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Nature of forest fires in Uttarakhand: frequency, size and seasonal patterns in relation to pre-monsoonal environment

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Man-made forest fires in the traditionally populated zone (about 800–2000 m altitude) are common in much of the Central Himalaya, and are a major topic of environmental debate. This study based on an analysis of data of the State Forest Department at Uttarakhand on incidence of forest fires shows that these are high-frequency, low-severity surface fires of small size, largely determined by the moisture conditions of the pre-monsoon season (from March to mid-June), and the traditional practices of biomass collection by local people.

Keywords: Biomass collection, forest fire, pre-monsoon season, moisture conditions.

FOREST fires remain a major hazard in many ecosystems of the world, and a fire event may burn areas, influencing the species composition and ecosystem processes[1]. In California, USA, a lightning-induced fire may burn thousands of hectares of forest, with rotation period ranging from 95 to 974 yrs (ref. 2).

In the Central Himalaya, particularly Uttarakhand, frequent man-made fires are an integral part of the chir-pine (*Pinus roxburghii*) – banj oak (*Quercus leucotrichophora*) forest zone (generally, between 800 and 2000 m altitude), and promote the regional domination of chir-pine at the expense of broadleaf oak forests[3,4]. These man-made forest fires are also a major source of pollutants including black carbon which is regarded as a major cause of glacier melt in the Himalaya[5], and has the capacity to influence regional climate[6]. Fire regime the world over is likely to change in many regions because of the global climate change and change in land-use patterns[1].

Fires in the Himalaya occur during the pre-monsoon summer period of moisture stress[3,7], which is intensified because of global warming and resultant depletion of snowmelt water[8]. Despite being referred to as a major environmental factor, studies on forest fires in the Himalaya, particularly from an ecological standpoint are limited[9]. One of the initial steps in this direction could be assessing their nature.

The main objectives of the present study are to: (i) characterize the nature of the manmade forest fires of the

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Uttarakhand Himalaya based on their timing, frequency and size; and (ii) analyse the role of pre-monsoon seasonal condition, biomass collection and chir-pine litter deposition on the forest floor in determining the fire regime. We hypothesize that the moisture conditions of pre-monsoon, of which small rainstorms are characteristic features (an average of the state level, about 94 of 1549 mm annual rainfall, India Meteorological Department, 2014), will play a critical role in determining the nature of fire regime. For this study, we collected information from the records of the Uttarakhand State Forest Department for two entirely mountainous forest divisions, Bageshwar Forest Division (BFD) and Chamoli Forest Division (CFD).

Though the amount of annual precipitation in BFD (1261 mm) and CFD (1231 mm) is similar, the pre-monsoon precipitation is distinctly higher in BFD (379.3 mm) than in CFD (207.1 mm). They have similar lists of forest types, but differ considerably in their proportional distribution (Table 1). In CFD oak (*Quercus leucotrichophora*, *Quercus floribunda* and *Quercus semecarpifolia*) forests account for 65.3% of the forest area, while in BFD the low altitude or subtropical chir-pine (*P. roxburghii*) forest covers about 80% of the forest area; in CFD it accounts for only 26.25% of the forest area. About 70% of the people in the study forest divisions are involved in livestock-based agriculture, extracting forest biomass almost daily for firewood, fodder and forest floor litter for preparing manure to maintain fertility of the crop field. On an average, forest biomass removal per year is approximately 3.6 times more in BFD than in CFD. This was estimated on the basis of the number of households (derived from district state profile, Uttarakhand) and forest biomass assumption per household[10] and forest areas in the two divisions (Divisional Forest Record of Uttarakhand Forest Department). Annual litter fall is 6.3–6.5 tonnes/ha/yr; about three-fourths of this occur during pre-monsoon months from March to May[3]. Annual litter decomposition is relatively slower in chir-pine (46%) than in banj oak (*Q. leucotrichophora*) (65%), resulting in the presence of higher inflammable material on ground in it[3].

Table 1. Comparative account of forest distribution in the two forest divisions under study

	Chamoli Forest Division (CFD)	Bageshwar Forest Division (BFD)
Total geographical area (km^2)	7820	1687.8
Total forest area (km^2)	854.74	626.81
Percentage area by major forest types		
(A) Low-altitude chir-pine	26.25	79.90
(B) High-altitude conifer forests	2.91	1.1
(C) Oak forests	65.3	17.4
Others	5.5	1.5

Source: Divisional Forest Record of Uttarakhand State Forest Department. (A) Includes *Pinus roxburghii* as dominant species; (B) includes *Cedrus deodara*, *Pinus wallichiana*, *Abies pindrow*, *Picea smithiana* as dominant species; and (C) includes *Quercus leucotrichophora*, *Q. floribunda* and *Q. semecarpifolia* as dominant species.

Data were available for six years from 2009 to 2014, for BFD and for 18 years from 1993 to 2014 (there were 4 gap years) for CFD. Data on forest fires were collected from the Uttarakhand Forest Department. They pertained to date of fire incidence, time and duration of fire, area affected by fire, and site where the fire occurred. In case of CFD data, time and duration of fire were not available. Information about forest fire was also collected through surveys and meetings with villagers and forest department workers in various forest ranges of the two forest divisions. Villagers were of the opinion that there has been a marked improvement in record-keeping of the Forest Department in recent years. Majority of respondents indicated that they used fire to hasten the growth of grasses and enhance production. Fodder scarcity is high in winter and pre-monsoon seasons. Fire is also used to clear the crop field of weeds and crop residues. Internal conflicts and carelessness are also noted as the cause of man-made fires. During 2014–15, repeated forest surveys were also undertaken to check whether fires remained surface fires or became crown fires.

Analysis of variance (ANOVA) was done between the affected area and fire frequency with the two factors without replication using Microsoft Excel for both the BFD and CFD. Correlation between the number of fire incidences and rainfall was developed in Microsoft Excel with the help of Chart-type scatter *XY* for both forest divisions across months and years. Also, correlation between affected area (burnt area) and duration per fire event was developed in Microsoft Excel for BFD only across years. The diurnal pattern was also developed between the number of fire events and duration (length of fire) per fire event for BFD.

The State Forest Department officially treats the period from mid-February to mid-June as fire season, during which it takes fire control measures. The average fire frequency per fire season (number of fire incidents in a fire season or year) across the two forest divisions was 30.5 ± 7.20. In BFD, on an average across six study years, 17.7 ± 4.13 fires/yr occurred and it ranged from 8 fires in 2013 to 94 fires in 2009 (Figure 1). In comparison, in CFD, on an average across study years, 25.9 ± 8.48 fires/yr occurred and it ranged from no fire incident (1994, 1997, 2000 and 2001) to 149 incidents (1995) (Figure 1). In CFD, the monthly mean fire frequency (across study years) increased steadily from March (2.22) to June (10.11) with the rise in temperature (Figure 2 *a*). In BFD it followed a unimodal curve (Figure 2 *a*), with a peak in April–May. A comparison of forest fire data of the State Forest Department and those of Moderate Resolution Imaging Spectroradiometer (MODIS) collected from Forest Survey of India (FSI) and checked by us

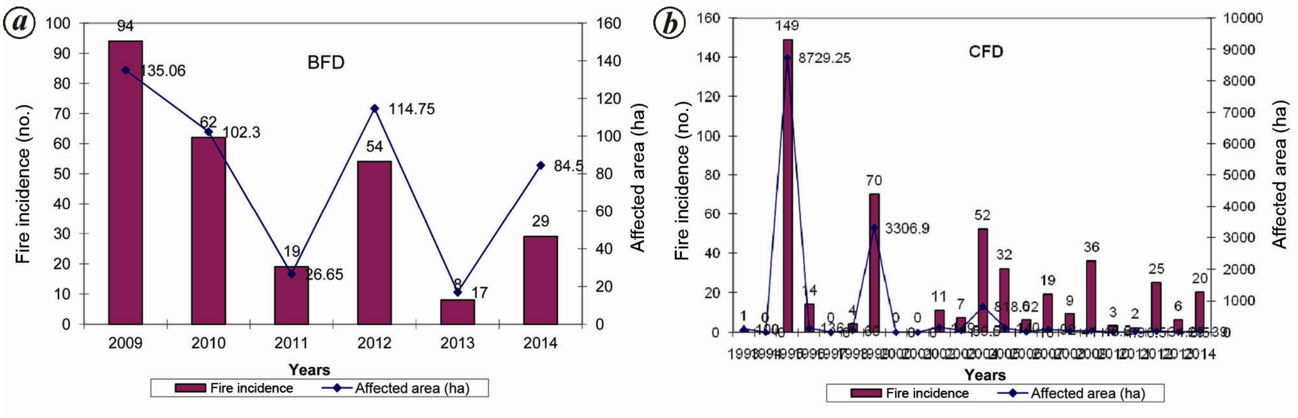

Figure 1. Relationship between fire incidence and burnt area (affected area) during a fire season from 2009 to 2014 in Bageshwar Forest Division (BFD) (***a***) and 1993 to 2014 in Chamoli Forest Division (CFD) (***b***).

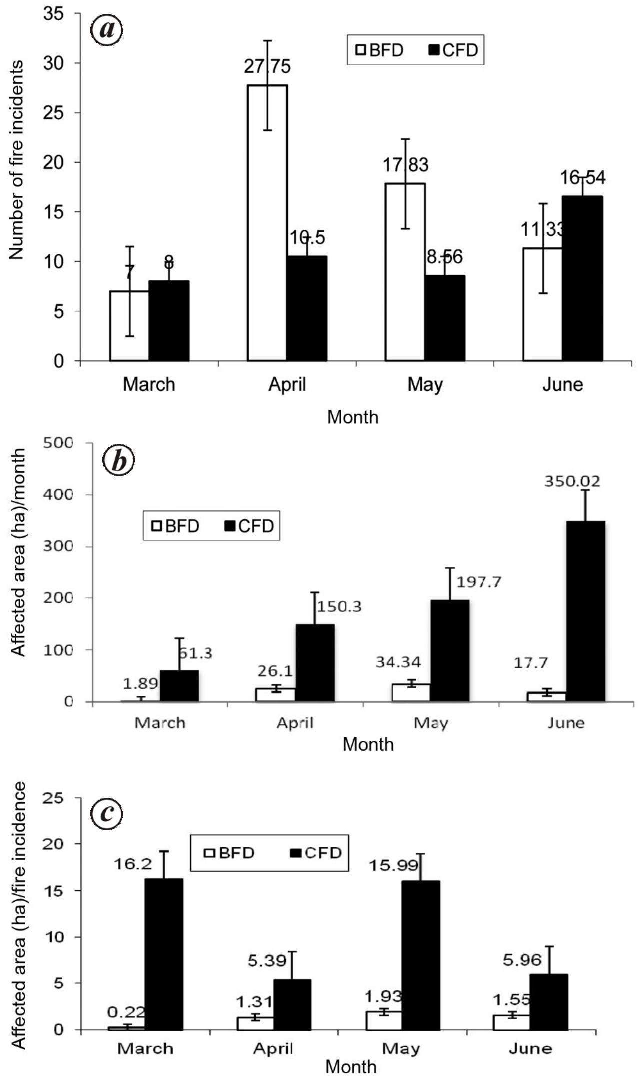

Figure 2. ***a***, Average monthly incidence of fire represented as fire frequency. ***b***, Forest area affected by all fires during a month. ***c***, Average forest area affected per fire. All values are averages of months across the studied period: 2009–2014 for BFD and 1993–2014 for CFD, excluding four gap years (1994, 1997, 2000 and 2001).

from NASA website for the two forest divisions (for the period 2009–2014 for BFD and 2006–2014 for CFD) indicates that MODIS captured only 5.64% and 19.04% fires recorded by the former in BFD and CFD respectively. The number of fires was 266 and 126 in BFD (2009–2014) and CFD (2006–2014) respectively, according to the State Forest Department records, compared to 15 and 24 respectively, according to MODIS data. Discussions with officials of the Forest Department suggested that the differences were because MODIS failed to detect small fires of short duration particularly from dense forests. MODIS is largely suited to record large fires, which are common in USA, Canada and Australia.

The highest monthly fire frequency across all months of the study years was 53, recorded in April 2009 in BFD, and 122 in June 1995 in CFD, but both being unusually dry years. The June fires in CFD in 1995 resulted in an unusually large area of fire, about 6099 ha. All fires were surface fires; only occasionally they burned the lower ends of tree crowns of 4–5 individuals in a burned forest stand. The total fire-affected area per month in CFD increased from March (61.3 ha) to June (350.02 ha) with the increasing temperature (Figure 2 *b*). In BFD it increased from March (1.89 ha) to May (34.34 ha), and then decreased in June (17.70 ha) (Figure 2 *b*). During the fire season in BFD, the average minimum temperature increased from 11.73°C (in March) to 22.01°C (in June), and the monthly fire frequency increased from 14 (in March) to 128 (in May). In CFD the minimum temperature increased from 8.56°C (in March) to 18.06°C (in June), and fire incidences from 40 (in March) to 182 (in June). The fire frequency (average of study period) and mean monthly temperature (average of last 40 years) were positively correlated in both BFD ($r = 0.41$; $P < 0.01$) and CFD ($r = 0.92$; $P < 0.01$), but were significant only in CFD. The relationship between the two is also affected by other factors, particularly rain storms.

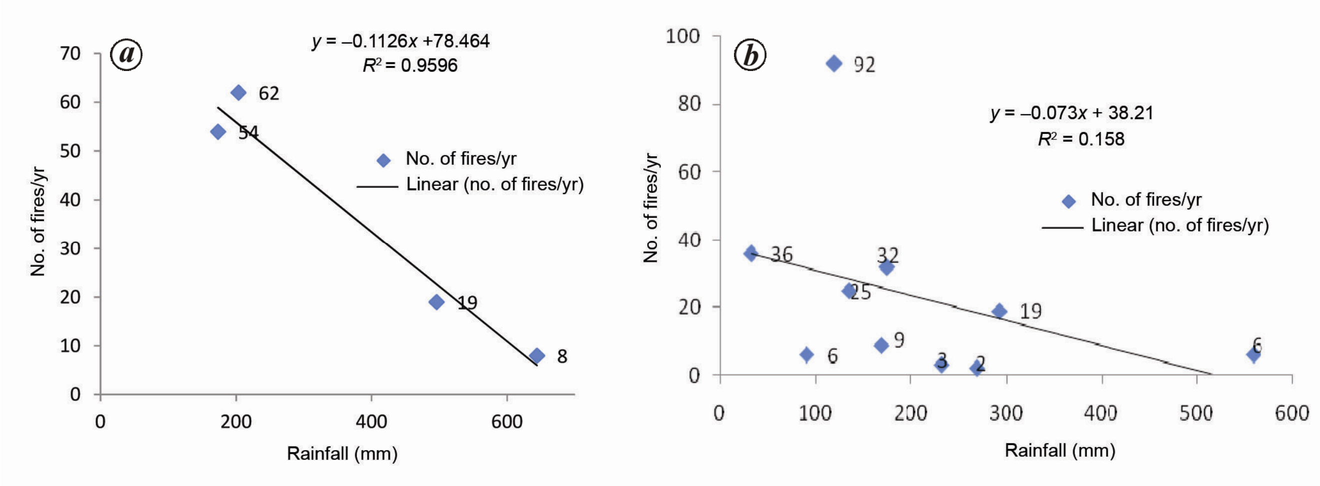

Figure 3. Relationship between fire incidences and rainfall during pre-monsoon season (March to mid-June) across the years, from 2010 to 2013 in BFD (***a***) and 2004 to 2013 in CFD (***b***).

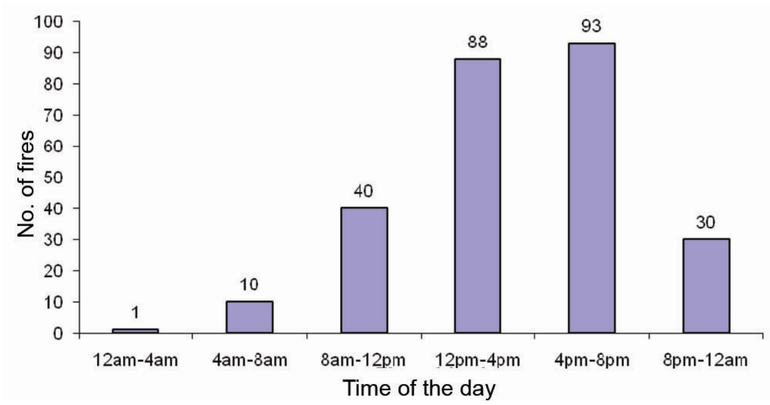

Figure 4. Diurnal pattern of fire incidents in BFD. Various include all fires that occurred from 2010 to 2013.

For example, in BFD in June the effect of high temperature on fire was offset by more rainstorms.

In BFD, the average cumulative area burned per year was 80.4 ± 19.64 ha, the yearly burned area ranging from 17 ha in 2013 to 135.06 ha in 2009 (Figure 1), the warmest year since 1901 on record in the country. The monthly average area burned per fire incident across the six study years was significantly lower in March (0.22 ha/fire) than in the warmer month of April (1.31 ha/fire) and May (1.93 ha/fire). In June in the years when monsoon was delayed, the average area burned per fire shot up to 1.55 ha/fire, but in three out of six study years no fire occurred (Figure 2 *c*).

In CFD, the mean of cumulative area burned per year was 766.0 ± 502.7 ha. Across the study years it ranged from no burning (in 1994, 1997, 2000. 2001) to 8729.5 ha in 1995 (Figure 1), the year which had several spells of heat wave. At the country level, the year 1995 had 34 spells of heat wave compared to those (223 ± 1.8) for the period from 1978 to 1999. The monthly average burned area per fire incident was significantly lower in February (5 ha/fire), and with increase in temperature it increased and reached 5.39 and 15.99 ha/fire in April and May respectively (Figure 2 *c*).

The yearly number of fire incidents and pre-monsoon precipitation were significantly negatively correlated in BFD ($r = 0.979$; $P < 0.01$), while in CFD the correlation was not significant ($r = 0.39$; $P < 0.01$) (Figure 3). On an average, the area burned per fire incident was greater in CFD (29.58 ha/fire) than in BFD (1.80 ha/fire), partly because of the lower amount of rainfall during a fire season in CFD (207.1 mm) than in BFD (379.3 mm). In total, across all months in the studied forest divisions, fire frequency was 15 per month or more eight times, out of which four times there was no precipitation, two times it was less than 20 mm/month, and two times it exceeded 50 mm. In CFD, the monthly fire incident was below 10 when monthly precipitation was more than 200 mm. Pre-monsoon dry conditions exacerbated by global warming and depletion of snowmelt water are being seen as a cause of depressing timberline in some parts of the Himalayas[11]. However, the monthly fire incident and monthly

Table 2. Causes of small surface forest fires and likely trends of change

Causes	Current and future trends
A high degree of forest fragmentation, particularly in most populated altitudinal zone (800–2000 m) of Uttarakhand[3,15,16]	While roads and other developmental activities continue to fragment forests[18], forests they have begun to recover because of reduced day-to-day biomass extraction of local people.
Small forest floor litter mass, less than 7 tonnes/ha during most of the year, compared to up to 40 tonnes/ha in some temperate forests of the world, because of relatively higher litter decomposition rates (turnover time 2 yrs and less, compared 2–15 yrs in typical temperate forests). People wait for fresh litter to accumulate on the ground during March and April to ignite fire and monsoon arrives by mid-June, thus limiting the burning season[17]	Warmer temperature is likely to increase litter decomposition, but decrease in moisture may work in the opposite direction. So the overall impact of climate change on decomposition will be only limited.
Collection of forest floor litter for making manure, and fallen wood for cooking food by local people limits the fuel mass for fires	While the removal of litter for agriculture is on a decline, litter is being used for making fire briquettes, at small scales. So forest floor litter mass is likely to increase and result in larger fires in future.
Cattle grazing, which keeps fuel mass low	Open cattle grazing is on the decline, particularly because of the reduced livestock density and improved stall-fed cows. Thus there will be more fuel build-up.
Effectiveness of the State Forest Department in controlling fires	Though cooperation of local people with regard to fire fighting has declined, because of improved transport and information communication, fire control has become more effective.
Pre-monsoon precipitation among Indian Himalayan states for which data have been analysed. It is the lowest in Uttarakhand (about 6% of annual rainfall).	Since precipitation is likely to become more seasonal due to global warming (AR5, IPCC), the intensification of drought may result in larger fires. Pre-monsoon droughts have been quite frequent in recent years.
Chir-pine forests, the centre of fires, were maintained as open type with periodical thinning and pruning in the past, so surface fires could not get ladder to became more destructive crown fires.	Because of ban on tree cutting, prescribed silvicultural operations are no more in practice, resulting in dense forest stands. Such forests are prone to crown fires and larger fires.

Sources: Refs 3, 14–17, FRI study on forest fire mapping in Uttarakhand communities, ref 18, 19, discussions with forest personnels and local experts.

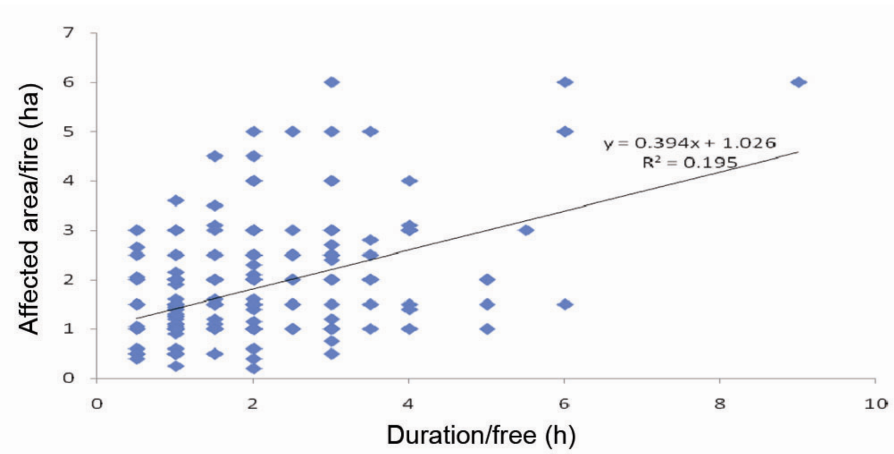

Figure 5. Relationship between area and duration of fire incident in BFD.

precipitation values were not significantly correlated (Figure 4), as incidence of these man-made fires could be affected by several social factors (Table 2).

Though fire could occur at any time of the day, 69% of recorded fires in BFD was during the eight-hour period from 12 noon to 8 p.m. (Figure 5). Of the total fire incidents (266) in BFD during six years, 93.6% was of 4 h or shorter duration (Figure 4).

In brief, our study shows that forest fire regime in Uttarakhand is characterized by frequent surface fires of small size (on an average 1.80–29.58 ha/fire incident) and short duration. Small and frequent fires, as data from

Sikkim (3.2–8.6 ha/fire incident) also indicates[7], seem to be common in much of the Himalaya. Majority of fires occur on drier and warmer facing (southern aspect) slopes, where chir-pine dominates[3] (FRI report: Spatial and temporal variations in forest fires in Uttarakhand). They are very different from lightning-ignited forest fires of the northwestern California, in which thousands of hectares are burned and the return interval of fire is long, between 95 and 974 years (ref. 2). There are several reasons why fires in the Himalaya are of small size: forest fragmentation (IIRS 2004, 2005), collection of forest floor litter for preparing manure, collection of fallen wood for firewood and pollarding of trees for firewood and relatively rapid litter decomposition which result in the presence of small fuel for fire, arrival of monsoon within two months after the peak of litterfall, grazing of livestock and the recently developed public sensitivity to burning, and control of State Forest Department (Table 2). Since in Sikkim the pre-monsoon precipitation exceeds 400 mm, fires are more common during winter when precipitation is low (7.4 mm) (from data of IMD, 2014).

The effect of temperature on an area burnt by a fire incident is apparent from monthly data available for BFD. As the mean monthly temperature increases from March to June, the burnt area per fire incident increases from 0.22 ha in March to 1.93 ha in May, and decreases to 1.15 ha in June (Figure 2).

Fires give a competitive advantage to chir-pine over banj oak. The exposed ground surfaces are suitable beds for the germination of small seeds of chir-pine, which being orthodox (desiccation tolerant-type, Rao 1989), are unaffected by pre-monsoon dry conditions. In contrast, oak acorns lying on the ground for several months are prone to desiccation, particularly when oak litters are removed by local people for composting and increase in temperature under the influence of global warming[12]. Low-severity and high-frequency fires are associated with pine and dry mixed-conifer forests in southwestern North America[13]. Since fire season in the Himalaya is followed by monsoon when most of annual precipitation occurs, soil nutrient loss is considerable, which favours expansion of low-nutrient requiring chir-pine[9]. Thus, though large fires which drastically change stand composition do not occur in the Central Himalaya, the high-frequency, low-severity fire regime has brought about considerable change in the proposed distribution of forests at a regional scale.

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