forests

MDPI

Article

Characteristics and Relationships between Species Diversity and Productivity of Different Grassland Types in the Burqin Forest Region of the Altai Mountains

Xiaoting Pan [1,2], Mao Ye [1,2,*], Xingbin Xu [1], Qingzhi He [1,2], Xinchen Gu [3,4], Guoyan Zeng [1,2], Weilong Chen [1,2] and Miaomiao Li [1,2]

[1] College of Geographical and Tourism, Xinjiang Normal University, Urumqi 830054, China; panxiaoting@stu.xjnu.edu.cn (X.P.); xuxb15@lzu.edu.cn (X.X.); he2543549455@stu.xjnu.edu.cn (Q.H.); zengguoyan@stu.xjnu.edu.cn (G.Z.); chenweilong2517@stu.xjnu.edu.cn (W.C.); 107622022210549@stu.xjnu.edu.cn (M.L.)
[2] Xinjiang Laboratory of Lake Environment and Resources in Arid Zone, Urumqi 830054, China
[3] State Key Laboratory of Hydraulic Engineering Simulation and Safety, School of Civil Engineering, Tianjin University, Tianjin 300072, China; gxc@tju.edu.cn
[4] State Key Laboratory of Simulation and Regulation of Water Cycle in River Basin, China Institute of Water Resources and Hydropower Research, Beijing 100044, China
* Correspondence: yemao1111@163.com

Abstract: The Altai Mountain is located at the intersection of cold and arid regions. Climate change and overgrazing directly affect the growth of the grassland ecosystem in this region. This study took the grassland community in the Burqin forest area of the Altai Mountains as an example to analyze the species diversity and productivity of different grassland types based on 50 sampling plots. The relationship between species diversity and the productivity of grassland types at different altitudes was also discussed. The results showed that: (1) In the Burqin forest area, the desert steppe was dominated by *Gramineae*, *Compositae*, and *Leguminosae*. Montane steppe and mountain meadows were dominated by *Umbelliferae*, *Gramineae*, and *Liliaceae*. *Gramineae*, *Ranunculaceae*, and *Liliaceae* were the dominant families in both montane meadows steppe and alpine steppe but occurred in varying proportions. (2) The variation in plant numbers at the family–species level was characterized as montane steppe > alpine meadow > montane meadow steppe > desert steppe > mountain meadows. (3) The similarity in species composition among communities of different grassland types was low. In DS and MM, the number of grasslands and species played a decisive role in determining the biomass. The biomass of MS and AM was determined using the Simpson and Shannon–Wiener indices, and the number of dominant species determined the biomass. The number of grasslands and species did not have a significant impact on the biomass of MMS, which may be due to human factors such as grazing. (4) The dominant species in the grassland at an altitude of 1200–1400 m is prominent. The number of individuals in the dominant species was large and evenly distributed. Margalef peaked at an altitude of 1600–1800 m, but the number of individuals was small, resulting in low biomass and diversity in this range. Most plants survive at an altitude of 2000–2200 m; therefore, in grassland protection and planning management, it is important to consider the specific situation of plant growth under different habitats at different altitudes and make reasonable protection decisions based on local conditions to maintain species diversity and sustainable development of grassland ecosystems. This study provides basic data to support the theoretical basis for the protection and sustainable utilization of grassland resources and the restoration of degraded grasslands in the study region.

Keywords: above-ground biomass; elevation; natural grassland; species composition; species diversity

check for updates

Citation: Pan, X.; Ye, M.; Xu, X.; He, Q.; Gu, X.; Zeng, G.; Chen, W.; Li, M. Characteristics and Relationships between Species Diversity and Productivity of Different Grassland Types in the Burqin Forest Region of the Altai Mountains. *Forests* **2023**, *14*, 1829. https://doi.org/10.3390/f14091829

Academic Editor: Runguo Zang

Received: 31 July 2023
Revised: 31 August 2023
Accepted: 31 August 2023
Published: 7 September 2023

1. Introduction

The grassland ecosystem has a high carbon storage capacity and stores nearly 1/3 of the organic carbon in the entire ecosystem. It maintains about 30% of the net primary productivity and has a vital role in the conservation of biodiversity and the maintenance of carbon balance [1]. Thus, it is important to determine the effects of productivity on biodiversity to maintain species diversity in the grassland ecosystem. The impact of global climate change on terrestrial ecosystems is increasingly evidenced in the IPCC reports [2]. The relationship between species diversity and productivity has become a central and hot issue in community ecology research in recent years [3,4]. Many studies have focused on grassland species diversity and productivity interactions at global and local scales. The results of these studies show that, depending on the scale of the study, the relationship between plant diversity and productivity is linear, "single-peaked", "U" and uncorrelated. The species richness and productivity of the Qinghai-Tibet Plateau increased logarithmic-linearly [5]. The relationship between species diversity and the productivity of grassland communities in the Songnen Plain followed a unimodal curve [6]. In grasslands controlled by human interventions, there was a negative covariance relationship between richness and diversity [7]. Increasing species richness increases grassland community productivity [8]. Second, the relationship between species diversity and above-ground biomass also varies based on the successional stage [9]. In summary, previous studies have explored the relationship between species diversity and productivity from different perspectives and in different geographical settings. The relationship between productivity and species diversity is complex due to differences in the types of plant communities studied, the types of environments, and timescale constraints.

Biomass and species diversity are important indicators of the quantitative characteristics of ecosystems, reflecting the health of grasslands and ecosystem production potential, and are a comprehensive reflection of ecosystem function and structure [10]. It is likewise one of the most direct, observable, and primary research aspects of grassland ecosystems [11–13]. The relationship between species diversity and productivity tends to reflect the species composition, function, and structure of grassland communities and responds to environmental factors (elevation, temperature, slope, precipitation, geographic location, and soil nutrients, among others) [14–17]. Therefore, the study of species diversity and above-ground productivity based on different grassland types is an important approach to understanding the response of grassland types to local ecological environmental factors. However, previous studies mostly relied on remote sensing or statistical data, and the estimation error was large and could not reflect the overall structural and functional recovery of the ecosystem. This study is based on relatively accurate field tests, especially in the identification of species.

The Altai Mountain grassland ecosystem is one of the most important ecological barriers in Xinjiang. Since the 20th century, the grassland resources in the Altai Mountains have been overexploited by humans. Extreme precipitation events in the Altai Mountains are also frequent, causing many ecological problems and affecting the local economic development [18,19]. This seriously threatens the stability of the ecosystem structure and the development of grassland animal husbandry as well as the quality of life of farmers and herders. In this study, field investigations and experiments were conducted to study the relationship between species diversity and productivity of the different grassland types. Species diversity changes in grassland ecosystems at different altitudes were considered to reflect the changes in environmental factors.

Based on this, our study focused on the following four scientific questions by investigating above-ground biomass and species diversity in 50 sample plots from five grassland types in the Burqin forest area: (1) What are the similarities and differences in species composition in different grassland types? (2) What changes characterize the plant species composition of different grassland types? (3) What are the intrinsic links between species diversity and above-ground biomass? (4) What patterns of vertical variation in species diversity and above-ground biomass are exhibited?

2. Materials and Methods

2.1. Study Area

The Altai Mountain Burqin Forest Region (86°25′–88°06′ E, 47°22′–49°11′ N) is located in the Xinjiang Uygur Autonomous Region, Altay Prefecture, Burqin County, in the southwestern part of the Altai Mountain Range (Figure 1). The highest elevation is 2958 m above sea level, and the lowest elevation is 730 m. The total forest management area is 3.77×10^5 hm^2. The terrain slopes from the northeast to the southwest, forming a pattern of high north and low south [20]. The study area falls within the temperate alpine mountain climate zone, with high wind and low rainfall, strong evaporation, and significant changes in vertical zonation. The average annual temperature is about −3.7 °C and the average annual precipitation is 300–600 mm. Due to the influence of air currents from the Atlantic and Arctic Oceans, precipitation gradually increases with altitude. Decreasing from west to east, the average annual precipitation in the lower mountains is around 500–600 mm [21]. The area is also associated with uneven seasonal distribution of water resources and prolonged snowpack with increasing altitude.

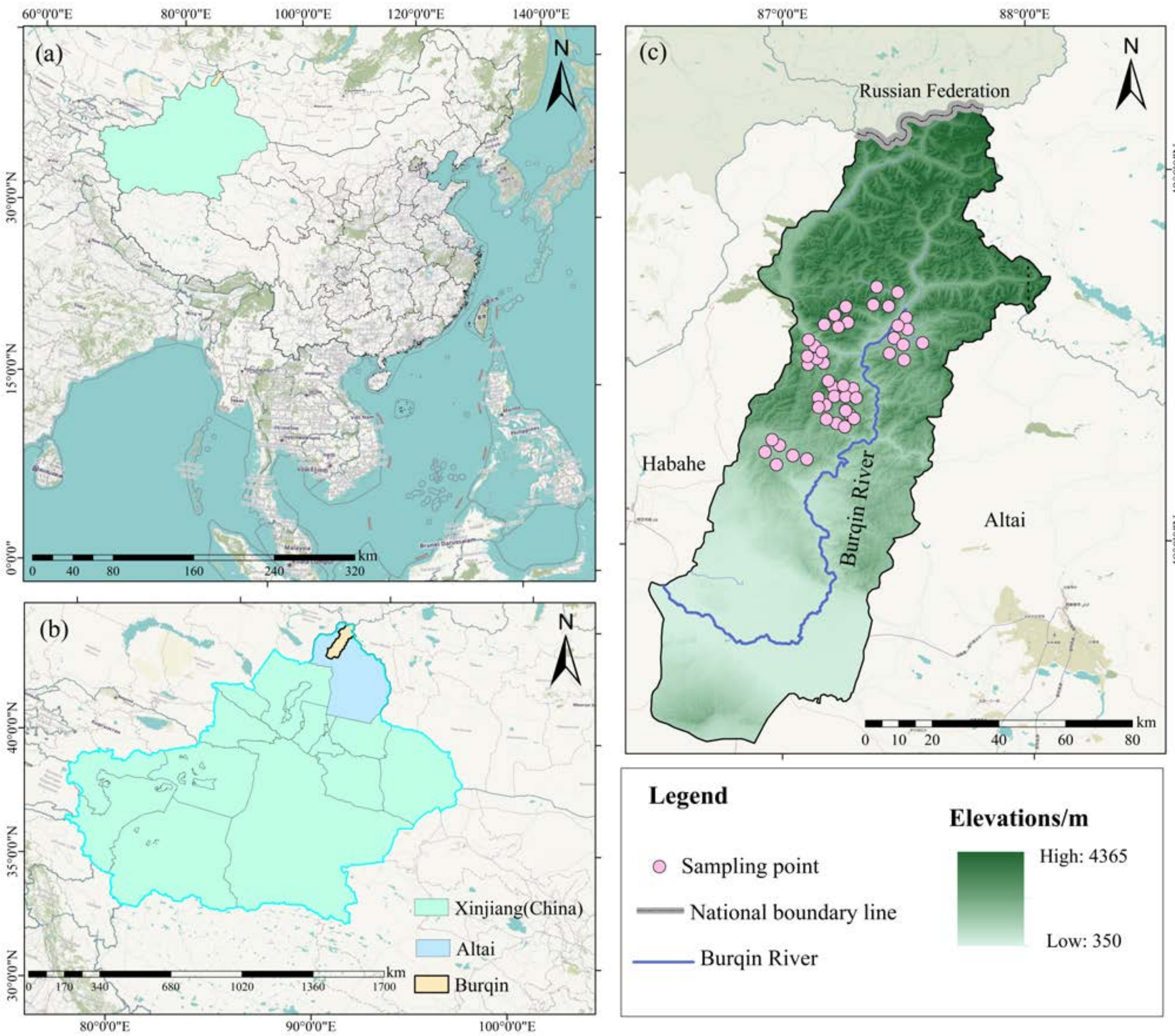

Figure 1. Study area: (**a**) Entire territory of China and its provinces; (**b**) Altai Mountain Burqin Forest region (China); (**c**) Sampling points.

The Burqin forest is one of the first important areas for the implementation of China's natural forest protection project, with a large number of grassland plant species in the forest area and a distinct vertical zonal distribution [18]. The vegetation types from the bottom to the top of the 1000–2300 m altitude range are desert steppe (DS), montane steppe (MS), montane meadow steppe (MMS), mountain meadows (MM), and alpine meadows (AM). More than 10 soil types are present in the study area, with the main soil types being black felt, grass felt, black calcareous soil, and brown coniferous forest soil, with a thickness of 2969 cm [22]. Grazing times vary in different locations in the Burqin forest region. Montane meadow steppe and mountain meadows are summer pastures, desert steppe, and montane steppe are winter pastures, while the alpine meadow is a transitional pasture.

2.2. Design of Experiments

This survey was conducted during the peak grazing season in June–July 2021. Sample strips from different elevations, river valleys, and pastures were set up. The summer pasture is 1.3×10^5 hm^2, the winter pasture is 1.9×10^5 hm^2, and the transition pasture is 0.5×10^5 hm^2 hectares. Based on areas with different grassland types, 50 sample plots (20 m × 20 m in size) reflecting the characteristics of typical grassland communities were laid out (Figure 1c). Relevant environmental factors in the sample plots were also investigated, including the number of species, latitude and longitude, altitude, and hazards. Three 1 m × 1 m sample quadrats were randomly selected within each sample plot. Among them were 15 sample plots of desert steppe, 9 sample plots of montane steppe, 6 sample plots of montane meadow steppe, 14 sample plots of mountain meadows, and 6 sample plots of alpine meadows. Information such as cover, number of species, plant height, and density of species within each sample plot was also recorded. After monitoring, the mowing method was applied to each sample plot, and the fresh weight of the above-ground biomass of each species was measured to determine the above-ground biomass.

2.3. Calculation of Species Diversity

The species diversity in a community can reflect the richness of plant species in the community, and α–diversity is often used to measure community species diversity. Relative height, relative abundance, relative coverage, and relative frequency were used to calculate the species importance value, and the α–diversity index was then obtained. This index not only reflects species richness and species composition in the community, it also reflects the uniform distribution of species in the community. In this study, the Margalef (S), Shannon–Wiener (H), Simpson (D), and Alatalo (Ea) indices were used to measure grassland species diversity. The calculation formulas are as follows [23,24]:

$$\text{Margalef (S)}: \ \text{S} = (\text{S}-1)/\ln(\text{N}) \tag{1}$$

$$\text{Simpson (D)}: \ \text{D} = 1 - \text{I}\sum \text{P}_\text{i}^2 \tag{2}$$

$$\text{Shannon–Wiener (H)}: \ \text{H} = -\sum \text{P}_\text{i}\ln\text{P}_\text{i} \tag{3}$$

$$\text{Alatalo (Ea)}: \ \text{EA} = \text{H}/\ln\text{S} \tag{4}$$

S is the total number of species in the quadrat, N is the total number of individuals in the quadrat, P_i is the proportion of the number of i plant individuals to the total number of individuals.

The Margalef index evaluates the abundance of species in a community or environment, and an index of species richness in a biome (or sample); a larger index value indicates greater species diversity.

As for the Simpson index, the larger the index value, the more unevenly species are distributed in the community and the more prominent the status of the dominant species.

The Shannon–Wiener index is based on the number of individuals of all species in an ecosystem combined with the relative abundance of each species to assess the diversity of an ecosystem. The larger the index, the more complex the community.

The Alatalo index refers to the distribution of the individual number of all species in a community or habitat, which reflects the evenness of the distribution of each species.

The Jaccard index was used to measure similarities between communities [25,26]. The index is calculated using the formula below:

$$C_j = \frac{j}{a + b - j} \quad (5)$$

where j is the number of common species in the two quadrats, and a and b are the species numbers in quadrat A and quadrat B, respectively.

According to the Jaccard similarity principle, 0–0.25 represents very dissimilar, 0.25–0.50 represents moderately dissimilar, 0.50–0.75 represents moderately similar, and 0.75–1.00 represents very similar species communities.

2.4. Statistical Analysis

Excel 2010 was used to count and organize survey data and to calculate species diversity. The samples we collected were independent random samples; Each sample was collected from a normally distributed population. Each population variance was equal; therefore, we used a one-way analysis of variance to analyze the variation characteristics of the family species between different grassland types. We used LSD multiple comparison of one-way ANOVA in IBMSPSS Statistics 25.0 to compare the quantitative differences between family species in different grassland types [27].

Based on the relationship between diversity and above-ground biomass, a regression equation was obtained using multiple regression analysis, and prediction and reliability tests were conducted. Pearson's correlation coefficient was used to determine the correlation between species diversity and above-ground biomass under the premise of normal distribution. Finally, LSD multiple comparisons were used to identify significant correlations between the diversity indices and biomass. We used Origin 2018 to map changes in species diversity indices and above-ground biomass across the elevation gradient. ArcGIS was used to draw the general map of the study area.

After identifying plant species in the field, the family, genus, and species of plants were classified by consulting the flora of China [28].

3. Results

3.1. Plant Family Differences between Grassland Types

The percentage of families in different grassland types was calculated in the 50 sample plots surveyed (Figure 2). There were large differences in the species composition of plants as well as in the dominant families in different grassland types. *Gramineae*, *Compositae*, and *Leguminosae* were the main families in the desert steppe (DS), with *Gramineae* accounting for 32% of the total number of families, *Compositae* accounting for 21.6% of the total number of families, and *Leguminosae* accounting for 16% of the total number of families.

Umbelliferae, *Gramineae*, and *Liliaceae* were the dominant families in the montane steppe (MS). The proportion of *Umbelliferae* increased from 2% to 16.2% compared to desert steppe; the proportion of *Ranunculaceae* also increased dramatically. *Liliaceae* plants appeared in the community with increasing elevation, accounting for 13.8% of the plants. The proportion of *Gramineae* decreased from 32% in DS to 14.4% in MS.

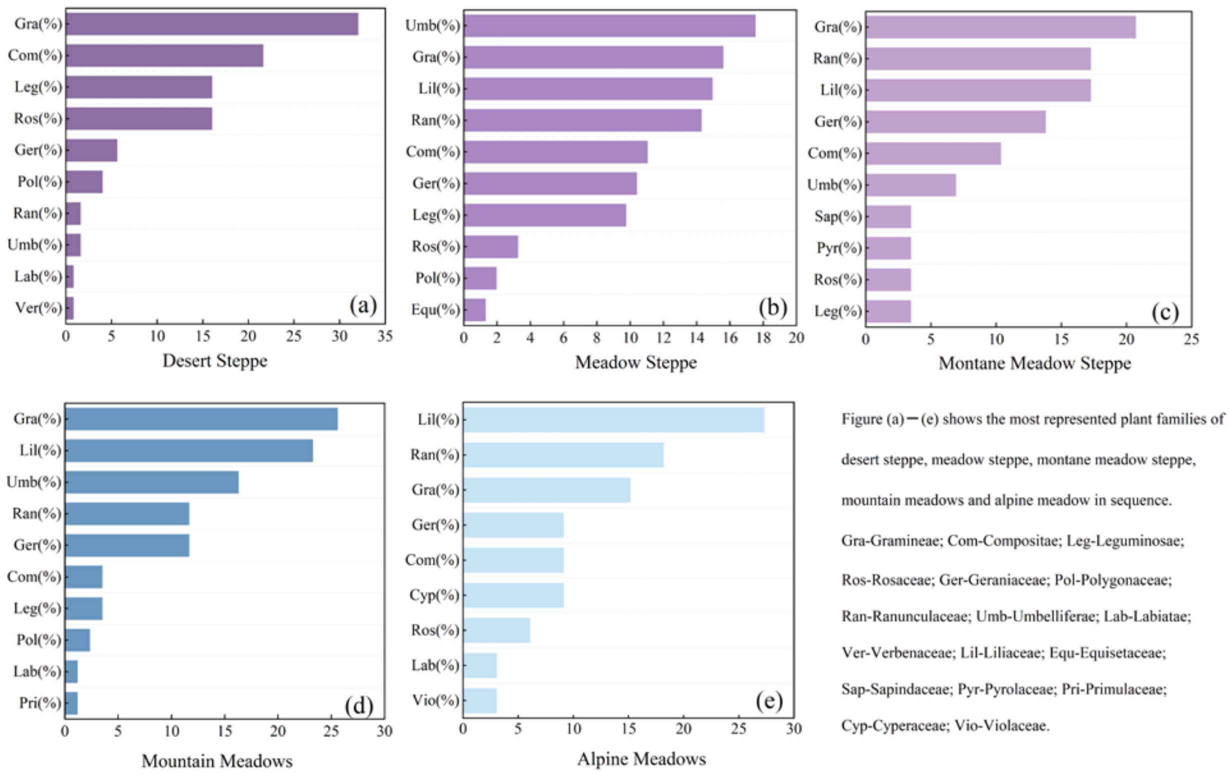

Figure 2. The most represented plant families in grassland types in the Burqin region (China).

Gramineae, *Ranunculaceae*, and *Liliaceae* were the dominant families in the montane meadow steppe (MMS), accounting for 20.7%, 17.2%, and 17.2% of the total, respectively. *Rosaceae* and *Polygonaceae* disappeared from this grassland type, and *Leguminosae* plants gradually decreased, reaching a frequency of only one.

Gramineae, *Liliaceae*, and *Umbelliferae* were the dominant families in mountain meadows (MM), accounting for 24.4%, 22.2%, and 15.6% of the total, respectively. *Liliaceae*, *Ranunculaceae*, and *Gramineae* were the dominant families in alpine meadows (AM), accounting for 20.7%, 18.2%, and 15.2% of the total, respectively. In addition, *Cyperaceae* (which grows mostly in moistened soils) was present in alpine meadows, indicating that this grassland type has better water conditions.

As can be seen in Figure 3, the dominant genera of grassland communities change and turnover with increasing elevation. In all grassland types, *Eleusine* is the main maintainer of ecological functions in grassland communities. However, its proportion in different grassland communities varied more significantly, and it was the most dominant genus in all grassland types, except MM and AM, where it accounted for only 8.9% of the total, and in MMS, where it accounted for 21.4% of the total. In DS, *Achillea* and *Imperata* were sub-dominant, accounting for 12.3% and 11.5% of the total, respectively. Multiple genera of *Taraxacum*, *Medicago*, *Fragaria*, *Geranium*, and *Potentilla*, among others, were also present. *Achillea* disappeared in the MS with increasing altitude, while *Hydrocotyle* and *Ranunculus* appeared with higher percentages—12.5% and 8.3%, respectively.

The proportion of *Geranium* and *Convallaria* in MMS increased with elevation. Compared with DS, the percentage of *Geranium* increased from 5% to 14.3%, while the percentage of *Convallaria* increased to 10.7%.

The proportion of *Eleusine* in MM decreased, with *Imperata* being the most dominant at 15.6%. *Geranium* was the next most dominant genus at 11.1%. *Convallaria*, *Ranunculus*, and *Eleusine* were the most dominant genera in AM. *Achillea* reappeared in AM but at a lower percentage.

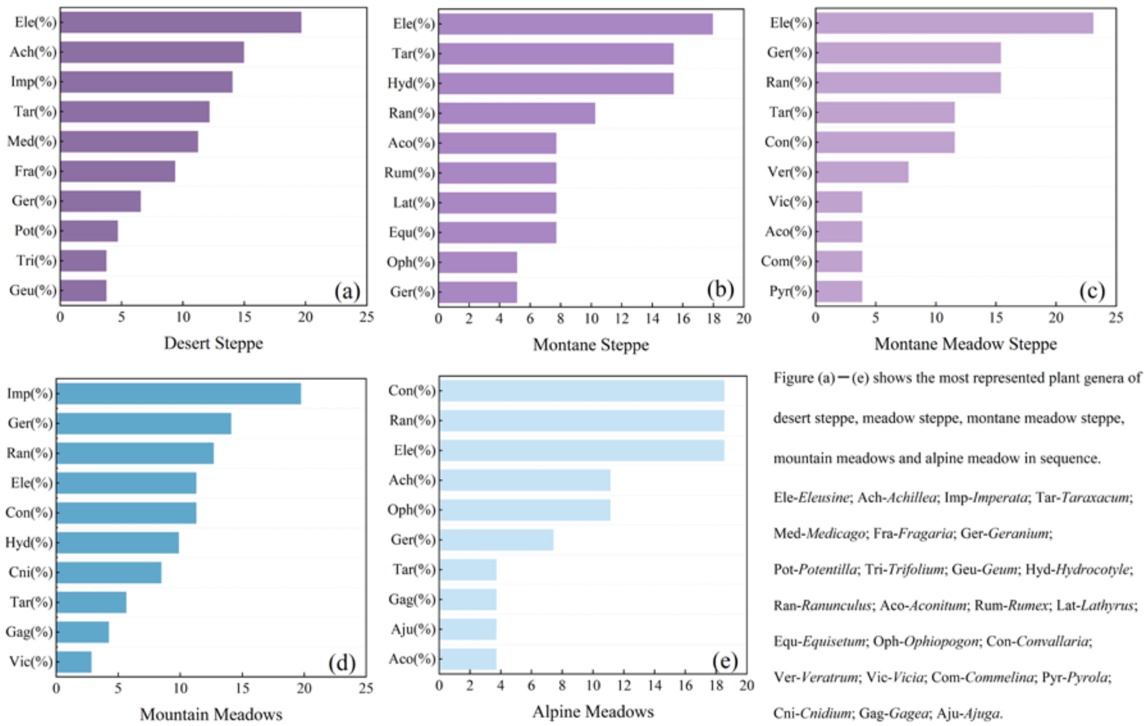

Figure 3. The most represented plant genera in grassland types in the Burqin region (China).

3.2. Characterization of Changes in Plant Family Species in Different Grassland Types

The variations in plant family species in different grassland types showed a specific pattern. The results of one-way ANOVA showed that MS had the highest number of families, with an average of 6.67, which was higher than for other grassland types. MM had the least number of families, with an average of 3.58; this was significantly different ($p < 0.05$) from the number of families in MS and MMS. The number of families in DS and AM averaged 3.94 and 4.67, respectively. LSD Tests for multiple comparisons found that DS was also significantly different from MS and MMS ($p < 0.05$). The differences between AM and other grassland types were not significant (Figure 4a).

The numbers of genera were the same and highest in MS and AM, at an average of 8, and differed significantly from MM. MMS averaged 7 genera. The number of families in DS (5.28) and MM (4.43) were similar. MM was significantly different ($p < 0.05$) from all other grassland types, apart from DS (Figure 4b).

MS had the highest species richness, with an average of 8.67 species, which was significantly different ($p < 0.05$) from the species richness of both MM and DS. The species richness in MMS averaged 7.33 species and that in AM averaged 8 species; these differences were not significantly different from each other. MM (4.64 species) was significantly different ($p < 0.05$) from all other grassland types, apart from DS (5.62 species) and MMS, which were not significantly different ($p < 0.05$) (Figure 4c). Detailed results of the one-way ANOVA and multiple comparisons are presented in Tables S1–S3 of the Supplementary Materials.

3.3. Similarity between Grassland Types and Correlations between Species Diversity and Above-Ground Biomass

Based on the results of the correlation analyses shown in Figure 5, the correlations between above-ground biomass and various diversity indices of DS were significant ($p < 0.05$). Above-ground biomass showed highly significant positive correlations ($p < 0.01$) with the Simpson index and the Shannon–Wiener index. The correlations between the four indices were also strong, with the Shannon–Wiener index and the Simpson index having the strongest correlation coefficient of 0.983, which was highly significant ($p < 0.01$).

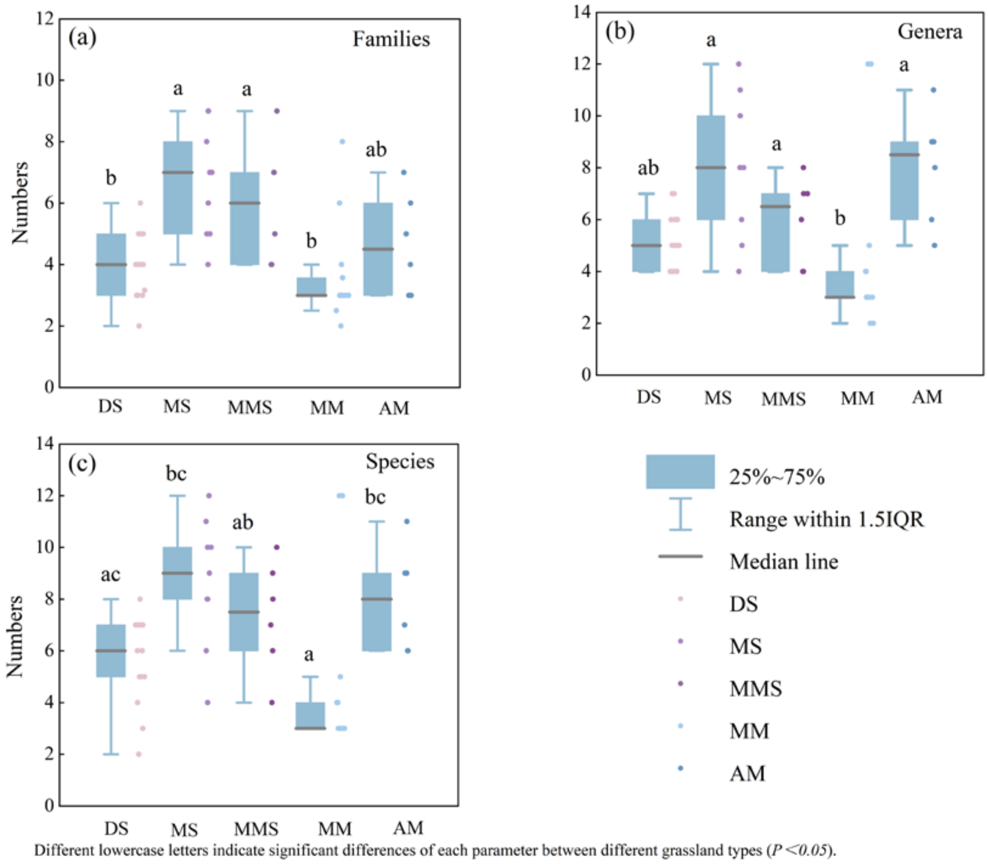

Figure 4. ANOVA between numbers of plant (**a**) families, (**b**) genera, and (**c**) species in grassland types in the Burqin region (China) (different lowercase letters indicate significant differences between the parameters in different grassland types).

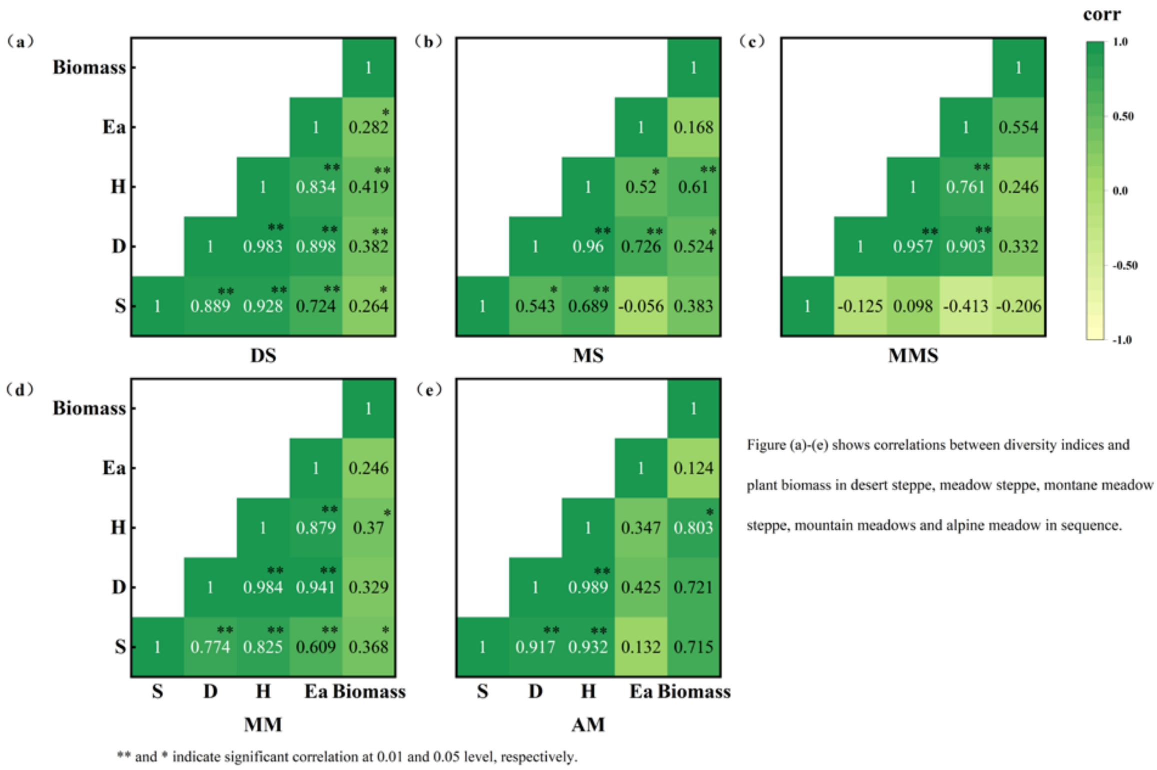

Figure 5. Correlations between diversity indices and plant biomass.

In MS, the Simpson index was highly significantly and positively correlated with Shannon–Wiener and Alatalo indices ($p < 0.01$). The Margalef index showed a highly significant positive correlation with the Shannon–Wiener index ($p < 0.01$) and a significant positive correlation with the Simpson index ($p < 0.05$). Above-ground biomass showed a significant positive correlation with the Simpson index ($p < 0.05$), a highly significant positive correlation with the Shannon–Wiener index ($p < 0.01$), and no significant correlation with the Margalef index or the Alatalo index.

In MMS, the Simpson, Shannon–Wiener, and Alatalo indices showed highly significant positive correlations with each other ($p < 0.01$). Above-ground biomass was not significantly correlated with any of the diversity indices.

In MM, the various species diversity indices were all highly significantly and positively correlated with each other ($p < 0.01$). Above-ground biomass was significantly positively correlated ($p < 0.05$) with the Margalef and Shannon–Wiener indices, but not with the Simpson and Alatalo indices.

Above-ground biomass of AM had a significant positive correlation with the Shannon–Wiener index ($p < 0.05$). The Alatalo index was not significantly correlated with above-ground biomass and other species diversity indices. The Simpson, Margalef, and Shannon–Wiener indices were highly significantly and positively correlated with each other ($p < 0.01$).

Table 1 shows that there are different degrees of similarity between different types of grassland communities. There was a very dissimilar relationship between DS and the other four grassland types, with similarity coefficients of 0.25–0.50. There were moderately dissimilar relationships between MS, MMS, and MM. The similarity coefficient between MS and AM was 0.19, indicating a very dissimilar relationship. The similarity between MMS and MM ranged from 0.25 to 0.50, showing a moderately dissimilar relationship. MMS and AM had a very dissimilar relationship, while MM and AM had a moderately dissimilar relationship.

Table 1. Intercommunity similarities between different grassland types in the Burqin forest area.

Similarity	DS	MS	MMS	MM	AM
DS	1.00				
MS	0.239	1.00			
MMS	0.093	0.382	1.00		
MM	0.171	0.378	0.363	1.00	
AM	0.185	0.185	0.165	0.355	1.00

3.4. Vertical Changes in Species Diversity and Above-Ground Biomass

Altitude determines the species composition and distribution of plant communities. As shown in Figure 6, above-ground biomass showed highly significant changes ($p < 0.05$) with increasing altitude from 1000–2400 m above sea level. Its correlation coefficient with altitude was 0.69 (Table 2). The elevation gradient shows an “S” pattern, with a decline followed by an increase and then another decline. The lowest values occur at 1400–1600 m and the highest values occur at an altitudinal gradient of 2000–2200 m.

Figure 6 shows that above-ground biomass does not vary consistently with species diversity. The species diversity of different grassland types also varied significantly with increasing elevation. Changes in diversity indices for each species in the grassland community were generally consistent, except for Margalef, which showed a unimodal relationship with elevation ($R^2 = 0.61$, $p < 0.05$). There was a 4-fold functional relationship with elevation, first increasing, then decreasing, and then increasing again. The peaks occurred at 1200–1400 m and 2100–2300 m above sea level. The peak in Margalef occurred at 1600–1900 m.

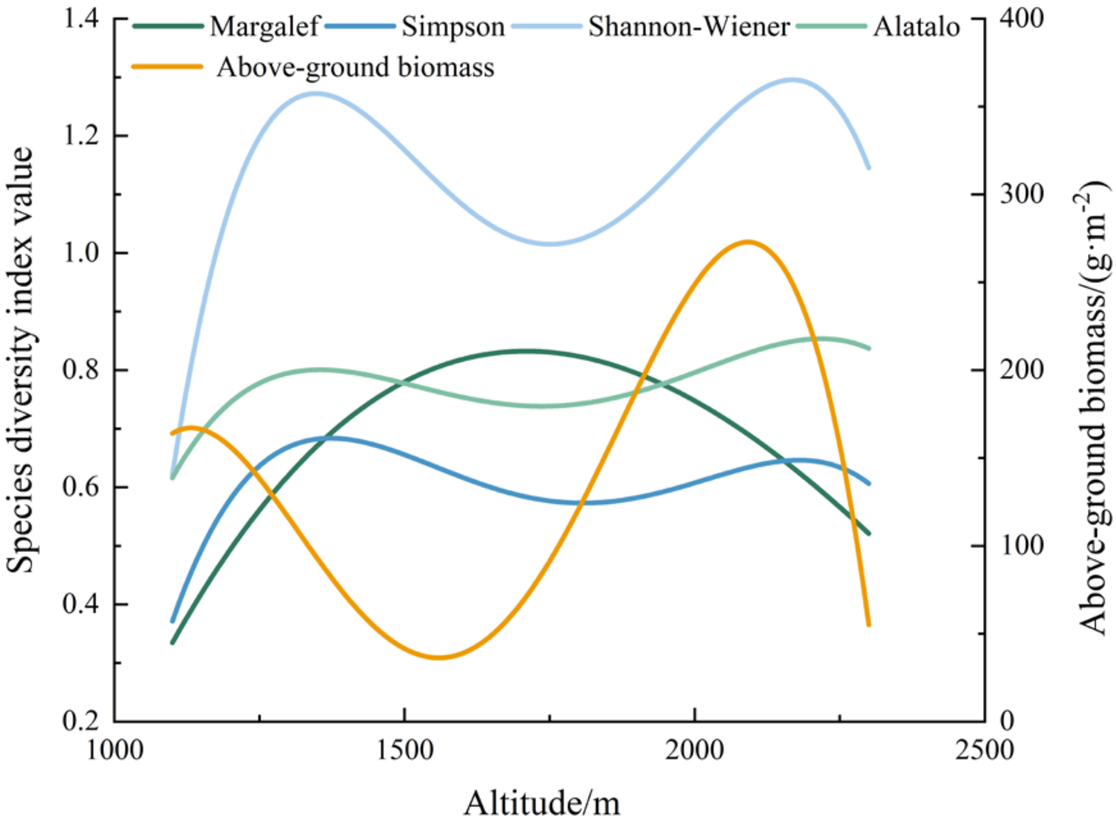

Figure 6. Species diversity indices and biomass in grassland communities at different altitudinal gradients.

Table 2. Fitting equations of species diversity and above-ground biomass on elevation gradient.

	Species Diversity Index and Above-Ground Biomass	Fitting Equations	Correlation (R^2)	Significance
Altitude	Above-ground biomass	$Y = -3.39 \times 10^{-9} x^4 + 2.16 \times 10^{-5} x^3 - 0.05 x^2 + 50.07 x - 18{,}061.95$	0.69	$p < 0.05$
	Margalef	$Y = 3.73 \times 10^{-10} x^3 - 3.02 \times 10^{-6} x^2 + 0.01 x - 4.28$	0.61	$p < 0.05$
	Simpson	$Y = -3.43 \times 10^{-12} x^4 + 2.45 \times 10^{-8} x^3 - 6.45 \times 10^{-5} x^2 + 0.07 x - 30.70$	0.58	$p > 0.05$
	Shannon–Wiener	$Y = -3.45 \times 10^{-12} x^4 + 6.64 \times 10^{-8} x^3 - 1.72 \times 10^{-4} x^2 + 0.19 x - 78.99$	0.69	$p < 0.05$
	Alatalo	$Y = -2.49 \times 10^{-12} x^4 + 1.76 \times 10^{-8} x^3 - 4.58 \times 10^{-5} x^2 + 0.05 x - 20.83$	0.71	$p < 0.05$

4. Discussion

4.1. Characteristics of Grassland Plant Species in Burqin

In the spatial distribution of grassland species, the pattern of species variation is not the same due to the geographical characteristics of the study area. The families, genera, and species in the Burqin grassland showed a trend of first rising, decreasing, and then rising again. The richness in the Horqin Sandy Land showed a trend of first declining and then increasing [29]. The results of this study are similar to those of other studies on the species composition of grasslands in Xinjiang [30], although the richness is somewhat different from that observed in this study. Species richness in the grassland in Burqin was significantly higher than the average species richness in the grassland in Xinjiang; a large part of the reason for this result was the effects of moisture and salinity. Low precipitation and high evaporation in the rest of Xinjiang cause salts to collect on the soil surface. This in turn affects plant growth and reduces the number of species in the community. The Altai Mountain region is influenced by the westerly wind-belt airflow, and the Altai Mountains play a role in blocking the uplift, hence precipitation is abundant [31]. Under moisture-sufficient conditions, species increase within the localized communities and interspecific mutualism, resulting in higher species richness in the grasslands of Burqin than in Xinjiang. A study of grassland richness in the Qinghai Lake basin [32] found that the mean species richness in alpine meadows was 5.5, while the species richness in alpine meadows in Altunshan was 3 [33]; both of these were lower than the richness in the Altai Mountains Burqin forest area. In comparison to the study of the Qilian Mountains [34], *Gramineae* and *Compositae* were the dominant families in the desert grassland of the Qilian Mountains, consistent with the findings in this paper. However, the alpine meadows of the Qilian Mountains have *Cyperaceae*, *Compositae*, and *Rosaceae* as the dominant families. The average species richness was 10, and the richness increased with the increase in altitude. This is somewhat different from the findings in this paper. Since the study area is from a different scale with different hydrothermal conditions, the mean annual precipitation and temperature in Burqin are less than in the Qilian Mountains, resulting in differences in the dominant families. The reason for the variations in abundance may also be due to anthropogenic causes such as grazing.

4.2. Similarities between Grassland Types and Correlations between Species Diversity and Above-Ground Biomass

The relationships between species diversity and biomass differed in different grassland types. Above-ground biomass was significantly positively correlated with various species diversity indices in desert grasslands. Studies in the mesothermal desert steppe area of Inner Mongolia also showed a linear positive correlation between species diversity indices and above-ground biomass [35]. The Shannon–Wiener index was influenced by both Simpson and Alatalo indices [36]. In the desert Steppe, the coefficient of correlation between the Shannon–Wiener index and the Simpson index was greater than that between the Shannon–Wiener index and the Alatalo index. This suggests that species richness contributes more to diversity in the desert steppe community in Burqin compared with the Alatalo index. The results of the study in the northeastern steppe belt [37] are similar to those reported in this paper. The main reason for this phenomenon is that in desert grasslands species are constrained by large-scale precipitation and there is less variation in species richness at small scales. Above-ground biomass was significantly and positively correlated with the Shannon–Wiener and Simpson indices in montane steppe communities. This finding is different from the results of other studies from the Altai region of Xinjiang, probably due to the different stages of grassland succession [36]. The successional model proposed by Guo suggests that species diversity and above-ground productivity are positively correlated in the early stages of succession [38]; above-ground productivity has a strong influence on species richness in the early successional period.

In montane meadow steppe, the Alatalo index had a highly significant positive correlation with the Simpson index. However, it was lower in the montane steppes, coupled with a relatively small number of plant species, with major species such as *Geranium wilfordii* (having taller plants, thicker rhizomes, and greater biomass). Thus, above-ground biomass was negatively correlated with the Simpson index but not with the other three diversity indices. In mountain steppes, the temperature decreases with increasing elevation. Despite the low interspecies competition, plants with thicker leaf textures and robust long root tubers, for example, *Imperata cylindrica,* were the dominant species. The effect of above-ground productivity on species specificity was weak due to temperature limitations. This is the main reason for the significant positive correlation between above-ground biomass and the Simpson index and the lack of correlation with the other species diversity indices. Above-ground biomass was significantly and positively correlated with the Shannon–Wiener index ($p < 0.05$) in alpine meadows. Studies in the Bayinbuluk alpine grassland [39] showed that there was a significant correlation between the Shannon–Wiener index and above-ground biomass, whereas there was no significant correlation between the Alatalo index and the

Simpson index. Community productivity declined as species diversity declined in Inner Mongolian needlegrass grasslands [40].

The similarities between grassland types in the Burzin forest area were low. The results showed great differences in community structure between different grassland types in the Burqin forest area. Altitude is the main factor affecting the differences between communities and, due to the large differences in spatial scale, the plant community structure and species composition also change, resulting in different community structures.

4.3. Characteristics of Elevational Changes in Species Diversity and Above-Ground Biomass

With the exception of the Margalef index, the overall species diversity of grasslands in the Burqin forest area showed an increasing, then decreasing, and then increasing trend with elevation. This is the same as that observed in the northern slopes of the Yili River Valley, where plant species diversity showed bimodal variation characteristics [41]. This variation may be due to the fact that moisture is more important at lower altitudes and temperature is more important at higher altitudes. In the Burqin area, desert grassland vegetation is found at an altitude of 1000–1400 m. With little precipitation and hot and dry summers, the grassland type becomes mountain grassland as the altitude rises. Although the climate is still arid, there is a significant improvement in thermal and hydrological conditions compared with desert steppe. The increase in the number of plant species able to grow and the increase in the richness index caused the first peak in the species diversity index of grasslands in the montane steppe of the Burqin forest area. Thereafter, as elevation increased, the grassland sequentially changed to montane meadow steppe and then to mountain meadows. The habitat gradually became unsuitable for plant growth and, together with the effects of summer pasture grazing, the community species diversity index declined. Plant photosynthetic capacity is limited at high altitudes in mountainous regions due to low temperatures. The above-ground portion of the site is growth-restricted, and competition between populations is not as intense as in the lower-elevation grasslands, although species diversity is higher. This may be the reason for the second peak occurring near mountain meadows versus alpine meadows.

Biomass did not vary consistently with species diversity, with the lowest values occurring between 1400 and 1600 m; this may be attributed to grazing [42]. The Burqin meadows set up summer pastures at mountain grassland elevations (1400–1600 m). Grazing alters the species composition of grassland communities [43]. As a result of grazing, mountain meadow grasslands are dominated by trampling-tolerant dwarf grasses, *compositae*, and *Ranunculaceae* plants. These plant species are more abundant but are shorter in appearance and have lower biomass. This may account for the inconsistency between the lowest biomass and the lowest species diversity index. Rainfall is higher at higher elevations in mountainous regions, resulting in higher water content in plants at that elevation. Higher elevations are inaccessible to livestock and are rarely affected by grazing. This may be the main reason why the highest biomass occurred at an altitude of 2100–2300 m.

5. Conclusions

In this study, the family, genus, and species composition of different grassland types were counted in a survey of different grassland types in the Burqin forest area. The interrelationship between species diversity and productivity was also analyzed, and the following conclusions were reached:

(1) Desert steppe has *Gramineae*, *Compositae*, and *Rosaceae* as the dominant families, and *Eleusine*, *Achillea*, and *Imperata* as the dominant genera. Montane steppe and mountain meadows have *Umbelliferae*, *Gramineae*, and Liliaceae as the dominant families, although these are present in different proportions. Montane steppe has *Eleusine*, *Taraxacum*, and *Hydrocotyle* as the dominant genera. Mountain meadows and montane meadow steppe have *Imperata*, *Geranium*, and *Ranunculus* as the dominant genera. Both montane meadow steppe and alpine meadows are dominated by *Gramineae*,

Ranunculaceae, and *Liliaceae*, although the dominant genera differ. *Convallaria*, *Ranunculus*, and *Eleusine* are dominant in alpine meadows.

(2) Variations in the numbers of plants at the family, genus, and species levels are characterized as montane steppe > alpine meadow > montane meadow steppe > desert steppe > mountain meadow.

(3) In DS and MM, the Margalef, Simpson, Alatalo, and Shannon–Wiener indices determine the biomass, and the number of grassland species affects the biomass. The biomass of MS and AM was determined using the Simpson and Shannon–Wiener indices. The number of dominant species determines the biomass of MS and AM. The number of grasslands and the number of species do not have a significant impact on the biomass of MMS, which may be due to human factors such as grazing. The similarity in species composition between different grassland types is low.

(4) The dominant species in the grassland at an altitude of 1200–1400 m is prominent. The number of individuals in the dominant species is large and evenly distributed. The Margalef index peaks at altitudes of 1600–1800 m, but the number of individuals is small, resulting in low biomass and diversity in this range. With the increase in altitude, the Simpson, Alatalo, and Shannon–Wiener indices and biomass peak at an altitude of 2000–2200 m, which is suitable for the survival of most plant species.

Most studies of grassland productivity and species diversity use remote sensing or statistical yearbooks. There are some errors in this estimation method, and the grassland species cannot be accurately identified by remote sensing, hence it is difficult to fully determine species diversity. In this study, field investigations and experiments were conducted to study the relationship between species diversity and productivity and the similarity between different grassland types. Species changes in grasslands at different altitudes were also considered to reflect the changes in environmental factors. The study of these issues can be used to assess the ecological benefits of natural grasslands in the Burqin forests.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/f14091829/s1. Table S1: ANOVA between number of plant families, genera and species in grassland types in Burqin region. Table S2: LSD Multiple Comparisons. Table S3: Descriptives.

Author Contributions: Conceptualization, M.Y.; data curation, X.P., X.G., G.Z. and Q.H.; investigation, X.P., X.G., W.C., X.X. and Q.H.; methodology, M.Y. and X.P.; software, M.Y. and X.P.; validation, M.Y. and X.P.; visualization, X.P., M.L., G.Z. and Q.H.; project administration, M.Y.; writing—original draft, X.P.; writing—review and editing, X.P., M.Y., W.C. and Q.H. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Ecological Monitoring Analysis of Altai Mountain State Forest Management Bureau (2021), grant No. 3010010251. National Natural Science Foundation of China, grant No. 42377449.

Data Availability Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Ye, X.; Zhou, H.K.; Zhao, X.Q.; Wen, J.; Chen, Z.; Duan, J.C. Review on grassland ecosystem health. *Pratacultural Sci.* **2011**, *28*, 549–560.
2. Gao, Q.H.; Qin, Y.Y.; Liang, M.C.; Gao, X. Interpretation of the Main Conclusions and Suggestions of IPCC AR6 Synthesis Report. *Environ. Prot.* **2023**, *51*, 82–84.
3. Deborah, S.; Valentin, H.K.; Till, K.; Boeddinghaus, R.S.; Hinderling, J.; Ellen, K.; Sven, M.; Sascha, N.; Llja, S.; Susanne, W.; et al. Recovery of Ecosystem functions after experimental disturbance in 73 grasslands differing in land use intensity, plant species richness and community composition. *J. Ecol.* **2019**, *107*, 2635–2649.
4. Hector, A.; Schmid, B.; Beierkuhnlein, C.; Calderira, M.C.; Diemer, M.; Dimitrakopoulos, P.G.; Finn, J.A.; Freitas, H.; Giller, P.S.; Good, J.; et al. Plant diversity and productivity experiments in European grasslands. *Science* **1999**, *1286*, 1123–1127. [CrossRef]

5. Du, G.Z.; Liu, Z.H. Relationship between species richness and productivity in an alpine meadow plant community. *Acta Agrestia Sin.* **2003**, *27*, 125–132.
6. Yang, L.M.; Zhou, G.S.; Li, J.D. Relationship between productivity and plant species diversity of grassland communities in Songnen plain of northeast China. *Acta Agrestia Sin.* **2022**, *26*, 589–593.
7. Frank, P.; Mikael, P.; Andrea, T.; Florian, A.; Roman, A.; Yves, C.; Fronhofer, E.A.; Pravin, G.; Aurélie, G.; Jason, I.; et al. Biodiversity increases and decreases ecosystem stability. *Nature* **2018**, *10*, 17.
8. Kirkman, K.L.; Mitchell, R.J.; Helton, C.R.; Drew, M.B. Productivity and Species Richness across an Environmental Gradient in a Fire-Dependent Ecosystem. *Am. J. Bot.* **2001**, *11*, 2119–2128. [CrossRef]
9. Yang, X.; Yan, X.H.; Li, M.H.; Tuo, X.X.; Zhang, B.; Wen, Z.M.; Li, W. The relationship between species diversity and aboveground productivity at temporal scale in Yunwushan typical grassland of Ningxia. *Acta Agrestia Sin.* **2022**, *30*, 259–268.
10. Jiang, F.Y.; Wei, X.T.; Kang, B.Y.; Shao, X.Q. Effects of warming on Alpine meadow diversity and primary productivity. *Acta Agrestia Sin.* **2019**, *27*, 298–305.
11. Wu, H.B.; Shui, H.W.; Hu, G.Z.; Wang, X.X.; Gan, Z.Z.B.; Yan, J.; He, S.C.; Xie, W.D.; Gao, Q.Z. Species diversity and biomass distribution patterns of alpine grassland along an elevation gradient in the Northern Tibetan Plateau. *Ecol. Environ. Sci.* **2019**, *28*, 1071–1079.
12. Jia, W.X.; Liu, Y.R.; Zhang, Y.S.; Cao, W.X. Species diversity and biomass of grassland steppe in Qinlian Mountains and their relationships with climate factors. *Arid Zone Res.* **2015**, *32*, 1167–1172.
13. Zhang, Y.; Zhao, J.L.; Xin, X.P.; Wang, M.; Pan, F.J.; Yan, R.R.; Li, L.H. Effects of stocking rate on the interannual patterns of ecosystem biomass and soil nitrogen mineralization in a meadow steppe of northeast China. *Plant Soil* **2021**, *5*, 1–23. [CrossRef]
14. Lu, H.; Cong, J.; Liu, X.; Wang, X.L.; Tang, J.; Li, D.Q.; Zhang, Y.G. Plant diversity patterns a long altitudinal Gradients in alpine meadows in the Three River Headwater Region, China. *Acta Agrestia Sin.* **2015**, *24*, 197–204.
15. Yin, X.K.; Ye, M.; Guo, J.X.; Zhang, K.L.; Zhao, F.F. Study on the relationship between species diversity and productivity of different grassland types in Buerjin forest area of Altai mountains. *J. Soil Water Conserv.* **2022**, *36*, 111–115.
16. Ma, J.J.; Liu, Y.H.; Sheng, J.D.; Li, N.; Wu, H.Q.; Jia, H.T.; Sun, Z.J.; Cheng, J.H. Changes of relationships between dominant species and their relative biomass along elevational gradients in Xinjiang grasslands. *Acta Prataculturae Sin.* **2021**, *30*, 25–35.
17. Li, Q.; He, G.X.; Liu, Z.G.; Guan, W.H.; Qiao, H.H.; Han, T.H.; Sun, B.; Pan, D.R.; Liu, X.N. Responses of vegetation Characteristics and Biodiversity to habitat in Alpine Meadows in Eastern Qi Lian Mountains. *Acta Agrestia Sin.* **2022**, *30*, 169–177.
18. Huang, J.H.; Lu, X.H.; Guo, Z.J. Service functions of the natural forest ecosystem in Burqin Forest Farm, Xinjiang. *Arid Zone Res.* **2014**, *31*, 866–873.
19. Huang, J.H.; Lu, X.H.; Guo, Z.J.; Wang, J.P.; Zang, R.G. Assessment of natural forest ecosystem services in Buerjin County, Xinjiang. *J. Beijing For. Univ.* **2015**, *37*, 62–69.
20. Zhang, F.; Liu, H.; Fang, Y.; Bai, Z.Q.; Ye, G.; Han, Y.L. Stand spatial structure of natural coniferous forest in the Altai Mountains of Xinjiang. *J. Anhui Agric. Univ.* **2014**, *41*, 629–635.
21. Zhang, D.L.; Li, Y.B.; Yang, Y.P.; Lan, B. Synthesized Climate Change in the North Altay Mountains in the Past 2000 Years. *Arid Zone Res.* **2019**, *36*, 176–185.
22. Xu, H.J.; Han, B.P. Main Soil Types and Soil Vertical Distribution in Altay Mountains Area, Xinjiang. *Chin. J. Soil Sci.* **2008**, *29*, 465–470.
23. Ma, K.P. Measuring methods of biodiversity i. Measuring methods of α diversity (part one). *Chin. Biodivers.* **1994**, *2*, 229–239.
24. Ma, K.P. Measuring methods of biodiversity i. Measuring methods of α diversity (part two). *Chin. Biodivers.* **1994**, *2*, 231–239.
25. Chen, B.; Ma, R.; Qin, J.H.; Sun, H. The Aboveground Biomass for Ecological Restoration of Highway Construction in the Zoige Wetland, NW Sichuan Province. *Hubei Agric. Sci.* **2015**, *54*, 4676–4681.
26. Zhang, J.L.; Shen, R.; Shi, W.; Liu, X.K.; Ou, X.K. The structure and similarity characteristic of the grassland community in hot-dry valley upper middle and lower of Jinsha River. *Ecol. Environ. Sci.* **2010**, *19*, 1272–1277.
27. Zhao, X.J.; Liang, Z.D.; Shao, L.J.; Zhao, X.F. Analysis and Evaluation on Nonlinear Regression Function of SPSS Software. *Stat. Decis. Mak.* **2021**, *23*, 20–22.
28. Luo, Y.; He, Y.B.; Li, D.Z.; Wang, Y.H.; Yi, T.S.; Wang, H. A Comparison of Classifications of Families of Chinese Vascular Plants among Flora Republicae Popularis Sinicae, Flora of China and the New Classifications. *Plant Divers. Resour.* **2012**, *34*, 231–238. [CrossRef]
29. Wang, M.M.; Liu, X.P.; He, Y.H.; Zhng, T.H.; Wei, J.; Che, L.G.M.; Sun, S.S. How enclosure influences restored plant community changes of different initial types in Horqin Sandy Land. *Chin. J. Plant Ecol.* **2019**, *43*, 672–684. [CrossRef]
30. Liu, L.L.; Sheng, J.D.; Cheng, J.H.; Liu, Y.H.; Li, R.X.; Zhao, D. Relationship between plant species characteristic sand climate factors in different grassland types of Xinjiang. *Acta Prataculturae Sin.* **2016**, *25*, 1–12.
31. He, B.; Wang, G.Y.; Su, H.C.; Shen, Y.P. Response of extreme hydrological events to climate change in the regions of Altay Mountains, Xinjiang. *J. Glaciol. Geocryol.* **2012**, *34*, 927–933.
32. Wu, Y.P.; Chen, K.L.; Zhang, F.; Cao, G.C.; Liu, Z.J.; Su, M.X. Relations between plant species richness and community productivity of typical grasslands in Qinghai Lake Basin. *Chin. J. Ecol.* **2011**, *30*, 1449–1453.
33. Sha, W.; Dong, S.K.; Liu, S.L.; Liu, Q.R.; Shi, J.B.; Li, X.W.; Su, X.K.; Wu, Y. Spatial patterns of plant community biomass and species diversity in Aerjin Mountain Nature Reserve and their influencing factors. *Chin. J. Ecol.* **2016**, *35*, 330–337.

34. He, M.Y.; Wang, Y.X.; Peng, Z.C.; Chang, C.H.; Saman, B.; Liu, Y.J.; Hou, F.J. Spatial pattern of aboveground biomass and species richness of Qilian Mountain grassland. *Pratacultural Sci.* **2020**, *37*, 2012–2021.
35. Sun, X.L.; Kang, S.L.R.; Zhang, Q.; Chang, C.M.; Ma, W.J.; Niu, J.M. Relationship between species diversity, productivity, climatic factors and soil nutrients in the desert steppe. *Acta Prataculturae Sin.* **2015**, *24*, 10–19.
36. Guo, Z.G.; Liang, T.G.; Liu, X.Y.; Zhang, H.J. Species diversity of grassland communities in the Aletai region of the northern Xinjiang province, Acta Bot. *Occident. Sin.* **2003**, *10*, 1719–1724.
37. Yang, L.M.; Han, M.; Li, J.D. Plant diversity change in grassland communities along a grazing disturbance gradient in the northeast China transect. *Chin. J. Plant Ecol.* **2001**, *25*, 110–114.
38. Guo, Q.F. Temporal species richness-biomass relationships along successional gradients. *J. Veg. Sci.* **2003**, *14*, 121–128. [CrossRef]
39. Liu, Y.Y.; Hu, Y.K.; Wang, X.; Gong, Y.M. Vertical differentiation of plant species diversity and biomass in alpine grassland in the middle section of Tianshan Mountains southern slope, Xinjiang of Northwest China. *Chin. J. Ecol.* **2013**, *32*, 311–318.
40. Bai, Y.F.; Li, L.H.; Huang, J.H.; Chen, Z.Z. The influence of plant diversity and functional composition on ecosystem stability of four Stipa communities in the Inner Mongolia Plateau. *Acta Bot. Sin.* **2001**, *43*, 280–287.
41. Tian, Z.P.; Zhuang, L.; Li, J.G. The vertical distribution of vegetation patterns and its relationship with environment factors at the northern slope of Ili River Valley: A bimodal distribution pattern. *Acta Ecol. Sin.* **2012**, *32*, 1151–1162. [CrossRef]
42. Lang, P.; Wang, Y.H.; Xu, H.L.; Zhao, W.Y.; Liu, X.H.; Jinesibieke, M.; Hlehashi, S.; Kulishayila, W. Effects of grazing prohibition years on community characteristics and soil factors in temperate desert grassland. *Pratacultural Sci.* **2022**, *39*, 431–442.
43. Zhang, Y.J.; Zhu, J.T.; Shen, R.N.; Wang, L. Research progress on the effects of grazing on grassland ecosystem. *Chin. J. Plant Ecol.* **2020**, *44*, 553–564. [CrossRef]