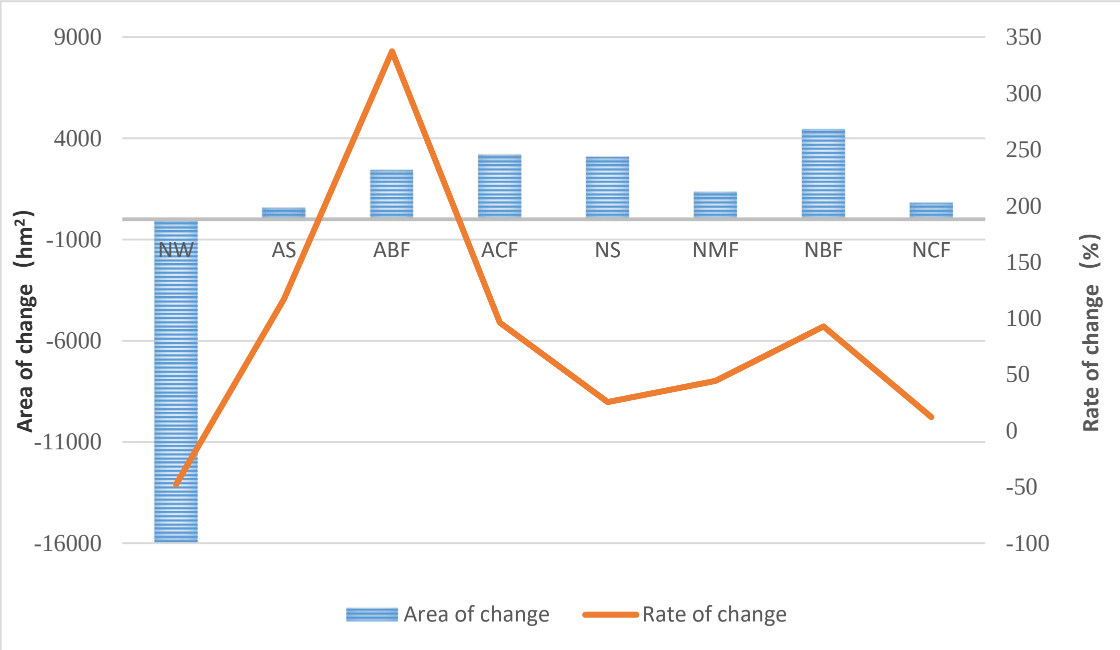

Figure 1. Area changes and change rates of forest land and non-forest land areas in 2003–2015.

Table 3. Features of classification transformation between 2003 and 2015 (hm^2).

Types	NW	AS	ABF	ACF	NS	NMF	NBF	NCF	Total Area
NW	10237	357.32	1118.45	4649.01	1110.12	2876.33	5884.94	3744	29,977.17
AS	52.11	0.00	27.54	94.28	89.16	35.97	109.39	94.56	502.34
ABF	7.05	1.09	9.76	21.05	8.44	4.51	26.77	1	79.67
ACF	330.22	94.71	74.87	270.31	139.26	116.12	325.26	67.32	1417.75
NS	1110.15	61.46	218.32	1425.53	2990.58	1552.23	1896.39	1843.09	11,097.75
NMF	145.53	2.10	57.12	268.27	415.65	530.39	467.20	598.75	2485.01
NBF	463.76	12.42	74.17	209.65	326.89	324.11	625.28	235.12	2271.4
NCF	514.87	16.23	124.38	1370.02	1311.00	1013.28	817.57	1836.43	7003.78
Total area	12,860.58	545.33	1704.61	8308.12	6391.1	6452.94	10,152.8	8419.39	—
Area of change	−17,116.59	42.99	1624.94	6890.37	−4706.65	3967.93	7881.4	1415.61	—
Rate of change	−1.33	0.08	0.95	0.83	−0.74	0.61	0.78	0.17	—

NW: non-woodland; AS: artificial shrubbery; ABF: artificial broad-leaved forest; ACF: artificial coniferous forest; NS: natural shrubbery; NMF: natural mixed forest; NBF: natural broad-leaved forest; NCF: natural coniferous forest.

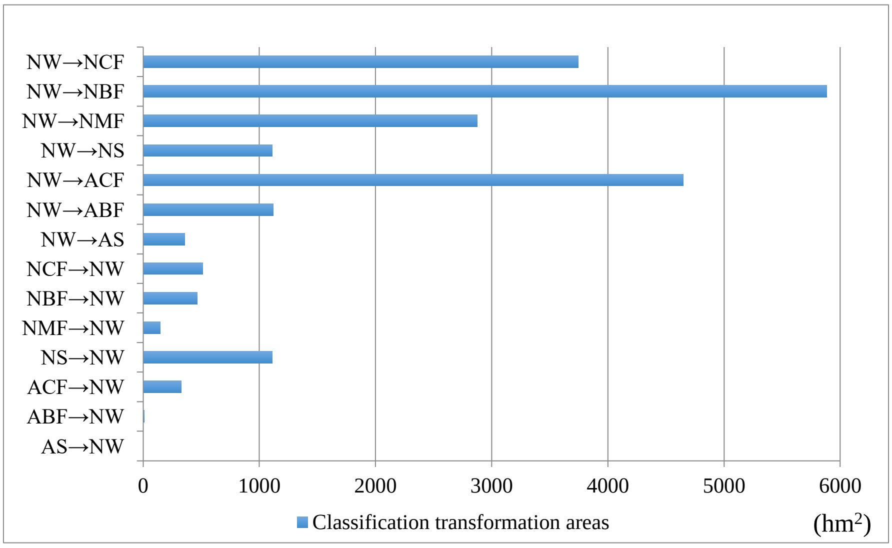

Figure 2. Conversion area between non forest land and woodland.

Conversion between Different Types of Land

In order to visualize the area of land conversion among different land types, we calculated the area of land conversion from each land type to other types by using land cover change data relating to the study area from 2003 to 2015, and constructed a land type distribution and transfer matrix to analyze the direction of land type change.

As shown in Table 3, the results of the transfer matrix showed that all land types, except natural shrubbery, were converted to each other. From 2003 to 2015, natural shrubbery turned into about 1110.15 hm^2 of non-woodland, followed by 514.87 hm^2 of natural coniferous forest; natural broad-leaved forests turned to non-woodland; artificial coniferous forests to non-woodland; amounting to 330.22 hm^2; natural mixed forests to non-woodland, amounting to 145.53 hm^2; and artificial shrubbery to non-woodland, which was the smallest area at 52.11 hm^2, due to road construction, mining, scenic area expansion, occupation of land, agricultural degradation of the original forest land, and other degradation. The most obvious change from non-forest land to natural broad-leaved forest was about 5884.94 hm^2, followed by artificial coniferous forest (4649.01 hm^2), natural coniferous forest (3744 hm^2), natural mixed forest (2876 hm^2), natural broad-leaved forest (118.45 hm^2), natural shrubbery (1110.12 hm^2), and artificial shrubbery (357.32 hm^2). During this period, the Natural Forest Protection Project and the project of returning farmland to forest were implemented. At the same time, many protected areas were established to restrict resource exploitation and land occupation. In addition, the government subsidized the ecological transfer of community residents. Farmers moved into new residences and transformed part of the cultivated land into woodland, thereby greatly reducing the amount of cultivated land. The implementation of these policies led to a rapid increase in vegetation areas, such as the forests seen in our study area, and the conversion of non-forest land to forest land.

4.2. Landscape Pattern Assessment

Due to the interference of human activities, the land cover of the giant panda reserve has been changed [29]. This is because the landscape pattern changes with the change of land use type [30]. Landscape pattern characteristics are closely related to the distribution of giant pandas and their habitats [31,32]. Therefore, the landscape pattern characteristics of each county in the region in 2015 were evaluated to provide a basis for the analysis of the distribution characteristics of giant pandas and their habitats; and the impact of land use change on giant panda habitat relative to regional economic development.

4.2.1. Overall Characteristics

The landscape index was used to quantitatively describe the characteristics of the landscape structure. Using the land use and cover data from 2015, Fragstats 3.3 software was used to calculate the landscape pattern index, as shown in Table 4. The patch density (PD) in the study area ranged from 0.1199 to 0.3135, but was generally high. The maximum plaque index (LPI) ranged from 11.3391 to 56.3974, but was generally low. With the increasing degree of landscape fragmentation, generally, the patch density increased and the maximum patch index decreased [33], indicating that the degree of landscape fragmentation in the study area was more serious. The contagion index (CON) of the study area ranged from 58.4196 to 71.0433, which is a low range. The contagion index was affected by the number of patches and decreased with the acceleration of urbanization. The results of the contagion index (CI) and the patch density (PD) were basically the same. However, if different patches were frequently adjacent, the value of the contagion index would also increase, which would have led to wrong conclusions. Therefore, considering the degree of the contagion index, the analysis of the landscape connectivity index was more comprehensive and scientific. The landscape connectivity index (LCI) was 97.8087–98.5434, a high level. Meanwhile, Shannon's diversity index (SHDI) of the study area ranged from 1.1715 to 1.6374. Generally, Shannon's diversity index increased with the acceleration of urbanization, and the higher the Shannon's diversity index, the more serious the landscape fragmentation was. In summary, the fragmentation degree of landscape in the study area was worrying.

Table 4. Landscape pattern of each county.

County	NP	PD	LPI	CON	SHDI	AI
Jiuzhaigou	1377	0.2624	25.9787	61.7299	1.5552	97.9981
Lixian	726	0.1691	11.3391	61.8208	1.4788	98.2860
Songpan	1984	0.2392	16.6818	60.6255	1.6035	97.9720
Wenchuan	620	0.1525	38.3179	66.1811	1.3098	98.4616
Dujiangyan	313	0.2626	25.3138	60.1672	1.6374	98.2554
Luding	368	0.1713	26.6443	60.6046	1.5402	98.5418
Qingchuan	792	0.2738	27.6179	66.3384	1.3576	97.9552
Ebian	533	0.2198	48.6775	66.5876	1.2866	98.3405
Mabian	717	0.3135	23.8598	63.3170	1.3933	97.8087
Leibo	752	0.2673	34.5297	59.9542	1.5510	98.2086
Meigu	714	0.2854	18.7354	60.0904	1.6269	98.0037
Mianning	926	0.2109	13.7403	62.2062	1.4584	98.2042
Hongya	538	0.2874	26.0181	59.7865	1.5538	98.1059
Anxian	320	0.2317	39.8600	58.4196	1.5098	98.3228
Beichuan	747	0.2623	38.6266	63.8589	1.4688	98.1004
Pingwu	995	0.1684	48.9271	69.5980	1.2441	98.5385
Baoxing	370	0.1199	36.3178	69.6442	1.1715	98.5287
Shimian	533	0.2002	26.8728	67.9656	1.3030	98.3280
Yingjing	345	0.1951	28.0792	64.8600	1.3674	98.5434
Tianquan	449	0.1887	56.3974	71.0433	1.1784	98.4763

4.2.2. Regional Characteristics

In order to analyze the landscape pattern characteristics of each county and explain the land use status of the giant panda protection area, the calculation results are shown in Table 4. The following conclusions can be derived from the table:

(1) The numbers of patches (NP) in Songpan, Jiuzhaigou, and Pingwu counties were high, at 1984, 1377, and 995, respectively, whereas those Dujiangyan, Anxian, and Baoxing counties were low, at 313, 320, and 370, respectively. Figure 3 shows that the counties with higher patch densities were Mabian, Meigu, and Hongya counties, whose densities were 0.3135, 0.2854, and 0.2874, respectively. The patch density of Baoxing County was low, at 0.1199, and the number of patches was small. To some extent, the landscape of Baoxing was relatively complete. Wenchuan and Pingwu are also counties where giant pandas are concentrated.

(2) Pingwu county had the highest patch index of 48.9271. Figure 4 shows that Pingwu also had a high degree of landscape connectivity, at 69.5980. To some extent, Pingwu had a low degree of habitat disturbance. In fact, Pingwu was also the county with the largest number of giant pandas.

(3) Dujiangyan city is close to Chengdu, the capital of the province, and has convenient transportation. Therefore, it exhibited rapid economic development, rapid urban expansion, and occupied a large amount of land. Because of the low economic level, the exploitation of mineral resources in Meigu seriously damaged the landscape. Songpan had the largest amount of panda data of all the counties in 2003, but due to the development of the Jiuzhaigou–Huanglong tourism line and a lack of reasonable planning, the number of pandas and the area of the panda's habitat declined as of 2015.

(4) The counties with the most landscape connectivity were Xingjing, Pingwu, and Luding, for which the values were 98.5434, 98.5385, and 98.5418, respectively. Yingjing mainly occupied a large proportion of construction land, whereas Luding mainly occupied a large proportion of farmland

and water, so the panda habitat quality in these two counties was not high. Pingwu was mainly forested land with high landscape connectivity, indicating that the giant panda habitat was good.

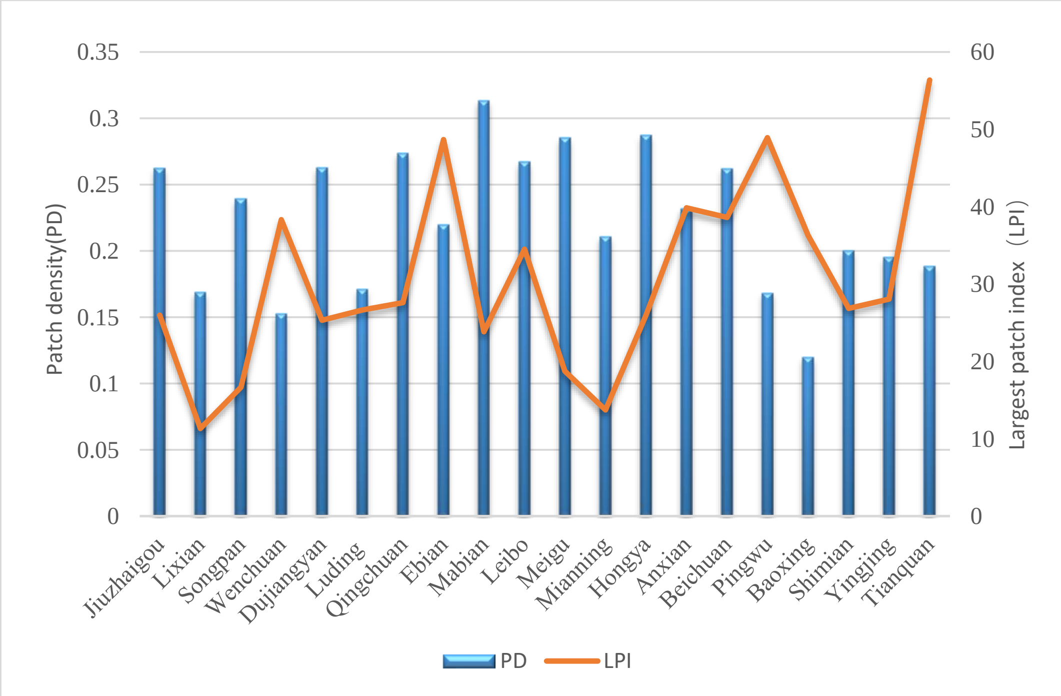

Figure 3. Patch density and largest patch index in counties.

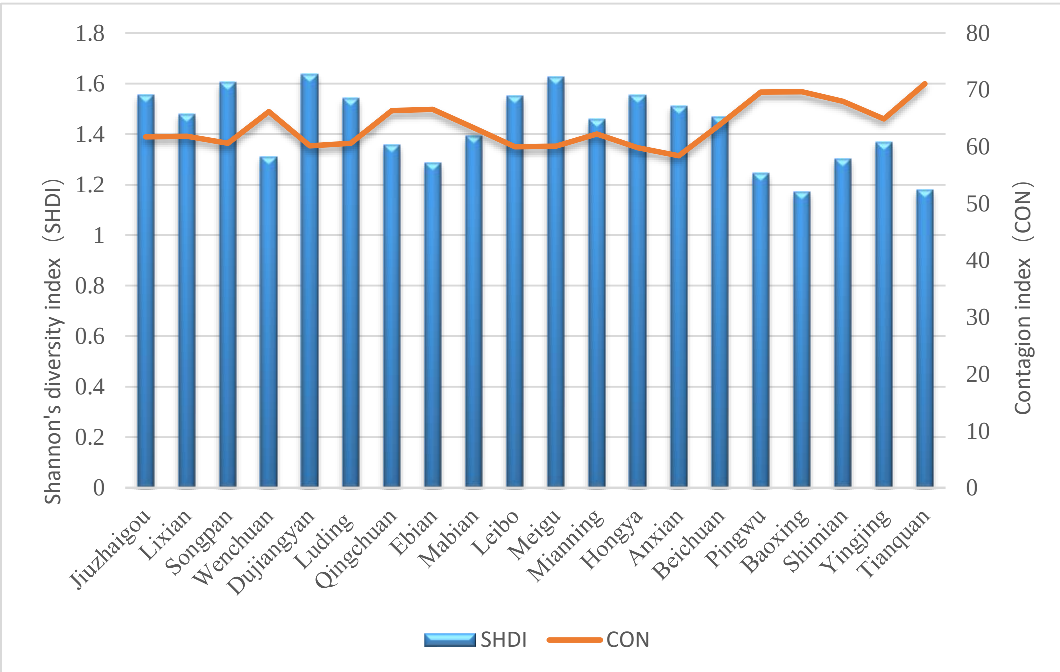

Figure 4. Shannon's diversity index and contagion index in counties

4.3. Correlation Analysis

In order to illustrate the impact of economic development on the landscape pattern, and the impact of the landscape pattern on the number of pandas and the distribution of panda habitat, we used social and economic data from 2015, the landscape pattern index, and data describing the numbers of pandas and the area of panda habitat to construct a correlation analysis model.

4.3.1. Relevance of Giant Panda Numbers and Habitat to Landscape Patterns

This study selected the number of patches (NP), the patch density (PD), the maximum patch index (LPI), the contagion index (CON), Shannon's diversity index (SHDI), and the landscape connectivity index (LCI) as independent variables, and the number of giant pandas and the habitat area of giant pandas as dependent variables. The landscape pattern index and the number of giant pandas in each county were calculated by SPSS19.0 software. The correlation relating to the habitat area of giant pandas is shown in Table 5.

Table 5. Correlation between landscape index and the number and habitat area of giant pandas.

	NP	PD	LPI	CON	SHDI	LCI	NGP	AH
NP	1							
PD	0.222	1	-					
LPI	−0.325	−0.277	1	.				
CON	−0.154	-0.544^{*}	0.599^{**}	1		.		
SHDI	0.288	0.596^{**}	-0.633^{**}	-0.946^{**}	1			
LCI	-0.520^{*}	-0.859^{**}	0.495^{*}	0.456^{*}	-0.521^{*}	1		
NGP	0.221	-0.501^{*}	0.504^{*}	0.620^{**}	-0.553^{*}	0.39	1	
AH	0.158	-0.537^{*}	0.615^{**}	0.748^{**}	-0.668^{**}	0.464^{*}	0.950^{**}	1

Note: ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. NGP: number of giant pandas; AH: area of habitats.

The patch density was significantly correlated with the number of giant pandas and the habitat area of giant pandas by 1%; the maximum patch index was significantly correlated with the number of giant pandas by 1%; and the habitat area of giant pandas was correlated by 5%. There was a significant correlation between the number of giant pandas and the area of giant panda habitat—5%. The landscape diversity was significantly correlated with the number of giant pandas—1%, and with the area of giant panda habitat—5%. There was a significant correlation between landscape connectivity and giant panda habitat area of 1%. Giant pandas need large and complete habitats for survival and reproduction. Habitat fragmentation is the biggest threat to the survival of wild giant pandas. All of the data obtained proved that the number of giant pandas and the area of giant pandas' habitat were generally smaller in counties and regions with large landscape fragmentation, even demonstrating a downward and decreasing trend, with the original habitat of some areas declining [34]. Giant pandas choose to migrate to other areas to survive. If the migration span is large and there are no suitable food and water resources along the way, the giant pandas cannot survive.

4.3.2. The Relevance between Landscape Pattern Characteristics and Economic Development

To illustrate the impact of economic development on landscape patterns, this study selected the total population (10,000 people), the rural population (10,000 people), the natural population growth rate (per mill), the gross domestic product (100 million yuan), the annual industrial output value (100 million yuan), the annual tourism income (100 million yuan), and road mileage (km) as independent variables. The number of patches (NP), the patch density (PD), the maximum patch index (LPI), the contagion index (CON), Shannon's diversity index (SHDI), and the landscape connectivity index (LCI) were selected as dependent variables, and the correlation between socio-economic development indicators and the landscape pattern index was calculated using SPSS19.0 software. The results are shown in Table 6.

(1) The total population and the rural population had significant effects on the patch density, indicating that the increase in population caused an increase in the use and development of

resources, thereby destroying the integrity of the landscape and increasing environmental pressure. The total population had a significant impact on landscape aggregation, but the rural population had no impact, indicating that the growth of the rural population did not seriously damage the landscape, and the growth of the total population, or more specifically, the urban population, had a greater impact on environmental damage.

(2) Gross domestic product (GDP) had a significant impact on patch density and landscape diversity, indicating that total economic growth and increasing demand for resources increased the pressure on the environment. The annual industrial output value had a significant impact on the number of patches and the degree of landscape aggregation. These results showed that land occupation and resource development directly caused landscape fragmentation in industrial development. At the same time, the fragmentation of the landscape and the embedding of some heterogeneous patches, such as mining areas or a hydropower station construction, reduced the degree of landscape aggregation.

(3) The landscape patterns of annual tourism income had no obvious impact. Highway mileage had a significant impact on patch density, landscape aggregation, and landscape diversity. Highway construction directly divided the original landscape pattern, resulting in the isolation and fragmentation of the landscape. At the same time, the increase in traffic flow and human flow also caused a large amount of disturbance to the habitat of giant pandas, forcing giant pandas to abandon the use of their surrounding habitats [35]. Along both sides of the highway, the distribution of residential areas increased the fragmentation of the landscape.

Table 6. Correlation between regional economic development index and landscape pattern index.

	TP	RP	NPGR	GDP	AIOV	AIT	HM	NP	PD	LPI	CONT	SHDI	AI
TP	1												
RP	0.835^{**}	1											
NPGR	−0.305	−0.069	1										
GDP	0.724^{**}	0.319	−0.354	1									
AIOV	0.681^{**}	0.595^{**}	−0.234	0.568^{**}	1								
AIT	0.331	−0.09	−0.307	0.823^{**}	0.144	1							
HM	0.649^{**}	0.721^{**}	-0.454^{*}	0.322	0.258	0.164	1						
NP	−0.304	−0.264	0.15	−0.187	-0.437^{**}	0.08	−0.019	1					
PD	0.488^{*}	0.474^{*}	0.108	0.553^{*}	0.076	0.15	0.417^{*}	0.222	1				
LPI	−0.063	−0.017	0.107	−0.089	−0.036	−0.042	−0.064	−0.325	−0.277	1			
CON	-0.445^{*}	−0.414	0.057	−0.322	-0.528^{*}	−0.075	-0.514^{*}	−0.154	-0.544^{*}	0.599^{**}	1		
SHDI	0.421	0.298	−0.04	0.486^{*}	0.14	0.248	0.482^{*}	0.288	0.596^{**}	-0.633^{**}	-0.946^{**}	1	
AI	−0.195	−0.226	−0.157	−0.039	0.163	−0.079	−0.304	-0.520^{*}	-0.859^{**}	0.495^{*}	0.456^{*}	-0.521^{*}	1

Note: ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. TP: total population; RP: rural population; NPGR: natural population growth rate; GDP: gross domestic product; AIOV: annual industrial output value; AIT: annual income from tourism; HM: highway mileage.

5. Conclusions

The most direct manifestation of the impact of human economic development on an ecological environment is the change of land use and cover, and the result is the change of landscape pattern. The contradiction between resource utilization and species conservation in giant pandas' conservation areas is still very prominent. Many social and economic activities are driven by their own laws and related factors and are in the process of dynamic change. The spatial pattern of their distribution and their influence on the attributes of the surrounding spatial elements are also in the process of dynamic change, as is disturbance to the habitat of giant pandas.

(1) From 2003 to 2015, the area of non-forest land decreased significantly, about 15953 hm^2, including farmland, water bodies, construction land, and meadows. The area of forest land in the study

area increased significantly. The natural broad-leaved forest increased by 4453 Hm^2, and the artificial coniferous forest increased by 3195.63 hm^2. The woodland areas of Pingwu, Beichuan, Lixian, Wenchuan, Baoxing, Tianquan, Meigu and other counties increased significantly.

(2) In order to analyze the landscape pattern characteristics as a result of land use and cover change, we subdivided the non-forest land of each county in 2015 and calculated the patch index and landscape index of each county. We found that, although the area of forested land in the counties of the study area increased substantially, in general, the fragmentation of the landscape was serious due to economic development, especially road construction and urban expansion. This phenomenon was more prominent in Anxian, Lixian, Jiuzhaigou, Dujiangyan, Hongya, Xingjing, Mianning, and Leibo counties.

(3) In order to illustrate the impact of land use and cover change on the distribution of giant pandas and their habitats, the landscape index of each county was used to analyze the correlation between the number of giant pandas and habitat area. We found that the patch density (PD), the maximum patch index (LPI), the contagion index (CON), Shannon's diversity index (SHDI), and the landscape connectivity index (LCI) were significantly correlated with the habitat area of giant pandas. These results showed that under the pressure of economic development, the acceleration of economic development, and the deepening of human activities further fragmented the habitat of giant pandas, causing the landscape pattern of giant panda distribution areas to change greatly. Despite the remarkable effect of various ecological projects, the fragmentation of the landscape pattern is still serious, and overall habitat quality is still deteriorating, thereby affecting the risk of panda mortality. The number of giant pandas in some areas, such as Daxiangling and Xiaoxiangling, declined, and a large area of habitat was degraded or even eliminated.

(4) Based on the research results above, the formulation and implementation of giant panda conservation management measures must adhere to dynamic optimization in order to adapt to the development of various social and economic activities and improve the effectiveness of conservation measures. In future protection work, government departments should closely monitor the development trends of various social and economic activities, grasp the spatial and temporal dynamic changes of various social and economic activities, and integrate existing decentralized monitoring of habitats, species, and social and economic development disturbances into the of 3S technology platform for the purpose of building a comprehensive early warning system. Pilot projects should be carried out for the construction of giant panda national parks, and a giant panda protection network should be built and consistently improved, consisting of giant panda nature reserves, giant panda national parks, and social welfare giant panda protection sites, so as to bring more giant pandas and their habitats into the scope of protection. With the development of infrastructure such as transportation, hydropower, mining, tourism, and other resource utilization activities, patches of giant panda habitat have been further segmented, affecting gene exchange among local populations. Any new trunk road should be strictly prohibited from crossing the interior of the giant panda habitat; projects should include traffic construction planning and building traffic corridors. According to the new urbanization construction plan regarding China's giant panda protection area, priority should be given to liberalizing the restrictions on the establishment of towns and small cities around the giant panda habitat. Without comprehensive planning, the current protected-area-system will not achieve its goals of improving biodiversity and the ecosystem. China should be cautious about reassigning strictly protected areas to less strict ones. Subsequently, this plan may provide a foundation for the delineation of boundaries of all types of protected areas [36]. Management departments should guide and support the aborigines in key areas of giant panda protection to voluntarily and orderly migrate to nearby towns where they can concentrate.

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