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Characterizing Forest Fire Fuel in mid-hills of Himachal Pradesh

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ABSTRACT: Forest fire is one of the main reasons of forest degradation in India and has adverse impact on environment, economy and human health. In Himachal Pradesh, mid hills forests are largely prone to ground fires due to accumulation of litter on the forest floor. Therefore, the present investigation was carried out in pure pine, pure oak and mixed forests of Himachal Pradesh with the aim of determining forest floor characters *viz.* fuel thickness (cm), biomass density (t ha^{-1}), moisture content (%) and calorific value (cal g^{-1}), using Randomized Block Design technique. Fuel thickness was measured using a meter rod, biomass and moisture content was estimated using green weight and oven dry weight of samples and calorific value measurements were taken using bomb calorimeter. Results revealed that pure pine forests had thicker fuel (5.62 cm) with highest biomass density (5.68 t ha^{-1}) and lowest moisture content (2.05%) among all three forests. Floor fuel of pine forests, which were primarily comprised of resinous pine needles, demonstrated highest calorific value (5731.2 cal g^{-1}). Among all three forests, pure pine forest provided most favourable fuel conditions for fires initiation and spread, hence fuel management practices are necessary to reduce fire occurrence in pine forests.

Keywords: Forest fire, forest floor characters, forest fuel.

Forest fires are pervasive and critical aspect of the earth system and climate change has lead to more intence and frequent forest fire incidences. The annual global area burned due to forest fire ranges from 300 and 450 Mha (Van *et al.,* 2006). Forest cover of India is 76.4 M ha, out of which 6.99% of area is affected by forest fires (Reddy *et al.,* 2014). The forest cover of the country is declining at an alarming rate. Along with various factors, forest fires are a major cause of degradation of Indian forests (FAO, 2002). Monitoring and management of forest fires are very important in India where forest fire cause adverse ecological, economical and social influences. In India, about 55% of the forest area, predominantly covered by dense forest, is prone to fires due to presence of thick dead vegetation on forest floor causing loss of about INR 7.6 billion every year (Giriraj *et al*., 2010; Roy, 2000 and Anonymous, 1999).
India witnesses most of severe forest fires during the summer season in the hills of Himachal Pradesh (FSI, 2003). Mid-hills zone of Himachal Pradesh encompasses ten per cent of total geographical area of state and is highly prone to forest fire (HPFD, 2018). Forest fires have caused extensive destruction in recent years leading to loss of wildlife habitat, biodiversity, change in micro-climate, adverse effect on livelihood of people, addition of green-house gases *etc*. Average estimated loss due to forest fire in Himachal Pradesh is INR 113 million per annum (HPFD, 2016). The total forest area of Himachal Pradesh is 37, 033 km^2 out of which 1,46,000 ha is sensitive to fire (Bahuguna and Singh, 2002). Mid-hills zone of Himachal Pradesh is highly prone to forest fires during summer due to the presence of conifer species like pine due to shedding of highly inflammable chir pine needles (Shah and Sharma, 2015). The forests of mid-hills zone are mainly comprised of Chir, Oak, Khair, Saal, Bamboo and other broad-leaved tree species.
Forest fires are generally more sensitive to variation in forest fuel characteristics as compared to climate and terrain complexity (Cary *et al*., 2006). Ground fire is the most common type of forest fire occurring in Himachal Pradesh. It destroys the organic matter, which is needed to maintain an optimum level of humus in the soil, and hence decreasing the growth of the grasses, herbs and shrubs, which may result in increased soil erosion (Kandya *et al.*, 1998). Ground fires are strongly influenced by forest floor characters such as fuel structure, fuel load, fuel continuity and fuel moisture level (Flannigan *et al.*, 2005). These characters are critical elements of fire occurrence and spread.

The present investigation was planned in order to characterize forest floor fuel *viz.* fuel thickness (cm), biomass density (t ha^{-1}), moisture content (%) and calorific value (cal g^{-1}), in pure pine, pure oak and mixed forests of Himachal Pradesh. Fuel is main component of forest fire and includes needles, grasses, twigs, shrubs and branches on the ground (Rothermel, 1983). Determination of fuel characters are important because at least 30% of the landscape needs to have forest floor fuel for the fire to start and spread (Hargrove *et al.,* 2000). Fuel moisture has been found to be an important factor in determining the amount of area burned (Meyn *et al.,* 2007) and it negatively correlated to calorific value or high heat of combustion of fuel, which control fire behaviour (Rothermel, 1983). Many studies have been conducted during past two decade for the assessment of vegetation factors which triggered forest fires *viz.,* canopy and over storey vegetation characters (Abramowicz *et al.,* 2021; Maulana *et al.,* 2020; Seydosoglu and Kokten, 2019; Fares *et al*., 2017; Yi and Bao, 2016; Venalainen *et al*., 2014; Rollins, 2009; Kumar and Thakur, 2008 and Scheller and Mladenoff, 2002). A small number of studies determined the character forest floor fuel, in different forest ecosystems (Joshi *et al.,* 2021; Arkadiusz, 2015; Baweja and Kundu, 2014; Zeng *et al*., 2014 and Gravalos *et al*., 2010). Fuels on the forest floor mainly contribute to the ground fire incidence in the study area. Therefore, present study focused on the forest floor characters of pure pine, pure oak and mixed forests in the mid hill zone of Himachal Pradesh.

MATERIALS AND METHODS

Study sites: Present study was carried out in pure pine, pure oak and mixed forests of mid-hills zone of Himachal Pradesh, which weremostly confirmed to lower Shiwalik chir pine ($9C_1a$) forest type (Champion and Seth, 1968).

Pure pine forests were situated between latitude of 30°51'03.5"N to 30°51'26.9"N and longitude of 77°09'58.6"E to 77°10'21.5"E with an elevation range of 1068 m to 1348 m (Table 1). *Pinus roxburghii* is the dominant species selected for the study as overstorey which was fairly dense with the average DBH of 20.25 cm and average height of 15.86 m. The understorey vegetation of shrubs and herbs were comprised of *Carrisa carandus, Indigofera pulchella, Murraya koenigii, Osyris arborea, Rubus ellipticus, Woodfordia fruticosa, Ziziphus jujuba, Bidens pilosa, Dicliptera bupleuroides, Apluda mutica, Arundinella nepalensis, Chrysopogon montanus, Cymbopogon martinii, Heteropogon contortus, Imperata cylindrica, Themeda anathera* and *Tricholepis elongata*.

Pure oak forests were situated between latitude of 30°51'27.0"N to 30°51'45.2"N and longitude of 77°09'01.7"E to 77°09'19.9"E with an elevation range of 1014 m to 1286 m (Table 1). *Quercus leucotrichophora* was the dominant species selected for the study as overstorey with the average DBH of 18.82 cm and average height of 12.63 m. The understorey vegetation of shrubs and herbs were comprised of *Adhatoda vasica, Asparagus adscendens, Berberis lycium, Debregeasia hypoleuca, Desmodium tiliaefolium, Mimosa rubicaulis, Myrsine africana, Prinsepia utilis, Rubus ellipticus, Zanthoxylum sp., Arundinella nepalensis, Avena fatua, Chrysopogon fulvus, Digitaria stricta, Imperata cylindrica, Themeda anathera, Fimbristylis rigidula, Adiantum capillus, Cheilanthes argentea, Fragaria vesca, Biden pilosa, Plectranthus parviflorus, Reinwardtia indica, Siegesbeckia orientalis, Thalictrum foliolosum* and *Urtica dioica.*

Mixed forests were situated between latitude of 30°51'30.4"N to 30°51'40.9"N and longitude of 77°09'49.7"E to 77°10'37.0"E with an elevation range of 1044 m to 1392 m (Table 1). *Acacia catechu, Acacia mollissima, Albizia chinensis, Alnus nitida, Bauhinia variegata, Dalbergia sissoo, Eucalyptus tereticornis, Ficus palmate, Grewia optiva, Melia azadirachta, Pinus roxburghii, Pistacia integremma, Populus deltoids, Toona ciliata* were the overstorey tree species with the average DBH of 17.48 cm and average height of 13.39 m. The understorey vegetation of shrubs and herbs were comprised of *Adhatoda vasica, Asparagus adscendens, Berberis lycium, Cestrum noctrnum, Debregeasia hypoleuca, Lantana camara, Mimosa rubicaulis, Murraya koenigii, Myrsine africana, Prinsepia utilis, Rosa moschata, Rubus ellipticus, Woodfordia fruticosa, Zanthoxylum* sp.*, Ziziphus jujuba, Apluda mutica, Arundinella nepalensis, Chrysopogon montanus, Cymbopogon martinii, Digitaria stricta, Eulaliopsis binata, Heteropogon contortus, Imperata cylindrica, Sorghum halepense, Themeda anathera,, Cyperus aristatus, Achryanthus aspera, Bidens pilosa, Cannabis sativa, Dicliptera bupleuroides, Fragaria vesca, Parthenium hysterophorus, Siegesbeckia orientalis, Solanum nigrumetc.*

Forest floor components were horizontal, compact and comprise of dead vegetation *i.e.* leaves/needle litter, bark and twig. Different forest floor characteristics were studied by sampling dead vegetation material from five quadrate of size 1.0 m^2 in each forest plot. Every forest type was having four plots each. Following are the floor characteristics studied:

Table 1: General details of study sites.

Sites	Latitude (N)	Longitude (E)	Slope (°)	Dominant tree species	Tree DBH (cm)	Tree Height (m)	Understorey vegetation
Pure Pine	30°51'05.9"	77°10'21.5"	22.0	*Pinus roxburghii*	19.5	16.5	*Carrisa carandus, Indigofera pulchella, Murraya koenigii, Osyris arborea, Rubus ellipticus, Woodfordia fruticosa, Ziziphus jujuba, Bidens pilosa, Dicliptera bupleuroides, Apluda mutica, Arundinella nepalensis, Chrysopogon montanus, Cymbopogon martinii, Heteropogon contortus, Imperata cylindrica, Themeda anathera* and *Tricholepis elongata*
	30°51'03.5"	77°10'17.5"	19.9		21.8	14.7	
	30°51'26.9"	77°10'00.1"	25.9		19.7	16.2	
	30°51'22.9"	77°09'58.6"	24.6		19.9	15.9	
Pure Oak	30°51'27.0"	77°09'19.8"	33.3	*Quercus leucotrichophora*	18.1	11.6	*Adhatoda vasica, Asparagus adscendens, Berberis lycium, Debregeasia hypoleuca, Desmodium tiliaefolium, Mimosa rubicaulis, Myrsine africana, Prinsepia utilis, Rubus ellipticus, Zanthoxylum* sp., *Arundinella nepalensis, Avena fatua, Chrysopogon fulvus, Digitaria stricta, Imperata cylindrica, Themeda anathera, Fimbristylis rigidula, Adiantum capillus, Cheilanthes argentea, Fragaria vesca, Biden pilosa, Plectranthus parviflorus, Reinwardtia indica, Siegesbeckia orientalis, Thalictrum foliolosum* and *Urtica dioica*
	30°51'27.9"	77°09'19.8"	35.2		18.8	14.2	
	30°51'44.6"	77°09'01.7"	37.0		18.7	11.6	
	30°51'45.2"	77°09'02.8"	35.5		19.7	12.9	
Mixed	30°51'30.4"	77°10'37.0"	24.5	*Celtis australis, Pistacia integremma, Bauhinia variegata, Ficus palmata* etc.	12.2	12.1	*Adhatoda vasica, Asparagus adscendens, Berberis lycium, Cestrum noctrnum, Debregeasia hypoleuca, Lantana camara, Mimosa rubicaulis, Murraya koenigii, Myrsine africana, Prinsepia utilis, Rosa moschata, Rubus ellipticus, Woodfordia fruticosa, Zanthoxylum* sp., *Ziziphus jujuba, Apluda mutica, Arundinella nepalensis, Chrysopogon montanus, Cymbopogon martinii, Digitaria stricta, Eulaliopsis binata, Heteropogon contortus, Imperata cylindrica, Sorghum halepense, Themeda anathera,, Cyperus aristatus, Achryanthus aspera, Bidens pilosa, Cannabis sativa, Dicliptera bupleuroides, Fragaria vesca, Parthenium hysterophorus, Siegesbeckia orientalis, Solanum nigrum*
	30°51'34.9"	77°09'49.7"	26.8	*Eucalyptus tereticornis, Pinus roxburghii, Melia azedarach etc.*	21.8	11.9	
	30°51'39.2"	77°10'10.2"	25.7	*Alnus nitida, Pinus roxburghii, Grewia optiva* etc.	14.8	14.6	
	30°51'40.9"	77°09'59.0"	28.5	*Eucalyptus tereticornis, Toona ciliata, Melia azedarach, Grewia optiva* etc.	21.1	14.8	

Fuel thickness: Fuel thickness was measured by using meter rod (Barbara and Valette, 2010).

Fuel biomass density: Fuel was collected from the quadrate that was laid out in each sample plot. Samples were carried out in paper bags of known weight to record fresh weight of samples. Samples were dried in an oven at 65 ± 5°C for 24 hours and then the dry weight of samples was recorded (Wotton *et al*., 2005).

Fuel moisture content: Samples with predetermined fresh weight and dry weight were used for estimation of moisture content of fuel in each quadrate. Gravimetric method was used to calculate moisture content using the equation given by (Barbara and Valette, 2010):

$$\text{Moisture Content (\%)} = \frac{\text{Fresh weight of sample} - \text{dry weight of sample}}{\text{dry weight of sample}} \times 100$$

Surface fuel calorific value: An oxygen bomb calorimeter was used to determine the calorific value (cal g^{-1}) of samples from each quadrate as per the procedure given by (Gravalos *et al.*, 2016). Samples with already estimated moisture content were used for estimation of calorific value. The instrument was calibrated and verified using a benzoic acid tablet. The biomass sample of 0.5-1.0 g was weighed on a precision balance. The crushed sample was inserted in the capsule and the capsule was pressed to compact the material. The capsule was carefully placed into the holder. The cotton thread was attached and the firing cotton was ensured that lies on top of the capsule. The bomb was lowered in the calorimeter and the cover was then closed. The start button was pressed to begin the test.

Statistical Analysis: Analysis of variance of the data collected from pure pine, oak and mixed forest was done using Randomised Block Design (Gomez and Gomez, 1984). The observations were replicated four times. Wherever, the effects exhibited significance at 5% level of confidence, the critical difference ($CD_{0.05}$) was calculated to find out the superiority of one treatment over the others. Analysis was carried out on computer using the statistical package "SPSS".

Critical difference ($CD_{0.05}$) for RBD was calculated as follows:

$CD_{0.05}$= S.E. (d) x $t_{(0.05)}$ (r-1) (t-1) df

SE (d) ± = $\sqrt{2\ Me/r}$

Where,

SE (m) ± = Standard error of mean

$CD_{0.05}$ = Critical difference at 5% level of significance.

RESULTS AND DISCUSSION

It was apparent from the data presented in Table 2 that there was significant variation among different forests for fuel thickness (cm), biomass density (t ha^{-1}), moisture content (%) and calorific value (cal g^{-1}).

Fuel thickness (cm): Among selected forests, pure pine showed thickest fuel (5.62 cm) during the study period, which was statistically identical to mixed forest (5.58 cm) and thinnest fuel was at pure oak forest (4.27 cm). Forest floor thickness recorded by (Baksic and Baksic, 2020) at the black pine forest stands ranged from 1.5 cm to 11.5 cm. (Banwel, 2011) observed 2.7 cm to 4.3 cm fuel thickness in pine-fir forests. (Egan *et al.*, 2011) reported greater litter depth in ponderosa (5-8 cm) than the sugar pines (2-6 cm), which increased with increasing tree diameter in both species. The high surface fuel thickness in pure pine forests were due to accumulation of fine needles on the pure pine forest floor and slow decomposition of dead material (Reinhardt *et al.,* 2010 and Albini, 1976).

Table 2: Forest floor characteristics at different forests.

Forests	Thickness (cm)	Biomass density (t ha^{-1})	Moisture content (%)	calorific value (cal g^{-1})
Pure pine	5.62_a	5.68_a	2.05_c (1.43)	5731.21_a
Pure oak	4.27_b	4.71_b	12.46_a (3.53)	4913.97_b
Mixed	5.58_a	4.27_b	10.78_b (3.28)	4029.23_c
$CD_{0.05}$	0.114	0.466	0.177	268.075
p-value	<0.0001	<0.0001	<0.0001	<0.0001

Note: Values sharing same subscript in a treatment are statistically at par or identical.
Figures in the parenthesis are square root transformed values.

Fuel biomass density (t ha^{-1}): Biomass density was maximum in pure pine forest (5.68 t ha^{-1}) and minimum at mixed forest (4.27 t ha^{-1}), which was statistically at par with pure oak forest (4.71 t ha^{-1}). (Joshi *et al.*, 2021) reported lower forest floor biomass (4.81t ha^{-1}) in the chir pine as compare to present study. (Ivanova *et al.,* 2020; Ivanova *et al.,* 2017 and Jhariya, 2014) observed 2.9 t ha^{-1} fuel biomass in scot pine forests, 5.85 t ha^{-1} in taiga pine forests, 3.38 t ha^{-1} in mixed forests of Chhattisgarh, respectively. Results can be attributed to accumulation of elevated fine dead material like pine on forest floor, which consisted of volatile material with minimum decomposition rate and leaded to increase in the fuel biomass density in pure pine forest (Jhariya, 2014; Prasad *et al.,* 2008 and Hill *et al.,* 2000).

Fuel moisture content (%): Pure pine forests showed significantly lower fuel moisture content (2.05 %) than pure oak (12.46 %) and mixed forests (10.78 %). (Baweja and Kundu, 2014) reported 0.08 kg/m^2 to 0.40 kg/m^2 fine fuel moisture content (FFMC) in pure pine forest of Himachal Pradesh, however (Singh and Kaur, 2018) reported 2.95% to 5.20 % moisture content in pine forests. (Banwel, 2011) observed 2.3 to 4.3 % moisture content in forest floor fuel of pine-fir forests. Pine forests had low moisture content due to the higher surface area-to-volume ratio of pine foliage, which facilitated water loss and heat absorption (Vasilakos *et al.,* 2009; Rawat, 2003; Dimitrakopoulos and Papaioannou, 2001).

Surface fuel calorific value (cal g^{-1}): Pure pine showed significantly higher surface fuel caloric (5731.2 cal g^{-1}) value than pure oak (4913.9 cal g^{-1}) and mixed forest (4029.2 cal g^{-1}). (Rupa, 2011 and BEC, 2011) found lower calorific value of 4690 cal g^{-1} and 4800 cal g^{-1} for pine needles as compare to present study. Gravalos *et al.,* 2010) observed that pine (4799.71 cal g^{-1}) had slightly higher calorific value than fir and birch. High surface fuel calorific value in pure pine forests were due to drier fuel and high volatile matter (Arkadiusz, 2015; Zeng *et al.,* 2014; Gravalos *et al.*, 2010; Bhatt and Todaria, 1992).

CONCLUSIONS

The objective of present investigation was to characterize fuel in pure pine, pure oak and mixed forests of Himachal Pradesh which mainly contribute to ground fire incidences. Results revealed that pure pine forest provided most favourable conditions to forest fire due to thicker fuel (5.62 cm), denser biomass (5.68 t ha^{-1}), lower moisture content (2.05%) and high calorific value (5731.2 cal g^{-1}). Fuel thickness and biomass density could play important role in spread of forest fire by providing continue fuel (Jhariya, 2014; Reinhardt *et al.,* 2010; Prasad *et al.,* 2008 and Hill *et al.,* 2000). Low moisture content with high calorific value can contribute to fire initiation (Arkadiusz, 2015; Zeng *et al.,* 2014; Gravalos *et al.*, 2010 and Dimitrakopoulos and Papaioannou, 2001). Hence fuel management practices are necessary to reduce fire occurrence in pine forests.

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Conflict of Interest. Nil.

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