fire

Article

Fire-Induced Vegetation Dynamics: An In-Depth Discourse on Revealing Ecological Transformations of the Mahaban and Surrounding Forests

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Abstract: Since the Palaeozoic era, fire as a potent driver of environmental changes, has dramatically shaped the terrestrial ecosystems. Fire affects soil structure and composition, which in turn affects the floral diversity of an area. This research work aims to examine the impact of fire on vegetation and the physicochemical nature of the soil in fire-affected and fire-free sites across the Mahaban and the surrounding forests, Swabi District, Khyber Pakhtunkhwa, Pakistan. Quadrat quantitative ecological techniques were used for vegetation sampling in fire-free and fire-affected sites. In total, 219 plant species belonging to 173 genera and 70 families were recorded. Among the 219 plant species, 173 species were recorded from fire-free sites and the remaining 122 species were from fire-affected sites. The incidence of fire results in elevated organic matter, nitrogen, phosphorus, and lower calcium carbonate concentrations in the soil. The greatest species richness and evenness were observed across the fire-free sites. Our study concludes that the influence of edaphic and topographic factors on species richness varies between fire-affected and fire-free sites. Fire has significantly altered the nutrient availability in the studied region, and this is confirmed by soil analysis and vegetation research. It is suggested that further research in the field of fire ecology can produce valuable insights.

Keywords: forest fire; vegetation dynamics; coniferous forests; species richness and diversity

Citation: Israr, A.; Khan, S.M.; Abdullah, A.; Ejaz, U.; Jehangir, S.; Ahmad, Z.; Hashem, A.; Avila-Quezada, G.D.; Abd_Allah, E.F. Fire-Induced Vegetation Dynamics: An In-Depth Discourse on Revealing Ecological Transformations of the Mahaban and Surrounding Forests. *Fire* **2024**, *7*, 27. https://doi.org/10.3390/fire7010027

Academic Editor: Alistair M. S. Smith

Received: 7 November 2023
Revised: 28 December 2023
Accepted: 4 January 2024
Published: 15 January 2024

1. Introduction

Fire has been a significant component of the Earth's system for the past 350 million years [1], influencing the evolution of plants and animals [2]. The natural growth of coniferous species, particularly since the Miocene epoch, has increased the occurrence of fires, making them dominant in all biomes, except deserts and scarcely vegetated areas [3]. Approximately half of global ecosystems, spanning from tropical savannas to boreal forests, are considered 'fire-prone' [4]. In recent decades, the heightened frequency of forest fire incidence has been connected to late 20th-century trends favoring warm and early springs [5].

This trend is attributed to various factors, such as the continuous increase of the human population and extreme climatic conditions, that contribute to forest fire incidence at a global scale [6]. Predictions based on a scenario of climatic changes show a significant temperature rise, leading to frequent fire incidences in the 21st century [7]. Frequent forest fires cause threats to the forest's ecosystem services, with about 15 million hectares of forests lost annually [8]. Vegetation is a prominent manifestation of an ecosystem and shows indispensable bonds between biotic and abiotic components controlled by edaphic, topographic, and climatic factors [9]. Moreover, vegetation is pivotal for projecting future changes in plant distribution, linking them to anthropogenic impacts on the ecosystem, and addressing conservation challenges [10,11]. In addition, environmental factors, including soil, topography, and various other non-climatic factors, play key roles in controlling vegetation structure and regeneration [12–15]. Altitude, aspect, slope, and slope location are topographic elements that may have a direct or indirect impact on soil and microclimatic conditions as well as on seedling establishment and growth [16,17]. Moreover, ground fires not only affect vegetation cover but also severely alter soil characteristics [18]. Sometimes, the soil surface is affected by fire leading to significant variations in soil nutrients [19] and soil textures, which tend to become rougher and harder [20], contributing to stable aggregates from clay and silt fractions influenced by tremendous heat [21]. Fire-induced changes in humus composition result in a complex interplay of physical, chemical, and biological features within soils. Different nutrients in organic matter (OM) are gradually released during decomposition and contribute to maintaining minimal loss during the leaching process to establish a reliable source of nutrients [22]. The impact of soil burning extends to the nutrient cycling process [23]. Burning OM makes certain nutrients available while causing the volatilization of others, such as phosphorus (P) nitrogen (N) and sulfur (S) [24–26]. The rise in accessible phosphate and nitrate following a fire is probably due to elevated microbial activity. Following a fire, ions may be moved as particulate matter through wind, surface runoff, or groundwater, even though the top layers of soil readily absorb cations [27]. Since the combustibility thresholds of woody fuels are higher than those of sulfur, phosphorus, nitrogen, and potassium, these nutrients are easily emitted from organic matter during a fire [22]. Several studies have been conducted to assess the impact of forest fires on vegetation and soil health across different regions of the globe (e.g., [26,28–32]). Concerning the simultaneous effects of forest fire on soil characteristics and plants, there is a substantial research vacuum. Little information is available on how soil characteristics, nitrogen cycling, and vegetation are affected by fire disturbances [25,33]. Like other areas of the world, the forests of Mahaban and the surrounding region in the Swabi District of Khyber Pakhtunkhwa, Pakistan, are facing a high incidence of fire, but no research has been carried out do date to incorporate the impact of forest fires on soil features and vegetation [34]. This study was designed to assess the impact of fire regimes in the forests of Mahaban and the surrounding region. Fires are initiated accidentally by lightning or intentionally by the indigenous people of this region. Ecologically, the impact of fire extends beyond biodiversity to overall ecosystem growth and nutrient availability. Ground fires affect vegetation cover and the soil's physical and chemical features.

This study aims to bridge an important research gap by studying the simultaneous impact of fire regimes on both soil and plants. We hypothesized that fire regimes in these regions cause drastic changes to soil fertility and subsequently affect species diversity and richness. By comparing fire-affected regions with fire-free ones, the study tries to analyze changes in the soil's physical and chemical features in relation to vegetation, contributing to a more detailed understanding of fire regimes in the forests of Mahaban and the surrounding region.

2. Materials and Methods

2.1. Study Area

The study area is located between latitudes 34–07 and 34–20 in the north and 72–39 and 72–46 in the east of Swabi District, Khyber Pakhtunkhwa, Pakistan. The average elevation ranges from 400 m to 2250 m. A major part of the hilly region belongs to Gadoon Hills in the northeast of the district; these hills are the continuation of the Mahaban Hills (on the gorges of the river Indus). The name "Mahaban" means dense forests, which is fitting given that the entire region is encircled by enormous forests [35]. At lower altitudes, the mountains are covered by forests of *Pinus roxburghii* whereas, at higher altitudes, dense forests of *Quercus leucotrichophora* dominate. In the lower levels, the climate is subtropical and semi-arid, transitioning to a temperate environment in the upper regions. Mahaban has a moderate summer and a harsh winter climate. The average summer temperature is around 10–15 °C for roughly seven months of the year, while the average winter temperature is considerably below zero [35]. The hottest months are June and July, with the highest average temperatures of 40 to 45 °C in the lower piedmont. Winters are chilly, with average monthly temperatures ranging from 4 to 10 °C. High-elevation areas experience snowfall during the coldest months of winter [10]. The annual precipitation ranges from 60 to 145 mm and increases as one travels further north [10].

These forests are highly fire-prone with frequently reported natural and anthropogenic instances of forest fires. This area was selected for this study because it has completely fire-free areas as well as forests that regularly experience forest fires (Figures 1 and 2).

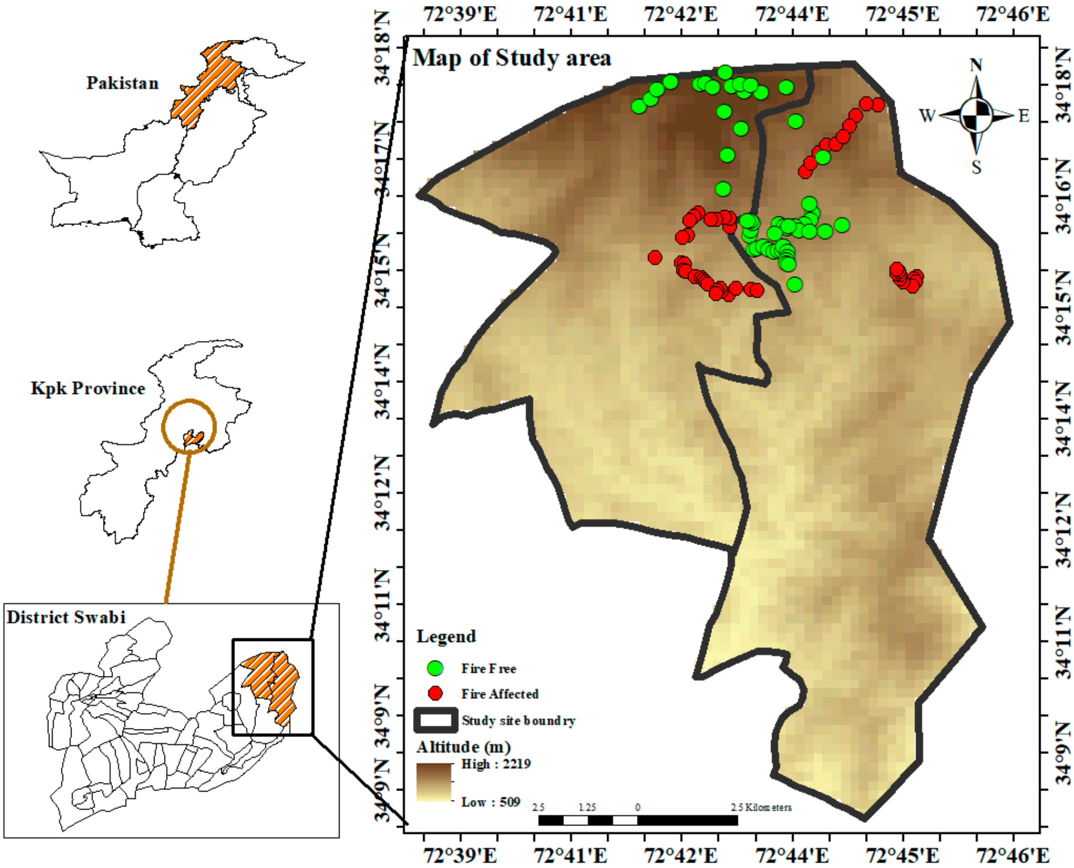

Figure 1. Map of the study area along with the geographical locations of the sampling points expressed as green dots for fire-free areas and red dots for fire-affected areas.

2.2. Data Collection

The whole study area was divided into two categories, i.e., fire-free and fire-affected areas. These areas were selected based on fire history and further confirmed based on their environmental conditions. The study area was split up into 12 different sites. Out of these 12 sites, six sites were in fire-free areas, having no recent incidents of fire, and six sites were in fire-affected areas. Data collection was carried out at the end of March 2022 to record spring data and a second field survey was carried out at the end of August 2022, following the monsoon season, to record summer plant species from the same quadrat across the fire-affected and fire-free sites of the studied region.

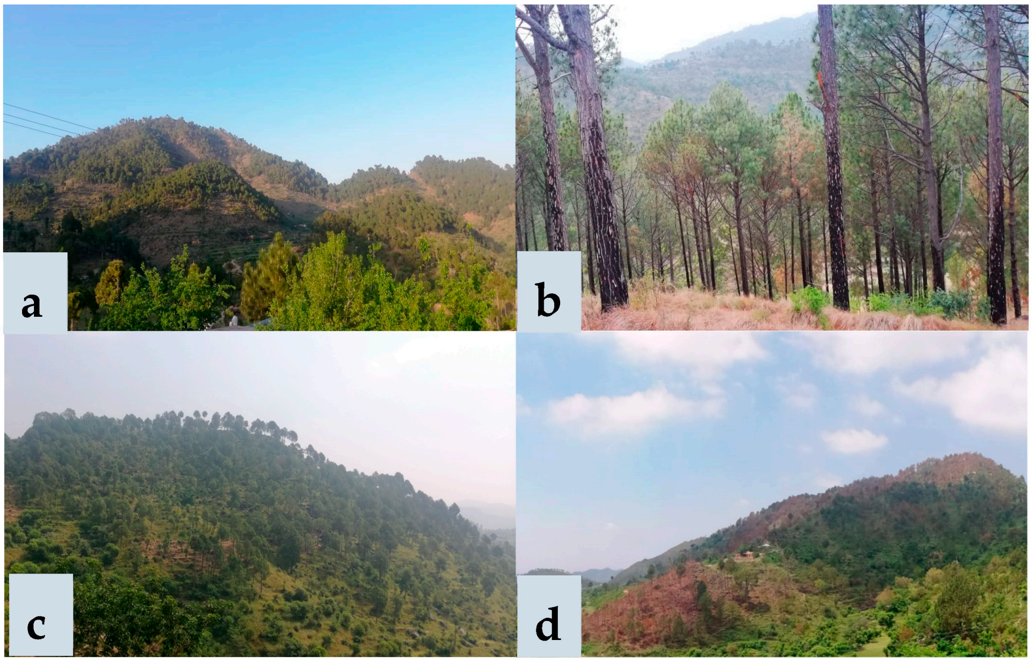

Figure 2. Images of the study area (**a**,**c**) fire-free areas, (**b**,**d**) fire-affected areas.

2.3. Vegetation Sampling

Vegetation sampling was carried out at each of these 12 sites along the altitudinal gradient to cover the whole forest. Sampling was carried along the entire stretch of the mountain from the bottom up to the highest peak. The quadrat method was utilized for data collection. Quadrats with sizes of 10 × 10 m square, 5 × 5 m square, and 1 × 1 m square were employed for trees, shrubs, and herb species, respectively. Two neighboring sample sites were separated by more than 100 m. A total of 315 quadrats were recorded for each season. Soil samples were collected and stored in zipper bags labeled with the quadrat particulars. Additionally, herb spread characteristics were documented [36,37]. DBH (diameter at breast height) measurements were taken for all the trees in a quadrat and calculated.

2.4. Environmental Gradients

The coordinates of each sampling site, including latitude, longitude, and altitude, were also documented by utilizing GPS (Global Positioning System, *Garmin Corp*., Olathe, Kansas, 2000). A compass was used to determine the mountain's aspect, and a clinometer was employed to determine the slope angle.

2.5. Soil Analysis

The collected soil samples were shifted to the drying trays for air drying. After two days, when the soil samples were well dried, the samples were ground using an electric grinder and then sieved using a No. 30 laboratory test sieve. These samples were then ready for analysis. Each sample of 10 g was placed into a clean beaker (100 mL) and the final volume was diluted up to 500 mL with distilled water. This was and allowed to rest for 30 min. The pH of each soil sample was noted using a pH meter [38]. For electrical conductivity (EC), a suspension of 1:5 (soil: water) was prepared in the same way as for pH determination, mixed, and allowed to stand for 30 min. The EC of each soil sample was then recorded using an EC meter. Organic matter was quantified through extraction with orthophosphoric acid [39]. Nitrogen and phosphorus were quantified through extraction with sulfuric acid. Calcium carbonate was extracted using hydrochloric acid [40].

2.6. Data Analysis

For analysis, MS Excel was used to sort the datasets of all plants and their parameters, and then their phytosociological attributes, including density, frequency, relative cover density, relative frequency, relative cover, importance value index (IVI), and species richness were calculated. Simpson's dominance index [41] (D = plant dominance) was calculated as,

$$D = 1 - \sum \frac{n_i(n-1)}{N(N-1)} \tag{1}$$

Species richness was computed by the formula,

$$\mathrm{d} = s/\sqrt{N} \tag{2}$$

where s = the total number of species in a community; N = the total number of individuals of all species [42].

The Shannon–Wiener diversity indices were calculated using the formula,

$$-\Sigma = \sum_{i}^{s} = 1 pi \ln pi \tag{3}$$

where pi is the proportion of individuals of a species i [43]. The Shannon index, abbreviated as H′, gauges the degree of order present in a community. A higher H index represents more order in a community. A low rating would signify a lack of order in the neighborhood. Species evenness was calculated using Shannon's evenness index,

$$\mathrm{E} = \mathrm{H}'/\ln \mathrm{S} \tag{4}$$

where S is the species number and H′ is the Shannon–Wiener diversity index [44].

R programming was used for regression analysis, as was structure equation modeling (SEM). The regression analysis was conducted to find the influence of environmental factors (both topographic and edaphic) on species richness in both fire-free and fire-affected areas. The environmental components were soil pH, EC, phosphorus, nitrogen, and organic matter, whereas the topographic variables were aspect, slope angle, and altitude. The regression line provides the strength of the influence. The blue color indicates data from fire-free areas whereas the red color represents fire-affected areas.

Structural equation modeling is a multivariate statistical analysis technique employed to examine structural relationships. Using structural equation modeling the impact of edaphic and topographic variables on species richness for the fire-free and fire-affected areas was analyzed.

As a function of the sampling effort, species richness can be quantified using rarefaction curves [45]. Species rarefaction curves for the fire-free and fire-affected areas were analyzed using an online version of the iNEXT package at a confidence limit of 95% [46]. Species richness was placed on the y-axis and the number of sampling units (quadrats) was placed on the x-axis.

3. Results

3.1. Floristic Composition

A total of 219 plant species were reported during this study. In the first field, 114 plant species were recorded and, during the second field that was carried out after the monsoon season, an additional 104 new plant species were recorded. These plant species belong to 173 genera and 70 families. Among these, 14 (7%) were trees, 30 (14%) were shrubs and 175 (79%) were herbs. The habit-wise distribution of plant species from fire-free areas, fire-affected areas and the total study area is displayed in Figure 3. On the basis of species richness and the dominance of the top thirty plant species mentioned in (Figure 3), herbs were the most dominant species. In the fire-free areas, out of a total of 30 species, 12 were herbs, 11 shrubs, and 7 trees; however, in the fire-affected areas, a total of 17 species were herbs, whereas 9 were shrubs and only 4 were trees. The top dominant species of both the sampled areas are tabulated in Appendix A (Table A1).

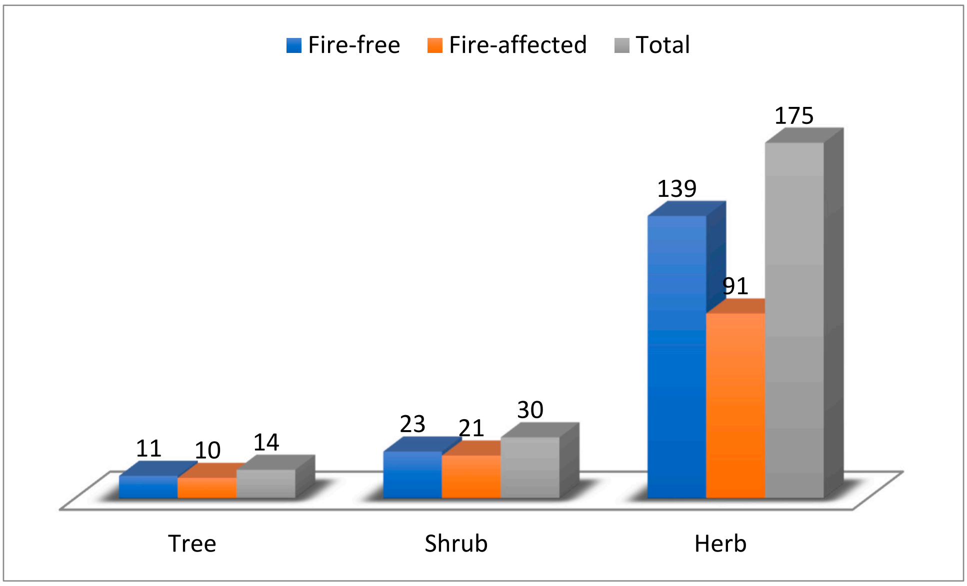

Figure 3. Habit-wise distribution of the recorded plant species from fire-free, fire-affected and the total study area.

3.2. Species Diversity Indices

The Shannon diversity indices revealed that, out of a total of 219 species, 173 species were from fire-free areas and the remaining 122 species belonged to fire-affected areas. Only 97 species were exclusive to fire-free areas while 46 species were limited to fire-affected areas. The remaining 76 species were found in both the burned and unburned areas. The species rarefaction curves demonstrate that, with the same sampling efforts, the species richness of vegetation in the fire-free areas was visibly higher than that of the in the fire-affected areas (at $p < 0.01$), (Figure 4). The highest and lowest values for species richness were recorded in the fire-affected areas but the average species richness and Shannon diversity index were higher for the fire-free areas with a mean or average value of 16.83 and an average Shannon diversity index value of 2.45. The fire-affected areas had a lower average species richness of 13.83 and an average Shannon diversity index of 2.21. Average species evenness was higher in the fire-free areas, having a value of 18.74 whereas species evenness was negative in the fire-affected areas, with a value of −47.08 (Table 1). Regression analysis also supported these results, the majority of the variables had a negative correlation with species richness. Species richness and the species evenness of individual quadrats are tabulated in Appendix B Table A2).

Table 1. Summary of Shannon diversity indices for the fire-free and fire-affected areas.

Summary of Shannon Diversity Indices of Fire Free Areas								
Species	chao	chao.se	jack1	jack1.se	jack2	boot	boot.se	n
173	207.255	13.37985	217.1509	9.611166	233.0838	194.7548	5.553475	53
Summary of Shannon Diversity Indices of fire-affected areas								
Species	chao	chao.se	jack1	jack1.se	jack2	boot	boot.se	n
122	137.5431	7.86368	148.4808	5.981573	152.7606	135.8537	4.166071	52

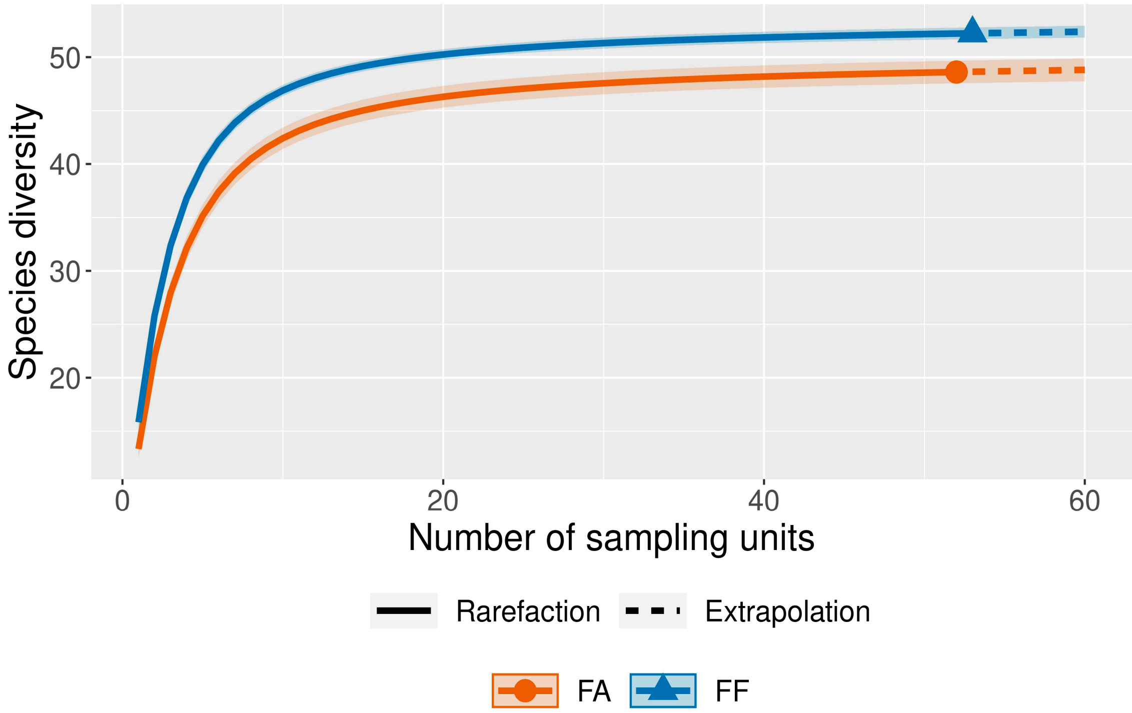

Figure 4. Species rarefaction curves for the Fire-free (FF) and Fire-affected (FA) areas.

3.3. Impact of Edaphic Factors on Species Richness

The influence of edaphic variables on species richness was demonstrated by regression analysis. The results indicated that organic matter in both the fire-affected and fire-free regions displayed a strongly positive correlation with species richness (with R = 0.52, p = 0.00007 and R = 0.36, p = 0.0084, respectively) (Figure 5a). Similarly, nitrogen also showcased a positive correlation in the fire-free areas (R = 0.32, p = 0.019) and fire-affected areas (R = 0.05, p = 0.00003) (Figure 5b). Phosphorus concentration in the fire-affected regions showed a strongly positive correlation (R = 0.36, p = 0.09) whereas, in the fire-free regions, it showed a non-significant slightly positive correlation with species richness (at R = 0.21, p = 0.12) (Figure 5c). This means that a rise in phosphorus leads to a rise in species richness as well. pH and EC showed negative correlations with species richness in both the fire-free and affected areas. The pH of the fire-free areas displayed a relatively stronger correlation with species richness (R = −0.47, p = 0.0003) than was the case for the fire-free areas (R = −0.07, p = 0.63), (Figure 5d). The EC of both the fire-free and fire-affected areas showed no significant correlation with species richness. (Figure 5e). Calcium carbonate did not display a significant correlation with species richness in the fire-free areas (R = 0.04, p = 0.76), whereas, in the fire-affected areas, it displayed a strongly negative correlation with species richness (R = −0.38, p = 00053). So, a higher level of calcium carbonate in the fire-affected soils resulted in a lower species richness (Figure 5f).

3.4. Impact of Environmental Gradients on Species Richness

The species richness of both the fire-free and fire-affected areas showed a negative correlation from north to south, and this was more visible in the fire-affected areas (R = −0.03, p = 0.83) (Figure 6a). Slope angle and species richness did not appear to be correlated in any visible way, with no significant R and p-values (Figure 6b). A visibly negative correlation between altitude and species richness was observed in the fire-free areas (R = −0.47, p = 0.0004) and a slightly negative correlation was evident in the fire-affected areas (R = −0.16, p = 0.24) indicating that species richness decreases with increasing elevation (Figure 6c). The species richness and complete environmental data of all quadrats are tabulated in Appendix B (Table A3).

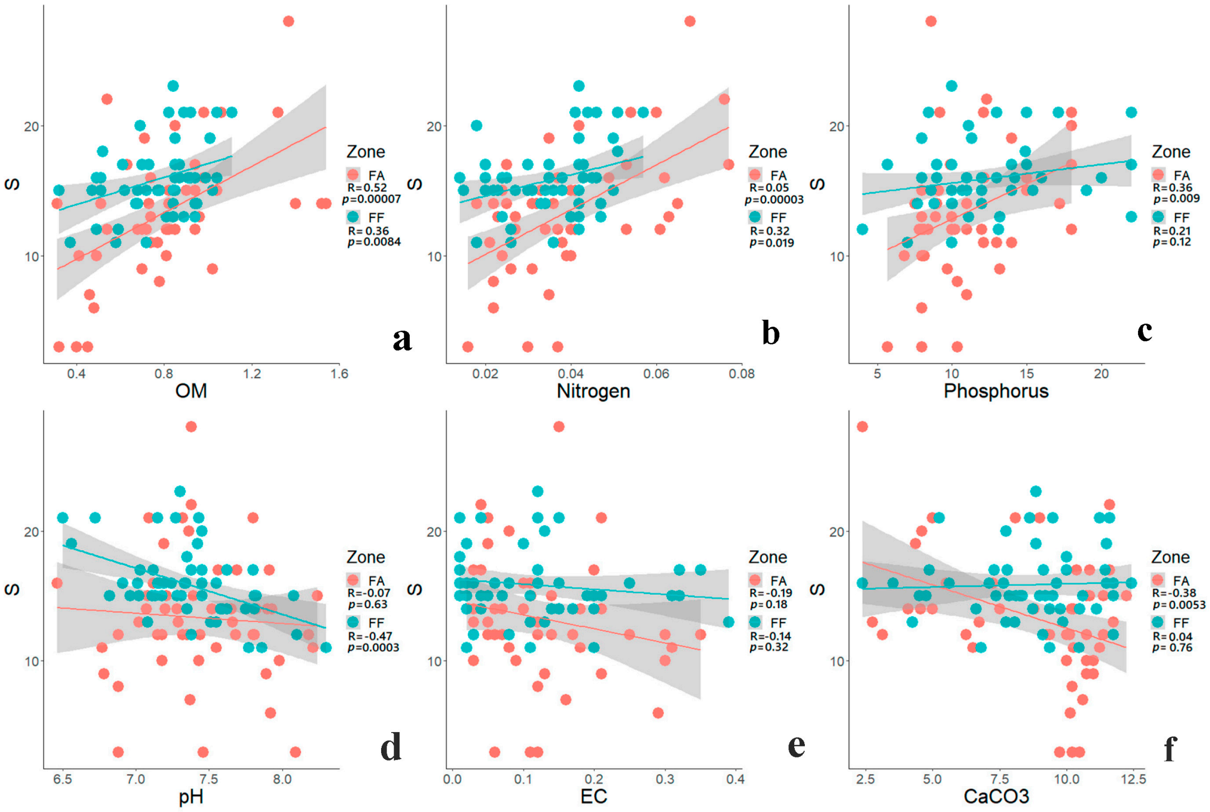

Figure 5. Regression analysis of plant species richness (*y*-axis) with soil factors (*x*-axis). Impact of soil (**a**) organic matter, (**b**) Nitrogen, (**c**) Phosphorus, (**d**) pH, (**e**) EC, and (**f**) Calcium carbonate on species richness.

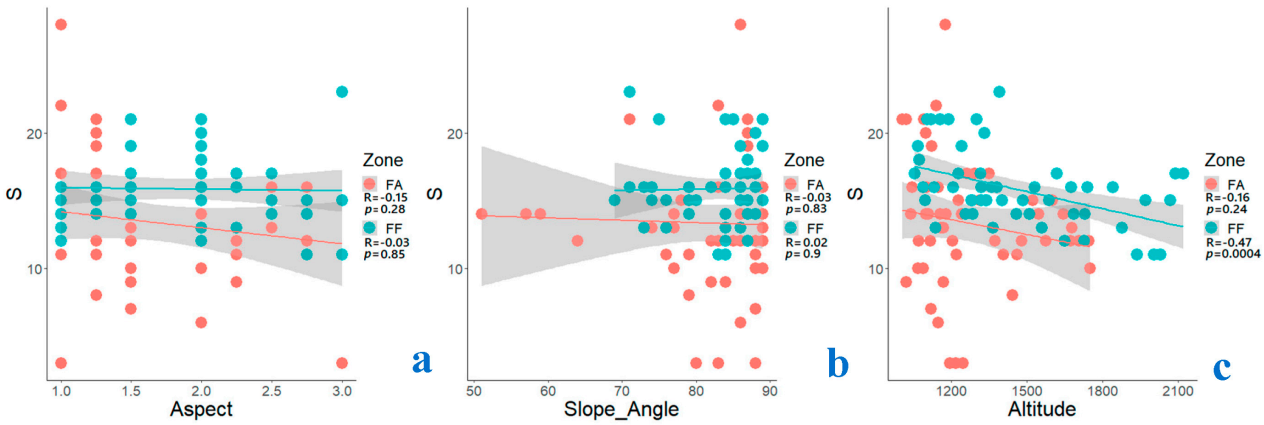

Figure 6. Regression analysis of plant species richness (*y*-axis) with topographic factors (*x*-axis). Impact of (**a**) aspect (**b**) slope angle, and (**c**) altitude on species richness.

3.5. Structure Equation Modeling

The structure equation model was used to analyze the effect of environmental variables on the species richness of fire-affected and fire-free areas separately. The SEM of the fire-free region showed that the organic matter of the soil had a positive and significant effect on nitrogen concentration and species richness with a *p*-value of 0.000 and β-value of 0.64. Organic matter and altitude have a negative and non-significant relation, having a *p*-value of 0.1948 and a β-value of −0.2345. Altitude has a positive and significant relationship with pH at a *p*-value of 0.0107 and a β-value of 0.3408. On the other hand, altitude has a negative and significant relationship with the species richness of fire-free areas with a *p*-value of 0.0124 and a β-value of 0.3470. pH has a negative and highly significant relationship with species richness, indicating that an increase in pH results in a decline in the species richness of fire-free areas with a p-value of 0.0046 and β-value of −0.3864 (Figure 7a), (Table 2).

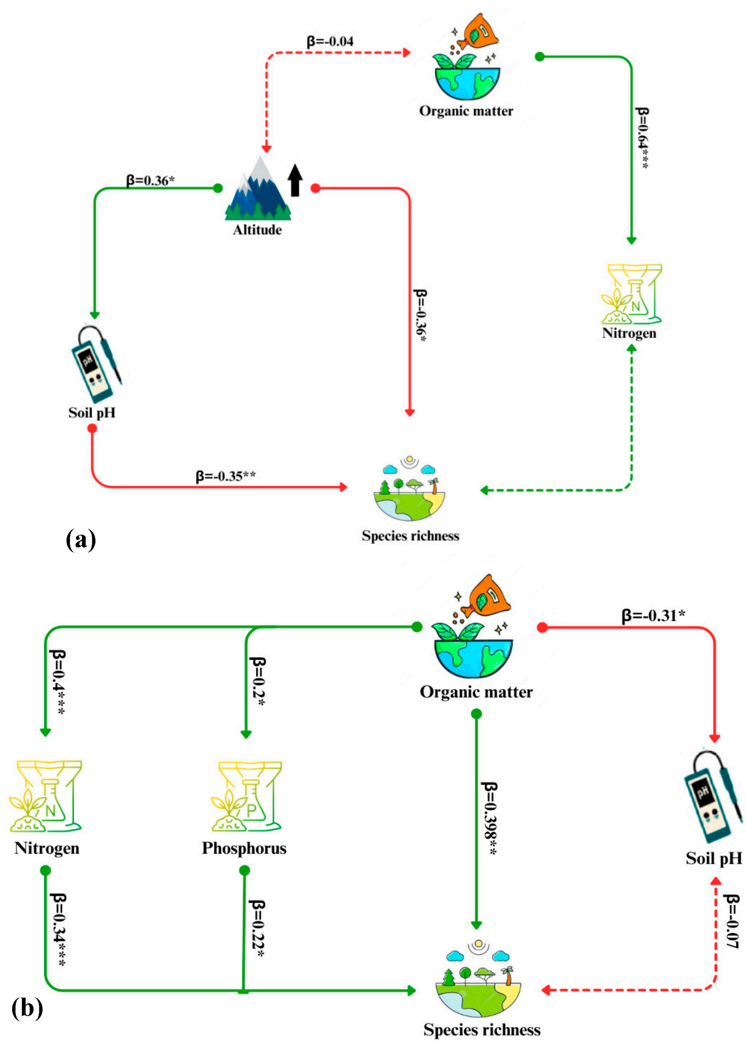

Figure 7. Structural equation model showing the impact of environmental factors on species richness of (**a**) the fire-free and (**b**) fire-affected areas. The solid lines indicate a highly significant effect among various variables, whereas the dotted lines indicate a significant effect among various variables. Red denotes a negative impact, while green depicts a positive effect. In this figure (* represents $p < 0.05$, ** represents $p < 0.01$, and *** represents $p < 0.0001$).

Table 2. Fit measurements of the SEM of edaphic factors on the species richness of the fire-free and fire-affected areas.

Fit Measurements of SEM of Edaphic Factors on Species Richness of Fire-Free Areas									
Chisq	**Pvalue**	**NFI**	**CFI**	**RMSEA**	**GFI**	**AGFI**	**SRMR**	**RMR**	**AIC**
4.165	0.384	0.931	0.997	0.028	0.959	0.946	0.063	0.062	408.022
Fit measurements of SEM of edaphic factors on species richness of fire-affected areas.									
Chisq	Pvalue	NFI	CFI	RMSEA	GFI	AGFI	SRMR	RMR	AIC
1.64	0.65	0.978	0.976	0.001	0.973	0.963	0.032	0.031	1135.254

Our results show that, in the fire-affected areas, organic matter has a significantly positive impact on the phosphorus content with a p-value of 0.0449 and a β-value of 0.1860. Additionally, organic matter has a highly significant and positive impact on the nitrogen content of the soil with a *p*-value of 0.0002 and a β-value of 0.3530. In other words, with the addition of organic matter to the soil, phosphorus and nitrogen content also increases. In contrast, organic matter has a significantly negative effect on the pH of the soil with a *p*-value of 0.0130 and a β-value of −0.2651, indicating that, at a high pH, organic matter concentrations in the soil decrease. Phosphorus also had a positive and slightly significant impact on species richness with a *p*-value of 0.0112 and a β-value of 0.2093. Organic matter also has a significant and positive impact on species richness with a *p*-value of 0.0015 and a β-value of 0.2962. Nitrogen also displayed a highly significant and positive impact on species richness with a *p*-value of 0.0002 and a β-value of 0.3256. It turned out that the higher the nitrogen, phosphorus, and organic matter concentrations are in the soil, the higher the species richness in that area would be (Figure 7b).

4. Discussion

Pakistan is a country with various sorts of climatic zones, ranging from tropical and desert ecosystems to the alpine and fridged zones of perpetual glaciers. In the subtropical, moist, and dry temperate regions of the country, coniferous forests are common. Sometimes these forests are highly affected by fire incidents. In this article, we tried to disentangle the impact of forest regimes on the vegetation of the study area. Our findings revealed that herbs were the dominant life form in the Mahaban forest, representing 79% (175 Species) of the total (219) plant species. Instances of fire at regular intervals are one of the reasons for the visible dominance of herbal life forms. Regular fires harm the major woody species, but appear to be advantageous for perennial and annual herbs [47]. Disturbances that leave gaps in the perennial grass-dominated landscape tend to favor annuals or short-lived perennials [48].

It is a general perception that changes in species diversity result from disturbance [49]. Diversity indices have been employed in numerous ecological studies to evaluate the effects of environmental disturbance [49]. According to our results, although average species richness, Shannon diversity index, and species evenness were high in the fire-free areas, the highest and lowest values of species richness were observed in the fire-affected areas, while the fire-free areas had a relatively narrow range of species richness. Repeated forest fires at regular intervals, which make the environmental conditions unsuitable for most species but favorable for some other species, could be a possible reason for the comparatively wider range of species richness values in the fire-affected areas. Significant changes in species diversity and species richness have also been documented by Biswa and Malik, [50] at various levels of disturbance. The intermediate disturbance hypothesis (IDH), which argues that species diversity would be highest at a moderate amount of disturbance, is further supported by our findings [49]. Similarly, Li et al. also reported that disturbance brought about due to grazing increased species diversity in northeastern China [51]. The reason for the difference in our results could be because grazing reduces competition, but fire is more severe than grazing, altering the physical and chemical characteristics of the soil and making the environment less favorable for certain species.

We observed that fire causes a slight decrease in the concentrations of organic matter and nitrogen in the soil, thereby causing an increase in species richness (Figure 8). Moreover, Ullah et al. reported that higher organic matter concentrations lead to higher species richness [52]. In our studied regions, we observed that those areas in which fire incidents happened are easily occupied by plant species. The fire leads to a significant amount of ash which is considered an important source of Phosphorus and a suitable substrate for various species. The ash of grass species is used by farmers in rural areas as a fertilizer for different crops. In indigenous societies, people believe that ash is crucial for root elongation due to its smooth texture. Therefore, we are of the opinion that the ash is the main driver of species richness. Phosphorus concentrations showed a noticeable effect on species richness in the fire-free areas but in the fire-affected areas, the higher percentage of phosphorus in the soil resulted in a steady rise in species richness. The phosphorus in organic matter is converted by forest fires into the soluble orthophosphate form which is easily taken up by plants [53]. We also observed that fire has a crucial impact on soil parameters (Figure 8).

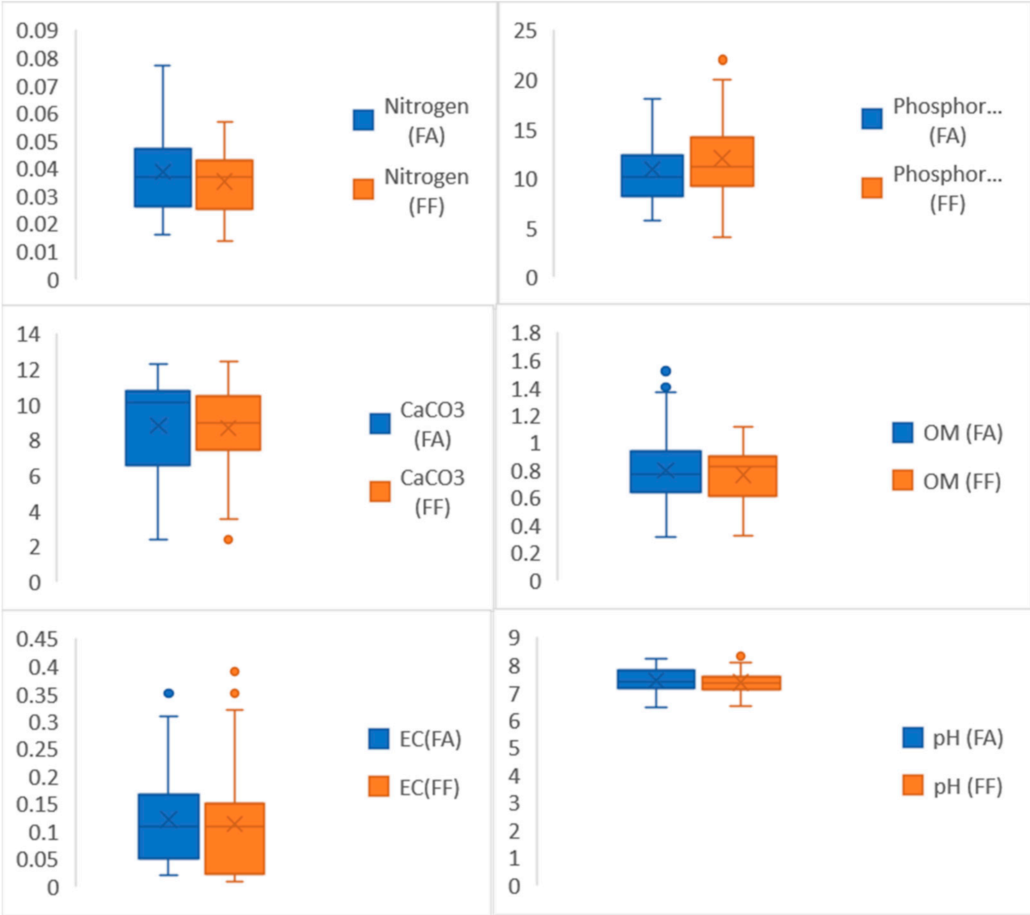

Figure 8. Comparative analysis of soil variables across the fire-free and fire-affected sites of the study area.

According to the research, nutrients in the soil drop after a forest fire, but their availability to plants rises [54]. High-intensity wildfires deplete nitrogen in the soil [55,56]; however, low-intensity wildfires result in higher nitrogen [57]. Kutiel and Naveh noted that different areas of the same forest that are dominated by distinct species show a noticeable variation in soil nutrient levels assessed after a wildfire. Most of these nutrients were most abundant in the pine forest-dominated soil, moderate in the oak soil, and least abundant in the open grass soil [58]. In comparison to the available nitrogen and phosphorus in the burned soil, the available nitrogen and phosphorus in the burned soil below pine trees was higher [59]. Verma and Jayakumar reported that fire decreases the amount of total nitrogen while increasing the readily available ammonium form. Volatilization is the cause of this nitrogen decline [60,61]. Research suggests that fire causes an increase in the water-soluble forms of nitrogen and phosphorus and higher species richness [62–64]. It has been reported that pH and nitrogen have a positive impact on the vegetation of an area [65].

In our study, the pH of the fire-affected areas remained relatively constant but in the fire-free areas increases in pH led to lower species richness. The soil in the *Pinus*-dominated forests has a relatively high pH since the humus produced by Pinus leaves increases the pH of the soil. This attracts some species, such as *Morchella* fungus, which is an indicator of humus produced from Pinus leaves. The average pH recorded in our study of the fire-free areas was 7.36. According to Pausas and Austin, most species occur when the pH is between 6.1 and 6.5. Species diversity decreased in both the acidic and alkaline soils [66].

Previous research has also shown that, at high pH levels, phosphorus and iron become scarcely soluble, which has an impact on the species variety of a region [67,68]. A rise in pH following a fire has been observed by several researchers [69–72], and others have argued that pH remains unchanged after a fire [73–75]. Environmental conditions after a fire could be considered a key factor [76].

According to our results, higher calcium carbonate in the fire-affected areas leads to lower species richness. An increase in the temperature decreases the solubility of $CaCO_3$ and accelerates the formation of calcium carbonate crystals [77], which cannot be absorbed by plants. In Pyrenean woods, Pausas also discovered a humped relationship between species richness and calcium concentration [66]. $CaCO_3$ had an inverse relationship with abundance [65]. Conversely, Ullah et al. have reported that in an environment free from fire disturbance, higher $CaCO_3$ concentrations in soil cause an increase in species richness [67].

The terrain of mountainous regions provides a wide range of varied ecosystems as well as a climate change buffer because temperature varies significantly over different elevation ranges [78,79]. In our study, environmental gradients, particularly topography, elevation, aspect, and slope angle values were recorded for each quadrat and analyzed. Our results indicated that slope angle had no visible effect on the species richness. The mountains of Mahaban are part of the outer Himalayan mountains with steep slopes; moreover, almost all our data had a very narrow range of slope angle data (i.e., 70–90 degrees). Steeper slopes are more resilient to changes in the composition of the vegetation [80]. Our study revealed that the north-facing aspect had higher species diversity as compared to the south-facing aspect. Temperatures are believed to be lower and soil and air moisture levels are believed to be higher on the northern slopes because of reduced solar radiation [81–83]. With increases in altitude species richness decreased due to the less favorable environment.

The vegetation study from Shangla District by Ullah et al. [52] also reported similar results [67]. The same correlation of species abundance and richness with altitude was reported by Kharkwal et al., from Kumaon, India [84]. Our findings concur with those of Bano et al., who also reported that the number and variety of species dropped as altitude rose [7]. One of the most significant factors that directly affected the distribution of species in the Durand Line district of Kurram was altitude [85]. In the Bhabha Valley of the western Himalayas in India, the greater elevation ranges reduced species variety [86]. Topographic factors (aspect and elevation), had a substantial impact on the abundance of *Pinus roxburghii* trees [65,87–89].

There is an urgent need for research on the impact of fire on soil health and vegetation on a broad scale in the Himalayan coniferous and other surrounding forest ecosystems. A considerable number of species are affected by fires incidents that happened intentionally or unintentionally in the forest ecosystems. To advance this research area, we need to have an accurate parametrization of how people cause incidences of fire, and what solutions can save our forests and natural biodiversity.

5. Conclusions

This study attempted to compare the species richness of fire-free and fire-affected areas. In total, 219 plant species were identified, of which 14 were trees, 30 were shrubs, and 175 were herbs. Diversity indices revealed that species richness and species evenness were higher in the unburned areas. The absence or presence of fire had visible effects on different environmental variables. The pH and calcium carbonate levels showed a highly negative correlation with species richness in the fire-free areas, whereas phosphorus and organic matter showed a highly positive correlation with species richness in the fire-affected areas. Among the environmental gradients studied, slope angle and aspect had no significant impact on species richness: however, an increase in altitude resulted in lower species richness.

It is concluded that fire incidence significantly affected the environmental variables of the study area, which in turn affected the species composition and diversity of the study area. The investigation of the burned and unburned areas revealed that the forest has significant potential for regeneration due to high nutrient levels in the soil and the availability of water; however, the frequent occurrence of forest fires in the research area has adversely affected this regeneration capacity.

6. Recommendations

Our study provides a direct and relatively simple approach to gaining an understanding of complex relationships in fire ecology. Based on the current study, it is recommended fire ecology be further explored and investigated to bolster our understanding of its crucial role in shaping ecosystems. By delving deeper into this field of research, we can gain valuable insights into community ecology, enabling us to devise more effective conservation strategies. To advance this research area, we need to have an accurate parametrization of how people cause fires, and how fire affects soil factors like soil moisture, soil texture, and soil porosity, as well as what solutions will save our forests and our natural biodiversity. To monitor the fluctuations of nutrients in the soil, we advise different modeling approaches using advanced techniques.

Author Contributions: Conceptualization, A.I. and S.M.K.; methodology A.A.; lab work, plant identification, data assessment and manuscript editing, A.I.; investigation, A.I.; data analysis, A.I., Z.A. and S.J.; writing the original draft, A.I.; supervision, S.M.K.; review and editing, S.M.K., U.E., S.J., G.D.A.-Q., A.H. and E.F.A.; funding acquisition A.H. and E.F.A. All authors have read and agreed to the published version of the manuscript.

Funding: The authors would like to extend their sincere appreciation to the Researchers Supporting Project Number (RSP2024R356), King Saud University, Riyadh, Saudi Arabia.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data are contained within the article.

Acknowledgments: The authors would like to extend their sincere appreciation to the Researchers Supporting Project Number (RSP2024R356), King Saud University, Riyadh, Saudi Arabia. The authors would like to thank the Soil and Water Testing Laboratory, Agricultural Research Station Swabi, Pakistan. Lastly, the authors would like to extend their gratitude to Muhammad Sheraz and Israr Ali Shah for their enormous support during the fieldwork.

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

Appendix A

Table A1. Plant species of the fire-free and fire-affected areas on the basis of Simpson's index of dominance.

	Fire-Free Areas			Fire-Affected Areas		
Sr.No.	**Plant Name**	**Habit**	**D**	**Plant Name**	**Habit**	**D**
1	*Pinus roxburghii* Sarg.	Tree	0.23777	*Pinus roxburghii* Sarg.	Tree	0.308946
2	*Berberis lycium* Royle	Shrub	0.074977	*Cynodon dactylon* (L.) Pers.	Herb	0.073945
3	*Cynodon dactylon* (L.) Pers.	Herb	0.070309	*Zanthoxylum armatum* DC.	Shrub	0.072871
4	*Zanthoxylum armatum* DC.	Shrub	0.048806	*Carissa spinarum* L.	Shrub	0.048141
5	*Quercus leucotrichophora* A.Camus	Tree	0.037879	*Rubus ellipticus* Sm.	Shrub	0.042647
6	*Dodonaea viscosa* (L.) Jacq.	Shrub	0.034698	*Berberis lycium* Royle	Shrub	0.04145
7	*Mallotus philippensis* (Lam.) Müll.Arg.	Shrub	0.029749	*Agrostis stolonifera* L.	Herb	0.024808

Table A1. *Cont.*

	Fire-Free Areas			Fire-Affected Areas		
Sr.No.	**Plant Name**	**Habit**	**D**	**Plant Name**	**Habit**	**D**
8	*Debregeasia saeneb* (Forssk.) Hepper and J.R.I.Wood	Shrub	0.027356	*Dodonaea viscosa* (L.) Jacq.	Shrub	0.022899
9	*Digitaria sanguinalis* (L.) Scop.	Herb	0.022099	*Digitaria sanguinalis* (L.) Scop.	Herb	0.020579
10	*Clinopodium serpyllifolium* subsp. fruticosum (L.) Bräuchler	Shrub	0.016923	*Desmostachya bipinnata* (L.) Stapf	Herb	0.015824
11	*Plantago lanceolata* L.	Herb	0.015587	*Salvia moorcroftiana* Wall. ex Benth.	Herb	0.013698
12	*Oplismenus compositus* P.Beauv.	Herb	0.015148	*Oxalis corniculata* L.	Herb	0.013586
13	*Desmostachya bipinnata* (L.) Stapf	Herb	0.01429	*Calendula arvensis* M.Bieb.	Herb	0.013026
14	*Rubus ellipticus* Sm.	Shrub	0.014026	*Geranium mascatense* Boiss.	Herb	0.012859
15	*Mimosa rubicaulis* subsp. himalayana (Gamble) H.Ohashi	Shrub	0.01381	*Mimosa rubicaulis* subsp. himalayana (Gamble) H.Ohashi	Shrub	0.011801
16	*Juncus inflexus* L.	Herb	0.012916	*Gymnosporia royleana* M.A.Lawson	Shrub	0.010727
17	*Adiantum capillus-veneris* L.	Herb	0.012766	*Rumex hastatus* D. Don	Shrub	0.010598
18	*Rumex hastatus* D. Don	Shrub	0.012337	*Colebrookea oppositifolia* Sm.	Shrub	0.01038
19	*Launaea secunda* Hook.f.	Herb	0.010385	*Adiantum pedatum* L.	Herb	0.010187
20	*Carissa spinarum* L.	Shrub	0.009804	*Achyranthes aspera* L.	Herb	0.010099
21	*Oxalis corniculata* L.	Herb	0.009693	*Grewia optiva* J.R.Drumm. ex Burret	Tree	0.009993
22	*Gymnosporia royleana* M.A.Lawson	Shrub	0.009395	*Erigeron floribundus* (Kunth) Sch.Bip	Herb	0.00843
23	*Ficus carica* L.	Tree	0.008816	*Cyperus alopecuroides* Rottb.	Herb	0.008414
24	*Melia azedarach* L.	Tree	0.007613	*Avena barbata* Pott ex Link	Herb	0.008146
25	*Olea ferruginea* Wall. ex Aitch.	Tree	0.007564	*Brachiaria ramosa* Stapf	Herb	0.00736
26	*Mentha longifolia* (L.) L.	Herb	0.00739	*Eragrostis minor* Host	Herb	0.007223
27	*Agrostis stolonifera* L.	Herb	0.007087	*Bombax ceiba* L.	Tree	0.005659
28	*Rhododendron arboreum* Sm.	Tree	0.006693	*Heteropogon contortus* Beauv. ex Roem. and Schult.	Herb	0.004973
29	*Grewia optiva* J.R.Drumm. ex Burret	Tree	0.006517	*Solanum nigrum* L.	Herb	0.004874
30	*Rumex dentatus* L.	Herb	0.006235	*Melia azedarach* L.	Tree	0.004398

Species richness and Shannon diversity of all the quadrats.

Appendix B

Table A2. Species richness and Shannon diversity of all the quadrats.

Fire-Free Areas			Fire Affected Areas		
Quadrats	**Species Richness**	**Shannon Diversity**	**Quadrats**	**Species Richness**	**Shannon Diversity**
S1Q1	18	2.487659	FS1Q1	22	2.814788
S1Q2	15	2.396967	FS1Q2	21	2.655287
S1Q3	16	2.324348	FS1Q3	14	2.316964
S2Q1	16	2.381747	FS1Q4	13	2.252507
S2Q2	17	2.346416	FS1Q5	14	2.245333
S2Q3	16	2.347237	FS1Q6	14	2.255042
S2Q4	14	2.260971	FS2Q1	17	2.580328

Table A2. *Cont.*

Fire-Free Areas			Fire Affected Areas		
Quadrats	**Species Richness**	**Shannon Diversity**	**Quadrats**	**Species Richness**	**Shannon Diversity**
S2Q5	24	2.741961	FS2Q2	14	2.268368
S2Q6	16	2.420426	FS2Q3	15	2.369721
S2Q7	17	2.260509	FS2Q4	12	2.258033
S2Q8	17	2.431093	FS2Q5	14	2.018089
S2Q9	16	2.44746	FS2Q6	12	2.062945
S2Q10	16	2.513053	FS2Q7	13	2.198842
S3Q1	20	2.620321	FS2Q8	14	2.334764
S3Q2	19	2.597952	FS2Q9	17	2.434357
S3Q3	16	2.548764	FS2Q10	12	2.185835
S3Q4	22	2.794055	FS2Q11	17	2.618541
S3Q5	14	2.335251	FS3Q1	12	2.079266
S4Q1	18	2.668152	FS3Q2	11	2.135406
S4Q2	17	2.488219	FS3Q3	11	1.98121
S4Q3	22	2.837677	FS3Q4	10	2.058286
S4Q4	17	2.520994	FS3Q5	8	1.77076
S4Q5	22	2.720286	FS3Q6	7	1.595613
S4Q6	22	2.783348	FS3Q7	7	1.62007
S4Q7	17	2.54875	FS3Q8	4	0.97633
S4Q8	20	2.709978	FS3Q9	4	0.941318
S4Q9	15	2.383271	FS3Q10	4	0.998696
S4Q10	16	2.442801	FS4Q1	16	2.435287
S4Q11	22	2.864515	FS4Q2	18	2.422332
S4Q12	18	2.565379	FS4Q3	18	2.639734
S4Q13	21	2.665254	FS4Q4	16	2.459811
S5Q1	15	2.417465	FS4Q5	18	2.451564
S5Q2	16	2.466072	FS4Q6	13	2.186223
S5Q3	15	2.294344	FS4Q7	12	2.115488
S5Q4	17	2.48977	FS4Q8	12	2.080375
S5Q5	14	2.272177	FS4Q9	13	2.297515
S5Q6	16	2.504384	FS4Q10	12	2.198479
S5Q7	18	2.619202	FS5Q1	16	2.378599
S5Q8	13	2.154757	FS5Q2	15	2.36489
S5Q9	17	2.589061	FS5Q3	13	2.091665
S5Q10	15	2.538078	FS5Q4	16	2.251122
S5Q11	15	2.272501	FS5Q5	15	2.395034
S5Q12	13	2.053219	FS5Q6	13	2.048712
S5Q13	17	2.332756	FS5Q7	14	2.32654
S6Q1	17	2.328227	FS5Q8	13	2.271589
S6Q2	14	2.239102	FS5Q9	13	2.21683
S6Q3	12	1.89413	FS5Q10	11	1.979097
S6Q4	16	2.517507	FS6Q1	22	2.936839
S6Q5	12	2.202981	FS6Q2	21	2.685807
S6Q6	12	2.031984	FS6Q3	19	2.57531
S6Q7	16	2.507694	FS6Q4	22	2.950197
S6Q8	18	2.576293	FS6Q5	28	2.39228
S6Q9	18	2.338526			

Table A3. Species richness and environmental data of all quadrats.

Sr.No	Stations	Species Richness	$CaCO_3$	OM	Nitrogen	Phosphorus	pH	EC	Altitude	Slope Angle	Aspect	Region
1	S1Q1	17	7.3	0.87	0.043	5.7	7.45	0.12	1227.134	88	2.5	FF
2	S1Q2	14	11.12	0.94	0.042	7.7	7.59	0.2	1285.061	79	2.5	FF
3	S1Q3	15	8.34	0.85	0.042	19	7.02	0.01	1317.988	87	2.5	FF
4	S2Q1	15	10.62	0.62	0.027	10	7.28	0.05	1282.622	86	2	FF
5	S2Q2	16	7.66	0.49	0.024	7.99	6.91	0.15	1318.902	73	2.25	FF
6	S2Q3	15	4.75	0.84	0.022	10	6.96	0.07	1340.244	76	3	FF
7	S2Q4	13	9.87	0.81	0.04	13.2	7.08	0.13	1364.634	73	2.25	FF
8	S2Q5	23	8.87	0.84	0.042	10	7.3	0.12	1390.549	71	3	FF
9	S2Q6	15	8.12	0.78	0.031	15.4	8.08	0.19	1401.524	80	1.25	FF
10	S2Q7	16	5.62	0.87	0.043	16	7.34	0.08	1380.793	71	1.25	FF
11	S2Q8	16	11.5	0.94	0.038	9	7.16	0.01	1359.756	74	1.25	FF
12	S2Q9	15	7.37	0.32	0.015	12	7.81	0.32	1337.5	87	1.25	FF
13	S2Q10	15	7.87	0.51	0.02	10.71	7.11	0.31	1319.512	74	2.75	FF
14	S3Q1	19	11.5	1.01	0.05	8	6.56	0.1	1066.463	89	2	FF
15	S3Q2	18	10	0.52	0.051	14.9	7.35	0.01	1072.866	87	2	FF
16	S3Q3	15	9.21	0.68	0.034	10	7.31	0.11	1095.427	69	1.5	FF
17	S3Q4	21	11.62	1.04	0.057	13	7.27	0.12	1117.988	75	2	FF
18	S3Q5	13	8.06	0.89	0.024	22	7.08	0.11	1138.415	76	2	FF
19	S4Q1	17	11.45	0.73	0.02	22	7.38	0.32	1053.659	88	1.5	FF
20	S4Q2	16	3.53	0.99	0.014	8	7.33	0.02	1087.5	84	2.25	FF
21	S4Q3	21	8.62	1.11	0.051	8.44	7.15	0.04	1104.878	89	2	FF
22	S4Q4	16	11.75	0.85	0.024	20.01	7.15	0.25	1130.793	82	1	FF
23	S4Q5	21	9.5	0.92	0.046	22	6.72	0.15	1155.183	85	1.5	FF
24	S4Q6	21	5.25	0.82	0.041	15	6.5	0.01	1187.805	84	1.5	FF
25	S4Q7	16	12.43	0.51	0.02	12	7.45	0.01	1206.402	84	1.5	FF
26	S4Q8	19	8.87	0.85	0.042	11.32	7.42	0.02	1239.939	86	1.5	FF
27	S4Q9	14	6.62	0.84	0.042	10	7.75	0.02	1255.793	84	1.5	FF
28	S4Q10	15	11.75	0.47	0.023	11	7.45	0.02	1279.573	76	1.5	FF
29	S4Q11	21	11.25	0.89	0.044	17.1	7.43	0.01	1300	84	1.5	FF
30	S4Q12	17	7.8	0.85	0.042	14	7.8	0.01	1315.549	88	2	FF
31	S4Q13	20	7.75	0.69	0.018	11.1	7.45	0.13	1331.402	88	2	FF
32	S5Q1	14	10.5	0.84	0.042	12	7.62	0.17	1457.012	88	1.25	FF
33	S5Q2	15	4.5	1.02	0.05	8.6	6.82	0.2	1484.451	79	1.25	FF
34	S5Q3	14	8.75	0.67	0.033	10.01	7.81	0.14	1510.366	84	1	FF
35	S5Q4	16	9.62	0.91	0.025	11	7.24	0.12	1530.488	86	1	FF
36	S5Q5	13	4.25	0.94	0.047	11.1	7.55	0.39	1558.841	84	1	FF
37	S5Q6	15	8.25	0.51	0.03	10	7.13	0.04	1586.28	89	1	FF
38	S5Q7	17	10	0.7	0.035	9	7.12	0.12	1617.988	87	2	FF
39	S5Q8	12	11.75	0.49	0.042	4	7.38	0.08	1649.085	84	2	FF
40	S5Q9	16	12.43	0.49	0.045	14.21	7.19	0.06	1675	88	2	FF
41	S5Q10	14	9.37	0.68	0.034	7.7	7.58	0.04	1685.976	87	2.75	FF
42	S5Q11	14	9.77	0.95	0.047	8.8	7.35	0.15	1729.573	88	2.5	FF
43	S5Q12	12	9.12	0.59	0.026	13.1	8.1	0.03	1728.049	87	1	FF
44	S5Q13	16	7.12	1.04	0.035	16	7.55	0.03	1740.244	79	1.25	FF
45	S6Q1	16	2.37	0.92	0.046	13	7.01	0.12	1840.244	84	1	FF
46	S6Q2	13	7.75	0.84	0.042	11.12	7.51	0.11	1878.354	86	1	FF
47	S6Q3	11	9.37	0.37	0.018	10	8.3	0.02	1937.5	84	2.75	FF
48	S6Q4	15	9	0.77	0.038	14	7.82	0.21	1971.037	87	1.25	FF
49	S6Q5	11	6.81	0.72	0.036	7	7.77	0.2	2004.573	84	3	FF
50	S6Q6	11	10.47	0.58	0.026	10	7.86	0.11	2029.268	83	2.75	FF
51	S6Q7	15	9.5	0.72	0.036	12	7.18	0.02	2068.293	87	3	FF
52	S6Q8	17	4.87	0.61	0.03	15	7.03	0.35	2120.732	84	2.5	FF
53	S6Q9	17	9.13	0.73	0.035	10	7.62	0.01	2088.72	86	2.25	FF
54	S1Q1	17	7.3	0.87	0.043	5.7	7.45	0.12	1227.134	88	2.5	FF
55	FS1Q1	21	8.1	0.98	0.054	9.2	7.32	0.12	1004.268	87	2	FA
56	FS1Q2	21	9.01	1.32	0.051	18	7.8	0.05	1021.341	71	2	FA
57	FS1Q3	14	8.8	0.31	0.065	9	7.9	0.07	1039.634	51	2	FA
58	FS1Q4	12	9.25	0.72	0.061	8	7.81	0.35	1070.427	89	2	FA
59	FS1Q5	14	10.2	1.4	0.018	9	7.2	0.18	1098.171	57	1.5	FA
60	FS1Q6	14	11.12	0.82	0.022	12	7.28	0.21	1110.061	59	2.5	FA
61	FS2Q1	16	7.25	0.91	0.062	12.15	7.12	0.15	1148.78	83	2.5	FA
62	FS2Q2	13	11.75	0.74	0.027	8	7.66	0.05	1157.317	77	2	FA
63	FS2Q3	14	4.09	1.52	0.036	11	7.82	0.04	1179.268	84	2.75	FA
64	FS2Q4	12	3.12	0.82	0.041	18	8.18	0.12	1205.183	86	2.75	FA

Table A3. *Cont.*

Sr.No	Stations	Species Richness	$CaCO_3$	OM	Nitrogen	Phosphorus	pH	EC	Altitude	Slope Angle	Aspect	Region
65	FS2Q5	14	7.5	1.54	0.031	11	7.93	0.1	1241.463	89	2.75	FA
66	FS2Q6	11	11.25	0.77	0.038	12.1	8.21	0.08	1218.902	79	1.25	FA
67	FS2Q7	13	2.75	0.94	0.023	8.9	7.29	0.03	1168.293	89	2.5	FA
68	FS2Q8	14	4.55	0.51	0.025	17.19	7.65	0.06	1156.402	77	1.25	FA
69	FS2Q9	16	5.62	0.74	0.037	15	7.15	0.11	1101.22	89	2.75	FA
70	FS2Q10	12	6.25	0.68	0.034	7.8	7.35	0.14	1070.427	83	2.75	FA
71	FS2Q11	16	5.5	0.98	0.049	12.14	6.46	0.1	1044.207	83	2.75	FA
72	FS3Q1	12	10	0.81	0.04	8.13	7.18	0.3	1115.549	88	2	FA
73	FS3Q2	10	10	0.81	0.04	8.13	7.18	0.3	1088.11	77	2	FA
74	FS3Q3	10	11	0.49	0.024	8	7.43	0.03	1067.683	88	1.5	FA
75	FS3Q4	9	10.75	1.02	0.026	13.2	6.78	0.21	1021.646	84	2.25	FA
76	FS3Q5	7	10.62	0.46	0.035	11	7.37	0.16	1117.988	88	1.5	FA
77	FS3Q6	6	10.15	0.48	0.022	7.99	7.92	0.29	1148.476	86	2	FA
78	FS3Q7	9	11	0.7	0.031	9.7	7.89	0.13	1167.073	82	1.5	FA
79	FS3Q8	3	9.75	0.32	0.03	5.67	8.09	0.06	1195.122	88	1	FA
80	FS3Q9	3	10.5	0.4	0.037	8	7.46	0.11	1217.073	83	3	FA
81	FS3Q10	3	10.22	0.45	0.016	10.37	6.88	0.12	1245.732	80	1	FA
82	FS4Q1	15	10.75	0.9	0.04	9.1	7.39	0.111	1227.134	87	1.5	FA
83	FS4Q2	17	10.87	0.94	0.053	10	7.69	0.2	1261.89	88	1	FA
84	FS4Q3	17	11.62	0.85	0.025	18	7.91	0.04	1293.293	88	1.25	FA
85	FS4Q4	15	11.37	0.94	0.033	14	7.08	0.05	1313.72	78	1	FA
86	FS4Q5	17	10.37	0.63	0.077	9.9	7.56	0.03	1349.695	87	1	FA
87	FS4Q6	12	10	0.54	0.027	10.2	7.15	0.25	1372.561	86	1.25	FA
88	FS4Q7	11	6.5	0.77	0.038	14	7.55	0.31	1406.098	76	1	FA
89	FS4Q8	8	10.22	0.78	0.022	10.37	6.88	0.12	1443.598	79	1.25	FA
90	FS4Q9	12	10.75	0.85	0.042	11	7.44	0.08	1478.354	86	2.25	FA
91	FS4Q10	11	10.25	0.74	0.021	13	6.77	0.18	1460.061	88	2.25	FA
92	FS5Q1	15	10.87	0.82	0.041	15	7.21	0.02	1522.561	86	1.5	FA
93	FS5Q2	14	10.25	0.67	0.032	9	7.52	0.03	1546.951	86	1.5	FA
94	FS5Q3	12	10.11	0.7	0.053	8	7.32	0.06	1574.39	87	1.5	FA
95	FS5Q4	15	12.25	1.04	0.024	8	8.24	0.14	1599.39	86	1	FA
96	FS5Q5	14	5	0.73	0.022	7.5	7.07	0.03	1643.598	87	1	FA
97	FS5Q6	12	11.37	0.94	0.042	10	6.88	0.07	1672.256	85	1.5	FA
98	FS5Q7	13	6.75	0.96	0.063	10	7.02	0.12	1677.744	74	1.5	FA
99	FS5Q8	12	9.37	0.54	0.027	12	7.8	0.17	1707.012	64	1	FA
100	FS5Q9	12	10.75	0.7	0.037	8.4	7.68	0.05	1744.512	82	1.5	FA
101	FS5Q10	10	10.75	0.41	0.039	6.8	7.98	0.09	1750.305	89	2	FA
102	FS6Q1	21	5	1.06	0.06	12.12	7.09	0.21	1090.549	75	1.25	FA
103	FS6Q2	20	4.59	0.85	0.042	18	7.36	0.08	1098.171	87	1.25	FA
104	FS6Q3	19	4.37	0.71	0.035	14	7.19	0.05	1121.951	87	1.25	FA
105	FS6Q4	22	11.62	0.54	0.076	12.31	7.38	0.04	1139.634	83	1	FA
106	FS6Q5	28	2.37	1.37	0.068	8.6	7.38	0.15	1175.61	86	1	FA

FF indicates Fire-Free and FA indicates Fire Affected.

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