Topographic factors drive natural understory revegetation in burned areas

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Abstract

Background: In nature, fire is an important disturbance in forest ecosystems and has important impacts on vegetation succession. To reveal the characteristics of natural understory revegetation after burning and its response to environmental factors, we studied burned areas in a subtropical climate (Xide County, China).

Results: Based on quadrat surveys and correlation analyses, the main results of this study were as follows. (1) Within four months after a fire, 71 species, 52 genera, and 20 families gained, representing rapid recovery after a fire. (2) The Shannon-Wiener, Simpson, and Margalef indexes increased with recovery, whereas the Pielou index decreased; the Margalef index was the most sensitive, increasing by 5.44 and 5.16 in lightly and severely burned areas, respectively. (3) The community stability was relatively low at the initial stage of revegetation and tended to increase with the intensity of the fire. (4) Elevation and slope were the main physical factors affecting the biodiversity indexes and distribution.

Conclusions: This study could help us to understand the relationships between revegetation and topographic factors in burned areas, thereby providing a scientific basis for related ecological restoration.

1 Background

Forests are the most widespread terrestrial biome, comprise an important part of the biosphere, and help maintain the Earth's ecological balance (Atul et al. 2015). Forests have complex structures and diverse functions and are subject to frequent disturbances by natural and man-made factors (Atul et al. 2015). One type of disturbances, forest fires, can be destructive but also serve as an important factor triggering forest secondary succession, increasing the heterogeneity of forest structures and promoting nutrient and material recycling (Fulé et al. 2004).

The severity of forest fires and subsequent recovery time have profound impacts on the richness and dominance of species in burned areas, and revegetation succession in burned areas is a complex process involving both positive and negative feedbacks (Liu et al. 2009). The composition of understory communities can differ following fires, and species diversity and alien species often increase (Evgeniya et al. 2008; Keeley et al. 2003; Hart et al. 2008). The climatic, topographical, and soil factors of burned areas strongly impact succession and revegetation after fires. Climate could affect the post-fire revegetation through altering competition. For example, when climatic conditions have a negative impact on one species and their impact on another species is neutral, then this differential impact could alter the competitive balance between the species (Johnson et al. 2017; Kemp et al. 2019; Meng et al. 2015).

As for topography, the regeneration probability of seedlings at low elevations in burned areas decreases with climate warming (Johnson et al. 2017; Kemp et al. 2019; Meng et al. 2015). Topographic factors are particularly important for the restoration of forest vegetation in burned areas because they affect the distribution of light, heat, and water. Canopy height, breast height, and maximum diameter after fires vary with the slope aspect, terrain, elevation, and stand age (Kong et al. 2004). The higher the elevation, the
poorer the soil and the more exposed vegetation is to wind, perhaps resulting in a decrease in the height of vegetation (Takaoka et al. 1996), as well as differences in community structures and species diversity (Bai et al. 2013). Plant growth is also closely related to soil characteristics. Fire directly causes the loss of soil minerals and significantly reduces the contents of nitrogen, phosphorus, and potassium. The loss of carbon mainly occurs in upper soil layers. Repeated burning of biomass on the ground of burned areas reduces the input of organic matter into the topsoil and forms a water-repellent soil layer, resulting in significant changes in soil structure and nutrient balance (Zhang et al. 2020). Soil microorganisms are sensitive to high temperatures, and soil respiration is lower when microbial biomass decreases (Sirin et al. 2020; Devanshi et al. 2021; Gorbunova et al. 2014).

The characteristics of natural succession and artificial restoration of vegetation in burned areas are commonly explored with two approaches, i.e., spatial zonation and time sequences. After a fire disturbance, the similarity of the shrub layer between differently burned areas is significantly higher than that of the herb layer, yet the similarity is high for herb layers in areas that have little time difference between fire occurrences (Schoennagel et al. 2004). When artificially intervening with different burn schedules, the vegetation renewal of moderately burned areas may reach expected goals earlier than for the natural renewal of burned areas (Wang et al. 2004). The succession of soil biomass and composition is also related to the duration after a fire and the original soil stoichiometry. The soil nutrient contents tend to decrease with increasing soil depths and directly affect revegetation processes following burns (Guo 2001; Yang et al. 2020; Zhe et al. 2019).

The study of topographic factors on natural revegetation in burned areas frequently uses a qualitative analysis; a further quantitative analysis of topographic factors is needed. Investigations are also needed at different burn intensities and areas burned at different times or by different manners. The burned areas in a mountainous region with subtropical climate were selected as the research areas for this study. Quadrat surveys were utilized to collect related data and the relationships between vegetation properties and environmental factors were quantified with correlation methods. The objectives of this study were as follows: (1) to explore patterns of succession and revegetation after burning, and (2) to identify the relationships between understory vegetation regrowth and topographical factors in burned areas. This study could elucidate response patterns of the understory vegetation in the burned areas following a forest fire disturbance and provide support for ecological restoration in burned areas.

2 Methods

2.1 Study area

The study area was located at the burned sites in Xide County (102°12′ − 102°16′N, 28°12′ − 28°14′E), which is characterized by a subtropical climate. The study area is highly diverse in terms of topography, slope and forest coverage. Climatic conditions are characterized by concentrated rainfall and large evaporation in the area. Both natural and human dimensions lead to the frequent occurrence of fires in this area, thus impacting forest production and resident well-beings. Compared with the other fire-prone
areas, the terrain and climate were quite different (Fig. 1). The forest fire occurred in this area on May 7, 2020. This burned area was dominated by Pinus densiflora Sieb. et Zucc. The mountains are steep with many gullies and cliffs, the average slope is over 40°, and the soil moisture content is low. These characteristics facilitate the rapid spread of forest fires.

### 2.2 Data sources

Due to the characteristics as described above, annual plants were dominant and the understory vegetation was rare in winter and spring. There was no significant difference in vegetation among different burn intensities. In this study, two surveys were conducted in the burned areas during the growing season. A total of 26 shrub quadrats (5 × 5 m) and a total of xx herb quadrats (1 × 1 m) were selected. The type, quantity, plant height, and coverage of herbaceous and shrub vegetation (vertical projection area of vegetation / quadrat area × 100%) in the quadrat were recorded. The first survey was conducted 51 days after the fire, and the second survey 171 days after the fire. The categories of the burn intensities in the study areas were classified according to the mortality rate of trees per quadrat (Fuju et al. 2005), and thus the quadrats were divided into seven subquadrats with light burn (the mortality rate of trees ≤ 30%), six subquadrats with moderate burn (30% < the mortality rate of trees < 70%), and 13 subquadrats with severe burn (the mortality rate of trees ≥ 70%) (Fuju et al. 2005).

### 2.3 Importance value and biodiversity index

The importance value (Iv) is a composite measure representing the relative importance of plant species in a community. The dominant shrub and herbaceous plant species in a quadrat was obtained through calculating and comparing the importance value (Iv) (Jin-tun 1995):

\[
Iv = (Dr + Fr + Pr) / 3 \tag{1}
\]

where Dr is relative abundance, Fr is relative frequency, and Pr is relative coverage.

A biodiversity index is a simple numerical value indicating the degree of species diversity in a community, which indicates the stability of communities or ecosystems (Vajari et al. 2011).

The Shannon-Weiner index (H') is one way to reflect the diversity of communities:

\[
H' = -\sum (P \log_2 P) \tag{2}
\]

The Pielou index (E) reflects the evenness of communities:

\[
E = H' / \ln S \tag{3}
\]
The Simpson index ($D$) represents dominance: the larger the index value, the lower the species dominance:

$$D = 1 - \sum P_i^2$$  \hspace{1cm} (4)

The Margalef richness index ($Ma$) refers to the number of species in a community or environment:

$$Ma = (S-1)/\ln N$$  \hspace{1cm} (5)

For these indices, $P_i$ is the proportion of individuals of $i$ species in the community, $S$ is the total number of species, $n$ is the number of individuals of the $i$ species, and $N$ is the number of individuals of all species.

### 2.4 M. Godron stability

The M. Godron stability was discovered by ecologists from industrial production and introduced into plant ecology research (M.Godron et al. 1971). It is calculated from the number of all species in a plant community and the frequency of these species. According to Zheng’s improvement of the M. Godron stability model (Zheng 2000), the analysis steps are as follows:

1. Convert the frequency of all plants into the quadrat to relative frequency.
2. Sort relative frequency from largest to smallest, then cumulate them.
3. Calculate the reciprocal of the total number of plant species in each quadrat and gradually cumsum according to the order of plant species to correspond the cumulative value of relative frequency. A plot based on cumulative relative frequency then fits a curve ($y = ax^2 + bx + c$). The corresponding results reflect how many percentages of species occupy how much cumulative relative frequency.
4. The intersection point of the straight line $y = 100 - x$ is the intersection point coordinate.
5. The closer distance of the intersection coordinates ($x, y$) to the stable point (20, 80), the more stable the quadrat.

The close distance of the intersection coordinates to the stable points represents that the composing proportion of species in the equilibrium community is close to the counterparts in the present situation, indicating that the community is at a stable state. The theoretical basis of this method has been described in detail by (Godron et al. 1971).

### 2.5 Correlation analysis

We used the SPSS 22.0 software to analyze the correlation of diversity indices with elevation, slope, and soil properties for October 2020 data. This analysis could reflect the effects of the environmental factors on vegetation composition in the burned areas.
2.6 Detrended canonical correspondence analysis (DCCA)

DCCA is a multivariate analysis technique analyzing the relationships between various environmental factors and vegetation (He et al. 2019; Wang et al. 2009). The environmental factors here included elevation, slope, aspect, and slope position. The slope position was quantified by assigning 1, 2, 3, 4, and 5 to the bottom, downhill, mid-slope, uphill, and top of the slope, respectively; the larger the number, the higher the slope position. The slope aspect was based on due west as the starting point (0°). The original value of the aspect could not directly represent the degree of sun exposure, so each aspect was represented by the assignment of a categorical number. Zero represented north slope (67.15°–112.15°), 1 represented the northeast slope (112.15°–157.15°) and the northwest slope (22.15°–67.15°), 2 represented the west slope (317.15°–22.15°) and the east slope (157.15°–202.15°), 3 represented the southwest slope (292.15°–317.15°) and the southeast slope (202.15°–247.15°), 4 represented the south slope (247.15°–292.15°). The larger the number, the drier and hotter the conditions (Yang et al. 2000).

3 Results

3.1 Vegetation during the growing season

3.1.1 The composition of vegetation

The first survey showed that there were 24 families, 33 genera, and 34 species of herbs and shrubs; the ratio of families, genera, and species was 1:1.37:1.41. The second survey revealed that there were 44 families, 85 genera, and 105 species of herbs and shrubs; the ratio of families, genera, and species was 1:1.9:2.4, and the ratio of genera and species was 1:1.23. The herb layer was dominated by Asteraceae and Gramineae, accounting for 21% and 12% of the herb species. There were more 71 species, 52 genera, and 20 families in the second survey than in the first survey.

The species with the importance values of over 0.1 and 0.05 for shrubs herbs were considered as dominant species. The importance values of dominant species were shown in Fig. 2. In the second survey, there were four dominant shrubs and five dominant herbs. The importance value of *Quercus guyavaefolia* (*Qg*) in the shrub layer was 0.49, accounting for 31% of the total number of individuals—it was the primary dominant shrub species. *Leptodermis potanini* (*Lp*), *Machilus pingii* (*Mp*), and *Vaccinium fragile* (*Vf*) had the values of 0.11, 0.11, and 0.1, respectively, and functioned as secondary dominant species. The important values of *Rabdosia adenantha* (*Ra*), *Elsholtzia rugulosa* (*Er*), and *Monogramma trichoidea* (*Mt*) were 0.08, 0.07, and 0.07, respectively, so they were primary dominant herb species. *Artemisia argyi* (*Aa*) and *Cymbopogon goeringii* (*Cg*) had the importance value of 0.05, suggesting they were secondary dominant herb species.

Four months after the fire, the importance value of the main dominant species of *Qg* increased from 0.49 to 0.69, and the importance value of *Lyonia ovalifolia* (*Lo*) decreased and became a subdominant species. The emergence of four additional secondary dominant species indicated that the dominant
shrub species had undergone obvious changes. A similar phenomenon also appeared at the herb layer, leading to obvious changes in the dominant species. The importance value of the dominant species *Mt* decreased from 0.22 to 0.07, and the importance value of *Paspalum paspaloides* (Pp), *Tripogon chinensis* (Tc), and *Potentilla leuconota* (Pl) decreased and broke away from the ranks of the dominant species.

### 3.1.2 Species diversity indices

Results of the first survey showed that the Margalef index decreased with increasing fire. The Simpson index was highest in the moderately burned areas (0.91), followed by the lightly burned areas and the severely burned areas. The Pielou index was highest in the severely burned areas (0.13), followed by lightly burned areas and severely burned areas. The Shannon-Weiner index was the lowest in moderately burned areas (0.31), followed by lightly burned areas and severely burned areas. Except for the Simpson index of moderately and severely burned areas (%0.05), there was no significant difference among biodiversity indices of different burn intensity areas (%0.05).

According to the second survey results, the Shannon-Weiner index and the Pielou index increased with increasing fire (Figs. 3). There were significant differences between lightly burning and the other two burnings for the Shannon-Wiener index (%0.05). The Simpson index was highest in the lightly burned areas, followed by the severely burned areas and the moderately burned areas (Fig. 3). The Margalef index was highest in lightly burned areas (10.08), followed by severely burned areas and moderately burned areas (8.09 and 6.41, respectively) (Fig. 3), and there was a significant difference between lightly and moderately burned areas (%0.05). The maximum values of the Shannon-Wiener index and Pielou index appeared in quadrat S5, which belonged to a severely burned area. After the fire, due to fewer competing species, the herbaceous vegetation quickly recovered, and the total number of individual plants was as high as 405. The maximum values of the Simpson index and Margalef index were in lightly burned quadrats L7 and L6 (0.92 and 4.67, respectively). Since these areas were burned at a low level, most of the vegetation was not burned, and the damage to the community structure was low. As a result, the dominant species of vegetation did not change obviously. The minimum value of the Margalef index was 2, which appeared in quadrat S5, a severely burned area. This quadrat was dominated by fast-growing herbs and shrubs. Although the total number of individual plants was high, there were only 13 species.

The comparison of data from the two survey periods showed that the Margalef index in burned areas increased with increasing fires in October. Among them, the increases in lightly burned areas and severely burned areas were the most obvious (%0.05), increasing by 5.44 and 5.16, respectively. Accordingly, the numbers of species and individuals recovered and increased quickly. The increase in vegetation was concomitant with a decrease in dominant species, significantly decreasing the Shannon-Wiener index and Pielou index (%0.05), and increasing the Simpson index.

### 3.1.3 Stability analysis
The stability measurements of the first survey on June were presented in Fig. 7. The stability fitting curve of the lightly burned areas was \( y = -0.0015x^2 + 1.0647x + 7.5858 \) \((R^2 = 0.99)\), the coordinate of the intersection point was (46.2, 53.8), and the distance to the stable point (20, 80) was 37.05. The stability fitting curve of the moderately burned areas was \( y = -0.0059x^2 + 1.5729x + 1.3283 \) \((R^2 = 0.99)\), the coordinate of the intersection was (42.4, 57.6), and the distance to the stable point (20, 80) was 31.68. The stability fitting curve of the severely burned areas was \( y = -0.0021x^2 + 1.1234x + 7.6974 \) \((R^2 = 0.99)\), the coordinate of the intersection was (45.6, 54.3), and the distance to the stable point (20, 80) was 36.27. The stability of moderately burned areas was highest and that of lightly burned areas was lowest.

The stability measurements of the second investigation on October were shown in Fig. 7. The stability fitting curve of the lightly burned area was \( y = -0.0092x^2 + 1.7693x + 10.087 \) \((R^2 = 0.99)\), the coordinate of the intersection (37.2, 63.1), and the distance to the stable point (20, 80) was 24.11. The stability fitting curve of the moderately burned area was \( y = -0.0105x^2 + 1.9195x + 7.2274 \) \((R^2 = 0.98)\), the coordinate of the intersection (36.5, 63.7), and the distance to the stable point (20, 80) was 23.19. The stability fitting curve of the severely burned areas was \( y = -0.0116x^2 + 2.0278x + 8.579 \) \((R^2 = 0.99)\), the coordinate of the intersection was (35.1, 65.2), and the distance to the stable point (20, 80) was 21.14. The overall community stability in descending order was severely burned areas, moderately burned areas, and lightly burned areas.

Two surveys showed that the vegetation of the severely burned areas and the moderately burned areas quickly recovered within a short period after the fire, and the stability of individual quadrats was significantly improved. However, the intersection of the stability curve for each burned area and the standard line was far from the stable point (20, 80) so that the community stability at the early stage of vegetation restoration was relatively low in this research area.

### 3.2 Correlations between vegetation diversity and environmental factors

Elevation was positively correlated with the Shannon-Wiener index (0.621, \(P < 0.001\)) and Pielou index (0.624, \(P < 0.001\)), whereas elevation was negatively correlated with the Margalef index (-0.628, \(P < 0.001\)) and the number of species (-0.616, \(P < 0.001\)) (Table S1). With the increase of elevation, only the species with strong tolerance and fast growth rates survived in the successional process; as such, species uniformity in these higher elevation quadrats increased. As the elevation increased, the Shannon-Wiener index and Pielou index of herbs and shrubs gradually increased, while the Margalef index gradually decreased. The fitted straight lines, respectively, were \( y = 0.0003x - 0.2902 \) \((R^2 = 0.3529)\), \( y = 0.0002x - 0.2697 \) \((R^2 = 0.4566)\), and \( y = -0.0071x + 18.921 \) \((R^2 = 0.6021)\). Fitting straight lines were successful (Fig. 5). This showed that elevation was an important factor affecting the diversity of understory vegetation, and vegetation diversity showed regular changes with elevation.

The slope had a significantly negative correlation with the Shannon-Wiener index (-0.482, \(P < 0.05\)) and the total number of individuals (-0.435, \(P < 0.05\)), and the slope showed a significantly positive correlation
with the Simpson index (0.48, \( P < 0.05 \)). Soil moisture showed a significantly positive correlation with the Simpson index (0.39, \( P < 0.05 \)) and a significantly negative correlation with the Simpson index (-0.43, \( P < 0.05 \)); the soil temperature showed a significantly positive correlation with the total number of individuals (0.392, \( P < 0.05 \)) (Table S1). The wetter the soil was, the lower the dominance of certain species was.

### 3.3 The relationship between vegetation and topographical factors

Vegetation was divided into five categories according to the environment (Fig. 6). The sum of the eigenvalues of the first two axes of DCCA accounted for 61.09\% (> 50\%) of the total eigenvalues. The characteristic value of the first axis was 0.36 and showed a significantly positive correlation with slope position and elevation, a positive correlation with slope direction, and a negative correlation with slope. Along the direction of the first ordination axis, the vegetation survival presented a gradient that shifted to high elevation and damp and cold directions, which mainly reflected the changing trend of elevation. The characteristic value of the second ordination axis was 0.21 and showed a positive correlation with slope, slope position, and aspect, and a weak negative correlation with elevation. Along the second ordination axis, the vegetation survival presented a trend of water and heat conditions that changed to steep (dry), sunny (warm), and uphill (dry) directions. Based on the angle between each environmental factor and the ordination axis, elevation was the most important environmental factor affecting the distribution of vegetation in burned areas.

The vegetation types I, II, and V were in the second and third quadrants of the ordination graph, and the vegetation types III and IV were in the first and fourth quadrants of the ordination graph. The type I vegetation appeared on the downslope of steep and shady slopes at low elevations, and its environment was characterized as being shady and dry. The vegetation of types II and V appeared on the downhill slopes of gentle and shady slopes at low elevations, and their environment was shady and wet. The vegetation of type III occurred on the downhill parts of gentle, sunny slopes at low elevations, and its environment was warm and wet. The vegetation of type IV was found on the upper slopes of gentle and sunny slopes at high elevations, and its environment was warm and dry.

### 4 Discussion

#### 4.1 The influence of fire on the stability of communities

The relationship between species diversity and stability is not a simple linear relationship (Poudel et al. 2019; Thibaut et al. 2013). The results of the first survey showed that the species diversity in the burned areas was in the order: lightly burned > moderately burned > severely burned, whereas the species stability was in the order: moderately burned > severely burned > lightly burned. The results of the second investigation showed that the species diversity of the burned areas was in the order: lightly burned > severely burned > moderately burned, while the species stability was in the order: severely burned > moderately burned areas > lightly burned. After the fire disturbance, a large amount of vegetation was
burned, and gaps were created for new plant growth. The nutrient resources and space resources available for the new vegetation greatly increased, especially in severely burned areas. Fast-growing vegetation colonized rapidly, improving the stability of severely burned areas. Because the vegetation was dominated by fast-growing vegetation, the species richness was low. Therefore, although severely burned areas had the highest stability, their species diversity was lower than lightly burned areas (Xie et al. 2005).

We found that the intersection of the community stability curve and the standard line in each burned area was distant from the stable point (20, 80). The species of the quadrats hid not form stable interspecific relationships, the community structure was unstable, and the species composition and quantity were still variable. The competition among species was intensified after the fire and the community structure changed accordingly, improving the stability of the communities (Thibaut et al. 2013). Due to the dry climate and complex topography in the study region, the factors of interest were quite different from those in other burned areas. Our results were not consistent with previous findings that the greater species diversity and the more complex community structure, the higher stability of the community (Ives et al. 2007; Loreau et al. 2013). Due to the short survey period in our research, the changes in community stability might not be fully reflected.

4.2 The impacts of other factors on vegetation restoration in burned areas

The speed and duration of the secondary succession of the burned areas depend on the timing and intensity of the fire. The more severe the fire, the longer the succession duration and the slower the revegetation (Wonkka et al. 2018). Environmental factors also had a significant impact on the rate and distribution of natural vegetation regrowth. Previous studies have showed that elevation and slope are the main influencing factors (Dolezal et al. 2002; Wonkka et al. 2018; Zhao et al. 2005). With the increase in elevation and slope, the drainage conditions of the soil become better, the soil water tends to be lower, the soil layers become thinner, water and soil erosion is greater, and vegetation is affected by wind stronger. These conditions are not suitable for vegetation growth, declining vegetation diversity, and only those species with high tolerance can thrive. Soil moisture, temperature, and pH affect soil nutrients essential for vegetation, which in turn affects species diversity and distribution (Ozkan et al. 2009). Due to lower canopy coverage and higher light intensities for understory vegetation, fewer nutrients and space resources can be utilized by trees but understory vegetation can grow faster and develop better (Gilliam 2019; Shirima et al. 2016).

Additionally, changes in nitrogen, phosphorus, and potassium in the soil have an important impact on the growth and development of understory vegetation (Granged et al. 2011). In the process of ecosystem recovery, the succession of vegetation and soil occur simultaneously. The succession of community not only reflects the changes in the species compositions and community structures of vegetation itself, but also does the changes in habitats, especially in the soil environment. Therefore, the synergistic coupling between vegetation succession and soil succession should be further considered in the future studies, which is of great significance for ecological reconstruction and vegetation ecological restoration.
4.3 Revegetation in burned areas by artificial intervention

Due to the death of trees following the fire, various nutrient resources and spaces increase, and more light is available for seed germination, resulting in the rapid emergence of herbs and shrubs (Zhang and Dong 2009). The dominant species at the initial stages following the fire were largely herbs, among which Asteraceae and Gramineae were common. There were fewer shrub seedlings, and the species diversity of the herb layer was significantly higher than that of the shrub layer (Poudel et al. 2019). The rapid growth of herb vegetation usually leads to intensified interspecific competition. The soil and overall ecological structure are improved after fires (Lohbeck et al. 2015). However, because of the dominance of one or a few herb species, natural regeneration and positive vegetation succession are limited. Manual intervention may be needed to facilitate regrowth in the burned areas. In the process of artificially intervening vegetation restoration, more attention is needed to soil and water conservation and vegetation diversity. The restoration of natural vegetation can be accelerated through artificial measures such as seed reproduction and vegetative reproduction. The restoration of shrubs may be particularly important (Schoennagel et al. 2004) and it is necessary to consider the influence of environmental factors, such as elevation and slope. For example, it may be optimal to carry out restoration projects on gentle and shady downhill slopes at low elevations. According to the different degrees of fire damage, corresponding restoration measures should be adopted to save costs while optimizing ecological structure and function (Li et al. 2006).

5 Conclusions

In October 2020, there were 105 species, 85 genera, and 44 families of herbs and shrubs. The species diversity of herbs was significantly higher than that of shrubs, with an increase of 71 species, 52 genera, and 20 families four months following fires. The total genera and species increased significantly by 157% and 209%, respectively, after a short period of vegetation restoration. With the increase of fire severity, the stability of the community gradually increased, the Shannon-Wiener index and Pielou index increased, and the Simpson index decreased. The Margalef index was in the order: lightly burned areas > severely burned areas > moderately burned areas. The Shannon-Wiener index, Simpson index, and Margalef index increased, while the Pielou index decreased significantly.

Elevation and slope were the main topographic factors that affected the herb and shrub diversity in the burned areas. The Shannon-Wiener index and the Pielou index increased with the increase of elevation and slope, while the Margalef index decreased. The DCCA sequence diagram showed that the vegetation of the burned areas was distributed regularly during the half-year restoration period, and the vegetation succession mainly occurred in the gentle and shady slope at low elevations, where rainfall is adequate and the climate is humid.

Abbreviations
H: The Shannon-Weiner index; E: The Pielou index; D: The Simpson index; Ma: The Margalef richness index; Qg: Quercus guyavaefolia H. Leveille; Lp: Leptodermis potanini Batalin; Mp: Machilus pingii Cheng ex Yang; Vf: Vaccinium fragile Franch; Ra: Rabdosia adenantha (Diels ) Hara; Er: Elsholtzia rugulosa Hemsl; Mt: Monogramma trichoidea J. Sm; Aa: Artemisia argyi H. Lév. & Vaniot; Cg: Cymbopogon goeringii (Steud.) A. Camus; Lo: Lyonia ovalifolia (Wall.) Drude var. elliptica Hand.-Mazz; Pp: Paspalum paspaloides (Michx.) Scribner; Tc: Tripogon chinensis (Franch.) Hack; Pf: Potentilla leuconota D. Don

Declarations

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Availability of data and materials

The datasets generated and/or analysed during the current study are not publicly available due [REASON WHY DATA ARE NOT PUBLIC] but are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

All authors read and approved the final manuscript.

Consent for publication

All authors read and approved the Final manuscript.

Competing interests

The authors declare that they have no competing interests

References


**Figures**
Figure 1

Study area
Figure 2

Importance value of dominant species

[Bar chart showing the importance value of dominant species for June and October, with species listed as Qg, Ld, Vf, Mc, Lp, Mt, Pp, Pl, Tc, Ra, Aa, Er, Cg, categorized as shrub and herb.]
Figure 3

The Species diversity indices among different burn intensities (The error bar is the standard deviation. Different lowercase letters indicate significant difference, $P < 0.05$)
Figure 4

The stability results of survey

Figure 5
Relationship between biodiversity index and elevation

Figure 6

The DCCA sorting of vegetation and topographical factors. The larger the number which represent the number of species in similar environmental conditions, the larger the circle. The large ovals represent five groups of species found in similar environmental conditions. ( (): the first group vegetation. ( (): the second
group vegetation. The third group vegetation. The fourth group vegetation. The fifth first group vegetation.

**Supplementary Files**

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