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Temporal and spatial changes of biodiversity in Caverns of Heaven and Places of Blessing, Zhejiang Province, China from 1990 to 2020

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Abstract

Caverns of Heaven and Places of Blessing (CHPB) are the earliest Ecological Reserve in China, but in recent years, due to the accelerated process of urbanization and weak protection, the Chinese traditional ecological reserve represented by CHPB has been damaged to a certain extent. How to accurately measure the dynamic changes of ecological value in existing ecological protection and construct is an initial topic of CHPB protection. To understand the temporal and spatial changes characteristics of biodiversity in CHPB, this paper selects three-time nodes in 1990, 2005, and 2020, and takes CHPB in Zhejiang Province as an example, comprehensive three influencing factors: habitat quality, landscape pattern, and nighttime-light. To provide a relevant theoretical basis for the protection of CHPB, this paper quantitatively analyzes the changes of ecological environment and biodiversity in recent 30 years. The results showed that from 1990 to 2020, the biodiversity of CHPB in Zhejiang Province showed a positive change, the decline in Caverns of Heaven overall area slowed down, and the core area rebounded. The spatial distribution change of biodiversity is highly consistent with the land-use changes. The low value regions of biodiversity are mainly concentrated in the regions with intensive human activities, and the area decreases with the expansion of construction land. The core areas are primary areas with high biodiversity and overlap with nature reserves, natural parks, Scenic and Historic Interest Area, and other protected areas. In a word, CHPB still plays a vital role in ecological and environmental protection. In the future development, we should still pay attention to its biodiversity protection, and give full play to its role in ecological and environmental protection, and realize the contemporary application of CHPB's traditional ecological knowledge.

Keywords
Comprehensive biodiversity, habitat quality, landscape pattern, nighttime-light, traditional Protected Areas

Introduction

Biodiversity refers to all species and organisms on the earth or in a specific ecosystem, which can provide human beings with a large number of and multifaceted well-being (Berry et al. 2018), and is the infrastructure to support all life. However, with the increasingly serious global environmental changes, the loss of biodiversity gradually intensifies under the influence of multiple factors. The rate of species disappearance is 1000 times faster than any period in human history (UNEP 2020), which reduces the elasticity of the ecosystem and the supply of ecosystem service functions. It accelerates the spread of the virus (Lorentzen et al. 2020), global warming, and other hazards that significantly impact human livelihoods. In 2020, the world economic forum listed the loss of biodiversity as one of the five major social risks in the world. It is urgent to strengthen the research on biodiversity and its protection.

Protected Areas are currently the most effective biodiversity conservation measures globally (Geldmann et al. 2018; Hockings et al. 2019; MacKinnon et al. 2020). By September 2021, the total number of protected areas recorded in the World Database of Protected Areas (WDPA) has reached 266658, covering 245 countries and regions. The Protected Areas will carry out special protection and management for natural enrichment, good biodiversity conditions, and special significance. Chinese religions had similar protection ideas in ancient times. They would call the area with an excellent ecological environment, superior natural resources, and rich biodiversity as Caverns of Heaven and Places of Blessing (CHPB) and delimit a specific scope for protection. CHPB is the earliest Protected Areas in China (Lemche 2019), and Caverns of Heaven (CH) has an almost perfect ecological structure. Therefore, from the perspective of biodiversity, CHPB is a hot area with high biodiversity. In addition, CHPB integrates religious, social, cultural, and ecological meanings, significant in biodiversity protection. Strengthening the security of CHPB is China's significant contribution to biodiversity protection worldwide.

Since establishing the CHPB system in the Tang Dynasty, CHPB has been effectively protected under official-led protection measures. However, in recent years, with the excessive tourism development and the acceleration of urbanization, the land-use and the spatial density of human activities in CHPB and its surrounding areas have changed greatly. These two changes are the main driving factors for the reducing biodiversity (Gosselin and Callois 2018). The advantages and disadvantages of this change on the biodiversity of CHPB have not been discussed. Whether the favorable conditions of CHPB can play a specific protective role against these effects has not been quantitatively studied. Many scholars have analyzed species richness (Zhou 2019, 2020, 2021; Wang et al. 2020), community diversity (Ding et al. 2015; Wang et al. 2018) and landscape diversity (Zhang 2015) in the areas overlapping with CHPB in spatial distribution. However, these studies are not aimed at CHPB, and there is still a lack of systematic analysis of CHPB biodiversity. Therefore, it is of great significance to understand the changes of CHPB in the temporal and spatial sequence of gradual development and intensified interference, the contribution of CHPB to the regional biodiversity protection, and the key factors causing the biodiversity changes of CHPB under the influence of regional urbanization and intensified human activities.

In recent years, with the rapid development of remote sensing technology, there have been more and more studies on landscape biodiversity assessment by building models or based on qualitative scoring systems. Compared with the traditional field measurement and statistical methods (Bai et al. 2020), this evaluation method has the characteristics of low cost and high speed (Compson et al. 2020). It is especially suitable for biodiversity analysis on a large regional scale.

Based on remote sensing data, people often analyze biodiversity changes on a large regional scale from the perspective of landscape biodiversity with habitat quality (Nelson et al. 2009; Berta et al. 2020; Hong et al. 2021), landscape pattern (Plexida et al. 2014; Rastandeh et al. 2018), and nighttime-light intensity (Li and Li 2015; Venter et al. 2016; Shi et al. 2018) as indicators.

Habitat quality is an important indicator of regional ecological security and can reflect the level of regional biodiversity (Bai et al. 2019). Habitat refers to the space that provides resources and conditions for species survival and breeding. Habitat quality refers to the ability of the ecological environment to provide suitable conditions for species survival and reproduction in a certain time and space (Hall et al. 1997), and affects the adaptability of organisms through the changes of resources and environmental conditions (Bernstein et al. 1991; Ah-King 2010). Habitat quality focuses on the overall situation of ecosystem state (Polasky et al. 2011; Czúcz et al. 2014), which can lay the basic level of regional biodiversity to a great extent and play a leading role in the biodiversity of some regions or species (Leira and Sabater 2005; Dures and Cumming 2010). In addition, studies have shown that habitat deterioration is the most prominent factor leading to the reduction of biodiversity (Wilcove et al. 1998; Myers et al. 2000; Horváth et al. 2019), while areas with high habitat quality can contain more organisms (Terrado et al. 2016). Therefore, habitat quality is an important embodiment of regional ecological environment and can be used as an alternative method for biodiversity analysis (Griffen and Drake 2008; Terrado et al. 2016; Sun et al. 2019; Li et al. 2021a). At present, this method has been widely used in biodiversity assessment in mountainous areas, wetlands, protected areas, cities and other regions (Gong et al. 2019; Huang et al. 2020b; Yu et al. 2020; Hong et al. 2021).

Landscape pattern also has a profound impact on biodiversity and its dynamics. Landscape pattern refers to the spatial arrangement and combination of landscape elements with different sizes and shapes, including the type, number, spatial distribution and configuration of landscape components (Turner et al. 2001). It is not only the concrete embodiment of landscape heterogeneity, but also the result of various ecological processes on different scales (Levin 1978; Forman and Godron 1981). Landscape pattern emphasizes the dynamic characteristics of landscape (Walz 2011; Uuemaa et al. 2013; Duarte et al. 2018), which affects biodiversity by affecting ecological processes, such as the range of activities, migration law, population size and so on (Olff and Ritchie 2002; Correa Ayram et al. 2016; De Oliveira-Junior et al. 2020). Landscape pattern is also often used as an alternative indicator of species richness (Griffiths and Lee 2000; Dauber et al. 2003; Santini et al. 2017). Landscape ecology has developed a large number of landscape pattern indexes, such as landscape diversity index, evenness, landscape fragmentation and connectivity, which can realize the rapid evaluation of regional biodiversity (O'Neill et al. 1988; Sahani and Raghavaswamy 2018).

With the intensification of urbanization, the impact of human activities on biodiversity is expanding (Shochat et al. 2006). Climate change, environmental pollution and alien species invasion caused by human activities will seriously affect the change of local biodiversity (Bowler et al. 2020). Therefore, the intensity of human activities is often used to assess biodiversity changes. Nighttime-Light directly highlights the intensity of human activities (Elvidge et al. 1997; Zhao et al. 2019), which can directly reflect the process of urbanization and evaluate the ecological and environmental problems caused by urbanization (Li et al. 2016). In addition, nighttime-light will interfere with and change the living habits of organisms, especially nocturnal animals, and then affect biodiversity (Koen et al. 2018). At present, many studies have shown the negative effects of nighttime-light on different organisms (Longcore and Rich 2004; Hölker et al. 2010; Rodrigues et al. 2012; Gaston et al. 2013). Therefore, nighttime-light can be used as an indicator to reflect the impact of human activity intensity on biodiversity.

Previous studies mainly evaluated biodiversity changes from a single dimension of habitat quality, landscape pattern, and nighttime-light. However, the changes in biodiversity are not only affected by one factor and often affected by multiple factors simultaneously (De Chazal and Rounsevell 2009; Watson et al. 2014). For example, the change of land-use will change the habitat quality and landscape pattern at the same time: when an urban land is converted to forest land, it will improve the habitat quality of the region, but it may also lead to the fragmentation of the landscape pattern of the area, which is not conducive to most organisms (Hargis et al. 1999; Verga et al. 2017). To make a more scientific and objective quantitative evaluation of biodiversity changes in CHPB, Zhejiang Province, this study will integrate the above three dimensions for biodiversity analysis. Existing studies have shown that combining multi-dimensional indicators is feasible and necessary to evaluate biodiversity (Riedler and Lang 2018; Gong et al. 2019; Li et al. 2021a).

Zhejiang Province is the area with the most concentration of CHPB in China. In addition to the traditional mountain type, its landscape characteristics also include characteristics such as coastal and plain, including the main landscape types of CHPB in China. Therefore, the study of CHPB in Zhejiang Province has guiding significance for CHPB in China. The modern construction of CHPB is mainly reflected in the development of tourism activities, especially in the development of Scenic and Historic Interest Area (Han 2006). The Scenic and Historic Interest Area is essential for China's famous mountains and rivers to carry out ecotourism. Their system originated in 1982 and has developed rapidly since the 1990s. After 2005, the Scenic and Historic Interest Area application speed has decreased significantly (Zhu et al. 2021a). The large-scale tourism development activities in CHPB have dropped considerably, and the tourism development activities pay more attention to ecological protection. In addition, since 2005, Zhejiang Province has practiced the economic and social green development model of "lucid waters and lush mountains are invaluable assets (Two Mountains)". Urban development also pays more attention to ecological and environmental protection, impacting biodiversity (Yunlong 2020). Therefore, 1990, 2005, and 2020 are three key time nodes that may be closely related to the change of the ecological environment of CHPB: 1990 was the period of rapid development and construction of CHPB in Zhejiang Province, 2005 was a significant turning point when the construction speed slowed down and paid more attention to ecology, and 2020 was the phased achievement under the new development model.

Therefore, combined with the actual situation of the natural conditions, human activity interference degree and the operability of the assessment, three key time nodes that may be closely related to the ecological environment change of CH blessed land in 1990, 2005, and 2020 are selected. The three indicators of habitat quality, landscape pattern index and night light intensity are integrated to reflect the temporal and spatial changes of biodiversity in CHPB, Zhejiang Province, in order to provide reference for the management and protection of CHPB.

Study area and methods

Study area

Zhejiang Province (118°01'–123°10'E, 27°02'–31°11'N), located in the south wing of the Yangtze River Delta along the southeast coast of China, in the transition zone between Eurasia and the Northwest Pacific, belongs to a typical subtropical monsoon climate zone. The monsoon is remarkable, the four seasons are distinct, the annual temperature is moderate, the sunshine is sufficient, the rainfall is abundant, the air is humid, the rain is hot in the same season, the climate resource allocation is diverse. There are many meteorological disasters. Zhejiang Province has a land area of about 101800 km^2. The terrain fluctuates wildly. The landscape tilts from southwest to northeast. There are mountains in the southwest and northwest, hills and basins in the middle and Southeast, and plains in the northeast. The forest area reaches 60591 km^2, and the forest coverage rate reaches 61%, ranking in the forefront of the country.

In Taoism, CHPB refers to a famous mountain resort where immortals live. It has an ideal natural environment and rich biodiversity. The thought of CHPB originated in the Jin Dynasty (265–420 A.D) and matured in the Tang Dynasty (618–907 A.D). There are 10 "Great Caverns of Heaven", 36 "Lesser Caverns of Heaven" and 72 "Places of Blessing". Caverns of Heaven and Places of Blessing (CHPB) refers to the general name of Caverns of Heaven (including Great Caverns of Heaven and Lesser Caverns of Heaven) and Places of Blessing. In Taoism, it is considered that the natural environment of Caverns of Heaven (CH) is better than Places of Blessing (PB). According to the *"Plan of Celestial and Terrestrial Palaces and Residences"* (hereinafter referred to as *"Plan"*) written by Sima Chengzhen of the Tang Dynasty. Zhejiang Province has 30

CHPB, accounting for 25.4% of the total, including 3 Great Caverns of Heaven, 9 Lesser Caverns of Heaven, 18 Places of Blessing. Extant can be verified for 3 Great Caverns of Heaven, 9 Lesser Caverns of Heaven, 14 Places of Blessing. The ancient Chinese determined the central position of CHPB according to the advantages and disadvantages of the ecological environment. When delimiting the protection scope, not only the areas with excellent ecological environment will be included in the protection, but also the surrounding human activity areas will be included in the protection management. *"Plan"* indicates the central position of the mountain where the main caves and palace buildings area in CHPB and also clearly records the overall protection scope of CH. The broad protection scope of CH is "30 Li (a unit of length was used in ancient China) of Zhouhui (i.e., the circumference)" to "10000 Li of Zhouhui", and "1 Li" is about "531 m" of the modern international metric system. However, the overall scope of PB has not been determined.

To sum up, the study on the diversity of CHPB in Zhejiang Province includes two aspects: 1) core area: the area contained in the central outer contour of the mountains where each CHPB is located, which are respectively recorded as CH core area and PB core area, collectively referred to as CHPB core area. 2) Overall area: offset the main outer contour line of the mountain where each CH is located outward to the perimeter equal to the " Zhouhui" length of the CH, which is the scope of the CH. Since PB does not specify "Zhou Hui" in the *"Plan"*, this study does not delimit the overall area of PB. Hence, the overall area study only refers to the overall area of CH, which is recorded as the CH overall area. Considering that the scope of the second Great Caverns of Heaven is too large, some areas exceed the scope of Zhejiang Province, and overlap with most of CHPB in Zhejiang, to simplify the research and data display, this study reduces its scope to "thousands of Li". The specific distribution and scope of CHPB are shown in Fig. 1.

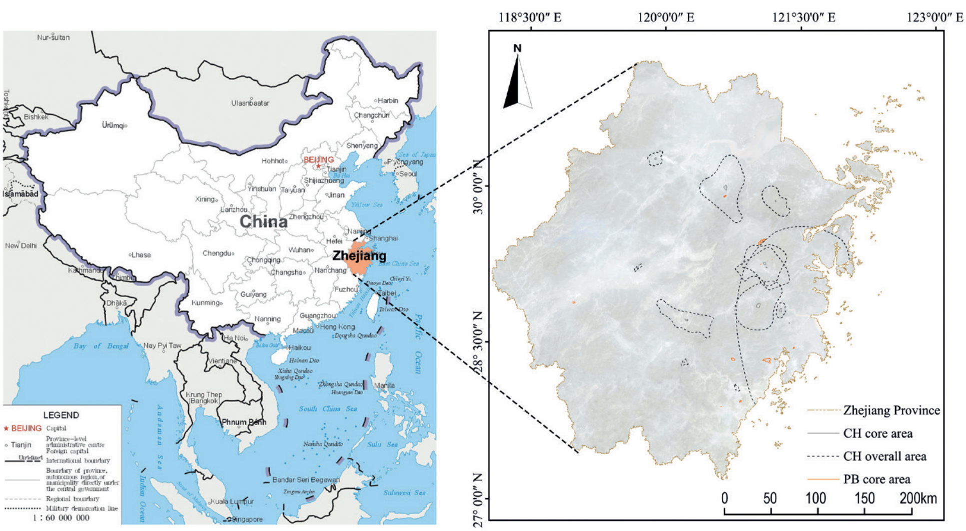

Figure 1. The overall area of Caverns of Heaven (CH) and the core area of Caverns of Heaven and Places of Blessing (CH, PB) in Zhejiang Province

Data sources and processing

The remote sensing data used for habitat quality assessment and landscape pattern index analysis were analyzed through Geospatial Data Cloud (www.gscloud.cn). The data in 1990 and 2005 are from Landsat5 TM, and the data in 2020 are from Landsat8 OLI_TIRS, the image resolution is 30 meters. The nighttime-light data is from the national Qinghai Tibet Plateau scientific data center (http://data.tpdc.ac.cn) (Zhang et al. 2021).

To include all the influencing factors as much as possible and eliminate the interference due to subjective reasons, this study first processes the data of Zhejiang Province. It then extracts the relevant data within the scope of the research object for analysis and discussion. The specific reasons are as follows: first, if only the content of CHPB is used to delimit the processing scope, the shape and size of the patch will be changed. As a result, the landscape pattern used for analysis differs from the actual landscape pattern. Secondly, the ecological environment and biodiversity of a region are often affected by internal and external environmental factors (Mcdonald et al. 2009); that is, the biodiversity of the study region may be affected by noise (Illner 1992; Mockford and Marshall 2009), industrial waste (Chang et al. 2019; Jia et al. 2021; Perlatti et al. 2021), and other factors at a certain distance from the region. If the scope of data analysis is consistent with the scope of the study region, the impact of surrounding towns on biodiversity in the study area is excluded.

Data analysis

Habitat quality

When using satellite remote sensing data to research on a large spatial scale, the Habitat Quality module of InVEST model is often used to evaluate the habitat quality (Huang et al. 2020a), which can better grasp the overall pattern and relatively truly reflect the threat of human activities to habitat and the relationship between ecosystem protection and human economic development. The InVest model considers that the habitat quality map is generated by analyzing land-use and land cover and its threat to biodiversity. Generally speaking, the higher the degree of naturalization, the higher the suitability and the smaller the threat (Sharp et al. 2020; Li et al. 2021b). As shown in Table 1, referring to the relevant studies (Lorenzo et al. 2017; Gong et al. 2019; Berta et al. 2020), combined with the actual situation of CHPB in Zhejiang Province, the parameters of threat factors, the habitat suitability of different habitat types and the sensitivity to threat factors are determined.

Landscape pattern index

FRAGSTATS is the most commonly used landscape pattern index calculation software, which is used to calculate various landscape indexes of classified map patterns and quantify landscape structure (McGarigal and Marks 1995; Zhang et al. 2020). Combined with the existing research (Cheng et al. 2020; Guo et al. 2021; Zhu et al.

Table 1. Parameters of threat factors, habitat suitability of different habitat types, and sensitivity to threat factors.

Land-use type code	Types of land-use	Relative habitat suitability	Threat factor†				
			Residential & industrial/mining land	Arable land	Railways and highways	National/provincial roads	County roads
1	Arable land	0.30	0.20	0.30	0.20	0.20	0.15
2	Forest & grasslands	1.00	0.70	0.50	0.45	0.40	0.30
3	Waters	1.00	0.80	0.70	0.60	0.60	0.50
4	Residential & industrial/mining land	0.00	0.00	0.00	0.00	0.00	0.00
5	Unused land	0.01	0.10	0.10	0.20	0.20	0.10
Maximum impact distance (km)			9	1	1.5	2	0.7
Weight			0.7	0.6	0.5	0.8	0.4
Relevance			exponential	exponential	linear	linear	linear

† the range of sensitivity of all threat factors is [0,1].

2021b) and the specific situation of CHPB in Zhejiang Province, the landscape pattern indexes significantly related to biodiversity were selected for landscape pattern analysis, including the largest patch index (LPI) (Su et al. 2015; Guo et al. 2021), the number of patches (NP) (Sahani and Raghavaswamy 2018; Cheng et al. 2020), patch density (PD) (Rüdisser et al. 2015; Liu et al. 2016), landscape shape index (LSI) (Liu et al. 2016; Guo et al. 2021), splitting index (SPLIT) (Sahani and Raghavaswamy 2018; Cheng et al. 2020; Guo et al. 2021), mean patch fractal dimension (FRAC_Mn) (Schindler et al. 2008; Guo et al. 2021), Shannon diversity index (SHDI) (Schindler et al. 2008; Su et al. 2015; Sahani and Raghavaswamy 2018), and Shannon evenness index (SHEI) (Sahani and Raghavaswamy 2018), and the landscape pattern indexes were weighted equivalently.

Nighttime-light intensity

Nighttime-light data are derived from satellite remote sensing data and based on the ArcGIS 10.2 platform for data processing. By using the Jenks classification method (North 2009; Chen et al. 2013), the nighttime-light data is divided into five levels according to the nighttime-light intensity, and the reverse value is assigned, which is a negative correlation.

Comprehensive biodiversity calculation method

Referring to the comprehensive biodiversity assessment model established by Gong (Gong et al. 2019) and Riedler (Riedler and Lang 2018). The habitat quality, landscape pattern index, and nighttime-light intensity were standardized, and the value range was [0,5]. The comprehensive biodiversity was obtained by superposition according to the weights of 0.45, 0.45, and 0.1. According to the results scored by experts, the weight value is obtained by using Analytic Hierarchy Process on SPSSAU online statistical analysis platform. The comprehensive biodiversity assessment model is as follows:

$$B_x = 0.58Q_x + 0.28P_x + 0.14L_x$$

In the formula, B_x represents the comprehensive biodiversity of CHPB in x year, Q_x is the habitat quality of CHPB in x year, P_x is the landscape pattern index of CHPB in x year, and L_x is the nighttime-light intensity of CHPB in x year.

Data resources

The remote sensing data come from Geospatial Data Cloud (www.gscloud.cn).

The nighttime-light data is from the national Qinghai Tibet Plateau scientific data center (http://data.tpdc.ac.cn).

Results

Analysis of habitat quality change

According to the calculation results of InVest model, the habitat quality change graph (Fig. 2) and habitat quality grade map (Fig. 3) were drawn. According to the figures: 1) the overall habitat quality of Zhejiang Province declined, and the decline rate in 2005–2020 was much higher than that in 1990–2005. In each stage, the habitat quality of CHPB core area was much higher than the average level of the whole province in the same period. The habitat quality in 2005–2020 of the CH overall area is lower than that in the whole province and higher than that in 1990–2005. 2) The habitat quality of the CH core area decreased by 0.039, but the extent was less than the average of the

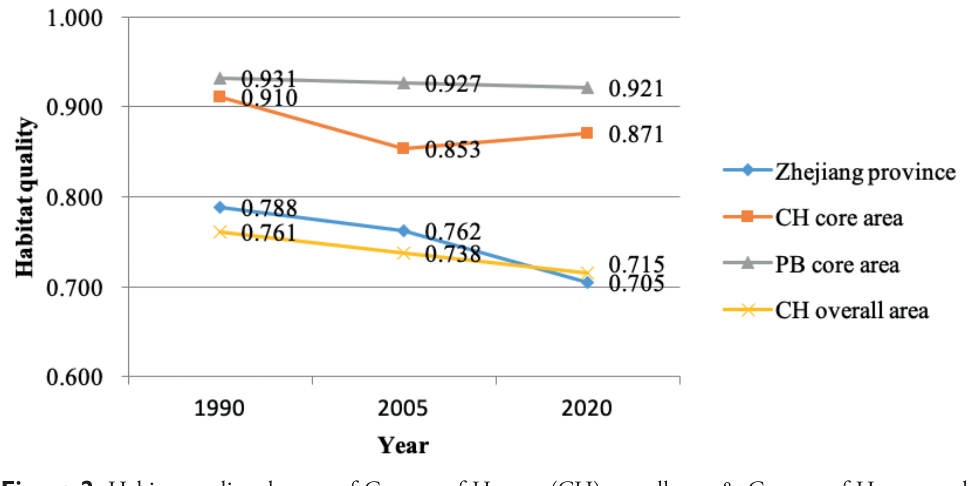

Figure 2. Habitat quality changes of Caverns of Heaven (CH) overall area & Caverns of Heaven and Places of Blessing (CH, PB) core area in Zhejiang Province from 1990 to 2020.

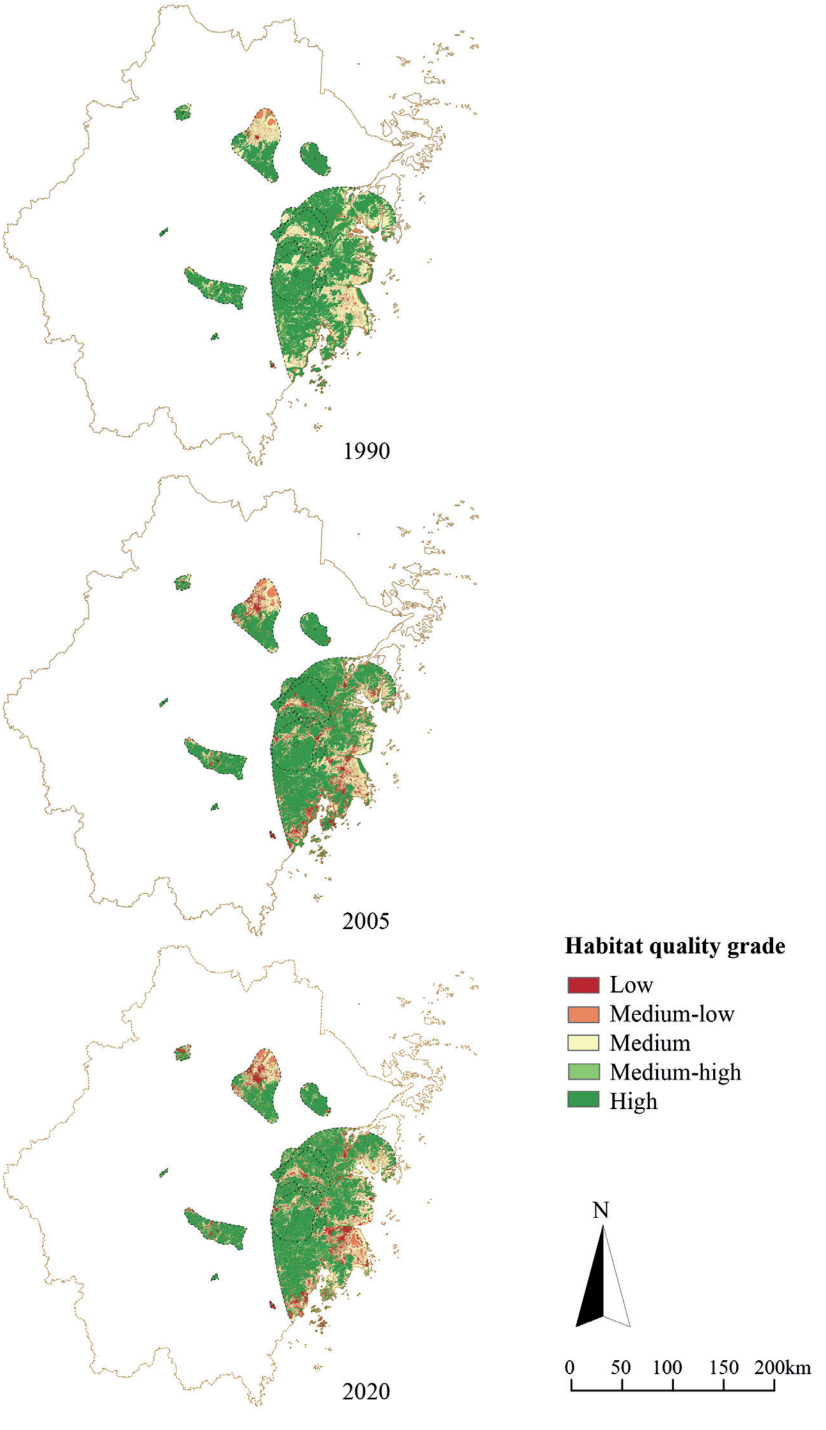

Figure 3. Habitat quality changes of Caverns of Heaven (CH) overall area in Zhejiang Province from 1990 to 2020.

whole province. The habitat quality of the CH core area decreased the fastest from 1990 to 2005, with a decrease of 0.057, which was higher than the average level of the whole province. Although it recovered in 2005–2020, the level was still lower than that in 1990. As to the PB core area, the habitat quality continuously went down, with a slight overall decline, but the decline in 2005–2020 was slightly higher than that in 1990–2005. 3) The overall habitat quality in the CH overall area showed a downward trend. In 1990, the habitat quality was high, and the low value areas were relatively few and concentrated. After that, the low value areas expanded greatly, and showed a trend of dispersion and fragmentation, indicating that the degree of habitat degradation was increasing.

Analysis of landscape pattern index

The results of landscape pattern index calculation showed that: 1) the indexes of CH overall area and CHPB core area have, except for LPI, all values increased, and the scope of landscape pattern index changed gradually expanded (Fig. 4). 2) The overall comprehensive landscape pattern index showed an upward trend. CH core area increased rapidly from 1990 to 2005, with an increase of 0.268, then the growth rate remained unchanged, and the comprehensive landscape pattern index was lower than the average level of the whole province in the second half. The change of PB core area first decreased and then increased, but it was always lower than the average level of the whole province. The growth rate of CH overall area was low in 1990–2005, but it ac-

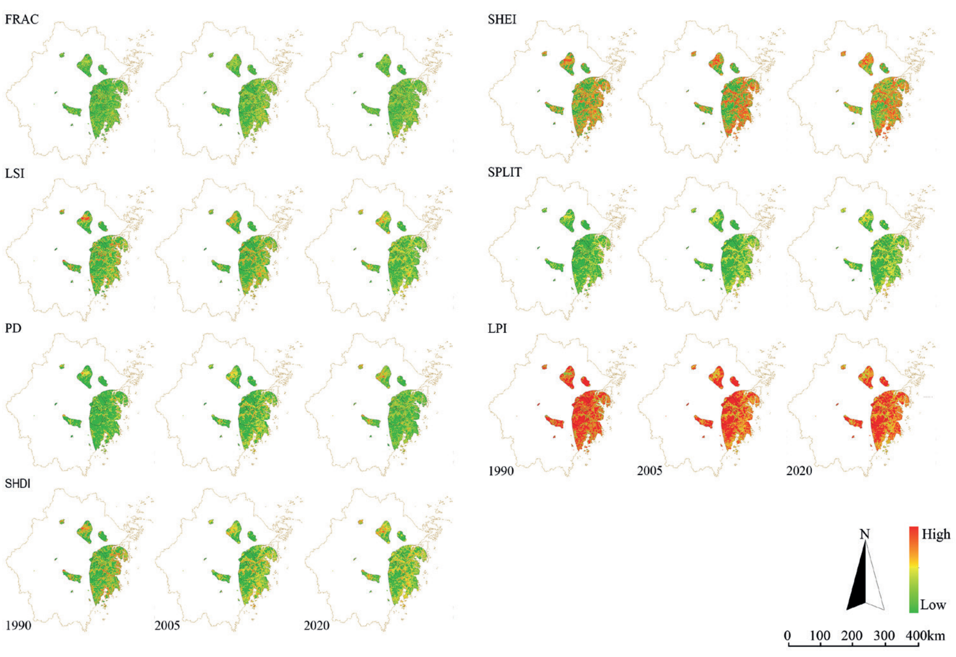

Figure 4. Landscape pattern indices' changes of Caverns of Heaven (CH) overall area in Zhejiang Province from 1990 to 2020.

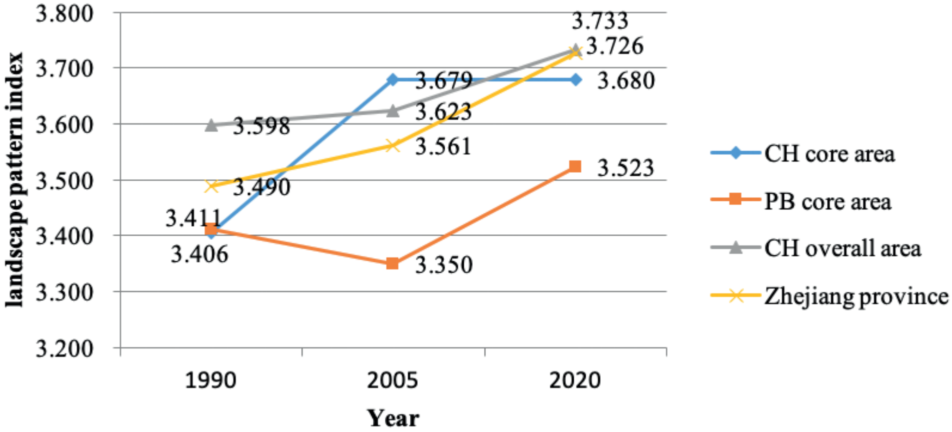

Figure 5. Comprehensive landscape pattern index changes of Caverns of Heaven (CH) overall area & Caverns of Heaven and Places of Blessing (CH, PB) core area in Zhejiang Province from 1990 to 2020.

celerated and increased in 2005–2020, and it would be slightly higher than the average level of the whole province in 2020 (Fig. 5). 3) The comprehensive landscape pattern index of CH overall area is high. The areas with a high comprehensive landscape pattern index have increased spatial distribution, but the overall change is small. (Fig. 6).

Analysis of nighttime-light intensity

The overall increase of nighttime-light intensity in Zhejiang province is large. 1) In 1990, the nighttime-light intensity of CH overall area and CH core area was almost the same level as the average of the whole province. After that, it was higher than the average level of the whole province. Besides, the growth trend of the CH core area was the most prominent, with both intensity level and the growth rate higher than other areas obviously. 2) The nighttime-light intensity of the PB core area was lower than that of other areas at all stages, and the growth rate in 2005–2020 slowed down, 368.553 less than that in 1990–2005. (Fig. 7). 3) During the whole period, the area without nighttime-light in the CH overall area shrunk considerably, and the area with high and low nighttime-light intensity expanded in a large area (Fig. 8)

Comprehensive biodiversity analysis

The habitat quality, landscape pattern index and nighttime-light intensity were standardized, and the comprehensive biodiversity evaluation results were obtained by weighted superposition (Table 2). The results showed that: 1) the comprehensive biodiversity of the whole province obvious linear downward trend. 2) The comprehensive biodiversity of CHPB core area in each period was much higher than the average value of the whole province, showed a trend of first decreasing and then increasing, especially in the PB core area; The comprehensive biodiversity in the CH overall area decreased

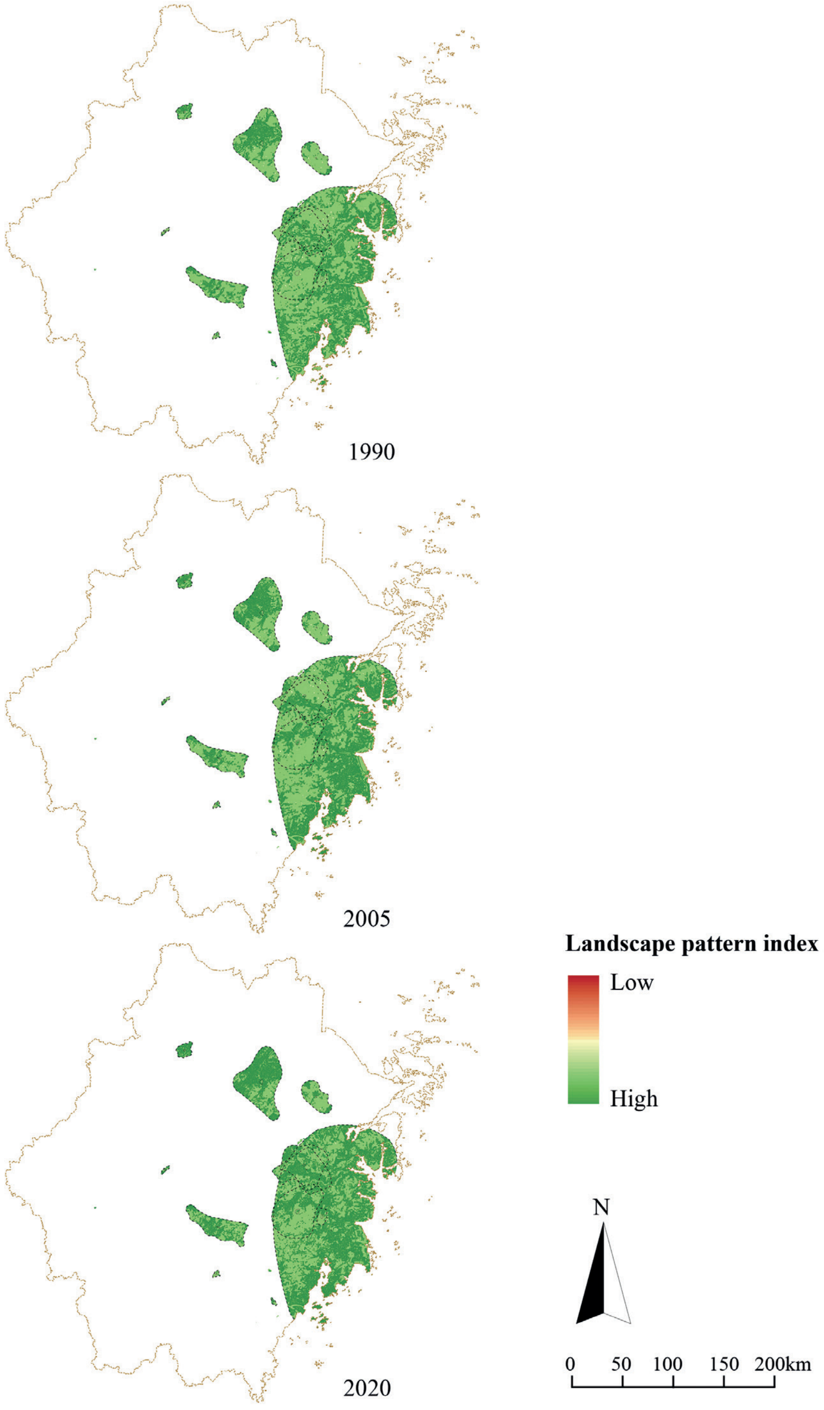

Figure 6. Comprehensive landscape pattern index changes of Caverns of Heaven (CH) overall area in Zhejiang Province from 1990 to 2020.

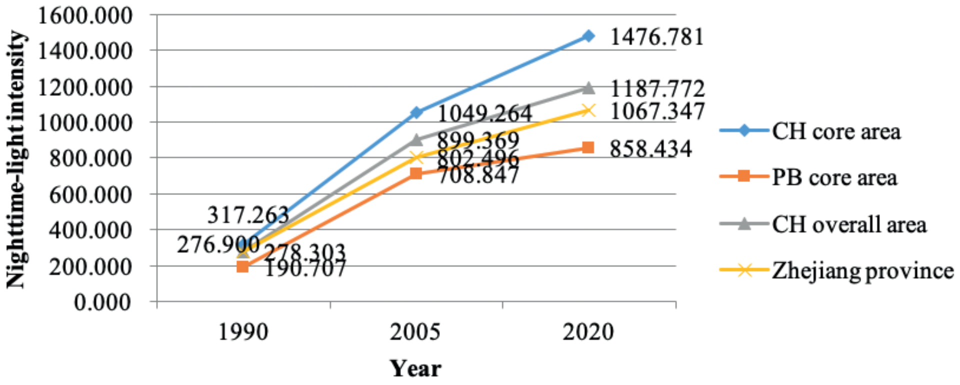

Figure 7. Nighttime-light intensity changes of Caverns of Heaven (CH) overall area & Caverns of Heaven and Places of Blessing (CH, PB) core area in Zhejiang Province from 1990 to 2020.

generally, but the decline speed slowed down in the second half, made it changed from lower to a slightly higher level compared with the average level of the whole province. 3) The standard deviation of comprehensive biodiversity evaluation of CH overall area and CHPB core area gradually increased, and was higher than the average value of the whole province; especially in 2020, the figure had reached 1.170, which indicated that the comprehensive biodiversity difference in CH overall area was evident. 4) The spatial distribution of comprehensive biodiversity was highly consistent with land-use change and the spatial density of human activities. The low value comprehensive biodiversity areas were mainly concentrated in the residential and industrial/mining land areas with intensive human activities, and are positively related to expanding of such land-use (Figs 9, 10).

Habitat quality, landscape pattern, and nighttime-light intensity had different influences on regional biodiversity were distinct in different periods. The CH overall area was mainly affected by the habitat quality and nighttime-light intensity in 1990–2005, and mainly by the habitat quality and landscape pattern in 2005–2020; From 1990 to 2020, the effects of the three factors were evident in the CH core area, and the impact of habitat quality is dominant; the main influencing factors of the PB core area were nighttime-light and landscape pattern in 1990–2005, and was landscape pattern in 2005–2020 (Fig. 11).

Table 2. Average and standard deviation of comprehensive biodiversity in Caverns of Heaven (CH) overall area & Caverns of Heaven and Places of Blessing (CH, PB) core areas in Zhejiang Province from 1990 to 2020.

	PB core area		CH core area		CH overall area		Zhejiang Province	
	Average	Standard deviation	Average	Standard deviation	Average	Standard deviation	Average	Standard deviation
1990	4.309	0.615	4.216	0.710	3.875	1.010	3.922	0.983
2005	4.187	0.667	4.014	0.977	3.728	1.125	3.797	1.098
2020	4.277	0.669	4.049	0.919	3.661	1.170	3.649	1.202

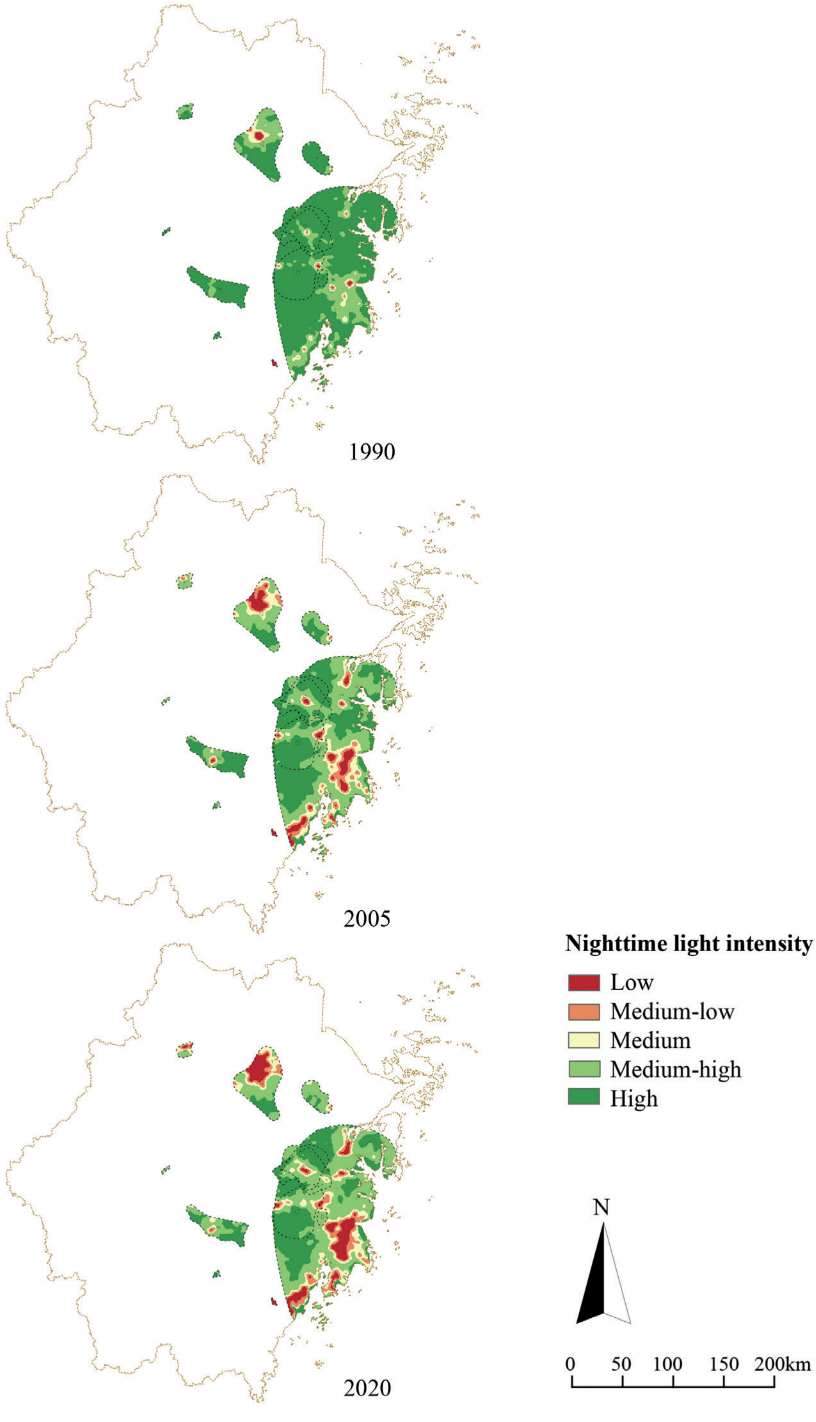

Figure 8. Nighttime-light intensity changes of Caverns of Heaven (CH) overall area in Zhejiang Province from 1990 to 2020.

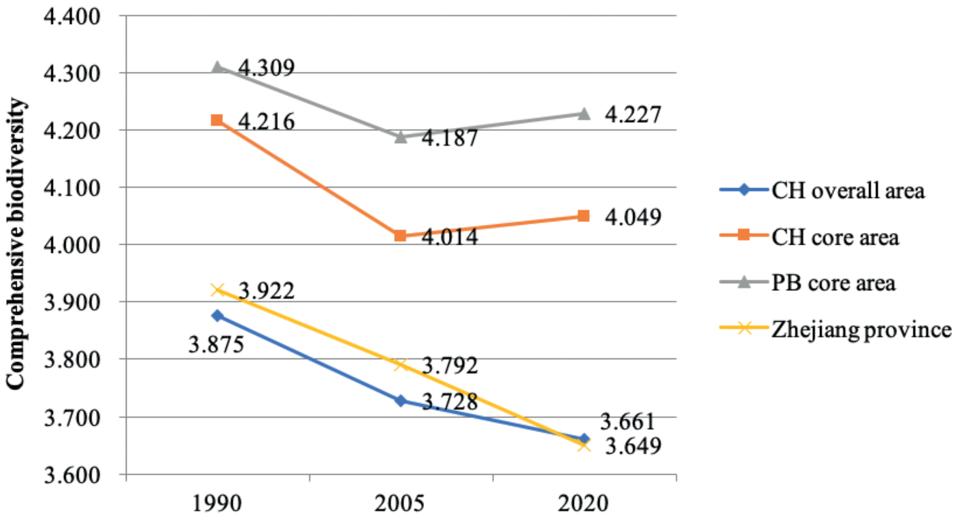

Figure 9. Comprehensive biodiversity changes of Caverns of Heaven (CH) overall area & Caverns of Heaven and Places of Blessing (CH, PB) core area in Zhejiang Province from 1990 to 2020.

Discussion and conclusion

Compared with the biodiversity changes in the whole province, CHPB has played a positive role in biodiversity protection. Under the influence of habitat quality, landscape pattern and nighttime-light, the temporal and spatial differentiation is evident: from 1990 to 2020, the trend of biodiversity change in CHPB in Zhejiang Province showed positive changes,in which the decline rate of CH overall area slowed down, and the CHPB core area rebounded. The spatial distribution change of comprehensive biodiversity is highly consistent with the land-use change. The low value areas of comprehensive biodiversity are mainly concentrated in the areas with intensive human activities, which continue to decrease with construction land expansion. The core areas are primary areas with high comprehensive biodiversity, which are highly overlapped with natural parks, Scenic and Historic Interest Area, and other protected areas.

Although there is no research on the biodiversity of CHPB at present, the research on nature reserves has found that the spatial change of biodiversity at the landscape level is significantly related to land-use changes, and the downward trend has slowed down under effective protection measures, and the biodiversity in the core area is higher than that in other areas. The results of this study are similar to those of other countries (Ren et al. 2015; Gong et al. 2019; Katoh and Matsuba 2021; Yang 2021). Some studies also show that during the period from 1990 to 2005, the forest coverage in Zhejiang Province of China decreased, and the forest fragmentation accelerated (Li et al. 2011), and the construction land increased rapidly (Liu et al. 2008; Ruishan and Suocheng 2013). Especially in small cities in Zhejiang Province, the expansion rate increased of construction land was the fastest before 2000 (Li et al. 2014). From 2005

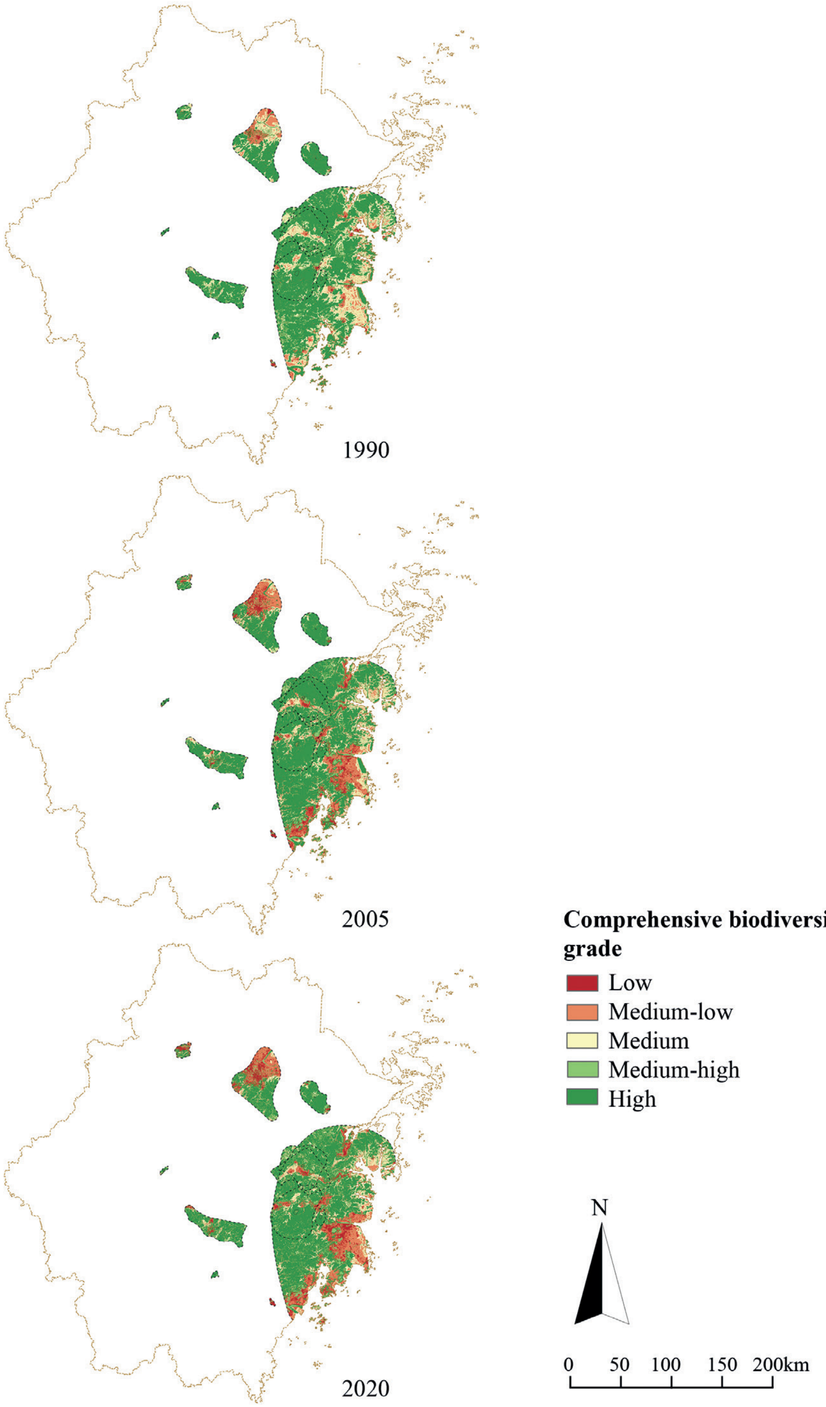

Figure 10. Biodiversity changes of Caverns of Heaven (CH) overall area in Zhejiang Province from 1990 to 2020.

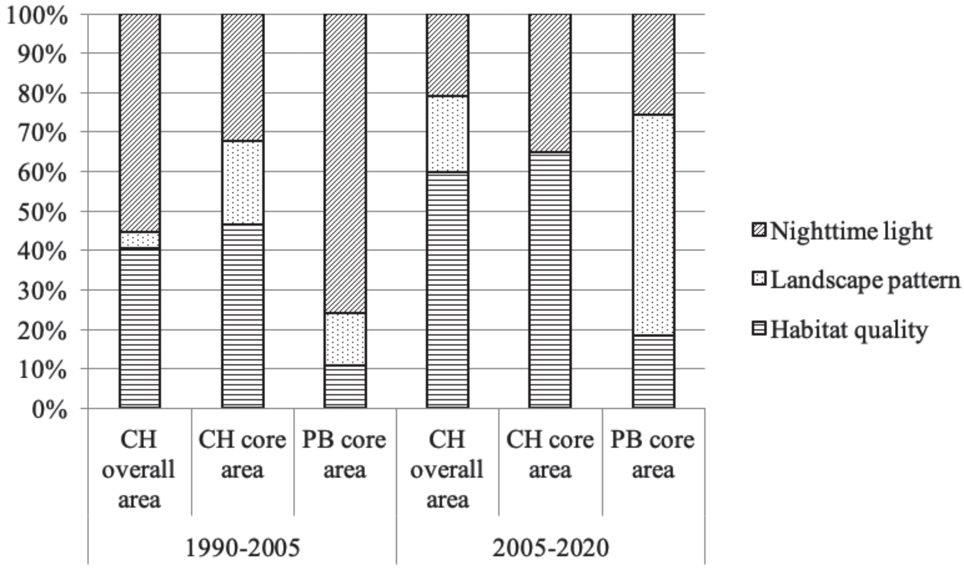

Figure 11. Effects of different factors in different periods on biodiversity in different areas.

to 2020, according to the announcement of the Zhejiang Provincial Bureau of Statistics and the Zhejiang Provincial Department of Ecological Environment, the area of construction land in Zhejiang Province is still increasing. However, the decline rate of forest land area is slowing down, the forest coverage rate still has a small increase, the forest land has high habitat quality, and the general biodiversity will be higher (Sharp et al. 2020; Li et al. 2021b). In addition, the research results of some areas overlapping with CHPB also show that the land-use intensity increased (Cao et al. 2018) and the diversity of some biological species decreased (Yang et al. 2005) from 1990 to 2005, and the net primary productivity of plants increased from 1990 to 2020 (Chen et al. 2017), and the ecosystem pattern in some regions has improved (Zhang 2015). The results of this paper are similar to these.

Combined with the actual situation of CHPB and the differences of habitat quality, landscape pattern and nighttime-light on biodiversity changes in different periods, it is speculated that the reasons for these changes may be as follows: 1) most of the core areas of CHPB are far away from the urban center and close to mountains and forests, mainly relying on natural landscapes such as mountains and lakes, with rich biodiversity, high habitat suitability, and ecological environment. The system is relatively stable and has a stronger recovery ability after being damaged. As for CH overall area, in addition to forest land, grassland, lakes and other areas, it also covers a large number of cultivated land, construction land, and other areas, which is more related to human activities. Biodiversity change is greatly affected by economic and social development concepts (Liu et al. 2008; Yunlong 2020). Rapid economic development, urbanization, industrialization and population growth directly lead to land-use change (Randall and Mulla 2001; Han et al. 2016), affecting habitat quality, landscape pattern, nighttime-light intensity, and then biodiversity. 2005 is the key turning point of the concept of economic and social development in Zhejiang Province. Before that, the development concept based on economic construction has led to the acceleration of urbanization, the rapid expansion of construction land (Kamal-Chaoui et al. 2009), and the weak awareness of ecological protection. Therefore, the declining trend of biodiversity is obvious. In 2005, China's President Xi Jinping put forward the theory that "lucid waters and lush mountains are invaluable assets (Two Mountains)" for the first time in Zhejiang province. Emphasizing the importance of ecological and environmental protection, the concept of green development has gradually taken root in the hearts of the people. With the implementation of the "Five Water Treatment", "The Renovation of Old Residential Areas,Old Industrial Plant Reformation and the Renovation of Urban-village, and Demolish the Illegal Building" and "Demonstration of Thousands of Villages, Renovation of Thousands of Villages" project (The project won the highest environmental protection honor of the United Nations – "Earth Guardian" Award in 2018), etc, the forest coverage rate, air quality and section water quality in Zhejiang Province have increased significantly. Therefore, from 2005 to 2020, the ecological environment of Zhejiang Province will steadily improve, which is conducive to the growth of biodiversity in CHPB. 2) The biodiversity change in the core area of CHPB may be affected by the development process of Scenic and Historic Interest Area. The temporal variation characteristics of biodiversity change in CH core area, which is highly overlapped with Scenic and Historic Interest Area in spatial distribution, are consistent with the characteristics of the development process of Scenic and Historic Interest Area. The large-scale construction of the CH core area in Zhejiang Province is mainly concentrated in the 1990s (Mao et al. 2002; Han 2006), while the construction of the PB core area is relatively late, mostly in the 21st century. In 2006, "*the Regulations on Scenic and Historic Interest Area"* were issued, which has become the highest legal form for the management of Scenic and Historic Interest Area. Before that, although it was emphasized to protect the natural resources of Scenic and Historic Interest Area, it was not implemented in practice. As the main carrier of ecotourism activities, Scenic and Historic Interest Area also lead to the change of management rights of some Scenic and Historic Interest Area into tourism enterprises (Song and Yan 2020). Therefore, from 1990 to 2005, the tourism of CHPB, which is associated with Scenic and Historic Interest Area, developed vigorously and attracted many citizens. Coupled with the construction of supporting tours and service facilities, the habitat quality was inevitably affected, thus affecting biodiversity. It was not until "*the Regulations on Scenic and Historic Interest Area"* issued in 2006 that the development of the system of Scenic and Historic Interest Area was relatively mature: paying more attention to the protection of the background of scenic resources, clarifying the management of Scenic and Historic Interest Area, and implementing the planning, protection, supervision, and management. Because of the lag of ecological protection measures, they need to accumulate for a certain period of time to be effective (Moglen and Palmer 2014; Watts et al. 2020). The ecological protection measures carried out before 2005 may not see the ecological effect until after 2005. Therefore, the comprehensive biodiversity of the core area of CHPB showed an upward trend from 2005 to 2020. From the time difference of the impact of landscape pattern on biodiversity in the core area, it can also be seen that tourism development and other behaviors will greatly impact on biodiversity in the core area. Therefore, the development process of Scenic and Historic Interest Area may be an important reason for the change of biodiversity in the core area of CHPB. 3) CH is a Taoist holy mountain, and Taoist traditional ecological protection thought runs through its development process. Taoism advocates nature, pays attention to environmental protection (Ji et al. 2017); traditional ecological protection ideas are contained in the teachings of Taoism. Taoism has also actively advocated ecological protection in recent years and put forward the concept of " Taoist ecological concept". Since 2006, it has successively put forward or issued *"Qinling Mountain Manifesto"*, *"Maoshan Mountain Manifesto of ecological Taoist concept and Outline of the Eight Years (2010–2017) Plan of Chinese Taoism for Environmental Protection"*, and other ecological protection measures have played a vital role in the protection of biodiversity in CHPB, especially in the core area.

Therefore, in the follow-up development planning, we should fully consider the ecological regulation capacity of CHPB, avoid over development and construction, and exceed our ecological balance capacity. We should standardize the tourism development behavior, especially the construe of supporting tourism facilities such as homestay (B&B), rural tourism around the core area, and deal with the relationship between natural ecology, social economy and community residents at the boundary of CHPB. Paying attention to protecting human activity areas is the best way to preserve biodiversity and effectively reduce the pressure on protected areas (Hilborn and Sinclair 2021). Therefore, while covering areas with high biodiversity, it is also necessary to protect sites with rapid biodiversity reduction to avoid their free spread. Protect biodiversity with traditional ecological knowledge (Gavin et al. 2015; Niesenbaum 2019), give full play to the ability of CHPB in biodiversity protection, and actively explore the strategies provided by Taoist traditional ecological knowledge represented by CHPB in biodiversity protection and revitalizing local resource utilization.

In a word, CHPB, which has a history of nearly 2000 years, is the prototype of the protected areas and still has important historical, cultural and ecological value. From 1990 to 2020, based on the site conditions of CHPB in Zhejiang Province, the comprehensive biodiversity reflected by CHPB in Zhejiang Province showed positive changes in habitat quality, landscape pattern and nighttime-light intensity under the joint action of the concept of economic and social development, the construction of Scenic and Historic Interest Area and Taoist ecological protection measures. It plays a vital role in ecological and environmental protection. Understanding the temporal and spatial changes of CHPB biodiversity is of great significance to CHPB protection. In the future development, we should still pay attention to its biodiversity protection. Play its role in ecological and environmental protection and realize the contemporary application of traditional ecological knowledge in CHPB.

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