

Article

Comparing the Effectiveness of Biodiversity Conservation across Different Regions at County Scale

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Abstract: The central government of China encourages enthusiasm for biodiversity conservation by implementing a transfer payment policy targeted at Biodiversity National Key Ecological Functional Areas at the county scale. Biodiversity National Key Ecological Functional Areas are types of PAs that were designated by the State Council of China for the implementation of biodiversity conservation. However, regional comparative assessment results of biodiversity conservation effectiveness in different county-level administrative units are still lacking. In this study, we developed a reference condition index to represent the ecological background, and we then constructed a conservation effectiveness index to compare the conservation efforts among 131 counties in seven Biodiversity National Key Ecological Functional Areas. The results showed the following: (1) The biological background could be well reflected by the reference condition index. The Tropical Rainforest Ecological Function Area in Mountain Areas in the Middle of Hainan Island had the best biological background, while the Desert Ecological Function Area on the Northwest Qiangtang Plateau had the worst. (2) The biodiversity conservation effectiveness of the Desert Ecological Function Area on the Northwest Qiangtang Plateau was the best, and that of the Wetland Ecological Function Area of the Three River Plain was worst. (3) Among the 131 counties, Taibai County in the Biodiversity Ecological Function Area of Qinba Mountain performed best, while Fujin City in the Wetland Ecological Function Area of the Three River Plain performed worst. Our study could provide valuable insights for the transfer payment. Meanwhile, it can also supply a scientific reference for the management of Biodiversity National Key Ecological Functional Areas to enhance biodiversity.

Keywords: biodiversity conservation; effectiveness; comparative assessment; county scale



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1. Introduction

Biodiversity loss is a global biological crisis. It is estimated that the current species extinction rates are 10–100 times higher than the average over the past 10 million years, and this is still accelerating [1]. The establishment of protected areas (PAs) is the most effective path to curb this trend [2–4] and is also an important way to achieve the United Nations' sustainable development goals [5]. Nearly 15.7% of the Earth's surface and 7.9% of the oceans are covered by PAs [6]. According to the Kunming-Montreal Global Biodiversity Framework, 30% of the land and ocean should be protected. However, evidence shows that PAs might not be able to fulfill their mission if good management effectiveness cannot be guaranteed. Therefore, it is particularly important to improve the management of PAs through various management measures. An effective way to enhance these conservation efforts is by using an incentive mechanism achieved by conservation fund allocation. So, how to allocate these limited funds reasonably is particularly important [7–9].

To realize the dual goals of ecosystem service protection and poverty alleviation, the State Council of China established 25 National Key Ecological Function Areas in 2010, including water conservation, water and soil conservation, windbreak, and sand fixation,

giving four biodiversity maintenance types. Biodiversity National Key Ecological Function Areas (BNKEFAs) are types of PAs that were designated by the State Council of China for the implementation of biodiversity conservation [10,11]. BNKEFAs receive ecological transfer payments from the central government in exchange for protecting and restoring natural ecosystems to enhance the provision of vital regulating services. The object of the transfer payment is the county-level government located in the BNKEFAs.

The central government assesses the conservation efforts of the management departments of key ecological functional areas, and then makes transfer payments according to the assessment results to encourage them to better protect biodiversity. Therefore, a scientific and practical method is needed to assess the biodiversity effectiveness among different PAs.

In previous studies, researchers have assessed whether PAs perform better than unprotected sites in reducing deforestation rates [12,13], reducing human disturbance [14,15], and increasing species diversity [16,17] by using before–after or control–intervention study designs. Before–after studies compare the conservation outcomes before and after PA designation [18–21] but cannot ensure whether the observed difference was induced by the PA or by other factors. Control–intervention studies compare conservation outcomes between inside and outside the PA [16,22–24], but the observed difference may be just because the PA was placed in an area with abundant biodiversity. In a recent study, researchers proposed the BACI (Before–After–Control–Intervention) framework, which combines the before–after and control–intervention methods to remedy these defects [25]. BACI can provide credible results for assessing individual PAs. However, it is weak when comparing the effectiveness of PAs across different regions. This is mainly because there are large differences in the biological and socio-economic backgrounds of PAs located in different geographic regions [26–29], and BACI does not consider these differences.

To compensate for these shortcomings, Dong, et al. [30] proposed a framework to compare the biodiversity conservation effectiveness among different regions. The core idea of the framework is that they constructed a reference condition index based on the concept of a reference ecosystem. Then, the biological background difference could be eliminated by the difference between a PA's biodiversity level and its reference condition. They compared the effectiveness of biodiversity conservation among different biological function areas using this framework. Chen, et al. [31] extended the comparative study to 24 national biological function areas, proving the practicability of this method. However, an important point is that they omitted the fact that the transfer payment is targeted not at biological function areas but at BNKEFAs. In addition, the basic unit of transfer payment is the county-level administrative unit. Therefore, comparative assessment results for counties in BNKEFAs are needed urgently.

The main objective of this study was to compare the biodiversity effectiveness among different BNKEFAs at the county scale in China. These comprehensive results can provide better scientific guidance for the implementation of transfer payments. Furthermore, they are of great significance to the management of BNKEFAs.

2. Materials and Methods

2.1. Study Area

For this study, we chose seven BNKEFAs: the Forest and Biodiversity Ecological Function Area of Yunnan and Sichuan (CD), the Tropical Rainforest Ecological Function Area in Mountain Areas in the Middle of Hainan Island (HND), the Biodiversity Ecological Function Area of Qinba Mountain (QB), the Wetland Ecological Function Area of the Three River Plain (SJPY), the Biodiversity and Soil Conservation Ecological Function Area in Wuling Mountain (WLS), the Forest Ecological Function Area on the Edge of the Plateau in the Southeast of Tibet (ZDN), and the Desert Ecological Function Area on the Northwest Qiangtang Plateau (ZXB).

The total area of BNKEFAs in China is 9.65×10^5 km²; they are located from Heilongjiang province in the north to Hainan Island in the south, excluding eastern China

(Figure 1), and their climate types include tropical monsoon, subtropical monsoon, temperate monsoon, temperate continental, and plateau mountain climates. The annual average temperature in these areas varies from 2.8 to 27 °C and declines gradually from south to north. Annual precipitation ranges from 15 mm to 1600 mm and declines gradually from southeast to northwest. The major vertebrates in CD are the giant panda, takin, and golden monkey; those in HND are the gibbon and peacock pheasant; those in QB are the giant panda and golden monkey; those in SJPY are red-crowned cranes and white storks; those in WLS are the falcon, golden pheasant, and giant salamander; those in ZDN are the otter and Yunnan golden monkey; and those in ZXB are the Tibetan antelope, Tibetan wild donkey, and wild yak.



Figure 1. Distribution of BNKEFAs in China.

2.2. Data Sources

In this study, land use/cover data from 1980, 1990, 1995, 2010, 2015, and 2018 were downloaded from the Data Center for Resources and Environmental Sciences of the Chinese Academy of Sciences (<https://www.resdc.cn/>, (accessed on 1 February 2023)); the spatial resolution of the data is 1 km × 1 km. According to the aim of this study, we reclassified the data (see Table 1). The boundaries of BNKEFAs were taken from the “National Planning for Key Function Areas” document [32]. The boundaries of national nature reserves

were obtained from the Resource and Environmental Science and Data Center (<https://www.resdc.cn/>, (accessed on 1 February 2023)).

Table 1. Land use reclassification.

Original Land Use Classification		Land Use Reclassification
1st-Level Classes	2nd-Level Classes	
1 Cropland	11 Paddy land	1 Cropland 11,12
	12 Dry land	
2 Forestland	21 Forest	2 Forestland 21,24
	22 Shrub	3 Shrub 22
	23 Open Forest savanna	4 Open forest savanna 23
	24 Others	
3 Grassland	31 Dense grass	5 Grassland 31, 32, 33
	32 Moderate grass	
	33 Sparse grass	
	41 Stream and rivers	
4 Water body	42 Lakes	6 Wetlands 41, 42, 43, 44, 45, 46, 64
	43 Reservoir and ponds	
	44 Permanent ice and snow	
	45 Beach and shore	
	46 Bottomland	
5 Built-up areas	51 Urban built-up	7 Urban built-up 51
	52 Rural settlements	8 Rural settlements 52
	53 Others	9 Others 53
	61 Sandy land	
	62 Gobi	
6 Unused land	63 Salina	10 Unused land 61, 62, 63, 65, 66, 67
	64 Swamp land	
	65 Bare soil	
	66 Bare rock	
	67 Others	

2.3. Methods

Because the geographic locations of BNKEFAs are different, there are great differences in their own origin, internal nature, and environment, leading to large differences in the background of biodiversity protection functions. For areas with a poor background of biodiversity conservation, even if the relevant department and organizations make more of an effort to protect the ecosystem in BNKEFAs, it will be difficult to achieve the level of biodiversity protection achieved in areas with better backgrounds. Therefore, in order to compare the effectiveness of biodiversity conservation in BNKEFAs in different regions, a reference benchmark that reflects the differences in ecological background must be established.

The procedures for comparing the biodiversity conservation effectiveness among different BNKEFAs are as follows:

- (1) Computing habitat quality as a proxy for biodiversity. Habitat quality computed using the InVEST-HQ model has previously been used successfully to represent the biodiversity level in regions [33–37]. Therefore, in this paper, habitat quality was used as a proxy for biodiversity.
- (2) Computing the reference condition index. To eliminate the background difference, a reference condition index was computed to represent the biological background based on the idea of the reference ecosystem.
- (3) Computing the conservation effectiveness index. The conservation effectiveness index can be constructed based on the reference condition index.

2.3.1. Proxy for Biodiversity

In the InVEST-HQ model, four factors are considered: (1) the weights of different threat sources; (2) the relative sensitivity of each habitat to each threat source; (3) the distance between the habitat and the threat source; and (4) the degree of habitat protection. The habitat quality Q_{xj} was computed as follows:

$$Q_{xj} = H_j \left(1 - D_{xj}^z / (D_{xj}^z + k^z) \right) \quad (1)$$

where Q_{xj} is the habitat quality of raster x in land use type j ; D_{xj} is the level of threats of raster x in land use type j ; and H_j is the habitat suitability of land use type j , always assigned a value ranging from 0 to 1. The bigger the value of H_j , the higher the level of habitat suitability. The z and k terms are scaling parameters. In general, z is assigned as 2.5 and k is assigned as 0.5. The computation of D_{xj} is as follows:

$$D_{xj} = \sum_{r=1}^R \sum_{y=1}^{Y_r} \left(w_r / \sum_{r=1}^R w_r \right) r_y i_{rxy} \beta_x S_{jr} \quad (2)$$

where r is one threat to the habitat type, R is the total number of ecological threat factors; y refers to a grid cell on a raster map of r ; Y_r represents all the grid cells on the threat map of r ; r_y refers to the impacts of the habitat threat r originating from grid cell y ; W_r is the weights parameter; β_x is the accessibility factor of raster x ; and S_{jr} is the sensitivity of land use type j to threat r , with values closer to 1 indicating greater sensitivity. The i_{rxy} term refers to the distance between the habitat source and the source of the threat. The model suggests either a linear or exponential distance decay function to describe the impact of threats over space. This explains how quickly the threat spreads into the habitat.

$$i_{rxy} = 1 - \frac{d_{xy}}{d_{rmax}} \quad (3)$$

$$i_{rxy} = \exp \left(- \left(\frac{2.99}{d_{rmax}} \right) d_{xy} \right) \quad (4)$$

Here, d_{xy} is the linear distance between raster x and raster y ; d_{rmax} is the maximum distance of ecological threat r .

According to [38,39], cropland, urban built-up areas, rural settlements, and construction land were chosen as threat layers. Given that our aim was to compare the effectiveness of biodiversity conservation across different regions, the same strategy was adopted for the model parameter calibration among the seven BNKEFAs. Specifically, the habitat suitability of each habitat, the habitat sensitivity to the threat factors, the scope of impacts, the weights, and the maximum weighting distances were determined according to the InVEST user manual and results from previous studies [38–41]. For the specific parameters, see Tables 2 and 3.

Table 2. Sensitivity of different habitat types to each threat.

Land Use/Land Cover Type	Habitat	Cropland	Urban Built-up	Rural Settlements	Construction Land
Forestland	0.95	0.60	0.90	0.85	0.90
Shrub	0.60	0.60	0.65	0.60	0.65
Open forest savanna	0.50	0.20	0.60	0.55	0.60
Grassland	0.60	0.40	0.47	0.80	0.80
Wetlands	1.00	0.70	0.70	0.65	0.70
Unused land	0.10	0.10	0.30	0.30	0.30
Cropland	0.00	0.00	0.00	0.00	0.00
Urban built-up	0.00	0.00	0.00	0.00	0.00
Rural settlements	0.00	0.00	0.00	0.00	0.00
Construction land	0.00	0.00	0.00	0.00	0.00

Table 3. Relative impact of each threat on different habitats.

Threat	Max Distance	Weight	Decay
Cropland	7	0.8	exponential
Urban built-up	10	0.95	exponential
Rural settlements	9	0.9	exponential
Construction land	10	1	exponential

After parametrization, the habitat quality of the seven BNKEFAs was computed based on the InVEST-HQ model. The habitat quality of the counties in the BNKEFAs was obtained by using the zonal statistical tool in ArcGIS 10.5.

2.3.2. Reference Condition Index

In reference ecology, reference ecosystems have been widely used to evaluate ecological environment and river health. There are several principles when choosing a reference ecosystem: (1) the absence of significant human disturbance; (2) the condition that current sites could achieve if they were better managed; and (3) the best of the existing conditions. Therefore, the ecosystem condition of the reference ecosystem can well reflect the ecological background.

As the most strictly protected PAs in China, national nature reserves suffer little human inference, especially the core areas of them. Therefore, the core areas of national nature reserves in each BNKEFA were chosen as the reference ecosystem. To avoid the influence of reference ecosystem evolution, the maximum value of habitat quality through 1990–2018 was used as the Reference Condition Index (RCI); its calculation formula is as follows:

$$RCI = \text{MAX}(\text{MEAN}(HQ_t)) \quad (5)$$

where RCI is the reference condition index of the BNKEFA, HQ_t is the habitat quality of the core area of national nature reserve in each BNKEFA, and t represents the study year from 1980 to 2018. The RCI represents the biological background level of the BNKEFAs. A high CEI value means a better biological background.

It is worth noting that all the counties in one BNKEFA shared the same RCI value.

2.3.3. Conservation Effectiveness Index

The conservation effectiveness index (CEI) can be computed as the difference between the HQ of a BNKEFA and its corresponding RCI. The formula is as follows:

$$CEI = HQ - RCI \quad (6)$$

The central government provides biodiversity transfer payment funds at the county scale. After the CEIs of the BNKEFAs were computed, the CEI of each county was calculated using the zonal statistics tool in ArcGIS 10.5 software.

3. Results

3.1. Ecological Background of the BNKEFAs

Figure 2 shows the RCI values, which reflect the ecological background across the seven BNKEFAs. HND had the biggest RCI, with its value of 0.95. SJPY had the second biggest RCI; the value was 0.90. This was followed by the RCI values for QB, WLS, ZDN, and CD; their corresponding values were 0.76, 0.75, 0.70, and 0.63, respectively. The smallest CEI value was 0.55 in ZXB. These results indicate that HND had the best biological background, whereas ZXB's background was the worst.

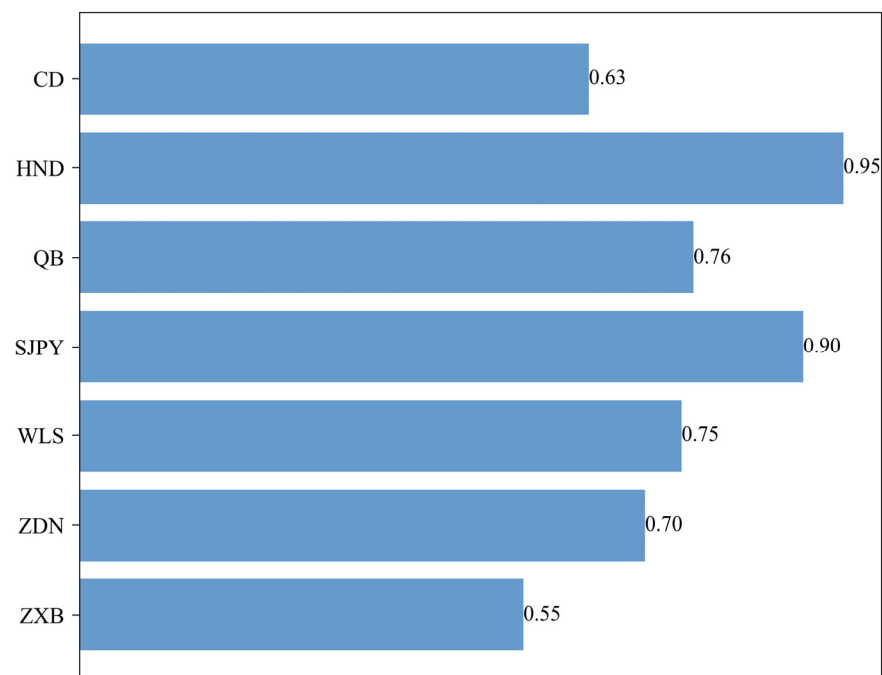


Figure 2. RCI values across different BNKEFAs.

3.2. Temporal Trends in HQ and CEI across Different BNKEFAs

In this article, the CEI was constructed to represent the biodiversity efforts across different regions. Figure 3 shows the temporal evolution of HQ and CEI from 1980 to 2018. For HQ, we can see the order $HND > ZDN > CD > WLS > QB > ZXB > SJPY$. For CEI, from best to worst, the order was $ZXB > HND > ZDN > WLS > QB > CD > SJPY$. The HQ value of ZXB was second to worst, but the CEI of ZXB performed the best. This means that the CEI can be significantly influenced by the biological background.

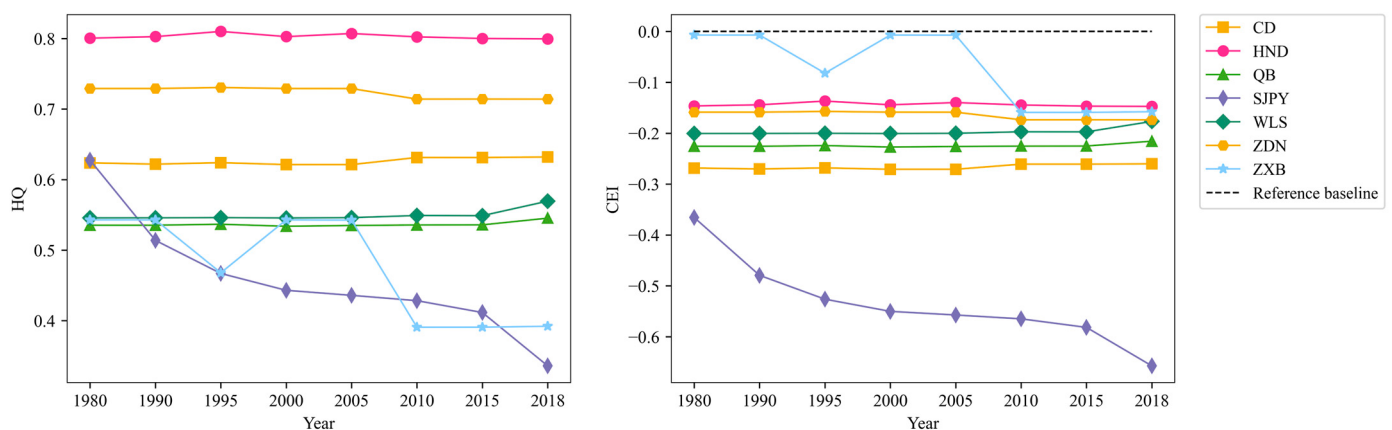


Figure 3. Temporal trends in HQ and CEI across different BNKEFAs.

3.3. CEI across Counties

Transfer payments aim to stimulate the conservation enthusiasm of county governments. Therefore, comparison results of CEI across counties can directly guide initiating measures for biodiversity conservation. Figure 4 shows the CEI across different BNKEFA counties in 2018. The largest CEI was 0.0324 in Taibai County in QB. The smallest CEI was -0.858 , observed in Fujin City in SJPY.

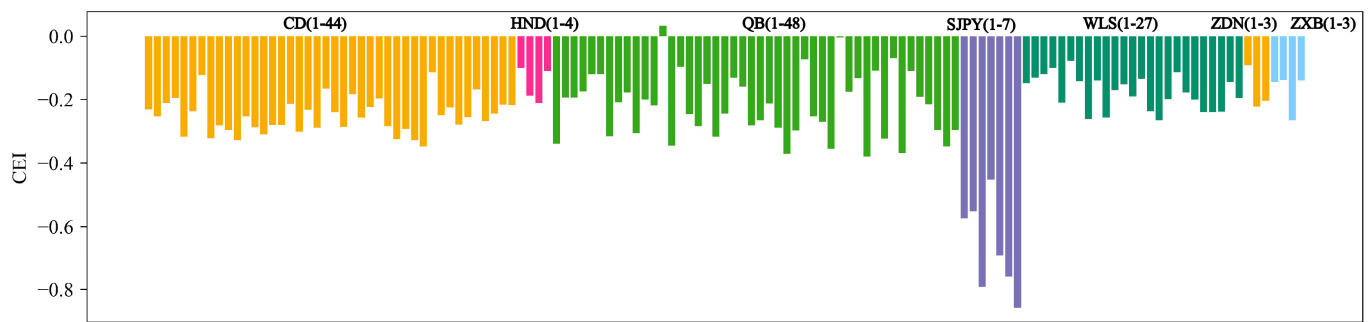


Figure 4. CEI across different BNKEFA counties in 2018. For the BNKEFA county names, see the Supplementary Data.

Intra-BNKEFA counties also showed an apparent difference. Figure 5 shows the spatial differentiation of CEI values across different counties within KBEFZ in 2018. In CD, the southern counties' CEI values were much better than those for the northern part. In QB, the central part had the smaller CEI. For SJPY, Hulin City in the middle had the largest CEI. Counties in ZXB, except for Geni County, had nearly the same value. In ZDN, Motuo County's CEI was obviously larger than those of Chayu County and Cuona County. In WLS, the counties located in the central northern part performed better than did those in the northwest, eastern, and southern parts. For HDN, Wuzhishan City in the southern part had the greatest conservation effectiveness compared to other counties.

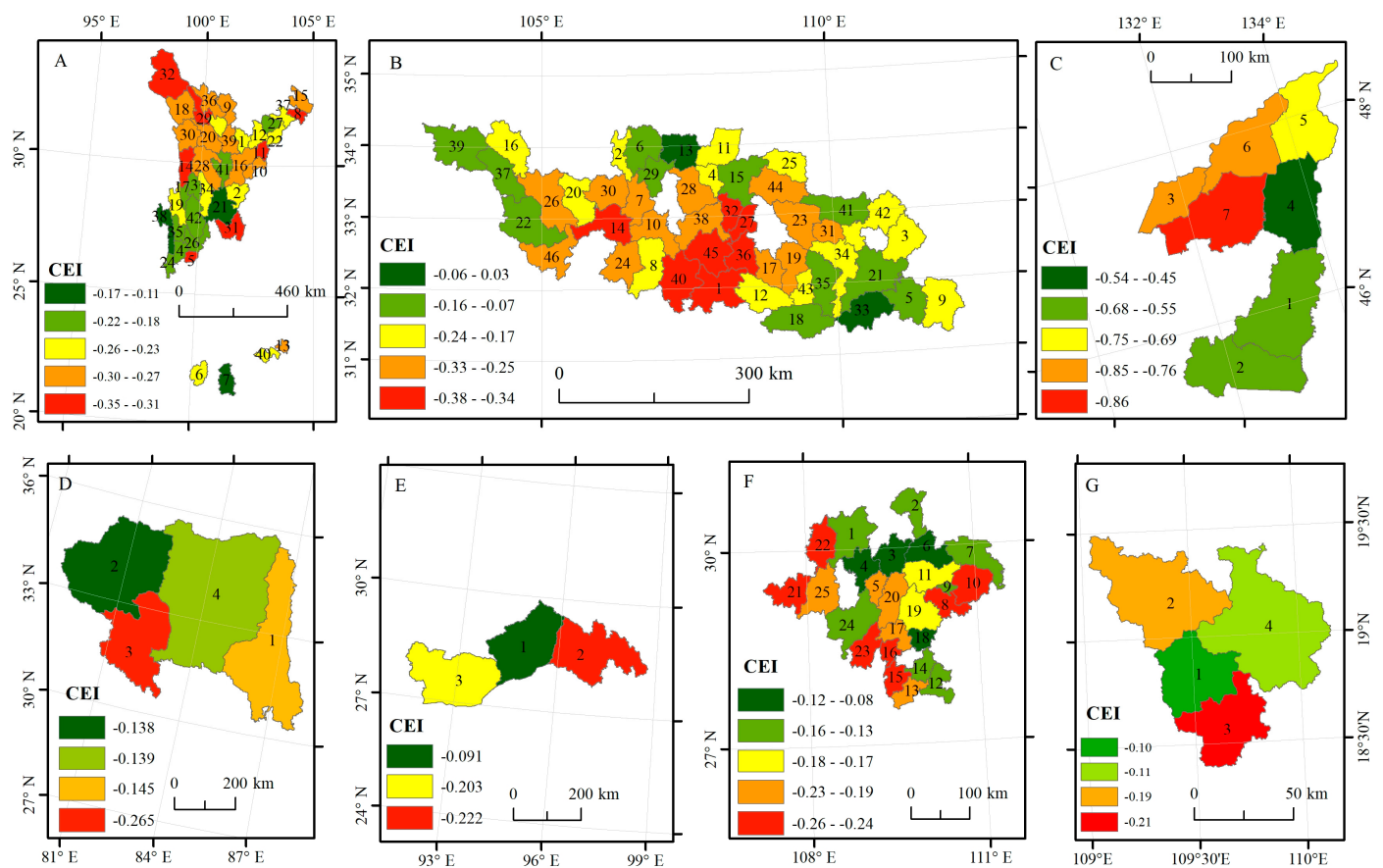


Figure 5. Spatial differentiation of CEI across different counties within KBEFZs in 2018. (A) CD; (B) QB; (C) SJPY; (D) ZXB; (E) ZDN; (F) WLS; (G) HDN. For the BNKEFA county names, see the Supplementary Data.

3.4. Change in CEI from 1980 to 2018

We calculated the numbers of counties showing improvement or degradation of the CEI from 1980 to 2018. For the period from 1980 to 2000, 91 of 131 counties improved, 5 of 131 counties remain unchanged, and 35 of 131 counties degraded. From 2000 to 2018, 76 of 131 counties improved, while 55 counties degraded.

4. Discussion

4.1. Significance of Comparative Assessment of Biodiversity Conservation across BNKEFAs at the County Scale

Evaluating the effectiveness of PAs is of great significance for optimizing protected areas to most efficiently conserve species and their habitats. In previous studies, researchers assessed the effectiveness of PAs aiming at the scale of individual levels, lacking a comparative assessment among different regions. There are large ecological background differences in climate, topography, and other aspects for PAs located in different geographic regions. In our previous study [30], the biological difference was represented by a reference condition, and the effectiveness of different biological function areas among different regions was compared by examining the difference between biological function areas and their corresponding reference condition. However, these assessment results considered biological function areas as a whole, which cannot accurately describe conservation effectiveness across different BNKEFAs. In addition, China's transfer payment policy is targeted at county-level administrative units. The central government assesses the BNKEFA's protection status, allocates transfer payment funds according to the assessment results, and rewards areas with better assessment results; for areas with worse assessment results, transfer payment funds for the year are deducted according to the actual situation. The seven BNKEFAs are also managed at the county level. For example, from 2012 to 2020, the central government implemented reward and punishment regulations on transfer payment funds in more than 450 counties. Therefore, this study evaluated biodiversity conservation across BNKEFAs at the county level, which is of great significance for the management of BNKEFAs.

4.2. Implications for Management

In this paper, we found that Taibai County in Qinba had the highest CEI value, while Fujin City in SJPY had the lowest CEI value. These assessment results eliminated the biological background difference, so we can draw the conclusion that Qinba County made greater efforts in biodiversity conservation than did SJPY in 2018. This result coincides with the results of previous studies [42]. We also found that the CEI values of counties in all BNKEFAs showed spatial heterogeneity. Therefore, transfer payments should be allocated strictly according to the biodiversity conservation effectiveness of the counties. Moreover, management measures should be tailored to the specific county. Further, some BNKEFAs such as CD, QB, and WLS are managed by different provinces, so these provinces should work together to enhance ecological quality and biodiversity conservation in the BNKEFAs.

4.3. Limitations of this Study

This study had some limitations. Firstly, habitat quality estimated by the InVEST-HQ model was used as a proxy for biodiversity to compare the biodiversity conservation effectiveness among different BNKEFAs at the county scale. There is some subjectivity when determining the parameters of the InVEST-HQ model. The NDVI [43], NPP [44], and human disturbance index [14,45] could be employed in future studies. Secondly, in this study, the core areas of national nature reserves in the BNKEFAs were chosen as the reference ecosystem. However, some national nature reserves are also disturbed by human activities. For example, the CEI of Taibai County in the Qinba BNKEFA was positive. Thirdly, the CEI constructed as the distance to the reference condition was used to reflect the effectiveness of biodiversity conservation. But the CEI is a combination of the effects of natural processes and human conservation efforts. Inevitably, there are some

inequities. Therefore, we will clarify the conservation effectiveness attributable to humans in future studies.

5. Conclusions

This study compared the effectiveness of biodiversity conservation across different BNKEFAs at the county scale. The results could provide a reference for the transfer payment policy and are also significant for the management of BNKEFAs. The main conclusions are as follows:

1. The ecological background was well reflected by our RCI. For the RCI values of the seven BNKEFAs, the following order was observed: HND > SJPY > QB > WLS > ZDN > CD > ZXB.
2. The CEI value was computed as the difference between the habitat quality of a BNKEFA and its corresponding RCI, so the CEI eliminated the ecological background difference. In the comparative results for the CEI, the order was ZXB > HND > ZDN > WLS > QB > CD > SJPY.
3. Taibai County in QB had the biggest CEI, while Fujin City in SJPY had the smallest CEI. The difference in CEI in different counties could reflect the biodiversity conservation efforts of their administrative departments. This will stimulate enthusiasm for protecting biodiversity.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/d15101043/s1>, Table S1: County names of BNKEFAs.

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Abbreviations

PAs	Protected areas
BACI	Before–After–Control–Intervention
BNKEFAs	Biodiversity National Key Ecological Functional Areas
CD	Forest and Biodiversity Ecological Function Area of Yunnan and Sichuan
HND	Tropical Rainforest Ecological Function Area in Mountain Areas in the Middle of Hainan Island
QB	Biodiversity Ecological Function Area of Qinba Mountain
SJPY	Wetland Ecological Function Area of the Three River Plain
WLS	Biodiversity and Soil Conservation Ecological Function Area in Wuling Mountain
ZDN	Forest Ecological Function Area on the Edge of the Plateau in the Southeast of Tibet
ZXB	Desert Ecological Function Area on the Northwest Qiangtang Plateau
HQ	Habitat quality
CEI	Conservation effectiveness index
RCI	Reference condition index

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