Responses of Natural Revegetation to Topographic Factors in Burned Areas

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Abstract

Background

Fire is an important disturbance of forest ecosystems and has important impacts on the subsequent succession of vegetation. To reveal the characteristics of natural understory revegetation and its response to environmental factors in burned areas, we studied a mountainous region with a subtropical climate (located in Xide County, China).

Results

Based on quadrat surveys and correlation analysis. the main results of this study were as follows. (1) Within four months after a fire, a total of 71 species, 52 genera, and 20 families of vegetation were found, representing significant increases from the first to second sampling periods. (2) The Shannon-Wiener, Simpson, and Margalef indexes increased between sampling periods, whereas the Pielou index decreased. The Margalef index had the most obvious change, increasing by 5.44 and 5.16 in lightly and severely burned areas, respectively. (3) The vegetation community stability in burned areas was low at the initial stage of revegetation. It tended to increase with the intensity of the fire that had affected a given sampling area. (4) Elevation and slope were the main physical factors affecting the vegetation biodiversity indexes and distribution. (5) The regrowth of understory vegetation was optimal in the gentle, shady slopes at low elevations.

Conclusions

This study elucidates the relationship between revegetation and topographic factors in burned areas and provides a scientific basis for guiding future ecological restoration.

Background

Forests are recognized as the most widespread terrestrial biomes, 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 disturbance by natural and man-made factors (Atul et al. 2015). One type of disturbance, forest fires, can be destructive, but also serve as an important factor in triggering forest secondary succession which increases the heterogeneity of forest structure and promotes nutrient and material recycling (Fulé et al. 2004).

The severity of forest fires and subsequent recovery time has a significant impact on the richness and dominance of species in burned areas, and revegetation succession in burned areas is complex involving both positive and negative feedbacks (Liu et al. 2009). The composition of the understory community is different following fires, and species diversity and alien species often increase (Evgeniya et al. 2008;

Keeley et al. 2003; Hart et al. 2008). The climate, topography, and environmental factors of the burned area have a significant impact on succession and revegetation after fires. Climate could affect competition through various mechanisms to affect the post-fire revegetation. For example, when climate conditions have a negative impact on one species and the impact on another species is neutral, this 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 elevation 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 the burned area because they affect the distribution of light, heat, and water. The status of the canopy height, breast height, and maximum diameter after fire varies 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 structure and species diversity (Aiqin et al. 2013). Vegetation growth is also closely related to soil characteristics. Fire directly causes the loss of minerals in the soil and significantly reduces the content of nitrogen, phosphorus, and potassium. The loss of carbon mainly occurs in the upper soil layers. Repeated burning of biomass on the ground of burned areas reduces the input of organic matter to 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 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 time after a fire and the original soil stoichiometry. The soil nutrient content tends to decrease with the increase of soil depth and directly affects processes during revegetation 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 qualitative analysis; further quantitative analysis of topographic factors is needed. Investigations are also needed on different burn intensities and areas burned at different times or by different means. The burned areas in a mountainous region with subtropical climate were selected as the research areas for this study. Our data collection utilized quadrat surveys and analysis was carried out with correlation methods. The objectives of this study were as follows. (1) Exploring patterns of succession and revegetation after burning. (2) Identifying the relationship between understory vegetation regrowth and topographical factors in burned areas. These data elucidate response patterns of the understory vegetation in the burned areas following forest fire disturbance and can be used to guide ecological restoration in burned areas.

Methods

Study area

The study was located in the burned areas near Zhongba Village, Luji Township, Xide County (102°12' - 102°16'N, 28°12' - 28°14'E), which is located in the climatic transition zone between northeast and southwest of Liangshan Prefecture, a subtropical climatic region. This area has a wide mountain area with significant regional differences in topography and slope and large spatial variability in forest coverage. Climatic conditions include concentrated rainfall and large evaporation in the area. Both natural and human factors lead to the perennial occurrence of fires in this area, which impacts forest production and the lives of residents. Compared with other fire-prone areas, the terrain and climate are quite different, as is shown in Figure 1. A forest fire started 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 above 40°, and the soil moisture content is low. These characteristics are conducive to a fire spreading rapidly.

Data sources

Due to the characteristics of climate and environment in this area, annual vegetation was the main vegetation type and understory vegetation was rare in winter and spring. There was no significant difference in vegetation in the different burn intensity areas. In this study, a total of two surveys were conducted in the burned areas during the vegetation growing season. A total of 26 shrub quadrats (5 × 5 m) and herb quadrats (1 × 1 m) were selected. The type, quantity, plant height, and coverage of herbs and shrub vegetation (Measure percentage of vertical projection area of vegetation as a percentage of quadrat area by visual measurement) in the quadrat were measured and recorded. The first quadrat survey was conducted on the burned area 51 days after the fire ended, and the second quadrat survey 171 days after. The categories of the burn intensity for the study areas is classified by the mortality rate of trees near each quadrat (Fuju et al. 2005), the quadrats were divided into 7 areas with light burn (the mortality rate of trees ≤ 30%), 6 areas with moderate burn (30% < the mortality rate of trees < 70%), and 13 areas with severe burn (the mortality rate of trees ≥ 70%) (Fuju et al. 2005).

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 species of shrubs and herbaceous plants in a quadrat could be obtained through the calculation and comparison of the importance value (Iv) (Jin-tun 1995):

$$Iv = (Dr + Fr + Pr)/3 \qquad (1)$$

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

The biodiversity index was a simple numerical value to indicate the degree of species diversity in a community, which was used to judge the stability of the community or ecosystem (Vajari et al. 2011).

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

$$H' = -\sum (P_i \log_2 P_i) \qquad (2)$$

The Pielou index (E) reflects the evenness of a community:

$$E = H'/\ln S \qquad (3)$$

The Simpson index (D) represents dominance, and the larger the index value, the lower the species dominance:

$$D = 1-\sum Pi^2 \qquad (4)$$

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

$$Ma = (S-1)/\ln N \qquad (5)$$

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.

M. Godron stability

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

(1) Convert the frequency of all plants in the quadrat to relative frequency.

(2) Sort relative frequency from largest to smallest, then cumsum 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, in order to correspond the cumulative value of relative frequency. Plot based on cumulative relative frequency then fit a curve ($y = ax^2 + bx + c$). The corresponding results can be seen how many percent 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 point represent that the composing proportion of vegetation species in the equilibrium community was very close to the composing proportion of vegetation species in the present situation, indicating that the community was in a stable state. The theoretical basis of this method is referred to the literature (Godron et al. 1971).

Correlation analysis

We used SPSS 22.0 software to analyze the correlation between elevation, slope, soil information, and the vegetation species diversity indices for October 2020 data. This was used to determine the effect of the environmental factors on vegetation composition in the burned areas.

Detrended canonical correspondence analysis (DCCA)

DCCA is a multivariate analysis technique to analyze the relationship between various environmental factors and vegetation (He et al. 2019; Wang et al. 2009). The environmental factors in this survey include elevation, slope, aspect, and slope position. The slope position was represented by the assignment of 1, 2, 3, 4, and 5 to represent 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 north as the starting point (0°) and then moving in a clockwise rotation angle. 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 more exposed to the sun, and thus drier and hotter conditions (Yang et al. 2000).

Results

Vegetation during the growing season

The composition of vegetation

The results of the first quadrat survey on the burned areas showed that there were 34 species, 24 families, and 33 genera of herbs and shrubs; the ratio of families, genera, and species was 1:1.37:1.41. The results of the second quadrat survey revealed 105 species, 85 genera, and 44 families of herbs and shrubs, with the ratio of families, genera, and species being 1:1.9:2.4, 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. In the second survey, there were 71 species, 52 genera, and 20 families more than the first survey.

The vegetation with an importance value for shrub species above 0.1 and that of herb species above 0.05 was considered as a dominant species. The importance values of each dominant species are shown in Figure 2. In the results of the second survey, there were 9 dominant species of herbs and shrubs, including 4 shrubs and 5 herbs. The importance value of *Qg* (*Quercus guyavaefolia* H. Leveille) in the shrub layer was 0.49, accounting for 31% of the total number of individuals— it was the main dominant shrub species. *Lp* (*Leptodermis potanini* Batalin), *Mp* (*Machilus pingii* Cheng ex Yang), and *Vf* (*Vaccinium fragile* Franch) had values of 0.11, 0.11, and 0.1, respectively, and were considered the secondary dominant species. The important values of *Ra* (*Rabdosia adenantha* (Diels) Hara), *Er* (*Elsholtzia rugulosa* Hemsl), and *Mt* (*Monogramma trichoidea* J. Sm) were 0.08, 0.07, and 0.07, respectively, so were the dominant herb species. Aa (*Artemisia argyi* H. Lév. & Vaniot) and *Cg* (*Cymbopogon goeringii* (Steud.) A. Camus) had an importance value of 0.05, which suggests they were secondary dominant species.

After four months of the growing season, the importance value of the main dominant vegetation species of *Qg* increased from 0.49 to 0.69, and the importance value of *Lo* (*Lyonia ovalifolia* (*Wall.*) Drude var. *elliptica* Hand.-Mazz) decreased and deviated from the ranks of dominant species. The emergence of 4 additional secondary dominant species indicated that the dominant species at the shrub level had undergone significant changes. New vegetation also appeared in the herb layer, leading to significant changes in the dominant species. In June, the importance value of the dominant species *Mt* decreased from 0.22 to 0.07, and the importance value of *Pp* (*Paspalum paspaloides* (Michx) Scribner), *Tc* (*Tripogon chinensis* (Franch.) Hack), and *Pl* (*Potentilla leuconota* D. Don) decreased and broke away from the ranks of the dominant species.

Vegetation species diversity indices

Results of the first survey showed that the Margalef index decreased with an increase in the severity of burning. 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 ($P < 0.05$), there was no significant difference among biodiversity indices of different burn intensity areas ($P > 0.05$).

According to the second survey results, the Shannon-Weiner index and the Pielou index increased with the increase in fire intensity (Figure 3, 4). There was a significant difference between lightly burning and the other two burning degrees for the Shannon-Wiener index ($P < 0.05$). The Simpson index was highest in the lightly burned areas, followed by the severely burned areas and the moderately burned areas (Figure 5). 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) (Figure 6), and there was a significant difference between lightly and moderately burned areas ($P < 0.05$). 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 to cover the surface, 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 had not been burned, and the damage to the community structure was low. As a result, the dominant species of vegetation were not as obvious. 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 with any degree of fire had increased in October. Among them, the increase in lightly burned areas and severely burned areas were the most obvious ($P < 0.05$), increasing by 5.44 and 5.16, respectively. This indicates the numbers of species and individuals quickly recovered and increased in quadrats. The increases in vegetation were concomitant with a decrease in dominant species, which led to the significant decrease of the Shannon-Wiener index and Pielou index ($P < 0.05$), and the increase of the Simpson index.

Stability analysis

The stability measurement result of the first survey is shown in Figure 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 the highest and lightly burned areas was the lowest.

The stability measurement result of the second investigation is shown in Figure 8. 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 community stability of the quadrats in descending order was severely burned areas, moderately burned areas, and lightly burned areas.

From the results of the two surveys, it was determined 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 of each burned area and the standard line was far from the stable point (20, 80). This shows that the community stability of each quadrat in the early stage of vegetation restoration was low in this research area.

Correlation between vegetation diversity and topographical factors

The results of the correlation between vegetation diversity and topographic factors in the second survey showed that elevation had a significantly positive correlation with the Shannon-Wiener index (0.621, $P < 0.001$) and Pielou index (0.624, $P < 0.001$), whereas elevation showed a significant negative correlation 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 growth rates can survive 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 was successful (Figure 9). This showed that elevation was an important factor affecting the diversity of understory vegetation, and vegetation diversity showed regular changes with an increase of elevation.

The slope had a significant 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 significant positive correlation with the Simpson index (0.48, $P < 0.05$). Soil moisture showed a significant positive correlation with the Simpson index (0.39, $P < 0.05$) and a significant 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, the lower the dominance of certain species.

The relationship between vegetation and topographical factors

The DCCA shows the relationship between the distribution of vegetation and environmental factors in the second survey in the study area. Vegetation was divided into 5 categories according to the environment (Figure 10). 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, positive correlation with slope direction, and negative correlation with slope. Along the direction of the first ordination axis, the vegetation survival presents 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 environment presented a trend of water and heat conditions that changed to steep (dry), sunny (warm), and uphill (dry) directions. From the angle between each environmental factor and the ordination axis, it can be seen that elevation was the most important environmental factor that affects the distribution of vegetation in burned areas.

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

Discussion

The influence of fire on the stability of vegetation communities

The relationship between vegetation 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 of burned areas was lightly burned > moderately burned > severely burned, whereas the species stability was moderately burned > severely burned > lightly burned. The results of the second investigation showed that the species diversity of burned areas was in the order of lightly burned > severely burned > moderately burned, while the species stability was severely burned > moderately burned areas > lightly burned. After the fire disturbance, a large amount of vegetation was burned, and gaps were formed for new growth. The nutrient resources and space resources available for the new vegetation greatly increased, especially in severely burned areas. Fast-growing vegetation colonized rapidly, allowing the stability of severely burned areas to improve. 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).

The intersection of the community stability curve and the standard line in each burned area was distant from the stable point (20,80). The vegetation species of the quadrats have not yet formed stable inter-species relationships, the community structure was unstable, and the species composition and quantity were still undergoing dynamic changes. With time after the fire, the competition among species intensified and the community structure changed accordingly, which improved the stability of the communities (Thibaut et al. 2013). Due to the dry climate and complex topography in this region, the factors which were studied are quite different from other burned areas. The results of this research were not consistent with another study which found 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 the stability of the communities may not be fully reflected.

The impact 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. The research showed that elevation and slope were the main influencing factors (of the ones we tested) (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 were good, the soil environment tended to be dry, the soil layers became thinner, water and soil erosion were high, and vegetation was affected by wind. These conditions are not suitable for vegetation growth, which caused a decline in vegetation diversity, and only the species with high tolerances can thrive. Soil moisture, temperature, and pH affect nutrients that vegetation requires, which affects vegetation species diversity and distribution (Ozkan et al. 2009). With lower canopy coverage and higher light intensity for understory vegetation, and fewer nutrients and space resources utilized by trees, the faster growth, and development of the understory vegetation (Gilliam 2019; Shirima et al. 2016).

Also, 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 succession, the succession of vegetation and soil is carried out simultaneously. The succession of vegetation community not only reflect in the species composition and community structure of vegetation itself, but also in the habitat, especially in the soil environment. Therefore, the synergistic coupling between vegetation succession and soil succession should be further studied in the future, which is of positive significance to the study of ecological environment construction and vegetation ecological restoration.

Revegetation in burned areas by artificial intervention

Due to the death of trees following the fire, various nutrient resources and living space increased, and more light was 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 mainly 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 the shrub layer (Poudel et al. 2019). Because of the rapid growth of herb vegetation, competition between species intensified. The soil and overall ecological structure began to improve (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 artificial intervention for vegetation restoration, more attention is needed on 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).

Conclusion

In October 2020, there were 105 species, 85 genera, and 44 families of herbs and shrubs vegetation. The species diversity of herbs was significantly higher than that of shrubs, with an increase of 71 species, 52 genera, and 20 families compared with June. The total genera and species of vegetation increased significantly, which respectively were 157% and 209%. After a short period of vegetation restoration. With the increase of fire severity, the stability of the vegetation community gradually increased, the Shannon-Wiener index and Pielou index increased, and the Simpson index decreased. The Margalef index was in the order of Lightly burned areas > severely burned areas > moderately burned areas. After four months of vegetation growing season, 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 vegetation 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. From the DCCA sequence diagram, it could be seen 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 of low elevation, where rain collects and the environment 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; *Pl*:*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 fnal manuscript.

Consent for publication

All authors read and approved the Final manuscript.

Competing interests

The authors declare that they have no competing interests

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Figures

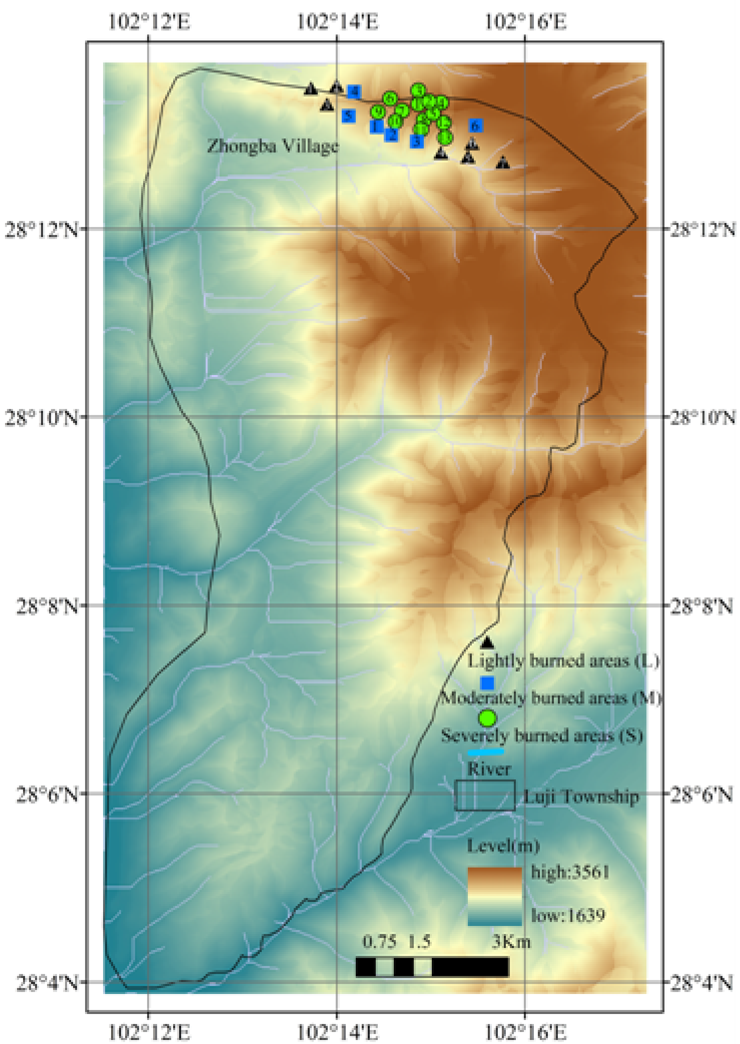

Figure 1

Study area

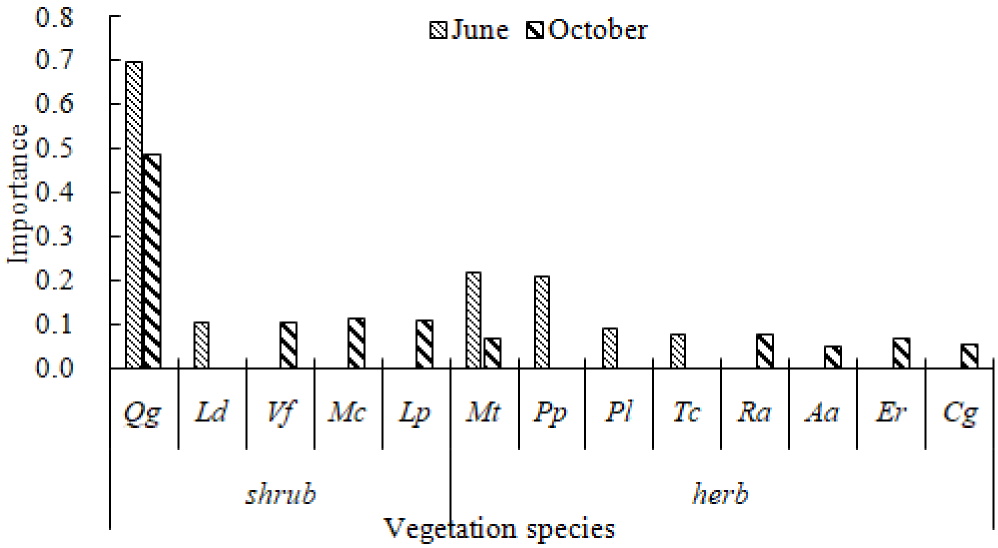

Figure 2

Importance value of domin antvegetation species

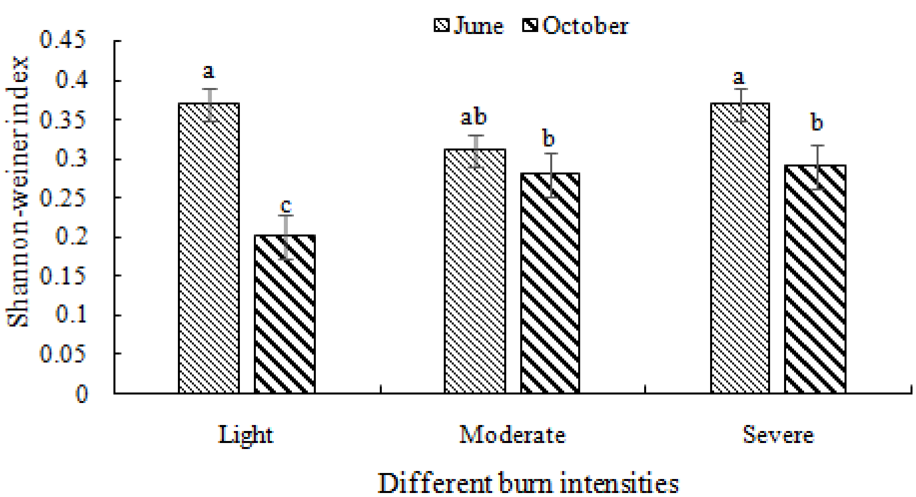

Figure 3

The Shannon-Wiener index of different burn intensities (The error bar is the standard deviation. Different lowercase letters indicate significant difference, $p < 0.05$)

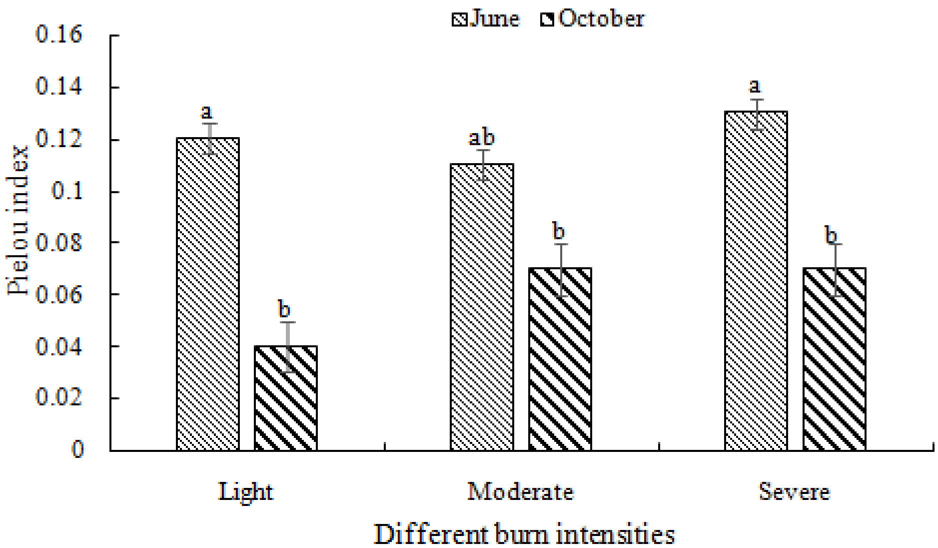

Figure 4

The Pielou index of different burn intensities(The error bar is the standard deviation. Different lowercase letters indicate significant difference, $p < 0.05$)

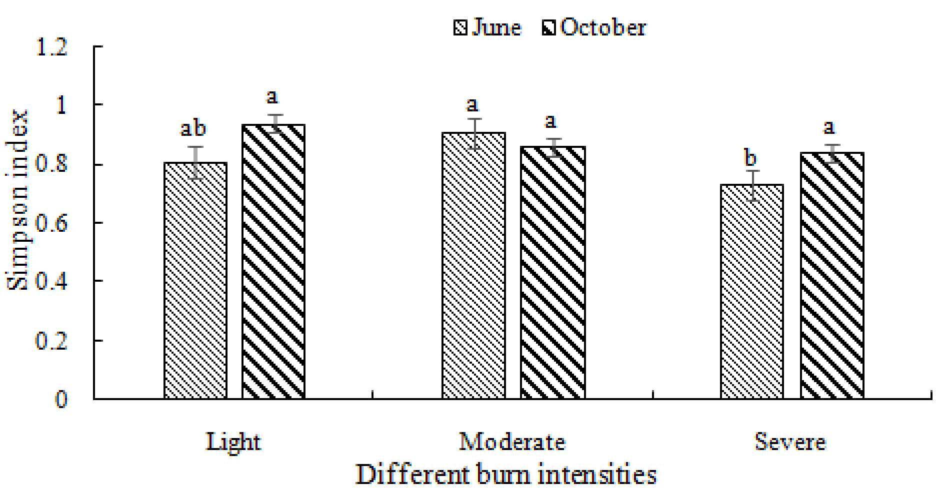

Figure 5

The Simpson index of different burn intensities(The error bar is the standard deviation. Different lowercase letters indicate significant difference, $p < 0.05$)

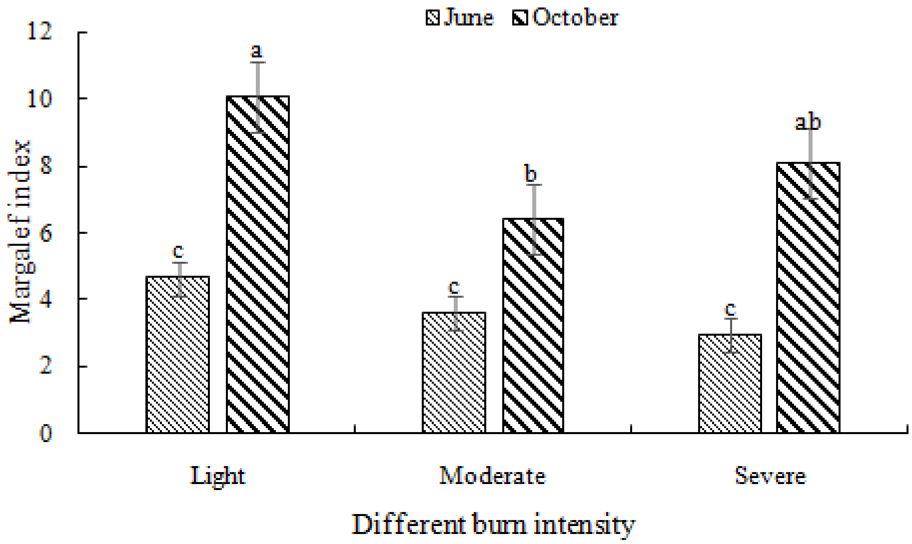

Figure 6

The Margalef index of different burn intensities (The error bar is the standard deviation. Different lowercase letters indicate significant difference, $p < 0.05$)

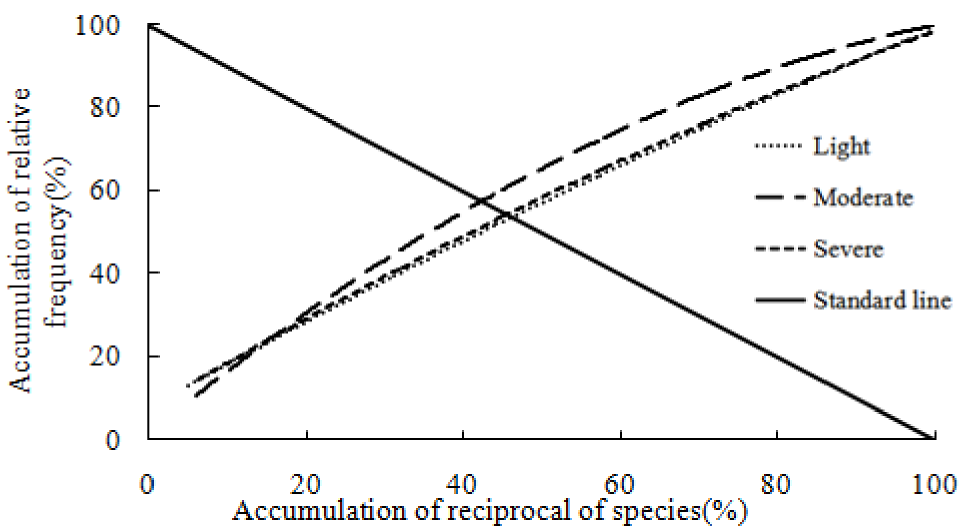

Figure 7

The stability results of the first survey

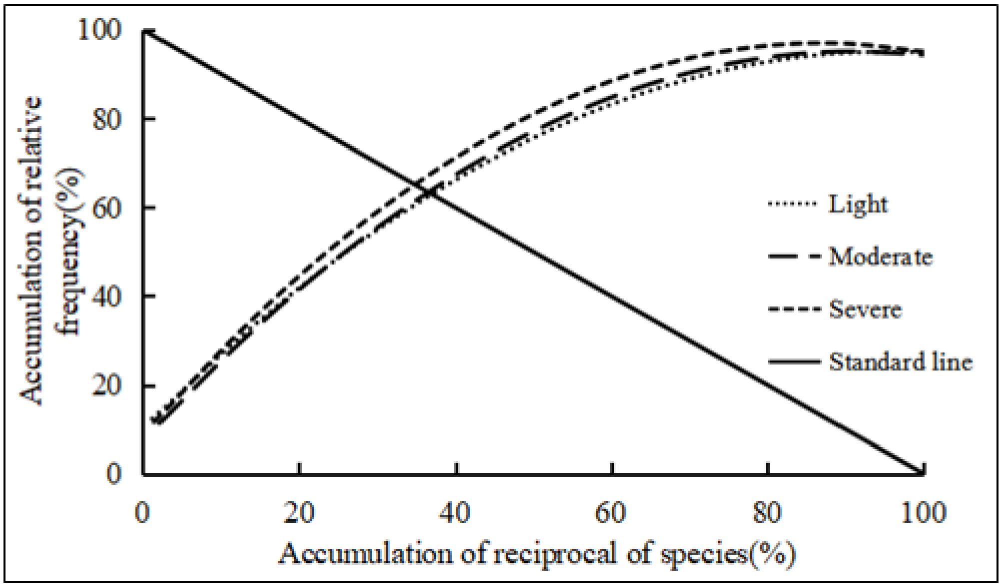

Figure 8

The stability of the second survey

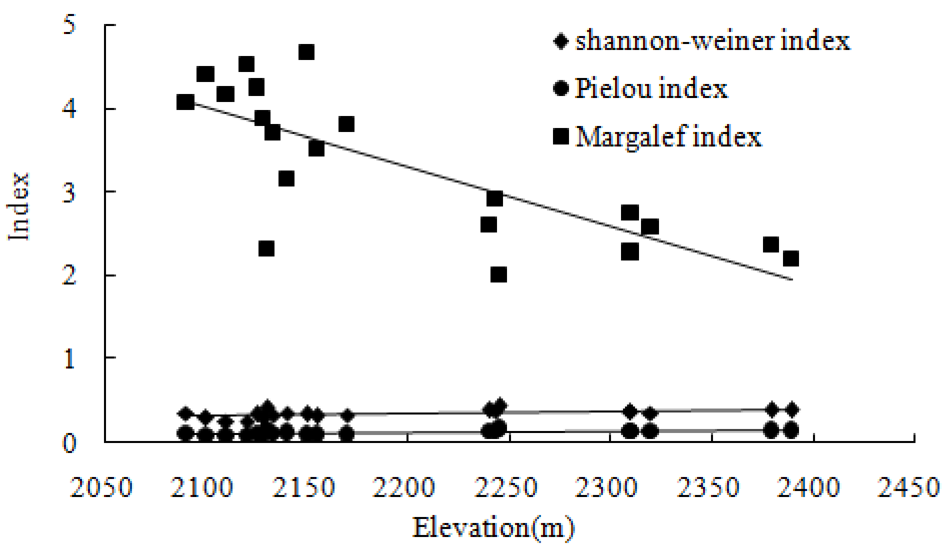

Figure 9

Relationship between biodiversity index and elevation

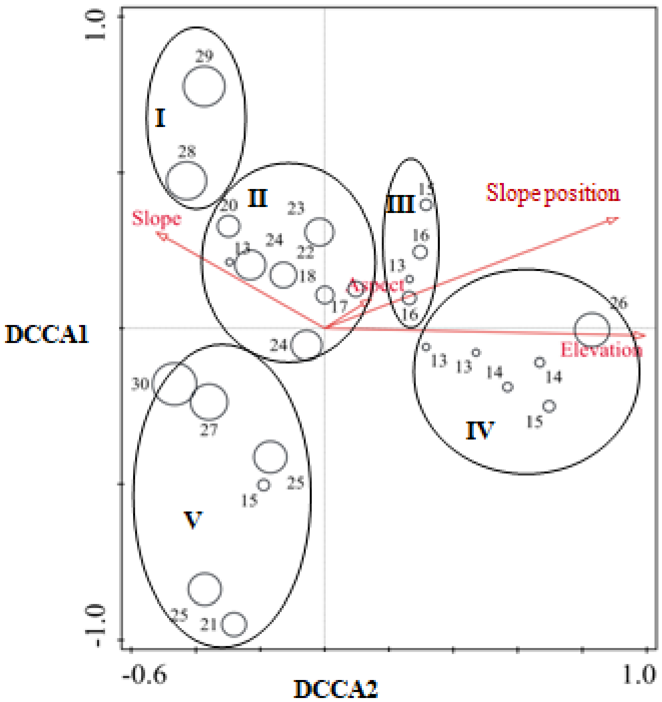

Figure 10

The DCCA sorting of vegetation and topographical factors.The larger the number

Supplementary Files

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- TableS1.docx