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Trends in the Altitudinal Gradient Evolution of Vegetation Ecological Functions in Mountainous Areas

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Abstract: Natural vegetation protects, maintains, and improves the environment through its ecological functions and is, thus, an important component of Earth's ecosystems. The distribution of natural vegetation and its corresponding ecological roles vary with the topographic gradient. Understanding this role is essential for effective ecosystem management and conservation efforts. This study analyzes vegetation composition across altitude gradients and the spatiotemporal evolution of water conservation, soil conservation, and carbon storage in the southern hill and mountain belt of China. We then explored the drivers of the ecological functions of vegetation at different altitude gradients. The results showed that water conservation increased by 108.56%, soil conservation increased by 97.04%, and carbon storage increased only slightly. The ecological functions of vegetation varied across altitude gradients, with the 500–800 m gradient exhibiting markedly higher ecological functions than the other gradients. The effect of precipitation on soil conservation increases with altitude. In addition, at higher altitudes, evergreen coniferous forests had a greater effect on carbon storage. Based on the results, we propose vegetation management measures for different altitudes. This study provides a reference for decision-makers to develop and adjust ecological restoration programs in mountainous areas for the improvement of the local ecological environment.

Keywords: ecosystem management and conservation; vegetation ecological function; driving factor; southern hill and mountain belt

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1. Introduction

Mountains are the backbone of the ecological security barrier, playing a key role in the provision of a wide range of ecosystem services [1,2]. The vertical climatic distribution of mountains provides a suitable living environment for various plants and animals. Obvious differences and hierarchies are present in ecosystems from the foot to the top of mountains, which promotes the spatial heterogeneity of ecological functions. Water conservation (WC), soil conservation (SC), and carbon storage (CS) are essential components of mountain ecosystems, particularly for maintaining ecological balance, safeguarding biodiversity, and promoting the sustainable development of human society [3,4]. However, mountain ecosystems are more fragile than other types of ecological areas, exhibiting a high vulnerability to natural and human-induced factors [5]. Currently, mountain areas face numerous threats. Deforestation and vegetation degradation have resulted in the decline of ecosystem services in mountain areas [6], and the development of agricultural activities and tourism exacerbates environmental pollution [7]. Therefore, it is crucial to ensure the maintenance and enhancement of ecological functions.

Vegetation is a major component of mountain ecosystems and provides a wide range of high-quality ecosystem services to humans [8–10]. It is complex and diverse, and its ecological functions vary with the vegetation type [11,12]. Exploring the ecological function supply capacity of different vegetation types has important implications for mountain ecology. Research on mountain vegetation ecosystems has advanced over the past few years, and the effect of mountainous terrain has gradually attracted widespread attention [13–15]. The structure and spatial pattern of vegetation, characterized by significant vertical heterogeneity, have a significant impact on the formation and diversity of vegetation ecological functions [16]. However, the effects of different altitude gradients on the ecological function of vegetation in mountainous areas remain unclear. A comprehensive understanding of the impact of topography on the ecological functions of vegetation can help regulate human activities, adapt vegetation protection measures to local conditions, and implement effective ecosystem management.

Vegetation ecological functions are influenced by a combination of natural and socio-economic factors. Topography influences surface and subsurface runoff, indirectly regulating water yield from vegetation [17]. Areas with high vegetation cover have less erosion and higher soil fertility [18]. Socio-economic factors also play a crucial role in vegetation ecological functions. For example, the ecological restoration policies implemented by the Liaoning Provincial Government in China, such as returning farmland to forests, significantly increased regional vegetation carbon storage [19]. Chen et al. [20] reported that population density strongly explains the spatial differentiation of ecosystem services in the Nanjing metropolitan area of China. Exploring the mechanism of factors influencing the ecological function of mountain vegetation and proposing targeted regional ecological management recommendations will help to maintain the harmonious development of the regional ecological environment. The majority of current studies on the spatial scale effects of ecological function drivers focus only on the horizontal heterogeneity of driver changes, while research on the vertical heterogeneity of drivers is lacking [21]. Exploring the quantitative relationships between the changes in the drivers of vegetation ecological functions across topographic gradients can help to develop appropriate vegetation management practices for different gradients, reduce the adverse impacts of human activities, and achieve sustainable development.

The southern hill and mountainous belt (SHMB) is a typical mountainous area in southern China. Resource demands are substantial in this region, leading to a noticeable conflict between areas designated for ecological protection and restoration and those assigned for utilization. As a consequence, some areas within the region face issues such as ecological function degradation and soil erosion. The SHMB is an important vertical tectonic belt with a variety of landforms, such as mid-mountains, mid-low mountains, and low hills. The pronounced topographic relief leads to significant vertical variation in vegetation, making it an ideal study area for examining the spatial heterogeneity of vegetation ecological functions and their drivers across altitude gradients. Taking the SHMB as the study area, the objectives of the study were to (1) quantify the three vegetation ecological functions of WC, SC, and CS; (2) investigate the spatial and temporal characteristics of the vegetation ecological functions at different gradients; and (3) explore the factors affecting the spatial heterogeneity of vegetation ecological functions at different altitude gradients.

2. Materials and Methods

2.1. Study Area

The SHMB, located in the south of China (102°30′ E–116°54′ E, 22°24′ N–26°42′ N), is the birthplace and watershed of the Yangtze and Pearl River Basins (Figure 1). Encompassing Guangdong, Jiangxi, Hunan, Guangxi, Guizhou, and Yunnan Provinces, the SHMB spans approximately 2.94×10^5 km^2. The topography varies from high in the west to low in the east and from high in the south to low in the north, with elevations ranging from −25 m to 3019 m. The region is characterized by predominantly gentle slopes, with hills, low mountains, medium mountains, and high mountains as the primary geomorphic types. The SHMB has a subtropical monsoon climate, with distinct seasonal temperature fluctuations and four well-defined seasons within a year. Land use is primarily forest land, paddy fields, dry land, and grassland, with forest land comprising 70% of the total area. With rich vegetation types and high WC, CS, and SC, the SHMB is a nationally important ecosystem protection area that is important for the sustainable development of the region.

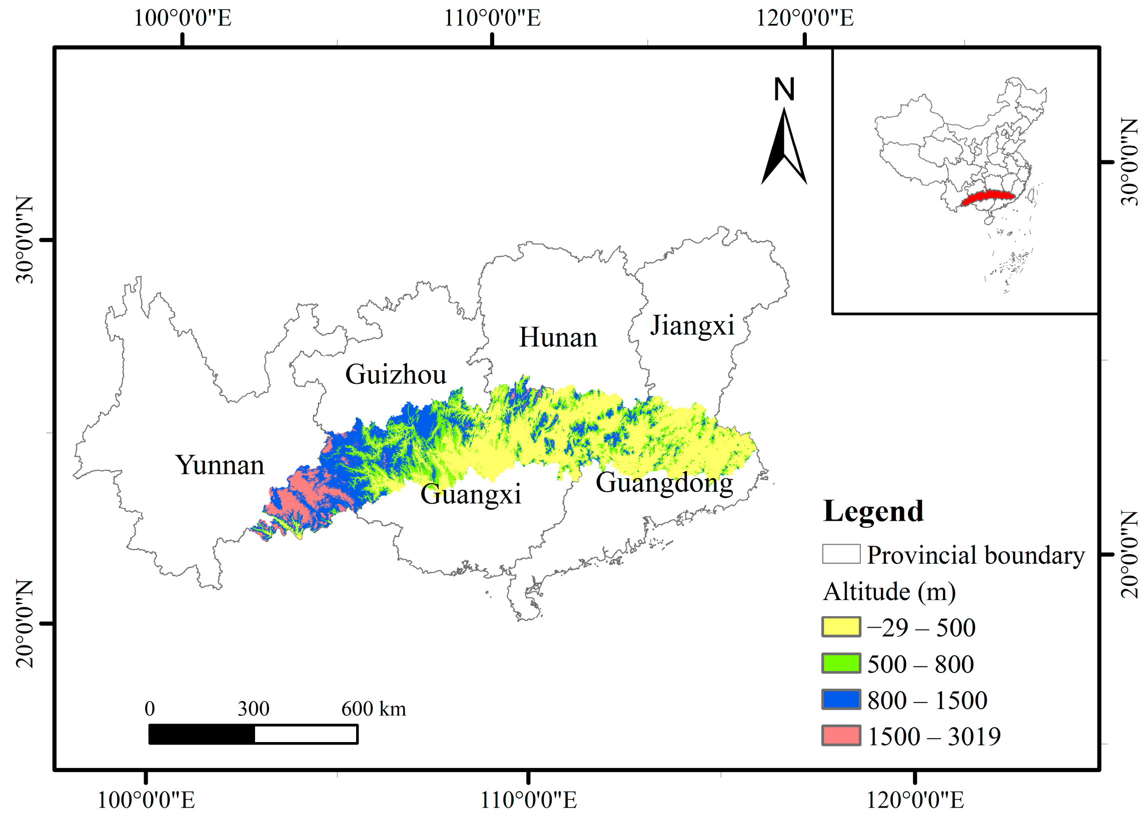

Figure 1. Geographic location of the SHMB.

2.2. Data Sources

The primary data for this paper include raster data of the vegetation types in the study area, a digital elevation model (DEM), soil data, precipitation, potential evapotranspiration, population density, and gross domestic product (GDP). The datasets were processed in ArcGIS10.8 (Esri). The spatial resolution of all data was unified to 90 m and projected onto the WGS 1984 Albers coordinate system. Vegetation types include evergreen broad-leaved forest (EBF), deciduous broad-leaved forest (DBF), evergreen coniferous forest (ECF), mixed coniferous and broad-leaved forest (BCF), evergreen broad-leaved shrub (EBS), deciduous broad-leaved shrub (DBS), sparse forest (SF), sparse scrub (SS), arbor orchard (AO), shrub orchard (SO), arbor greener (AG), shrub greener (SG), temperate meadow (TM), grassland (TS), paddy field (PF), and dry land (DL). Table 1 reports the specifications of the datasets.

Table 1. Specifications of the datasets used in this study.

Data Types	Type	Data Source	Resolution
Vegetation types	Raster	China Cover [22,23]	90 m
Precipitation	Raster	Resource and Environment Science and Data Center (https://www.resdc.cn/, accessed on 10 January 2022)	1000 m
Potential evapotranspiration;	Raster	MOD16A3 products from the US Geological Survey (http://modis.gsfc.nasa.gov/, accessed on 20 January 2022)	1000 m

Table 1. *Cont.*

Data Types	Type	Data Source	Resolution
NDVI	Raster	Resource and Environment Science and Data Center (https://www.resdc.cn/, accessed on 15 January 2022)	1000 m
GDP	Raster		1000 m
POP	Raster		1000 m
DEM	Raster	Geospatial data cloud (https://www.gscloud.cn/, accessed on 16 January 2022)	90 m
Soil properties	Raster	Harmonized World Soil Database (HWSD_China_Subset_v1.1)	1000 m

2.3. Ecological Functions of Vegetation

We quantified the water conservation, soil conservation, and carbon storage of the vegetation in the study area using the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST), which is widely used for ecosystem service assessments [24,25]. The simulation results of the model were validated using publicly published data, and the results are detailed in Supplementary Materials.

2.3.1. Water Conservation

The water yield module of the InVEST model was used to assess the water yield in the SHMB for 2000, 2010, and 2020. The module is based on the principle of water balance and calculates the difference between precipitation and actual evapotranspiration for each grid. The calculated difference is the water yield volume of each grid [26,27]. The specific equations involved are as follows:

$$Y_{xj} = \left[1 - \frac{AET_{xj}}{P_x}\right] \times P_x \tag{1}$$

where Y_{xj} is the annual water yield (mm) of raster cell x on vegetation type j; P_x is the annual precipitation (mm) on raster cell x; and AET_{xj} is the annual actual evapotranspiration (mm) of vegetation type j on raster cell x. The input parameters were obtained from previous literature and the biophysical parameters in the InVEST modeling manual [28–30].

The WC is the difference between the water yield and the amount of surface runoff, reflecting the ability of the soil layer to regulate water. It is taken as the water conservation capacity obtained by correcting the water yield data using parameters such as the topographic index, soil saturation hydraulic conductivity, and the flow rate coefficient. We determined the WC as follows:

$$WR_{xj} = \min\left(1, \frac{249}{V}\right) \times \min\left(1, \frac{0.9 \times TI}{3}\right) \times \min\left(1, \frac{0.9 \times K_{sat}}{300}\right) \times Y_{xj} \tag{2}$$

$$\mathrm{TI} = \lg\left(\frac{Drainage_{Area}}{Soil\_Depth \times Percent\_Slope}\right) \tag{3}$$

where WR_{xj} is the annual water conservation (mm) of raster cell x for vegetation type j; Y_{xj} is the annual water yield (mm) of raster cell for vegetation type j; V is the flow rate coefficient; TI is the topographic index; K_{sat} is the saturated hydraulic conductivity of the soil; $Drainage_{Area}$ is the number of grids in the catchment area; $Soil\_Depth$ is the soil thickness; and $Percent\_Slope$ is the percentage slope. The flow rate coefficient was calculated with reference to Zhang [31].

2.3.2. Soil Conservation

SC is the ability to reduce soil erosion and sediment export. Improving soil conservation is beneficial to land productivity and the development of a favorable ecological environment. The SC assessment in the InVEST model is performed using the sediment transport ratio module. This module is based on the Revised Universal Soil Loss Equation (RUSLE), which considers the interception of sediments by upstream plots, vegetation cover, and engineering measures. This is currently one of the most commonly used methods to calculate soil conservation [32]. SC was calculated as follows:

$$SC = RKLS_i - USLE_i \tag{4}$$

where SC is the soil conservation per unit area (t/hm^2·a); $RKLS_i$ is the potential soil erosion of raster cell i (t/hm^2·a); and $USLE_i$ is the actual soil erosion of raster cell i (t/hm^2·a). The input parameters were assigned with reference to the InVEST modeling manual.

2.3.3. Carbon Storage

Terrestrial ecosystems such as forests and grasslands reduce greenhouse gas emissions by fixing CO_2 released from the atmosphere and, thus, play a role in regulating the climate. The carbon storage module in InVEST is based on the carbon density of the vegetation type and its corresponding carbon pool. In particular, the carbon storage is taken as the product of the carbon density and the corresponding vegetation area [33,34]. The calculation equation is as follows:

$$S_{cx} = C_{above} + C_{below} + C_{soil} + C_{dead} \tag{5}$$

where S_{cx} is the total carbon storage in raster cell x (t/hm^2) and C_{above}, C_{below}, C_{soil}, and C_{dead} are the aboveground carbon density, belowground carbon density, soil organic carbon density, and dead organic matter carbon pools (t/hm^2), respectively. The carbon density data were obtained from the InVEST model handbook and relevant studies in areas with similar climatic conditions [35].

Supplementary Materials provide more details on the computational procedures and data requirements for all modules used in this study.

2.4. Altitude Gradient Classification

The altitude gradient of the SHMB was classified following the method described by Zhang [36]. The landforms in the study area with an altitude of less than 50 m are plain terraces, 50–500 m are hills, 500–800 m are low mountains, 800–1500 m are middle mountains, and more than 1500 m are high mountains. Note that the area within the study area <50 m accounted for less than 1% of the total and was classified into the range <500 m. Table 2 reports the altitude gradient categories.

Table 2. Altitude gradient division used in this study.

Gradient T	First Gradient T_1	Second Gradient T_2	Third Gradient T_3	Fourth Gradient T_4
Altitude (m)	<500	500~800	800~1500	>1500
Percentage (%)	46.59	21.67	24.81	6.92

2.5. Driving Factors of Ecological Functions

We selected 13 ecological impact factors with reference to previous research. The natural factors include elevation (ELE), slope (SLO), precipitation (PRE), temperature (TEM), and the normalized vegetation index (NDVI). The socio-economic factors include population density (POP) and gross domestic product (GDP). The landscape pattern factors include the patch cohesion index (PCI), the contagion index (CI), the Shannon diversity index (SDI), the percentage of evergreen broad-leaved forest (EBF), evergreen coniferous forest (ECF), and evergreen broad-leaved shrub (EBS).

Geodetector was used to detect the natural, socio-economic, and landscape pattern factors that affect ecological functions. Gerdetector can determine the influence of each factor on the spatial differentiation of variables and identify the interaction between different factors [37]. Independent variables containing numerical quantities were first discretized in ArcGIS. The influence of each independent variable on the dependent variable is described as:

$$q = 1 - \frac{1}{N\sigma^2} \sum_{h=1}^{L} N_h \sigma_h^2 \quad (6)$$

where q is the explanatory capacity of the independent variable on the dependent variable; L is the number of categories within the independent variable; N is the total cell count within the region; N_h is the quantity of cells categorized as type h within the independent variable; σ^2 is the overall variance across all samples within the research area; σ_h^2 is the variance of independent variable type h.

3. Results

3.1. Changes in Vegetation Types of the SHMB

The overall vegetation types in the SHMB remained relatively stable from 2000 to 2020 (Figure 2). The main vegetation types were ECF and EBF, accounting for approximately half of the total area. ECF was the most widely distributed, mainly in the western and eastern parts of the study area. There was a reduction in the area of ECF from 2000 to 2010 and from 2010 to 2020 by 155 km^2 and 285 km^2, respectively. EBF was mainly concentrated in the southwestern and southeastern parts of the study area, exhibiting a continuous increase in area with time, totaling approximately 975 km^2 between 2000 and 2020. EBS and DL accounted for about 10% of the total area in all three years. EBS was mainly located in the central and western parts of the SHMB, with some zones scattered in the southwest and east. The DL area decreased by about 1360 km^2 from 2000 to 2020 and was mainly concentrated in the south-central and east-central regions, with some zones scattered in the west. The areas of PF and TS remained relatively stable from 2000 to 2020, at approximately 8% and 6% of the total, respectively. PF was primarily located in the eastern part of the study area, while TS was mainly distributed in the southwest, with a few locations in the northwest.

The dominant vegetation types varied with altitude gradients (Figure 3). The T_1 gradient was dominated by EBF and ECF, both with about 24% of the area, and by PF and DL, with 15% and 13%, respectively. The area percentages of ECF are the largest at both T_2 and T_3, 35% and 31%, respectively, followed by EBF (27% and 20%). At the T_4 gradient, EBF, ECF, EBS, and TS were all larger at 22%, 20%, 21%, and 24%, respectively. The area percentages of TS and EBS gradually increased, and the area of PF gradually decreased with increasing altitude. EBF is widely distributed, and its area share is higher at all altitude gradients, remaining between 20% and 27%. The areas of PF and DL exhibited a decreasing trend in all gradients with time.

3.2. Spatiotemporal Variation in the Vegetation Ecological Functions

The spatial heterogeneity of the ecological functions is evident throughout the study area (Figure 4). The spatial distributions of WC, CS, and SC exhibit similar characteristics, with a greater distribution in the east and lower in the center and west. The total amount of ecological functions in the SHMB followed an upward trend (Table 3). Larger increases were observed in WC and SC compared to CS. The total amount of WC in the SHMB in 2000, 2010, and 2020 was 8.53×10^{10} m^3, 13.02×10^{10} m^3, and 17.79×10^{10} m^3, respectively, representing an increase of about 109%. The average total SC was determined as 6.41×10^9 t, 9.45×10^9 t, and 12.63×10^9 t, respectively, denoting an increase of approximately 97%. The total amount of CS in the SHMB was 1650.71×10^6 t, 1653.18×10^6 t, and 1655.46×10^6 t.

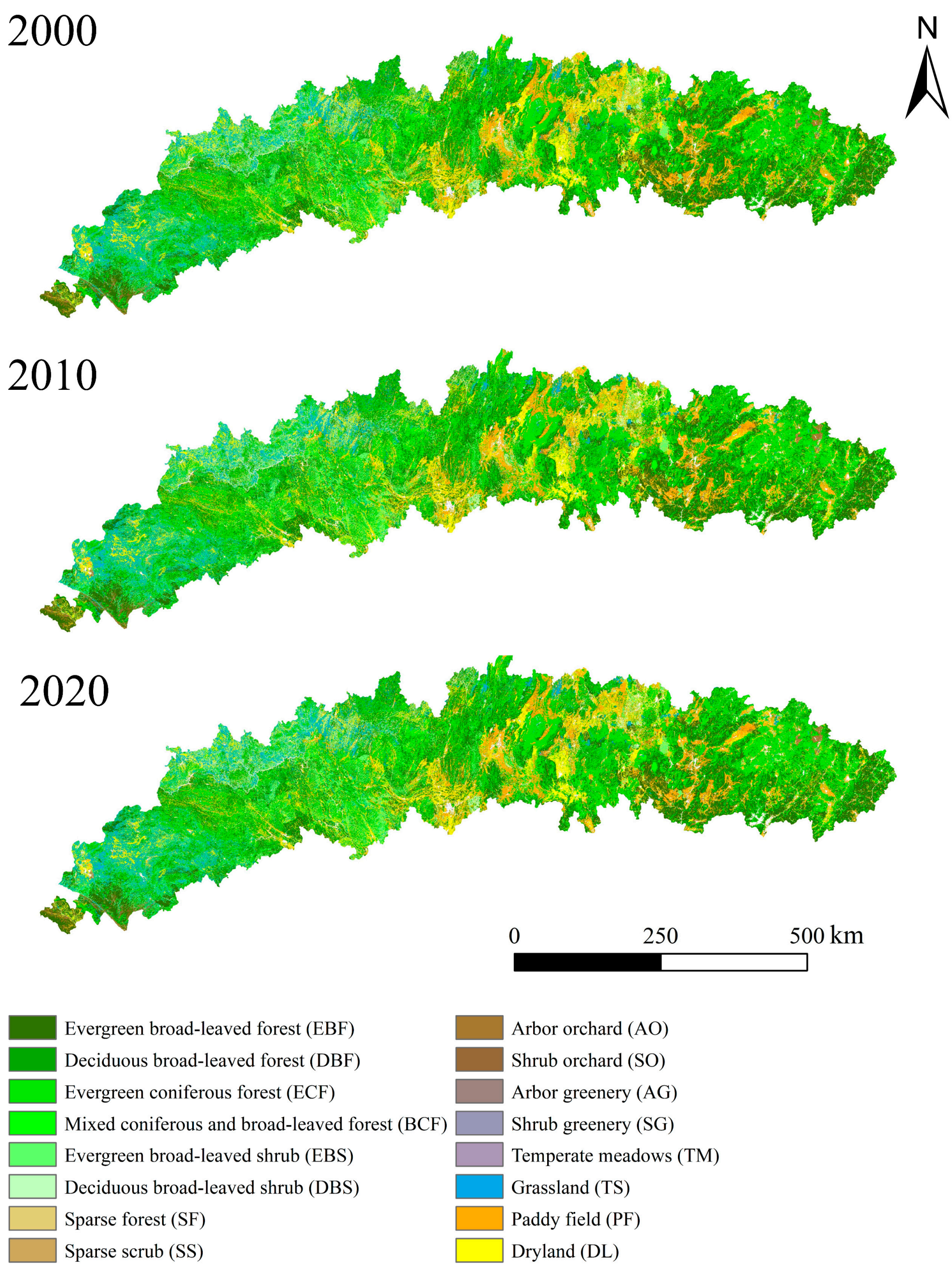

Figure 2. Distribution characteristics of vegetation in the SHMB.

Table 3. Total ecological functions in different years.

	WC ($\times 10^{10}$ m^3)	SC ($\times 10^9$ t)	CS ($\times 10^6$ t)
2000	8.53	6.41	1650.71
2010	13.02	9.45	1653.18
2020	17.79	12.63	1655.46

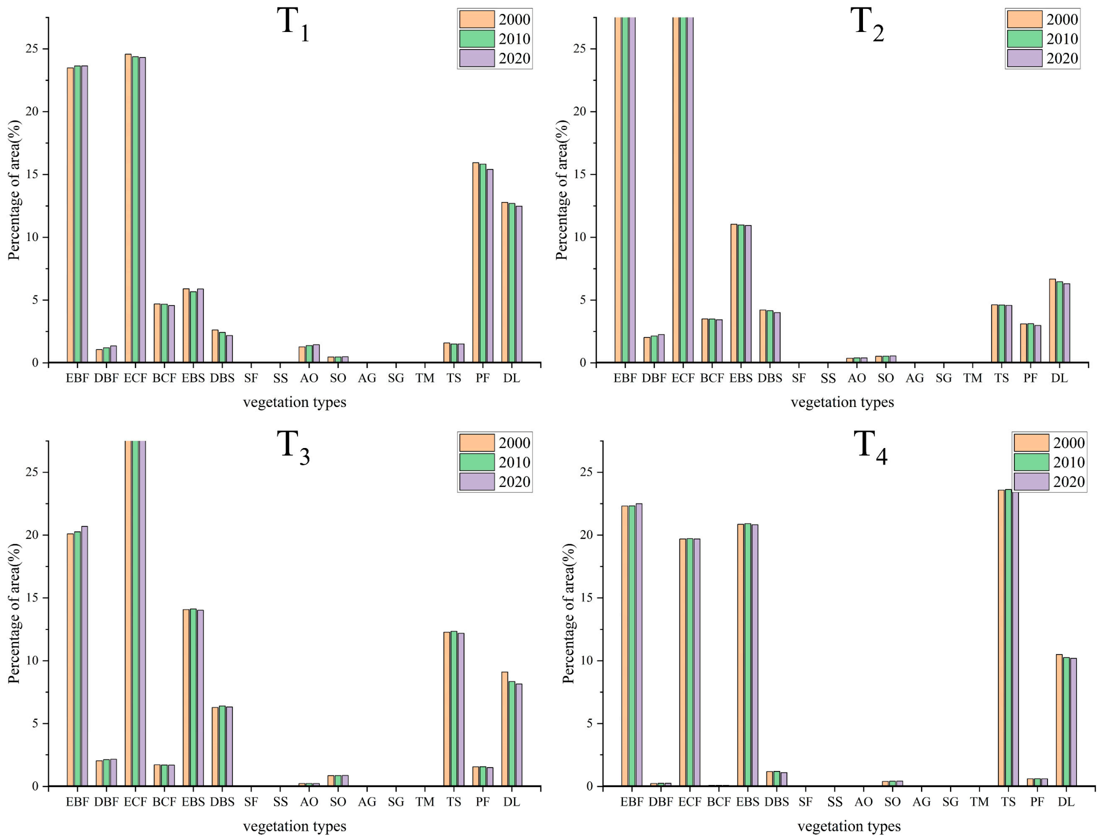

Figure 3. Proportion of the vegetation type areas under different gradients.

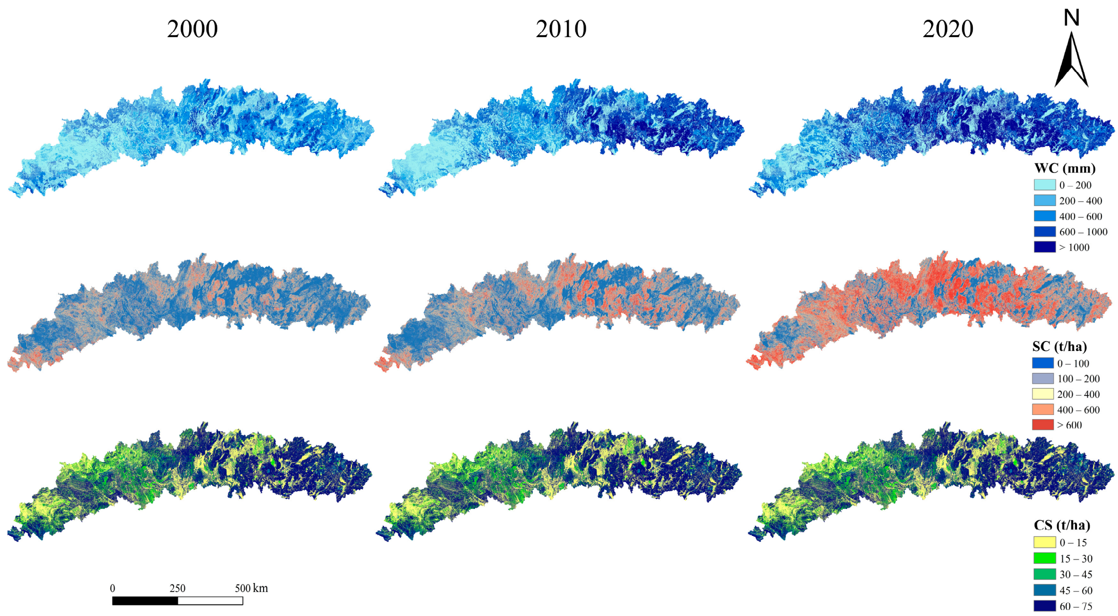

Figure 4. Spatial distribution of ecological functions in the SHMB from 2000 to 2020.

Following the ecological function assessment of the study area, ecological functions were extracted using the zonal statistics for major vegetation types in the years 2000, 2010, and 2020 (Figure 5). The WC varied significantly among the different vegetation types, with DBS exhibiting the highest WC of 1028 mm, followed by SS and BCF with 978 mm and 934 mm, respectively. This was followed by SG and evergreen forests. WC was observed to be markedly lower in TM, several orchards, TS, PF, and DL compared to other vegetation types. SS, EBF, and ECF exhibit the highest SC, followed by SO, DBF, and EBS. Vegetation types with the lowest SC capacity were determined as PF, DL, and AG. CS was highest in all forest types, followed by scrub. The lowest CS was observed in PF and DL.

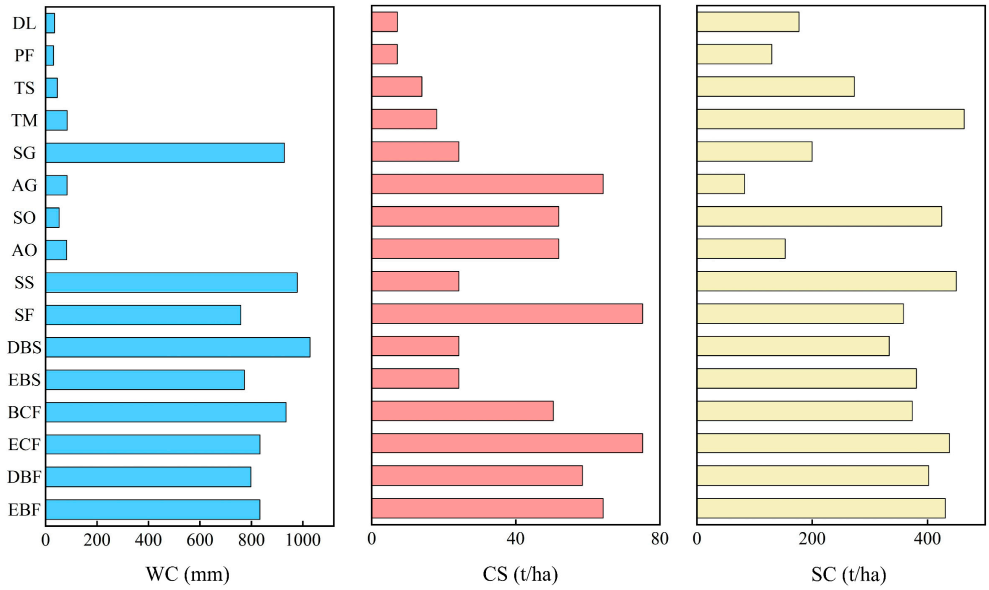

Figure 5. Differences in ecological functions of different vegetation types at SHMB.

3.3. Characteristics of Ecological Functions Distribution across Altitude Gradients

Table 4 reports the vegetation ecological functions at each altitude gradient, revealing significant differences in the ecological functions across altitude gradients. The ecological functions in the SHMB presented similar distribution characteristics. In the process of altitude gradient class from low to high, all the vegetation ecological functions showed a tendency to increase and then decrease. The T_2 gradient exhibited the highest ecological function values, while the lowest values were observed for gradients T_1 and T_4. Minimal changes were observed for CS with time across altitude gradients, and the ecological functions of most gradients in the SHMB maintained an increasing trend from 2000 to 2020. The WC and SC values of the T_4 gradient followed a slightly decreasing trend from 2000 to 2010.

Table 4. Ecological functions of vegetation at different altitude gradients.

Ecological Functions	Altitude Gradient	2000	2010	2020
WC (mm)	T_1	274	481	643
	T_2	329	518	692
	T_3	298	376	540
	T_4	246	187	293
SC (t/ha)	T_1	121	202	270
	T_2	234	368.	493
	T_3	236	307	412
	T_4	170	156	198
CS (t/ha)	T_1	42	42	42
	T_2	52	52	53
	T_3	46	46	47
	T_4	38	38	39

3.4. Driving Factors of Ecological Functions at Different Altitude Gradients

We selected 13 indicators from socio-economic, natural conditions, and landscape pattern factors (Figure 6). The results reveal PRE to have the strongest explanatory power (0.36–0.89) for WC in most of the gradients, followed by NDVI and PCI. However, the explanatory power of PRE for WC was weak in the T_1 gradient, with values of 0.13, 0.32, and 0.10 in 2000, 2010, and 2020, respectively. SLO was the strongest driver of SC, with the highest q-values across all altitude gradients (0.38–0.74), followed by ELE and PRE. The effect of PRE on SC was observed to increase with elevation. The effect of NDVI on SC was much greater in the T_4 gradient (0.55–0.59) than in the other gradients (0.02–0.28). At all altitude gradients, the effect of NDVI on CS was the strongest, followed by EBF and ECF. The q-values of the EBF percentage at the T_3 and T_4 high-altitude gradients were higher than those of the low-altitude gradient. The results indicate PRE, SLO, and NDVI as the main driving factors of the spatial changes in the ecological functions of the SHMB.

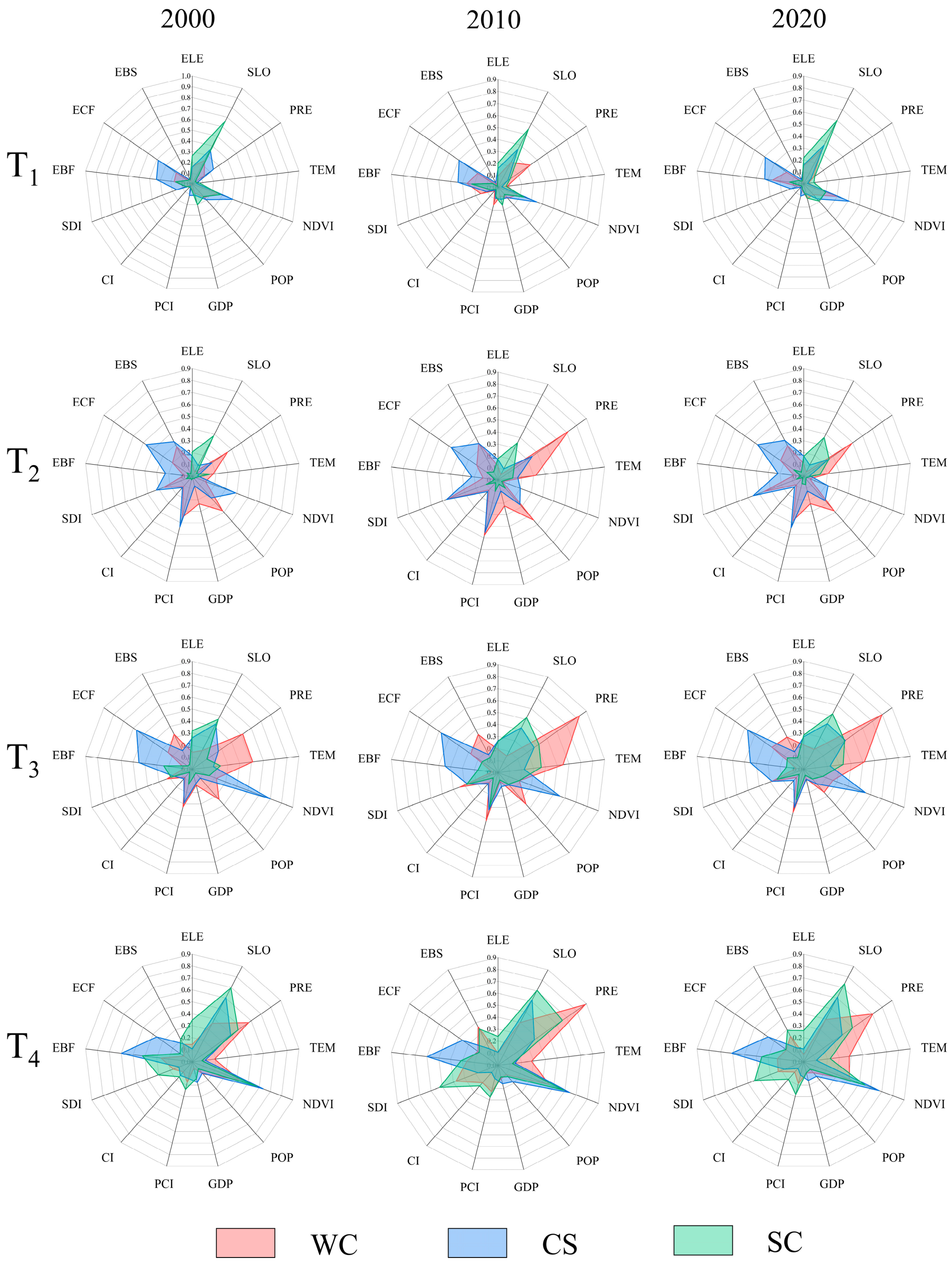

Figure 6. q-values of factors affecting ecological functions at different altitude gradients.

4. Discussion

4.1. Impact of the Altitude Gradient on Ecological Functions

The heterogeneity in the spatiotemporal distribution of vegetation types in the SHMB is a complex interplay of natural factors, such as topography and precipitation, and economic factors, such as population growth.

WC was stronger and SC and CS weaker at lower altitudes, with significant differences compared to the observations at higher altitudes. Precipitation is relatively high at low altitudes, and precipitation inputs are an important factor in WC. According to the water balance, the difference between precipitation and actual evapotranspiration denotes the ecosystem's capacity to produce water [26]. Despite the wider distribution of cropland with low WC at lower altitudes, the total WC along this gradient remains high in the SHMB. This can be attributed to the high vegetation cover at lower altitudes, whereby canopy throttling and ground-level apomixis mitigate runoff and increase water conservation [29]. This gradient has a higher proportion of drylands and paddy fields than the other altitude gradients, with high levels of human activity. Drylands and paddy fields are reported to provide fewer ecological functions than other natural vegetation [38]. This highlights the importance of strengthening ecological conservation in low-altitude areas and the need to develop targeted soil and water conservation strategies alongside afforestation activities.

All ecological functions were highest in the T_2 gradient. This can be attributed to several factors. For example, this gradient exhibits the largest proportion of forested area and the smallest proportion of agricultural land. It also has higher rainfall compared to other gradients. The canopy of the forest floor traps precipitation, while the layer of dead leaves and branches improves soil structure and enhances water infiltration, thus increasing WC capacity [39]. Moreover, forests contain a large amount of biomass, and both root carbon sequestration and photosynthetic carbon sequestration via vegetation increase the carbon sink capacity of the gradient [40]. Overall, an increase in forest area regulates climate, protects soil and water, and has the capacity to better serve humans [41]. Therefore, ecological protection should be prioritized in the T_2 gradient area. We recommend the establishment of ecological protection zones to strengthen the protection and management of broad-leaved evergreen and evergreen coniferous forests [42].

The T_3 and T_4 gradients are important areas for ecological restoration in the SHMB. All ecological functions decrease with increasing altitude in these gradients. As in other high-altitude mountainous areas, the areas of broad-leaved evergreen and evergreen coniferous forests have gradually shrunk, and the proportion of scrub and grassland has gradually expanded, with grassland eventually dominating [43]. Shrubs and grasslands have shallower root systems and a lower runoff interception capacity than forests. The steeper topography also increases runoff. These factors gradually reduce water conservation at higher altitudes [17,44]. Previous studies have shown that forests provide more carbon storage than shrubs and grasses [45]. In ecologically sensitive high-altitude areas, it is important to protect natural grasslands. Furthermore, farmers should be encouraged to graze their livestock in a reasonable manner, plant pasture on farmland, and build agro-pastoral ecosystems. This will help to minimize the negative impact of man-made activities.

4.2. Driver Factors of Ecological Functions at Different Altitude Gradients

Our results indicated that the ecosystems in the study area are mainly influenced by natural factors such as topography, climate, and vegetation. Precipitation is always the key limiting factor for water conservation and gradually becomes the dominant factor at higher altitude gradients where vegetation decreases and cover decreases. This is also evidenced by the increase in the q-value of precipitation with increasing altitude. Preserving the current vegetation in high-altitude gradients is essential, alongside augmenting vegetation coverage through artificial afforestation, grass seeding, mountain reforestation, and controlled grazing. These measures aim to optimize the WC of vegetation [46]. Studies have shown that landscape fragmentation has a negative impact on the spatial distribution of WC, and the higher the landscape connectivity, the more conducive it is to the interception and regulation of runoff [47]. Therefore, within the T_2 and T_3 gradients—where the explanatory power of the patch cohesion index is strong for WC—it is necessary to optimize the spatial configuration of the landscape, strengthen the landscape integrity, and reduce the degree of landscape fragmentation through intensive management of vegetation to improve water conservation.

We found that the percentages of both evergreen coniferous forests and evergreen broadleaf forests exerted significant influences on carbon storage. Forests can provide higher carbon storage, and the carbon density of woodlands is higher than that of other ecosystems [48]. Moreover, the community structure of woodlands is complex, with a high degree of forest closure. The understory of the forest creates a unique climate that is suitable for the renewal of plant and animal species, which is of great significance for ecological environmental protection [49]. This is evidenced by the strong driving force of NDVI on CS, which is an indicator of vegetation growth conditions and vegetation cover. Furthermore, excellent vegetation growth conditions and cover are favorable to CS.

Note that the effects of GDP and POP on the ecosystems in the study are relatively small. This is due to the large size of the SHMB and the concentrated distribution of the population. This uneven distribution may weaken the impact of GDP and POP. However, future population and economic growth will inevitably enhance land development, particularly the conversion into farmland or buildings. Ecological functions will eventually change as the ecosystem structure and vegetation types change. Therefore, in the future, comprehensive measures need to be adopted to focus on the harmonious coexistence of humans and nature. For example, in high-altitude areas, population density and economic activities need to be reduced, and the eco-economy should be promoted to enhance eco-efficiency [50]. In areas with intensive human activities, the landscape pattern of vegetation needs to be optimized to improve ecological functions.

4.3. Limitations of this Study and Future Work

Despite the progress made by this study, it has the following limitations. First, we used the InVEST model to assess vegetation ecological functions, which simplifies the ecological process. Although we validated the results and confirmed their reliability, the model uncertainty can be further optimized. The calculation of the amount of soil conservation requires vegetation cover, a management factor, and SC as inputs. The values of these inputs are determined from the model manual and previous research with similar natural climatic conditions. Future work will integrate field observations into the evaluation of the model to increase the applicability and accuracy of the results. Second, only three key vegetation ecological functions were considered in this study. In the future, multiple vegetation ecological functions can be rationally selected with more characteristics of the study area. Third, the ecological functions of certain vegetation types may be overestimated or underestimated due to the limitations of the sample size and the resolution of the data sources. In the future, researchers should use higher precision data sources to minimize errors.

5. Conclusions

In this study, we analyzed the spatiotemporal–temporal variability and driving factors of the ecological functions of vegetation across altitude gradients. The results indicated that the three ecological function categories showed a continuously increasing trend during the period 2000–2020, with a larger increase in WC and SC compared to CS. All ecological function categories were affected by altitude gradients. WC, SC, and CS exhibited an increasing and subsequently decreasing trend with elevation, reaching a maximum at the mid-altitude gradient (T_2). Distinct disparities exist in the driving factors influencing vegetation ecological functions across altitude gradients. The effect of precipitation on soil conservation increased with elevation. The patch cohesion index was stronger for water conservation at the mid-altitude gradient, and the effect of evergreen coniferous forests on carbon storage was greater at higher altitudes. We propose different ecological management measures according to the characteristics of the driving factors at each altitude gradient. Afforestation should be strengthened and soil and water conservation measures should be implemented in low-altitude areas, while in middle-altitude areas, we suggest strengthening the intensive management of vegetation and improving the landscape diversity of the urban fringe suburbs. In high-altitude areas, existing vegetation is protected, and vegetation cover has increased. This study provides a scientific reference for the development and adjustment of ecological restoration programs in mountainous areas to improve vegetation ecological functions.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/f15061000/s1, Figure S1. Model validation [51–54].

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