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Impact of forest fire frequency on floristic diversity in the forests of Uttarakhand, western Himalaya☆

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A R T I C L E I N F O

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A B S T R A C T

The Uttarakhand State of India is rich in forest wealth with 45.4% forest cover (India State of Forest Report (2021). However, forest cover may change due to a number of anthropogenic and environmental factors. One of the factors leading to forest degradation is forest fires. Forest fires are related to factors that may be biotic, such as heavy accumulation of Chir pine (*Pinus roxburghii,* a dominant forest forming tree) needles on the forest floor influencing fuel load accumulation and flammability, or abiotic, such as climate, topography, or soil type influencing fuel moisture and fire spread. This study was carried out using satellite images of study area where fire was classified using the geographical information system (GIS) into four frequency classes (no fire, low fire, moderate fire, and high fire). We sampled a total of 160 quadrates for trees, 320 for shrubs and 480 for herbaceous plants to assess vegetation diversity for each forest fire frequency class. No fire was recorded for 13,619 sample points, which covers an area of 84% of the study area, whereas low fire frequency was recorded for 1784 sample points covering an area of 11%. In the present study, significant differences in species diversity were observed across the fire frequency classes. While species diversity increased in the low fire frequency class, an increase in fire frequency led to a decline in diversity and increased dominance of certain fire-tolerant species. Our results show that species richness and density decreased in higher fire frequency classes, which could be due to a poor regeneration process. We found that tree species diversity was higher for the low fire frequency class, followed by moderate fire frequency class, no fire frequency class, and was lowest for the high fire frequency class. The diversity of herbs decreased with increasing fire frequency, from a minimum of 12 species in the high fire frequency class to a maximum of 37 in the no fire frequency class. Some of the fire-adapted species were *Myrica esculenta, Pyrus pashia, Lyonia ovalifolia, Carissa spinarum, Pyracantha crenulata, Desmodium microphyllum*, and *Micromeria biflora* the regeneration of which should be promoted rehabilitate the fire damage forest ecosystem of Uttarakhand.

1. Introduction

Forests provide a range of goods and services such as fuel, timber, food, bioproducts, greenhouse gas regulation, air, water supply, carbon storage, nutrient cycling (de Groot et al. 2002; Singh, 2002; Joshi and Negi, 2011), and genetic and species diversity, which are essential to support life (Joshi and Joshi, 2019). Owing to uniqueness, representativeness, and richness in floristic and faunal diversity, geology, and ecology, the Uttarakhand Himalaya is considered the repository of biological and cultural diversity (Kumar et al., 2015; Mathela et al., 2020; Bargali et al., 2022) and therefore needs to be conserved and managed for posterity (Negi and Dhyani, 2012). Owing to the important ecological and climate services provided by forests, the conservation of forests has been widely adopted as an important policy goal for environmental protection (Humpenoder et al., 2014; Capellesso et al., 2021; Maren and Sharma, 2021). Presently, there are 01 Biosphere Reserve, 06 National Parks, 07 Wildlife Sanctuaries, and 04 Conservation Reserves distributed in tropical, sub-tropical, temperate, sub-alpine, and alpine ecosystems in the region, covering 12% of the total geographical area of the Uttarakhand state (National Wildlife Database, Wildlife Institute of India, 2021;

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Bargali et al., 2021). According to India State of Forest Report (ISFR, 2021), the forest cover of Uttarakhand is 45.44%, which is considerably less than 12 units of 66% for hill states of India. One of the factors resulting in the degradation of forests is the presence of forest fires or wildfires. Forest fire is an important disturbance factor shaping forest vegetation worldwide (Skre et al., 1998; Podur et al., 2003). In Uttarakhand Himalaya, fire is generally supposed to be an integral part of the natural dynamics of the forests and ecosystems, and the role of fire in the functioning of local forest ecosystems has been traditionally marginalized, and forest fires have been perceived harmful without any relevance to natural processes (Bargali et al., 2020; Niklasson et al., 2010).

Palaeoecological and fire-history studies suggest that during the past period, the frequency of fire events was increased by human presence in the landscape (Bahuguna and Upadhyay, 2002). It is one of the Earth's most potent agents of ecological change (Allendorf and Hard, 2009; Stenseth and Dunlop, 2009), which has potentially far-reaching ecological consequences. Every forest fire brings with it significant losses of various types: human, economic, forest resources reduction, biogeocenoses destruction (Singh et al., 2016), and such alteration produces severe impacts on soils leading to their loss and erosion after fire occurrence, along with greenhouse gas emissions, change of climate patterns, and loss of ecosystem values and environmental services. Fire is either natural or anthropogenic, occurring throughout the world, causing adverse environmental, economic, and ecological impacts (Babu, 2019). Reduction of the floral productivity, alteration of regeneration rate, and loss of a number of endemic and endangered species of fauna are the major impacts of forest fires (Sati and Bandooni, 2018). In Uttarakhand Himalaya, fire has been a common phenomenon that may continue to increase more frequently in the years to come due to rising temperature and global warming. In this region most of the forest fires are anthropogenic in nature, both accidental and intentional (Semwal and Mehta, 1996). It has been reported that in those areas that have suffered high-intensity wildfires, species richness may be reduced temporarily, especially in the understory (Whelan, 1997). In the study region, forest fires were correlated with the heavy accumulation of Chir pine needles on the forest floor, thus leading to large destruction of forest in the hilly areas (Singh et al., 2016). According to Negi (2019), Chir pine (*Pinus roxburghii*), in the region accelerates the forest fire, and approximately 16.36% of the forest area is dominated by Chir Pine Forest. The altitudinal zone of the Chir pine forest is between 1000 and 1800 m above sea level and this altitudinal zone is regarded as the fire-prone zone in the study area.

It is believed that since the prehistoric period natural forest fires have been occurring mainly due to lightening. However, in the Indian context, the probability of occurrences of forest fires due to lightening is very low as compared to the anthropogenic occurrence (Babu et al., 2016). Studies indicated that half a century ago, there were fewer fires, and these were not considered as an important problem as they are today (Bargali et al., 2017). Anthropogenic activities such as the collection of non-timber forest products and agricultural activities are the cause of most forest fires (Negi, 2019). Besides, the indigenous communities of Uttarakhand used fire as a tool to clear grass that contributes to forest regeneration next year (Bahuguna and Upadhay, 2002). On the other hand, it is important to understand that indigenous communities have values and knowledge about fire environment role for the protection of biological and cultural ecosystems diversity (Ponce-Calderón et al., 2021). It has been reported that in the study region fires promote the growth of chir-dominated pine forests (Singh et al., 1984). It seems that most of the forest fires in Uttarakhand are man-made and more than 50% of mountain forests in Uttarakhand are prone to high incidence of fire during the months of March to June every year. Over 4500 forest fires are recorded in Uttarakhand, burning over 0.6 million hectares of forest annually (Babu, 2019). However, certain plant species have adapted to these fires by maintaining characteristics such as thick bark (Khan and Tripathi, 1989). Keeping the above background in view it was planned to monitor and understand the impact of the frequency of forest fire on the floristic diversity of forest ecosystems in the Uttarakhand, western Himalaya.

2. Material and methods

2.1. Description of the study area and study sites

Uttarakhand Himalayan ranges lie in the North Indian state of Uttarakhand. It lies at the eastern end of the west Himalaya bordering the Nepal frontier and abounds in a rich and varied flora and fauna, constituting the most species-rich part of west Himalaya. The Uttarakhand is situated between 28°43′ N to 31°28′ N latitude and 77°34′ E to 81°03′ E longitude and shares borders with Himachal Pradesh in the north & Uttar Pradesh in the south. It has a geographical area of 53,483 Sq km, which is 1.63% of the geographical area of the country. Physiographically, the State can be divided into three main zones known as the Himalayas, the Shivalik, and the Terai region. The human and livestock population are largely dependent on forests due to the dominance of an agrarian economy and pastoralism.

As per ISFR (2021), forest cover in the Uttarakhand State is 24,303.04 sq km, which is 45.44% of the State's geographical area. Out of total recorded forest cover, 5046.76 sq km falls under Very Dense Forest (VDF), 12,805.24 sq km under Moderately Dense Forest (MDF) and 6451.04 sq km under Open Forest (OF). Forest cover in the State has increased by 8.04 sq km as compared to the previous assessment reported in ISFR (2017). In Uttarakhand, the Chir Pine (*Pinus roxburghii*) forests (1000–1800 m asl) spread over appx. 16.4% of total forest area are particularly prone to fire due to resin-rich leaf litter (*Pirul*) accumulation on forest floor during summer and sometime in late winter (Negi, 2019). This early successional fire adapted species has also expanded into the socio-ecologically valued Oak forests (Singh et al., 1984) that is downgrading the forest ecosystem services (Joshi and Negi, 2011). Since the formation of the State a total of 44,518 ha of forest area has been burnt due to forest fires. The average annual rainfall is 1500 mm and the annual temperature varies from 0 °C to 43 °C. The total population of State is 10.09 million, which is 0.83% of country's population with tribal population 2.89% (2011 Census). The population density of the State is 189 persons km^2. As per the Forest Survey of India, the forests in Uttarakhand belong to nine forest categories (tropical moist deciduous forests, tropical dry deciduous forests, sub-tropical pine forests, Himalayan moist temperate forests, Himalayan dry temperate forests, sub-alpine forests, moist alpine scrub, dry alpine scrub and tree outside forests) (Champion and Seth, 1968; Fig. 1).

3. Selection criteria of sample forest sites

3.1. Fire frequency mapping

Forest fire frequency maps for Uttarakhand state were prepared using the Landsat 5, 7, and 8 images from 2011 to 2020 (10 years). MODIS hotspot data or active fire data (MOD14) were downloaded from the official website of the Fire Information for Resource Management System (FIRMS) of the National Aeronautics and Space Administration (NASA) at https://firms.modaps.eosdis.nasa. gov/ from 2011 to 2020 in shapefile format (.shp), using union operation in Arc map software, and all the fire points from 2011 to 2020 were merged in one shapefile. Satellite images of the study area, i.e., Uttarakhand state, were extracted, geo-corrected, and classified into four frequency classes, i.e., no fire, low fire, moderate fire, and high fire frequency classes using supervised classification (Lim et al., 2019). After that we created fishnet using data management tool in ARCMAP software. Fire points and raster were spatially joined to generate the fire frequency map. Thus, a total of 16,206 fire points were categorized into four fire frequency classes for entire Uttarakhand. The highest fire frequency of Uttarakhand was 34 (between 2011 and 2020), and it was further classified into four frequency classes, i.e., no fire frequency class, 1–5 (low fire frequency class), 5–12 (moderate fire frequency class), and

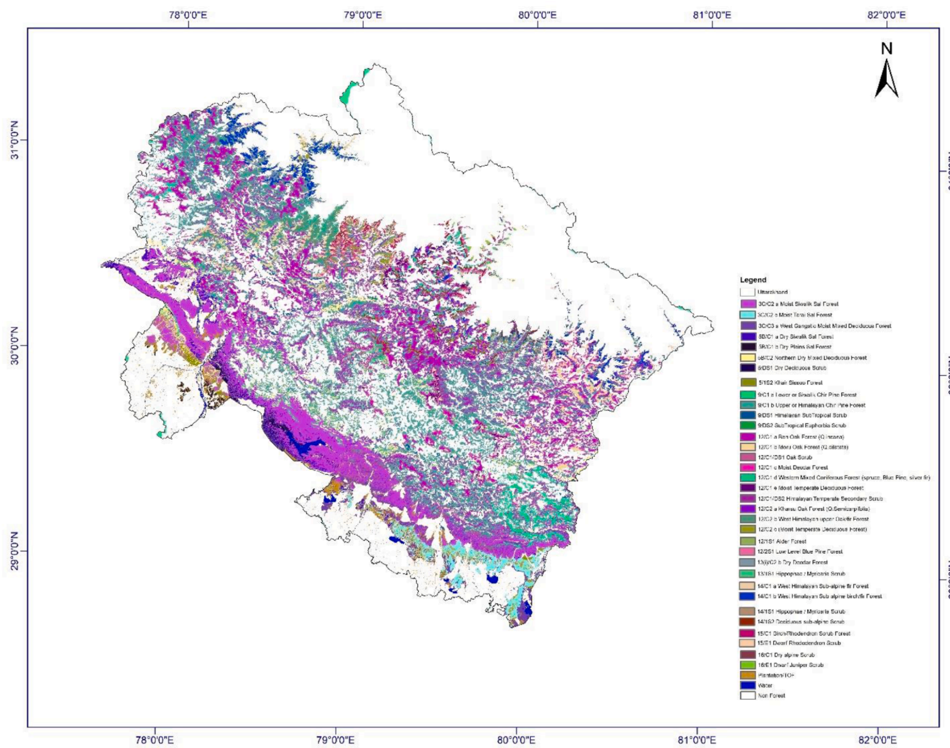

Fig. 1. Forest types of Uttarakhand as per the FSI classification based on Champion and Seth classification, 1968.

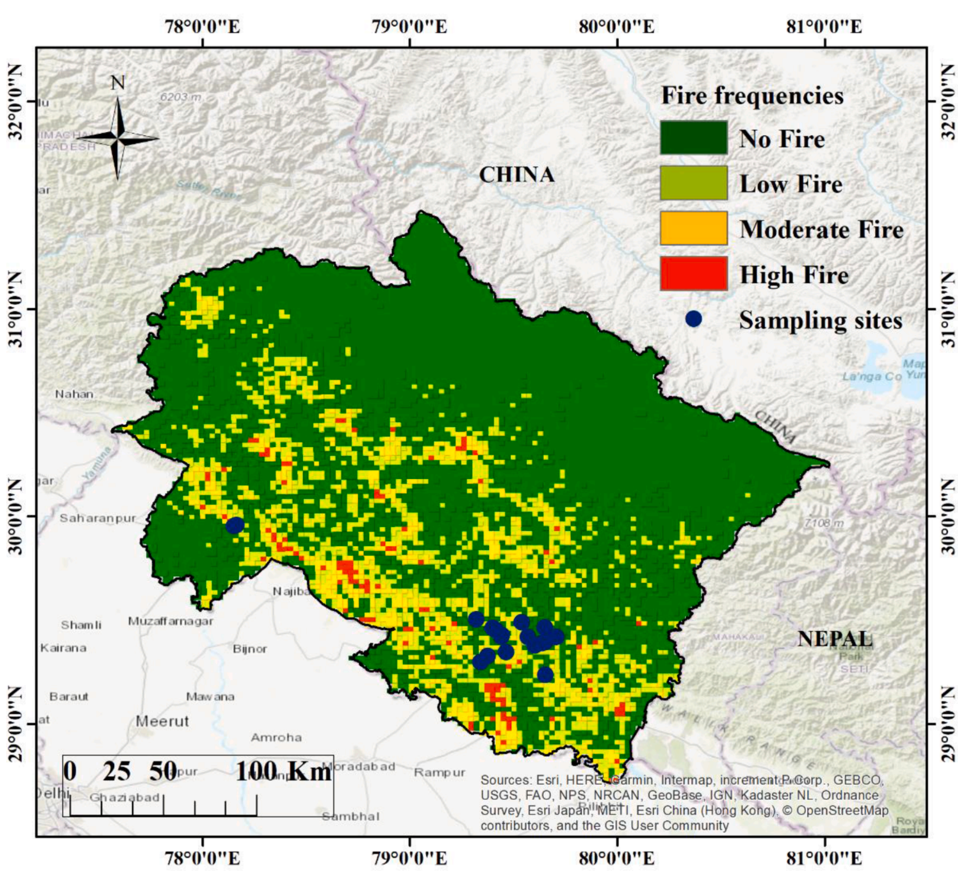

Fig. 2. Map showing fire frequency and sampling sites in Uttarakhand, western Himalaya.

12–34 (high fire frequency class) (Fig. 2).

3.2. Field data sampling/ vegetation analyses

In order to determine vegetation structure, species composition and abundance as well as the ecological dynamics of the forests, vegetation samplings were conducted. Based on fire frequency classes (no, low, moderate, and high), we selected 16 different forest sites in two districts of Uttarakhand, viz. Haridwar and Nainital between 29°00' N–30°46' N lat. and 77°48' E–79°12' E long. spanning an elevational range of 296 m. to 2138 m.a.s.l (Table 1).

In each frequency class, four sampling plots (of the same fire frequency) were selected. Initial reconnaissance was conducted, and different fire intensities were surveyed to find the representative regions of these frequency classes.

To gather quantitative data on the different forest layers (trees, shrubs, and herbs), standard phytosociological methods were followed (Mueller-Dombois and Ellenberg, 1974). Geographic coordinates and elevation were determined using a Garmin eTrex 20X Handheld GPS meter. Previous phytosociology studies in Northern, Central, and Eastern Himalayas (Saxena and Singh, 1982; Dhar et al., 1997; Dar and Sundarapandian, 2016; Sharma et al., 2018; Joshi et al., 2022) used randomly laid 100 m^2 or 1000 m^2 size quadrats covering up to 0.5 ha in each sampling location area per forest type. After a thorough reconnaissance survey of each frequency class, ten stands of the forests in each frequency class were delineated and they were representative of the entire vegetation types. In each frequency class, four sampling plots of the same frequency were selected. Within these stands, ten sampling plots (1.0 ha) were laid out for intensive data collection. The sample plots thus represented various forest types, topography, vegetation composition, historical fire regime (based on the consultation with the locals of the nearby study sites), frequency of fire and fire duration etc. Vegetation analysis in each 1.0 ha sampling plot was carried out by randomly placing ten quadrats of 10 m x 10 m for tree determination. Within these quadrats, two quadrats (5 × 5 m) were laid for shrubs and three quadrats (1× 1 m) for herbs. The circumference at breast height (CBH at 1.37 m from the ground) of each tree was recorded. The zigzag transect was established in each plot, and a sampling point was located every 100 m. A total of 160 quadrates for trees, 320 for shrubs and 480 for herbs were laid out in all the frequency classes for various parameters of vegetation such as species richness, the density of tree, shrubs, and herbs across the sampling sites.

3.3. Data analysis

The richness and density, as well as the Shannon and Wiener (1963) diversity index (H') were determined for each plot. The total number of species in all fire frequency classes was calculated in all the growth forms (herbs, shrubs, and trees). Density per hectare was calculated for each frequency class, and a two-way ANOVA was used to analyze any significant differences in these factors among the frequency classes. Results have been demonstrated in regard to density and the number of species for all growth forms per fire frequency class.

3.4. Statistical analysis

Data on floral density (ind./ha) under various forest fire frequency classes, viz. no fire, low, moderate, and high, were analysed and investigated for making statistical inferences using the Data Analyzed analysis tool in IBM SPSS 25. A two-way Analysis of Variance (ANOVA) was used for data analysis (Table 3) as it allows testing equality of more than one population means on instances where two assignable factor(s), namely (i) Various Forest fire conditions and (ii) Flora types are culpable for variation in the dataset i.e., number of individuals observed per

Table 1
List of study sites under different fire frequency classes in Uttarakhand, Western Himalayan.

Fire frequency class(Dominant species)	Site code	Locality	Elevation (m)	Slope aspect (facing)	Latitude (N)	Longitude (E)
No Fire (*Pinus roxburghii, Shorea robusta, Mallotus philippensis, Colebrookea oppositifolia, Oxalis corniculata, Desmodium microphyllum*)	S1	Mukteshwar	1478	North	2920′48.206′'	7927′40.505′'
	S2	Vinayak	2138	South	29°27′47.051′'	79°24′04.690′'
	S3	Mukteshwar	1995	West	29°27′56.309′'	79°39′07.832′'
	S4	Nartola	2006	West	29°23′42.447′'	79°39′09.842′'
Low Fire (*Pinus roxburghii, Myrica esculenta, Terminalia elliptica, Achmenthera gossypium, Barleria cristata, Colebrookea oppositifolia, Arundinella prunella, Anaphalis aristata*)	S5	Shyamkhet	1926	South	29°25′13.328′'	79°34′08.181′'
	S6	JyoliKote	1478	West	2920′48.206′'	7927′40.505′'
	S7	Kilbary	2133	North	29°25′44.136′'	79°26′36.491′'
	S8	Vilkeshwar	296	South	29°57′16.48″	78° 9′14.80″
Moderate Fire (*Pinus roxburghii, Shorea robusta, Eupatorium odoratum, Inula cuppa, Ajuga bracteosa, Anaphalis adnata, Geranium wallichianum*)	S9	Maheshkhan	1894	East	2914′13.846′'	7939′16.978′'
	S10	Mansa Devi	316	South	2929′29.912′'	7932′21.770′'
	S11	Hairakhan	856	East	2914′13.846′'	7939′16.978′'
	S12	Dhari	1757	East	29°23′26.696′'	79°38′14.823′'
High Fire (*Shorea robusta, Tectona grandis, Clerodendrum infortunatum, Flemengia strobilifera, Lantana camara, Murraya koenigii, Crysopogon grillus, Conyza aezibica*)	S13	Paharpani	2032	South	29°17′54.192′'	79°20′27.757′'
	S14	Padampuri	1645	South	2925′14.276′'	7942′24.724′'
	S15	Ghatgarh	963	North	2922′40.420′'	7936′14.795′'
	S16	Kaladhungi	356	South	29°17′54.192′'	79°20′27.757′'

hectare. The null hypotheses (H_0) for the problem were defined as (i) average flora density is the same for all the forest fire conditions, including the case of no fire, and (ii) average flora density under different forests fire conditions is the same for different flora types, namely, tree, shrub, herb, whereas the alternate hypothesis was that not all the average population means are the same.

4. Results

4.1. Fire frequency

An analysis of 16,206 fire points across Uttarakhand between 2011 and 2020, reveals that the highest forest fire frequency was 34. The no-fire frequency class occurred across 13,619 fire points which cover an area of 84.04%, whereas the low fire frequency class occurred across 1784 fire points covering an area of 11.08%; the moderate fire frequency class was found across 674 fire points, which covers 4.15% area. In high fire frequency class, only 129 fire points were recorded covering 0.79% of the total geographical area of the Uttarakhand state (Fig. 2).

4.2. Floristics diversity

Across the studied sites dominant tree species such as Pinus roxburghii, Myrica esculenta, Terminalia elliptica, Shorea robusta, and Tectona grandis, shrubs viz. Achmenthera gossypium, Barleria cristata, Eupatorium odoratum, Inula cuppa, and Murraya koenigii and dominant herbs such as Ajuga bracteosa, Anaphalis adnata, Desmodium microphyllum, and Arundinella nepalensis were found. Across all the sampled sites, a total of 107 species (herb, shrubs, and trees) belonging to 81 genera and 65 families of the plant were recorded in all the frequency classes. The maximum number of plant species was recorded in no fire (72), followed by low fire (57), high fire (50) and minimum in moderate fire frequency class (40).

Of the total recorded plant species belonging to 65 families, Asteraceae and Fabaceae were the most dominant families with 13 species, followed by Poaceae with 12 species and Lamiaceae with 10 species. Interestingly, 37 families were monotypic and represented by a single species, while 13 families comprised two species, six families with three species, three families with four species, two families with five species, six families with three species (Fig. 3).

Shannon-Wiener index (H') values across the study sites ranged between 3.02 and 3.45, being a maximum (3.45) at low fire frequency class, followed by moderate fire (3.33), no fire (3.18), and minimum at high fire frequency class (3.02) (Fig. 4b) (Table 2).

Across the fire frequency classes, the tree and shrub species richness did not show any trend of increase or decrease with increasing fire frequency. Strikingly, herb species decreased with increasing fire frequency class from 37 species in no fire frequency class to 28 at low fire frequency class. In moderate fire frequency the species number was 14 and lowest number of species (12) was found in high fire frequency class (Table 2). The Shannon-Weiner index also decreased for the herb layer with increasing fire frequency.

The tree species richness showed a positive linear relationship (R^2 = 0.3692) with fire frequency classes and increased with increase in fire frequency class, whereas the shrubs species richness showed a negative linear relationship (R^2=0.3913) with fire frequency classes and decreased with increase in fire frequency class. Similarly, the shrub's species richness showed a positive linear relationship (R^2 = 0.3692) with fire frequency classes and increased with an increase in fire frequency class. Total species richness (trees + shrubs + herbs) showed a negative linear relationship (R^2 = 0.1317) with fire frequency classes and decreased with increasing fire frequencies (Fig. 6).

The maximum richness (including herb, shrub, and tree) was recorded in no fire frequency class (72), followed by low fire frequency (57), high fire frequency (50), and minimum at moderate fire frequency (40). These values are higher as compared to an earlier study conducted in the subtropical and temperate forest stands in the western Himalaya region at similar elevation (300–2200 m) zone (Rana et al., 1989). Keith et al. (2010) reported the similar results and stated that the herb species increase in number immediately after fire because of a general reduction in the tree cover that brings more light to the soil.

Results of the statistical analysis indicated that indeed, the first null hypothesis is true i.e., forest fire conditions/type does not have a significant effect on the number of flora individuals observed per hectare as the F_{cal} (0.432) is less than the critical value (3.490) for the given level of significance. Though the second null hypothesis got rejected as its F_{cal} (37.049) is larger than that of the critical value (3.259), indicating that the flora type does significantly affect flora density over the sampled field plots, which were affected by different forest fire frequency classes. Tables 3 and 4 gives the numerical values for various indices of performed two-way ANOVA.

Towards identifying in which pair among flora types, i.e., tree, shrub,

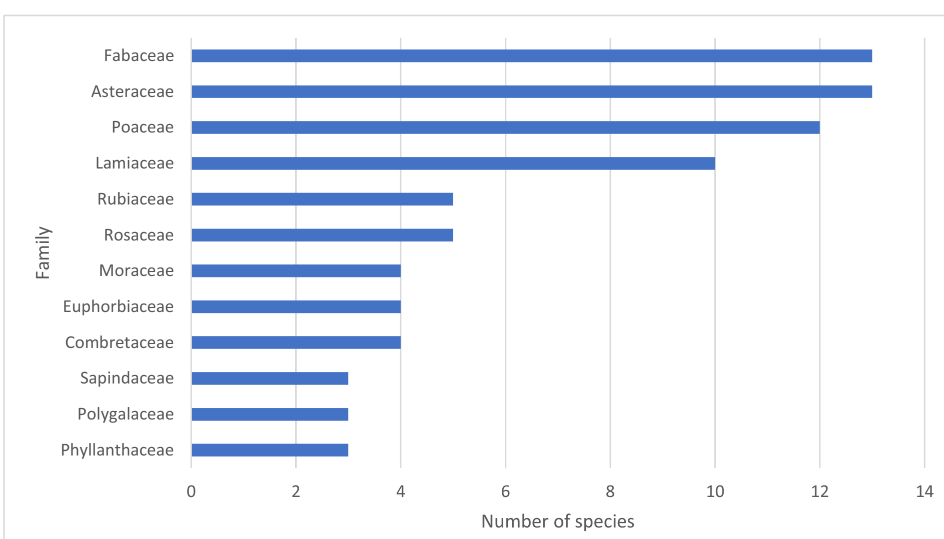

Fig. 3. Floristics richness under dominant (top 12) plant families recorded in all the fire frequency classes.

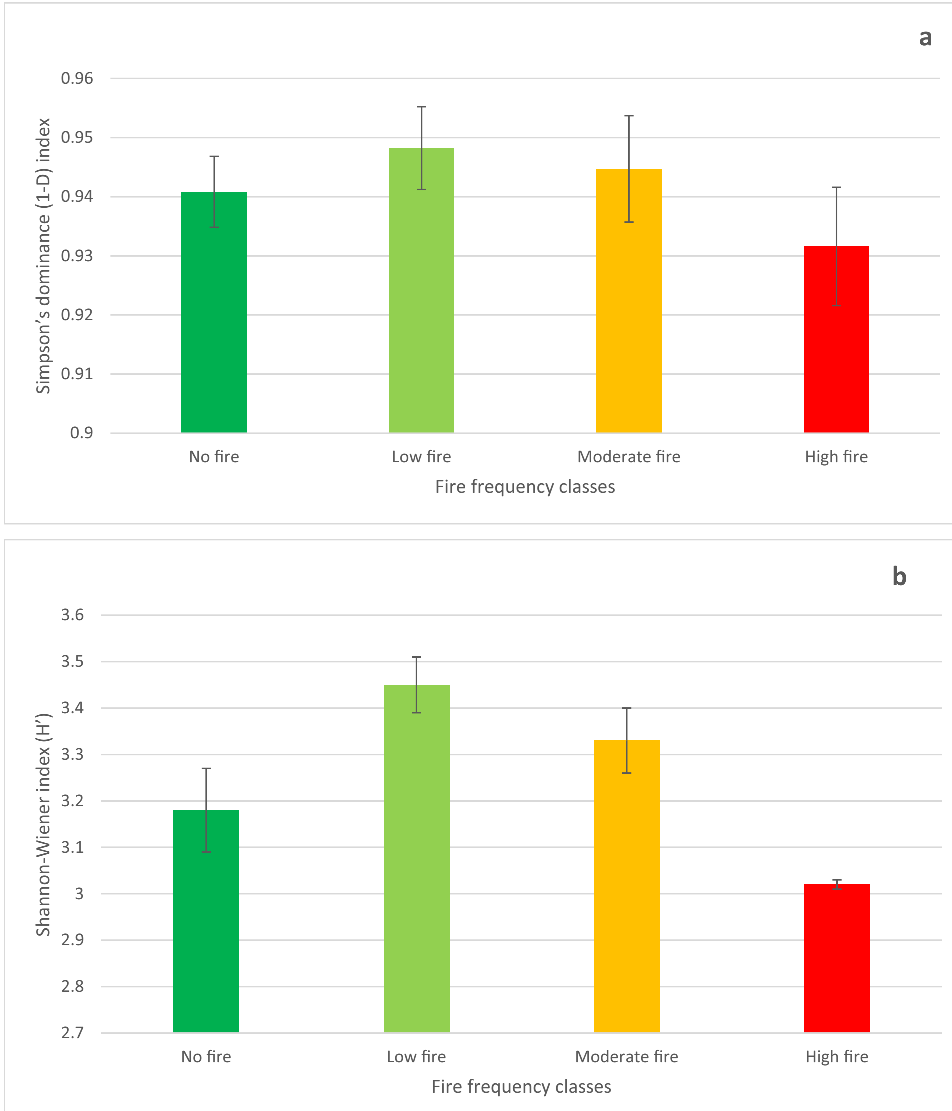

Fig. 4. Diversity indices: (a) Simpson's dominance index and (b) Shannon-Weiner index for all fire frequency classes.

herb, sapling, and seedling, the difference is significant, the additional computation was done to determine the Critical Difference (CD) and Actual Difference (AD). A total of ten (10) pairs from the column data were possible. Results from the computation are displayed in Table 5.

4.3. Vegetation density

Across the sampling sites, the tree density ranged between 332 ±51.03 and 435±54.14 ha−1, being maximum (435±54.14 ha−1) at low fire frequency class, followed by moderate fire frequency (417.5 ± 33.04 ha−1), no fire frequency (350±20.31 ha−1), and minimum at high fire frequency class (332.5 ± 51.03 ha−1) (Fig. 5a). The shrub density varied from 2485±651.54 to 3910±422.04 ha−1, maximum at low fire frequency class (3910±422.04 ha−1) followed by moderate fire frequency class (3532.5 ± 389.63), no fire frequency class (2867.5 ± 501.05 ha−1) and minimum at high fire frequency class (2485±.651.54 ha−1) (Fig. 5b). The herbs population showed decreasing trend with increase in fire frequency in all-frequency classes (5c).

5. . Discussion

The structure of plant populations is an indicator of the ability of a species to respond to disturbances such as wildfires (Rodriguez-Trejo, 2014). In the present study, significant differences in species diversity across the fire frequency classes were observed. While species diversity was higher in the low fire frequency class, the increasing fire frequency led to a decline in the diversity and increased dominance of certain fire-tolerant species. Our results show that species richness and density decreased in higher fire frequency classes which could be due to poor regeneration. The results also indicated that tree species diversity was higher at low fire frequency class, followed by moderate fire frequency class, no fire frequency class, and minimum at high fire frequency class. The findings of the present study are almost similar to the studies carried out by other workers e.g., Ray et al. (2019), in the tropical dry deciduous

Table 2
Diversity pattern of different vegetational layers in different fire frequency classes in the study area.

Frequency class	Parameters	Shannon Index (H')	Richness
No fire frequency	Tree layer	0.36646	12
	Shrub layer	1.53249	23
	Herb layer	1.2877	37
	Total	**3.18665**	**72**
Low fire frequency	Tree layer	0.28342	7
	Shrub layer	1.45697	22
	Herb layer	1.71373	28
	Total	**3.45**	**57**
Moderate fire frequency	Tree layer	0.15892	10
	Shrub layer	1.67188	16
	Herb layer	1.50535	14
	Total	**3.33433**	**40**
High fire frequency	Tree layer	0.37776	18
	Shrub layer	1.30958	20
	Herb layer	1.33657	12
	Total	**3.02375**	**50**

Table 3
Summary of two-way ANOVA factors.

Summary	Count	Sum	Average	Variance
No Fire	5	10,946.5	2189.30	9,112,996.70
Low	5	8810.0	1762.00	4,090,616.88
Moderate	5	9684.0	1936.80	4,010,216.70
High	5	8564.0	1712.80	4,267,832.20
Tree	4	1534.0	383.50	2516.33
Shrub	4	12,794.0	3198.50	412,143.00
Herb	4	20,889.0	5222.25	1,907,960.92

forest of Panna Tiger Reserve, Madhya Pradesh, India; Jhariya et al. (2012), in the tropical dry deciduous forest of Chhattisgarh; Kodandapani et al. (2008), in dry tropical ecosystems in the Western Ghats, India. Verma and Jayakumar (2015), Sathya and Jayakumar (2017) and Saha and Howe (2003) also reported decreased species richness due to fire in the dry deciduous forest of Central India. On the basis of present results it could be argued that the low and moderate fire frequency may be beneficial for the regeneration of herb and shrub species in the forests. We found that tree species diversity was higher at low and moderate fire frequencies than the no fire frequency but minimum at high fire frequency class. Therefore, the low-intensity fire does not seem to have a negative impact on the tree density. The results showed that the number of shrubs was lower in the high fire frequency class than other classes and highest in the low fire frequency class. The benefits of moderate or low disturbance for species regeneration have also been reported by Khan et al. (1987) and Maram and Khan (1988). In the present study the number of herb species was, however, found decreasing with the increasing fire frequency. According to Kodandapani et al. (2008), species diversity declined by 50% and 60% in the moderate and high-frequency classes, respectively, compared to the low fire frequency class. Sapling density also declined by about 30% in both moderate and high-frequency classes compared to low frequency class. The lower tree density at high fire frequency might be attributed to the effect of fire on trees in the region.

Our findings show that forest fire has different levels of impact on different frequency classes in the forests of Uttarakhand, Nonetheless, it can be said that a single fire event may not be beneficial for any forest. As mentioned earlier low and moderate fire frequencies increase the shrub and tree densities while herb density decreases with the increase

Table 5
Critical Difference (CD) and absolute Actual Difference (AD) for various column pairs.

Pair	CD	Absolute AD	Difference significant or not (Y/N)
Tree-Shrub		2815	Y
Tree-Herb	1128.44	4838.75	Y
Tree-Sapling		166.25	N
Tree-Seedling		96.50	N
Shrub-Herb		2023.75	Y
Shrub-Sapling		2981.63	Y
Shrub-Seedling		2718.50	Y
Herb-Sapling		5005.38	Y
Herb-Seedling		4742.25	Y
Sapling-Seedling		263.16	N

Y: Yes; N: No; If CD>abs (AD), then the difference is significant between the column pairs otherwise not.

Table 4
Various indices of two-way ANOVA.

Source of Variation	SS	df	MS	F_{cal}	P-value	F_{crit}
Rows	695,681.84	3	231,893.95	0.432	0.73370908	3.490
Columns	79,490,116.30	4	19,872,529.08	37.049	0.00000116	3.259
Error	6,436,533.60	12	536,377.80			
Total	86,622,331.74	19				

SS: Sum of squares; df: Degrees of freedom; MS: Mean squares.

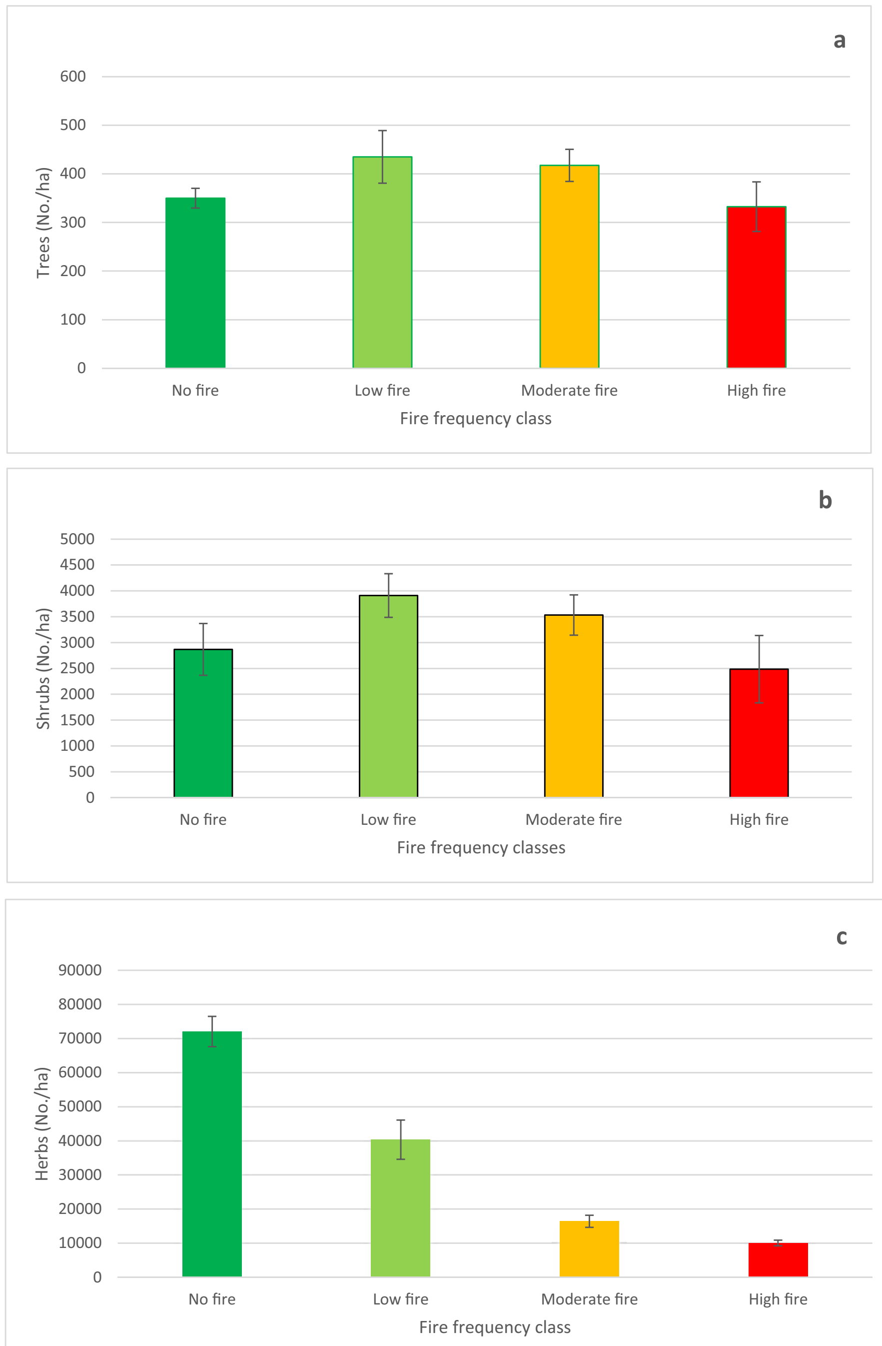

Fig. 5. Number of individual (density ind./ha) recorded per hectare: (a) tree, (b) shrubs, and (c) herbs.

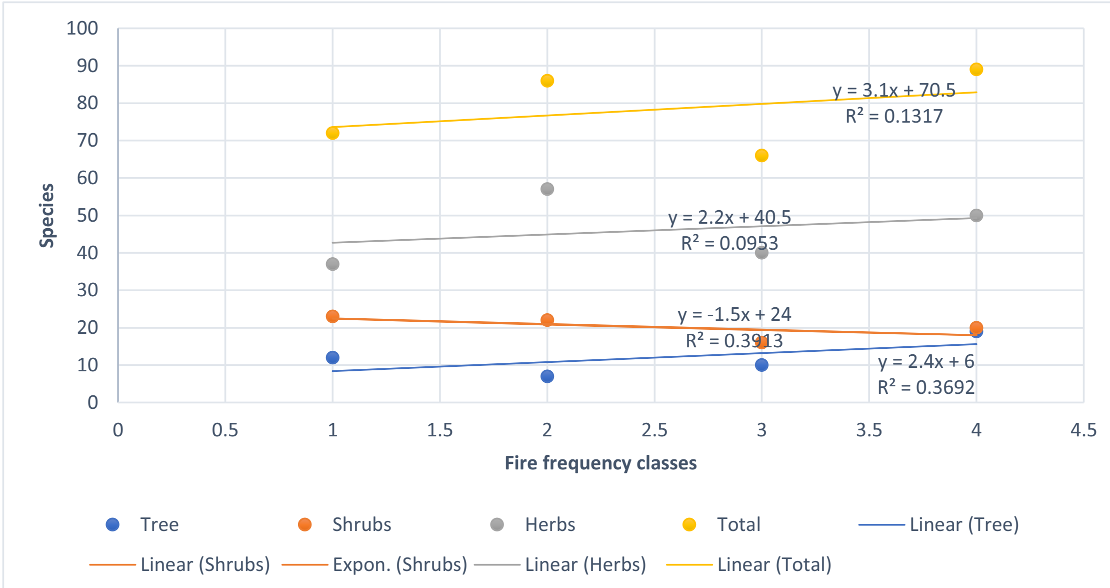

Fig. 6. Relationship of forest fire frequencies with total number of tree, shrubs, and herbs species.

in fire frequency. Thus, it is clear that the herbs are most affected by fires. In any ecosystem, plant species diversity and density are maintained by the healthy regeneration of species. This study forms a baseline dataset that may facilitate future in-depth studies related to the effect of forest fires and fire frequencies on vegetation structure in the western Himalayan region.

Declaration of Competing Interest

The authors declare that they have no competing interests.

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