Variation in species composition, tree and soil carbon stock between burnt and unburnt forest in Chure Range of Butwal, Nepal.

A dissertation submitted for the partial fulfillment of the requirement for the
M.Sc. in Botany

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October 2021

DEDICATION

(To my parents)

DECLARATION

I, Prakash Godar, hereby declare that the work enclosed here is entirely my own, except where states otherwise by reference or acknowledgement, and has not been published or submitted elsewhere, in whole or in part, for the requirement for any other degree or professional qualification. Any literature, data or works done by other and cited within this thesis has been given due acknowledgement and listed in the reference section.

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RECOMMENDATION

This is to notify that the master's thesis entitled **"Variation in species composition, tree and soil carbon stock between burnt and unburnt forest in Chure Range of Butwal, Nepal"** Carried out by **Mr. Prakash Godar** under our supervision. This entire work is based on original scientific investigations and has not been submitted for any other degree in any institutions, we therefore recommend this thesis work to be accepted for partial fulfillment of M.Sc. Degree in Botany.

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APPROVAL

This thesis work entitled **"Variation in species composition, tree and soil carbon stock between burnt and unburnt forest in Chure Range of Butwal, Nepal"** submitted to Department of Botany, Amrit Campus, Tribhuvan University by Prakash Godar, T.U. Registration No.: 5-2-37-892-2012 has been accepted for the partial fulfillment of the requirement for the master's degree in Botany.

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Abbreviations and Acronyms

AGB: Above Ground Biomass

AG: Above Ground

AGC: Above Ground Carbon

BA: Basal Area

BD: Bulk Density

BGB: Below Ground Biomass

BGC: Below Ground Carbon

BG: Below Ground

C: Coverage

D: Density

DBH: Diameter at Breast Height

F: Frequency:

GBH: Girth Base Height

IVI: Importance Value Index

RBA: Relative Basal Area

RC: Relative Coverage

RD: Relative Density

SCS: Soil Charcoal Stock

SOC: Soil Organic Carbon

t/ha: Ton per hectares

Abstract

Frequent forest fires in dry season are shaping forest vegetation and landscape in different parts of Nepal and cause great loss to the forest ecosystem. The main objective of this study was to to analyze impact of forest fire on species composition and carbon dynamics of *Shorea robusta* forest of burnt and unburnt forest in Chure region of Butwal area. Identification and selection of burnt areas were done based on historical ground fire data in conjunction with satellite remote sensing data provided by ICIMOD and Department of Forest and Environment, Nepal. The species composition, diversity indices and regeneration status of trees, saplings, seedlings, shrubs, and herbs in two different forests were conducted by systematic random sampling methods. Average vegetation carbon stocks of burnt and unburnt forest were calculated manually. Soil samples were collected by soil core methods from different soil depths (0-2, 2-10, 10-30, 30-60cm) to measure soil parameters like soil pH, bulk density, soil organic carbon and soil charcoal stocks. In burnt forest, *Shorea robusta* and *Lagerstromia parviflora* were dominant, with *Terminalia alata, Careya arborea*, etc. as associates' species whereas *S. robusta* and *Anogeissus latifolia* were dominant with *Tectona grandis, Mallotus philippensis* etc. as associates in unburnt forest tree layer. The value of Shannon-Wiener diversity index (1.80) and Margalef's species richness index (2.94) were higher in unburnt forest for tree layer. The average density of *S. robusta was* 749.71±25.15 (in/ha) and 1031.79±36.284 (in/ha) for unburnt and burnt forest, respectively. The average height of *S. robusta* was recorded 19.16±0.249m and 16.289±0.211m for unburnt and burnt forest respectively whereas average DBH was 0.412±0.011 m and 0.371±0.163m respectively. The total vegetation carbon stocks were 200.38±22.69 t/ha and 233.72±29.63 t/ha in burnt and unburnt forest respectively. Mean soil pH of burnt forest was (6.02 to 6.13) and unburnt forest range from (5.05 to 5.53). For bulk density, mean minimum value (0.85±0.038 g/cm^3) was recorded in topsoil of burnt forest and mean maximum value (1.05±0.01g/cm^3) was recorded in unburnt forest at the depths of 30 cm above. Total soil charcoal stock (SCS) was higher (35%) in the topsoil and lower (2%) in >30cm depth. The SOC was highest (251.90±10.73t/ha) at topsoil followed by (226.52±8.53 t/ha) at 0-2cm depth of burnt forest. Present study suggested that forest fire was essential to maintain the species composition, diversity, as well as soil organic stock in burnt forest of *S. robusta*.

Keywords: Chure, diversity, forest fire, regeneration, soil organic carbon,

CHAPTER 1: INTRODUCTION

1.1 Background

Forest fire is one of the major issues all over the world as it possesses possible threats to affect vegetation structure, soil behavior, animals, and microorganisms (Kafle, 2006). Fire plays an essential role in human life as well as wildlife and balances the ecosystems (Reddy *et al*., 2008). Severe burning and increased temperature are usually outcomes of the type and extent of fire (Certini, 2005). On the one hand, prescribed burning is currently being used by various countries as a management tool to reduce fuel load, enhance forest habitat, and repair the composition and function of the ecosystem. Normally, prescribed fires give desirable results if applied scientifically, but forest fires destroy the forest. (Elliott *et al*., 2009). On the other hand, forest fires are an important phenomenon that not only threatens forest richness. but also, to the fauna and flora seriously altering the biodiversity of a region. Forest fire is the principal disturbance factor in the forest community and organizes the abiotic and biotic aspects of the forest, shaping landscape diversity and manipulating the flow of energy and biogeochemical cycles (Weber and Flannigan, 1997). During the dry summer season, when there is no rain for months, the forests become littered with dry senescent leaves and twigs, which could burst into flames either naturally or sometimes by anthropogenic causes (Galdos *et al.,* 2009).

Globally, fire can participate in maintaining characteristic environments and human community. Although forest fire is one of the chief reasons for the loss of biodiversity, degradation of the environment also plays an imperative part in shaping forest and climate change (Kodandapani, 2001). But the degree of effectiveness of blaze in the landscape is largely determined by the mode of fire. Forest fire is used comprehensively to encourage the restoration of vegetation for livestock in the hilly areas. Occasionally some forests depend on blazing for regeneration, others are prone to severe damage as burning can escort to the loss of native species, changes in the composition of forest, succession stages, and activate generous changes in the functions of the ecosystem (Jackson and Moore, 1998). In the context of the world, man-caused fire is more common than natural fire. It is proved that there were 25% accidental and 75% intentional causes of the fire (Jhariya *et al.*, 2012).

Species composition provides the essential description of the character of vegetation in a forest. It can be expressed either on an individual species basis or by species groups that are defined according to the objectives of the inventory (Barbour *et al.,* 1987). The relative contribution of a species also signifies its dominance in the vegetation and its ability to capture resources

(Barbour *et al.,* 1987). Biodiversity is the formation of an ecosystem that is comprised of several levels for example: starting with genes, the individual species, then communities of creatures with various life-forms and regeneration strategies with physical and chemical components of the environment (Rawat *et al.,* 2015). Species composition of an area can be altered by various factors including natural disasters, anthropogenic causes, and fire.

Forest fires not only reduce much of the fallen trees to ash, but it also provides nutrients that are used by seedlings or new growing trees to nourish themselves and help in the formation of the new ecosystem (Pausas *et al.,* 2005). When fire burns through a forest, the natural recovery effort begins immediately. However, Forest fire plays a natural and useful role in the life-forms present in the ecosystem. Similarly, fire can also be one of the devastating long-term effects on ecosystems as frequent and large-scale fires, affect many forests and peatlands around the world (Almendros *et al.,* 2003).

The fire-affected areas support more herbaceous vegetation as compared to the unburnt areas because of a reduction in competition for space and resources (Keith *et al,*.2010). This is a pointer to the fact that some species were lost to burning and replaced by some relatively fire-tolerant species. The fire-tolerant species are adapted to burning by prolific production of coppices hence the higher values of multi stemming in the burnt forest as compared to the unburnt forest. Marrinan *et al.,* (2005) observed that resprouting was more common in burnt forests than in unburnt forests in a study in Australia. Prior *et al.,* (2009) suggests that an increase in the frequency or severity of fires is likely to change the tree density and basal area of savannas in North Australia. Another factor that could affect the impact of fires on the density of trees is tree clustering. For instance, Groen *et al.,* (2008) found that clustering reduces the damaging effect of fire on trees in African savannas.

Forest fire plays a natural and useful role to complete the life cycle of a forest and its ecosystem. Certain plants, like Sal trees, pine trees, the giant sequoia cannot grow unless exposed to fire. Without fire, sequoia seeds cannot germinate, and certain types of flowers are unable to bloom (Vega *et al.,* 2008). The role of fire in maintaining species diversity is probably the most recent development in the understanding of ecosystems events. During the last decade, many countries have experienced extremely severe wildfire episodes. The tropics lost around 12 million hectares of tree cover in 2018, of which 3.64 million hectares were primary forest, the most biodiverse and carbon-dense type of forest (Hansen and Jerram, 2019). According to them, tree cover loss by fire in Amazon, Africa, and Indonesia in 2018 was down nearly by 30 per cent as compared to tree loss in 2016.

The storage of carbon mostly on the forest floor and under the ground is called soil carbon. Its amount depends on the above-ground input received from leaf litter and on the decomposition of fine roots below ground (Rasse *et al.*, 2006). The recycling of the plant's carbon in the soil system also depends upon macro and micro faunal activity and on litter quality. Carbon fixed within plant biomass ultimately enters the soil, where it may reside for hundreds of years (Patterson *et al.*, 1987). Fire also impacts physical, chemical, and biological components of soil in both beneficial and detrimental ways that can affect long-term forest productivity. Soil nutrients such as N, P, K and Ca are usually tied up in the organic matter. All are released in a pulse at the burnt forest and leached into the soil, which increases availability to plants and soil microorganisms (Almendros *et al.*, 2003).

Soil carbon is an important part of the terrestrial carbon pool (Lal and Kimble 1997) and soils of the world are potentially viable sinks for atmospheric carbon and may significantly contribute to the mitigation of global climate change (Kirschbaum 2000; Bajracharya *et al.*, 1998; Lal *et al.*, 1998; Lal *et al.*, 1995). It is estimated that the world's soil contains about 1500 Gigaton (GT) of organic carbon to a depth of 1 meter and a further 900Gt from 1-2m. However, the soil is deteriorating at an alarming rate in developing countries like Nepal due to land-use change (IPCC, 2000) and lowering carbon sequestration.

Forests sequester carbon from the atmosphere, however, disturbances such as fire play a vital role and affect total carbon sequestration. Fire can influence the carbon cycle either by emission of CO_2 to the atmosphere during a forest fire or conversion of forest biomass into char and charcoal after the fire. After the fire, the incomplete combustion of plant material produces charcoal fragments of various sizes. Some of these fragments are incorporated into soils of the burnt forest, while other fragments are carried away by wind or water, in some cases to later settle on the surface of a lake or wetland (Horn and underwood., 2014), adding to another long-term carbon pool (Suman, 1984).

The previous research suggested the importance of charcoal in soils and sediments for the documentation of past fires and to understand long-term relationships between fire, climate, and human activity (Hart *et al.*, 2008; Berg and Anderson, 2006; Whitlock and Larsen, 2001; Horn *et al.,* 2000; League and Horn, 2000; Sanford and Horn, 2000). Charcoal stored in the soil also represents one of the ways by which carbon is stored in the form of the reservoir because charcoal does not easily recombine with the oxygen and form CO_2 (Druffel, 2004; Fearnside *et al.*, 2001; Seiler and Crutzen, 1980). This charcoal is characterized by a high concentration of carbon and high resistance to natural degradation processes (Foereid *et al.*, 2011; Kuhlbusch and Crutzen, 1995).

Nepal suffers severely from crawling and crown fire (Parajuli *et al.,* 2015). According to a report, Nepal commonly experiences some small forest fires each spring, which is the end of the dry season. However, conditions during the fall and winter of 2008 and 2009 were unusually dry, and fires set by poachers to flush game may have gotten out of control (Parajuli *et al.*, 2015). 268,618 hectares of forest were damaged by the fires in the period from January-May 2016 in Nepal. According to the Federation of Community Forestry Users Nepal (FECOFUN), 50 districts were impacted, and 12,000 community forests were damaged in 2016 (ICIMOD Fire report, 2017). In Nepal, wildfire incidences and burnt areas were sharply increase from 2000 to 2016. Overall recorded wildfire incidences were 35,374 times and the burnt area was 1,723,920 ha from 2000 to 2016 in Nepal (Bhujel *et al.,* 2017).

Nepal represents the confluence of both eastern and western flora which in terms of its floristic composition can be divided into three regions viz. eastern, central, and western. The present study area i.e., Butwal represents the western region of the country. Nestled in the laps of foothills of Chure range Butwal silently sprawls over the tropical plain. From the ecological point of view, the Butwal area can be regarded as an ecotone, reflecting the juncture of lower sub-tropical and tropical vegetation. Despite of the overall importance of the area, seasonal forest fire has been also noticed along with the loss of biodiversity. However, there was lack of quantitative data that can estimate the actual loss of biodiversity or overall scientific processes and the possible reasons impacted by seasonal fire events. In this background present research work has been designed to study the impact of fire on species composition and carbon dynamics and compared the same phenomenon with the areas not experienced with past fire events.

1.2. Justification

Forest fire is the principal disturbance factor in the forest community and organizes the abiotic and biotic aspects of the forest, shaping landscape diversity and manipulating flow of energy and biogeochemical cycles. Ecological impacts of forest fires as well the comparative and qualitative study of forest fire between burnt and unburnt forests are rarely studied. Forest fire and its impact on the nutrient cycle could contribute for a better understanding of forest ecosystem. Especially during the dry season, in Chure range of the Butwal area forest are frequently burnt, but in another forest (Basantapur area) of Chure range forest are mostly unburnt. Species composition and soil carbon dynamics of the burnt and unburnt forest may provide scientific information about the fire ecosystem. Forest fires play a natural and useful role to complete the life cycle of a forest and its ecosystem. Certain plants, like Sal trees, pine trees, the Giant Sequoia, cannot grow unless exposed to fire. The role of fire in maintaining species diversity is probably the understanding of ecosystems events. Because of frequent fires, forests in the study forest do not have a well-developed understory. The abundance and carbon content of charcoal was also found to vary through the forest. Uncertainties are remaining regarding the carbon content. Various species show a wide variety of sensitivity and resistivity against fire on the forest floor. The main purpose of this study is to know the comparative ecological impacts of forest fire between the burnt and unburnt forests. This research will not only be new in this study forest but also might be helpful to predict their community- or ecosystem-level functions and processes.

1.3 Research questions

- What is the status of species composition, diversity indices, regeneration status of *Shorea robusta* forest between burnt and unburnt forest?
- How do tree carbon stock and soil parameters (Soil pH, SOC and SCS) vary between burnt and unburnt forests?

1.4 Research Objectives

Based on the previous literature and developed research questions, the following objectives were set up to achieve the goal for the present research work:

General objective

- To analyze the species composition, tree carbon stock and soil carbon dynamics between the burnt and unburnt forest of church forest of Butwal.

Specific objectives

- To determine the IVI and diversity indices in both burnt and unburnt forests.
- To determine regeneration status of dominant plant species in both forests.
- To determine tree carbon stock in the burnt and unburnt forests.
- To determine soil organic carbon, bulk density, char content and pH from the various depths of soil profile.

CHAPTER 2: LITERATURE REVIEW

Fire has been central to terrestrial life as it is the core of various ecological processes on the earth. (Cochrane *et al.,* 2009). Humans use fire to manage natural vegetation to favour specific species succession, to conserve the ecosystem and decrease the risk of wildfire occurrence from various centuries. (Bond and Van Wilgen 1996). In the South Asian context, an intentional fire caused by man is more common than natural fire which is used comprehensively to encourage restoration of vegetation for livestock in the hilly areas. (Tiwari *et al.,* 1986).

Trees and shrubs are probably more susceptible to fire at the end of the dry season when the plant's moisture and food reserves are depleted due to new spring growth (West,1965). Regeneration of plants is generally controlled by various anthropogenic pressures such as felling, grazing, trampling, fire etc. (West *et al.,* 1981). The scientific literature shows that organic matter is strongly related to the stability of the structure and bulk density, and it is a well-known aggregate stabilizing agent in soils (Hillel, 1982). The rate of recovery depends on the extent of damage sustained by the plants, the method of regeneration and the favorability of the postfire environment and the temporal distribution of rainfall (Frost and Robertson, 1987).

Generally, seeders are expected to regenerate well after the fire, but fewer resprouting species may sprout following high-intensity fires, since high levels of soil heating may damage tissues. Although sprouts can reproduce from the seed bank, most species only produce a few seeds that are intolerant of heat exposure (Keeley, 1991).

The key stages of population can provide the structure and viability of the species in the community and ultimately the regeneration can provide the idea for the management and conservation of rare and endangered species and habitat (Boyce, 1992). Fire, a major disturbance factor, is regarded as an essential determinant of the structure and function of savanna vegetation and acts to modify broad patterns set primarily by rainfall and edaphic factors (Scholes and Walker, 1993). Areas with similar climate (mean temperature and moisture conditions) can have very different fire regimes because of different frequencies of extreme weather conditions (short, hot, dry periods), different lightning frequencies, different fuel properties of the vegetation, or differences in the frequency of natural firebreaks such as large rivers or barren areas (Bond and Van Wilgen 1996). Bond and Van Wilgen (1996) concluded that fire is a very general and influential ecological phenomenon. Fires are driven by biotic and abiotic factors that dictate their temporal (seasonality and frequency), spatial (size and patchiness), and magnitude (intensity, severity, and type) components (Van Wilgen and Scholes, 1997; Pyke et al., 2010). Fire as a management tool has caused dramatic changes in the structure and function of ecosystems (Lavorel *et al.,* 2001). A forest burn affects many aspects of ecosystem function from nutrient cycling, to grass productivity, to tree recruitment (Bond and Keeley, 2005; Prior *et al*., 2009).

Fire enhances the productivity of ecosystems by releasing chemicals and nutrients locked up in the old herbage, but the uncontrolled fire destructs the micro-flora and micro-fauna in the topsoil and litter layers in forests could have impacts on the organic decomposition and soil fertility (Kodandapani, 2001). Fire enhances the productivity of ecosystems by releasing chemicals and nutrients locked up in old herbages these results in the regeneration of seedlings who benefited from a forest fire (Kodandapani, 2001). The vegetation and the species composition of a forest are the decisive factors for a forest fire. Tree species diversity in the tropics varies dramatically from place to place (Pitman *et al*., 2002).

The intensity of the changes produced in the physical and chemical characteristics of the soil depends on the temperatures reached different soil depths, the time of residence of temperature peaks, and the stability of the different soil components (González-Pérez *et al*., 2004; Terefe *et al*., 2008). Low severity burning does not importantly affect soils, severe burning can affect a wide range of soil properties (e.g., nutrient availability, pH, organic matter content, texture, structure, etc.) (Certini, 2005).

Carbon emissions and carbon recovery rates vary widely depending on variables such as pre-fire vegetation composition and structure, fire severity and size, and post-fire productivity and successional trajectory (Kashian *et al*., 2006; Wiedinmyer and Neff, 2007; Campbell *et al*., 2008; Meigs *et al.*, 2009). Plants then release carbon dioxide into the atmosphere along several pathways, including respiration, decomposition, and smoke emissions from fires that consume plant tissues. Forests contain large reservoirs of carbon (i.e., carbon sinks) and facilitate flows of carbon from the atmosphere to the biosphere (i.e., carbon sequestration), they are an important component of the global carbon cycle and are thought to have the potential to mitigate climate change (Ingerson, 2007; Pan *et al*., 2011). The carbon sequestration potential of Earth’s forests is about 33% of global anthropogenic emissions from fossil fuels and land use (Denman *et. al.*, 2007).

Seasonally, carbon uptake rates are highest during periods with sufficient radiation and moisture to maximize photosynthesis (Baldocchi, 2008). Variations in the soil's organic matter content after burning depends both on the soil temperature reached and on the soil heating rate. Fire-induced changes in soil properties can have an impact on soil productivity of burnt areas, in some cases in an irreversible way (Robichaud, 2009). Regarding forest soils, not only there is more organic matter content but also a more humid understory since forests tend to benefit from the accumulation of water by the hydrophilic qualities of organic matter in direct relation to the edge effect (Hoffmann *et al*., 2009).

Fire can influence woody vegetation biomass, composition, and structure. Despite the importance of fire in shaping savannas, it remains poorly understood how the frequency, seasonality, and intensity of fire interact to influence woody vegetation structure, which is a key determinant of savanna biodiversity (Smit *et al.,* 2010). The terrestrial carbon cycle is a dynamic system with quantities and rates that vary in space (e.g., hemisphere, ecosystem) and time (e.g., decade, season). Tropical forests, for example, account for about 34% of global terrestrial total primary productivity as compared with savannahs (26%) and deserts (5%) (Beer *et al*., 2010). Species diversity is a key determinant of ecosystem functioning like productivity, stability, and nutrient dynamics. The formation of plant communities and their species diversity in tropical forests is maintained by negative plant-soil feedback (Mangan *et al.,* 2010), local climate and soil nutrients.

Forest fires severely damage and prohibit regeneration and growth of seedlings, destroy non-timber forest products and, in some cases, encourage invasive species (MFSC, 2010). Repeated burning in fothe rests destroys the ground flora and reduced vegetative growth rate leading to change in plant community structure (Spanos *et al.,* 1989). Some fires are accidental but most of the fires are initiated deliberately for some purpose such as to collect Sal seeds left after the forest is burnt, to conceal illegal timber extraction, to improve grass growth, to scare away wild animals, to collect honey or some other reasons including political agitations and community conflicts (Bhandari *et al.,* 2012). Fire at the forest floor damages the cambium of the trees leading to the formation of defective butt logs and consequently, reducing timber quality (Marschall, 2013).

Atmospheric CO_2, contributed from different medium including biological sources, is a primary Green House Gas (GHG) and its concentration in the atmosphere has been increasing steadily since 1958 (Kumar *et al*., 2013; Keeling *et al.,* 1989), due to fossil fuel combustion, cement manufacture, land use, deforestation etc. Every year extensive fire destroys considerable forest resources in Nepal, such destruction includes both timber and non-timber forest products. Among the forest types, *P. roxburghii* forests are extremely vulnerable to fires when they are in the dry forest (Kumar, 2013; Paudyal, 2008) and destroyed every year. Forest clear-cutting and burning cause soil disruption and reduce the amount of bacterial and fungal biomass (Holden and Treseder 2013).

The fire frequency limits to woody plant regeneration are unknown for most tropical species (Balch *et al.,* 2013). The recovery of microbial community structure to a similar level as observed in unburnt control soil may take as long as 11 years (Xiang *et al.* 2014). The effect of diversity loss is comparable to or exceeds the effects of herbivory, fire, and drought (Tilman *et al*., 2014).

In recent years, soil use change and disturbances such as fire have transformed these ecosystems and have currently converted them to a source of CO_2 emissions to the atmosphere (Berenguer *et al.*, 2014). Determination of forest composition, floral diversity including the structure of a forest is an essential feature in assessing the sustainability of protected forest areas of this country (Kanagaraj *et al.,* 2016).

Aryal *et al.* (2016/18) analyzed the amount of charcoal, soil organic carbon and CO_2 flux from 4 different soil depths (0-2, 2-10, 10-30 and & >30cm) in the fired and unfired forest of *Pinus. roxburghii* from Langtang National Park, Nepal. They measured total carbon stock in soil of unfired and fired forest of different intensities namely: high frequency and high intensity, high frequency and moderate intensity and high frequency and low intensity. They reported significantly different ($P=0.00$) soil charcoal stock at different soil depths. The value of CO_2 flux was found to increase with increasing volumetric water content and decreasing soil temperature. They concluded that high frequency and medium intensity of fire mitigates high CO_2 from the atmosphere.

Aryal *et al*. (2017) studied impact of surface fire on Carbon sequestration and CO_2 mitigation of *Pinus roxburghii* forest in Langtang National Park, Nepal. They measured total carbon stock and CO_2 mitigation of unburned and burned forest of different intensities namely: high frequency and high intensity (HFHI), high frequency and moderate intensity (HFMI), high frequency and low intensity (HFLI). They found, total CO_2 mitigation in all four forests according to higher to lower values as 3346.27, 3345.16, 2484.14 and 2037.95 t/ha in HFMI, HFHI, HFLI and CON, respectively.

Species composition and soil carbon dynamics of the burnt and unburnt forest may provide scientific information about the fire ecosystem. According to previous literature, forest fires play a natural and useful role to complete the life cycle of a forest and its ecosystem. Uncertainties are remaining regarding the carbon content and species composition. Various species shows a wide variety of sensitivity and resistivity against fire on forest floor which alters the vegetation composition and forest structure. The main purpose of this study is to know the comparative environmental impacts of forest fire between burnt and unburnt forests. This research will not only be the new in this study forest but also might be helpful to predict their community- or ecosystem-level functions and processes as very few research works have been performed related to fire in the Chure region.

CHAPTER 3: MATERIALS AND METHODS

3.1 Study area:

3.1.1 Location

Geographically, Butwsub-metro-Politian city of Rupandehi district of Nepal covers an area of 101.69 sq. km. The present study area was covered in ward no. 3,4,5,6 and 7 of Butwal sub-metro-Politian which lies between 27°42 ' to 27^{o} 44' N latitude and 83^{o} 23’ to 83^{o} 30’ E longitude extending 500 to 800 m in altitude. In the present study, one burnt forest and another unburnt forest was selected for the study in the Chure range of Butwal area. Frequently fired areas were recognized by ICIMOD termed as the burnt forest where *S. robusta* forest was set on fire during dry season. An unfired area was recognized from the north of the burnt forest, called unburnt forest. In the administrative study map, the yellow circle represents wildfire in Butwal sub- metropolitan area recorded by ICIMOD (Appendix 1, Figure 1). White circles represent each quadrat in the unburnt forest, whereas red circles represent each quadrat in burnt forest (Figure 1).

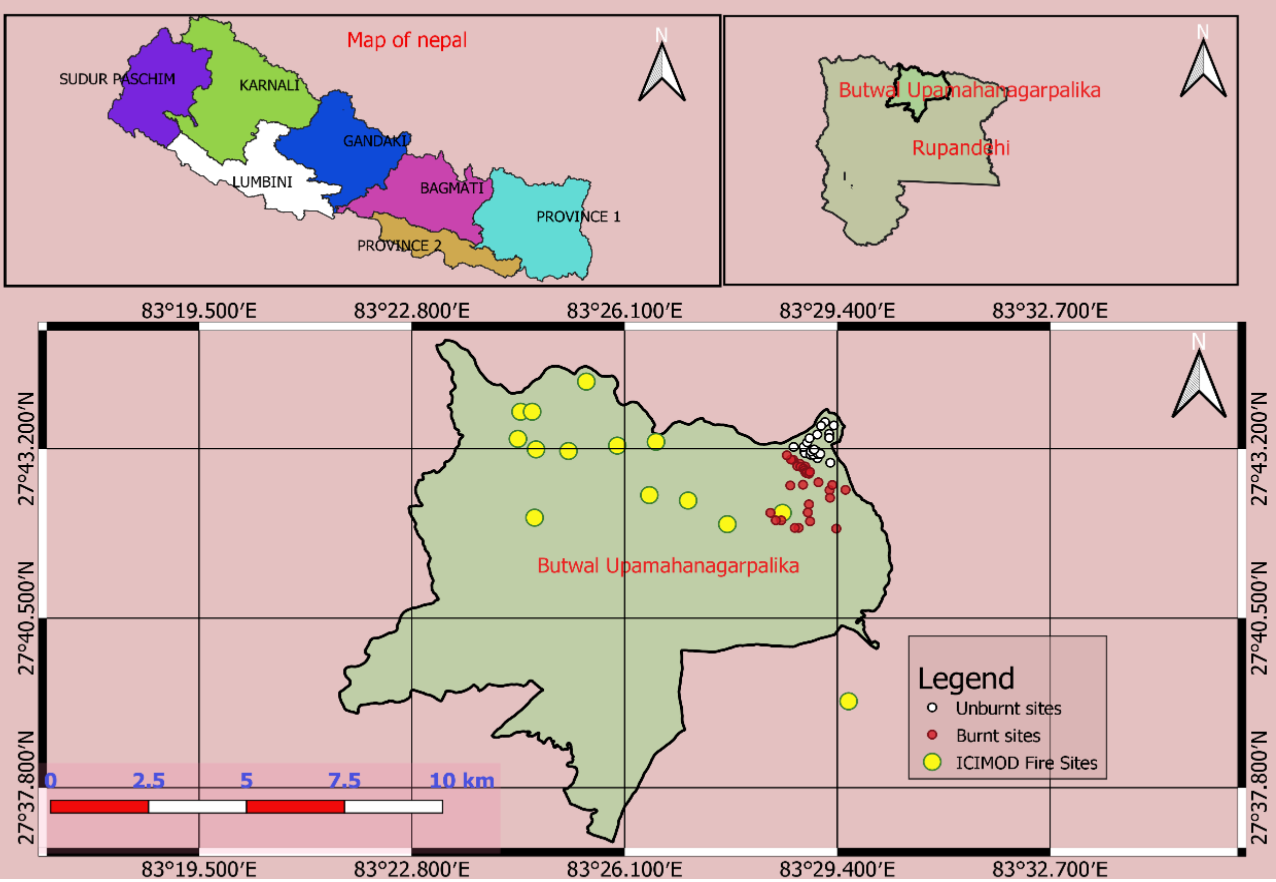


Figure 1: Administrative map of Nepal, Rupandehi district and Butwal sub-metropolitan showing wildfire, burnt forest and unburnt forest of study area.

Source: QGIS 3.4.8 with GRASS 7.6.1

Satellite map of study area showing yellow circles represents each quadrat of unburnt forest whereas white squares represent each quadrat of burnt forest (Figure 2).

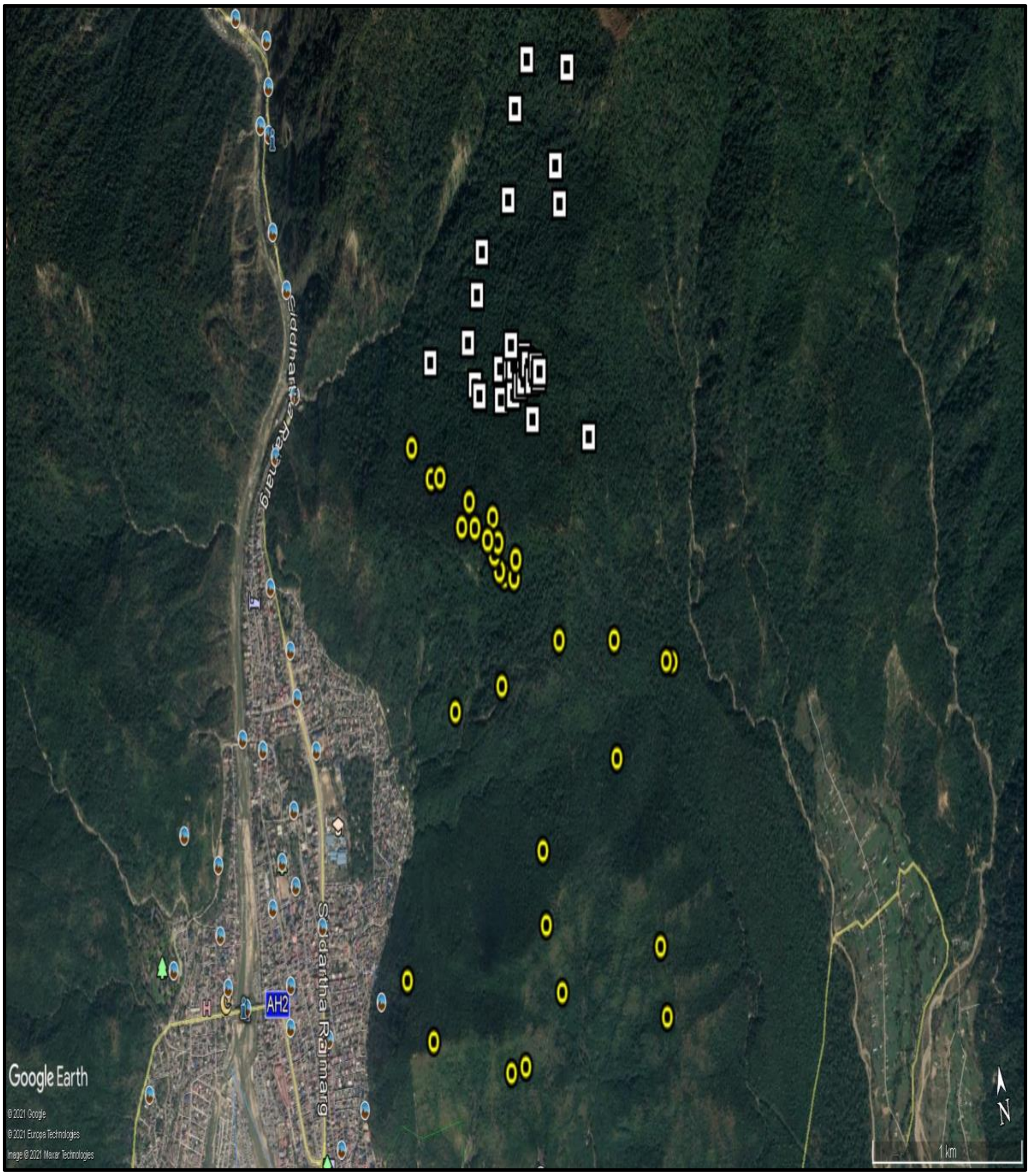


Figure 2: Satellite map of study area where the yellow circle represents each quadrat of unburnt forest and white square represents each quadrat of burnt forest.

Source: https://earthexplorer.usgs.gov/

3.1.2 Climate

Rupandehi district exhibits tropical type of climate dominated by the southwest monsoon. The area is characterized by four distinct seasons: Pre-monsoon from March to May, monsoon from June to September, post-monsoon from October to November and winter from December to February. The summer season of this region is very hot, and winter is very cold. In summer the monthly average temperature rises to 40°C and in winter the monthly average temperature falls below 10°C. There was a high variation in the annual temperature and precipitation. The total average of annual temperature was 25.2°C (Climatological data 1988-2017). As shown in the Figure 3 the average maximum temperature was 36.5°C in May and the minimum temperature was 11.1°C in January. Average monthly rainfall recorded was 198.48 mm and the total annual rainfall recorded was 2381.87 mm. Average maximum and minimum rainfall recorded was 695.8 mm in July and 9.97 mm in December (Figure 3). More than 80% of the annual rainfall occurs during the rainy season (monsoon rainfall) i.e., from June to September.

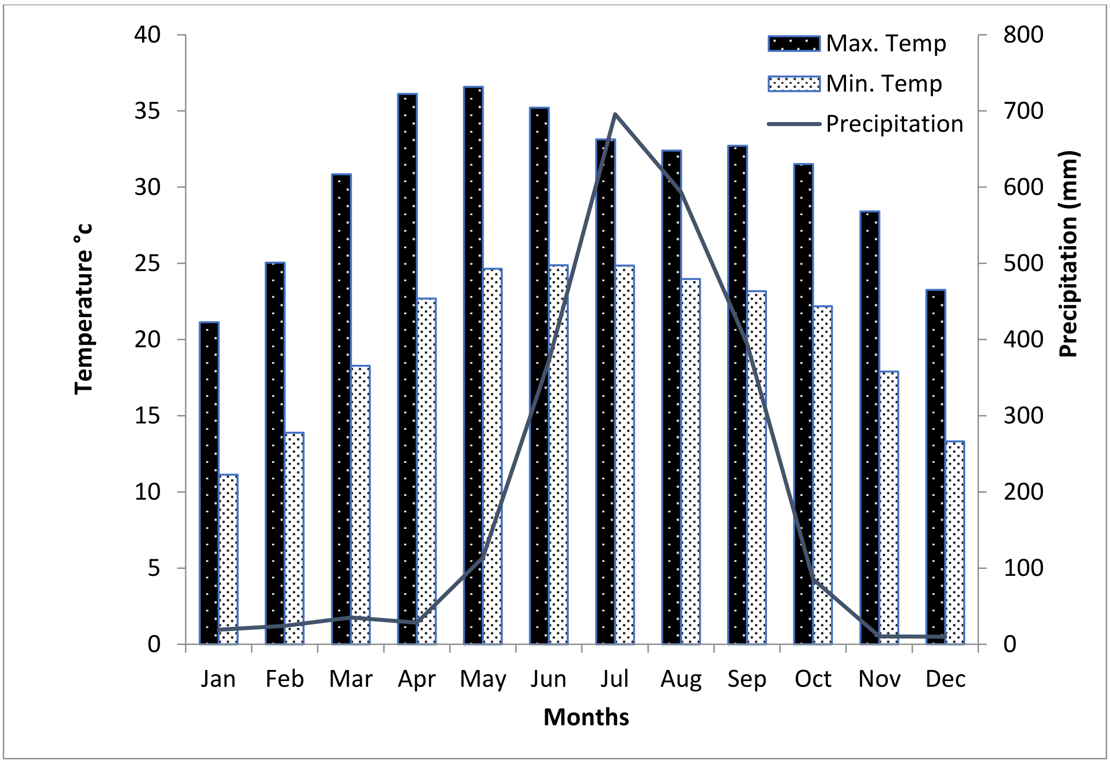


Figure 3. Variation in monthly average (minimum and maximum) temperature and precipitation of last 30 years (1988-2017) in Butwal sub-metropolitan.

Source: Department of Hydrology and Meteorology (DHM, 2020).

3.1.3 Vegetation

In Butwal sub- metropolitan forest area covers 65.15% of total land (DFO, 2013). The total green space available in Butwal Sub-Metropolitan City is found to be 86.37 km^2 i.e., 85.77% of the total area (Figure 4). From the ecological point of view, the Butwal area can be regarded as an ecotone, with lower sub-tropical and tropical vegetation. The Share Region of Butwal covers a diverse array of biomes, ecoregions, and ecosystems (DFO, 2013). Forests, rivers, cultivated lands and settlements are the prominent features of this area. There are 16 community forests registered in District Forest Office (DFO, 2013). The larger patches of community forests are found in the northern Chure hills (DFO, 2013). Most of the Chure forests are dense forests. Other smaller community forests, mostly plantations, are found in the southern semi-urban plains. They have a land cover of 4333.96 hectares (43.34 km^2) i.e., 42.62% of the total municipal area.

Vegetation of study area of bosth unburnt and burnt forest is characterized by tropical Sal (*Shorea robusta*) forest with tree associates like Sissoo (*Dalbergia sissoo*), Khayar (*Acacia catechu*), Saj (*Terminalia alata*), Banjhi (*Anogeissus latifolia*), Khaniyu (*Ficus semicordata*). Similarly, in shrubs layer species like T*ePhrosia Purpurea, Elatostoma sessile, Jasminum dispermum, Cassia occidentalis, Pogostemon bengalensis, Bauhinia vahlii,* etc. are prominently found. Also, *Imperata cylindrica, Eranthemum pulchellum Cassia tora, Eragrostis tenella, Capillipedium assimile, Blumea lacera* etc. are characterized in herb layer.

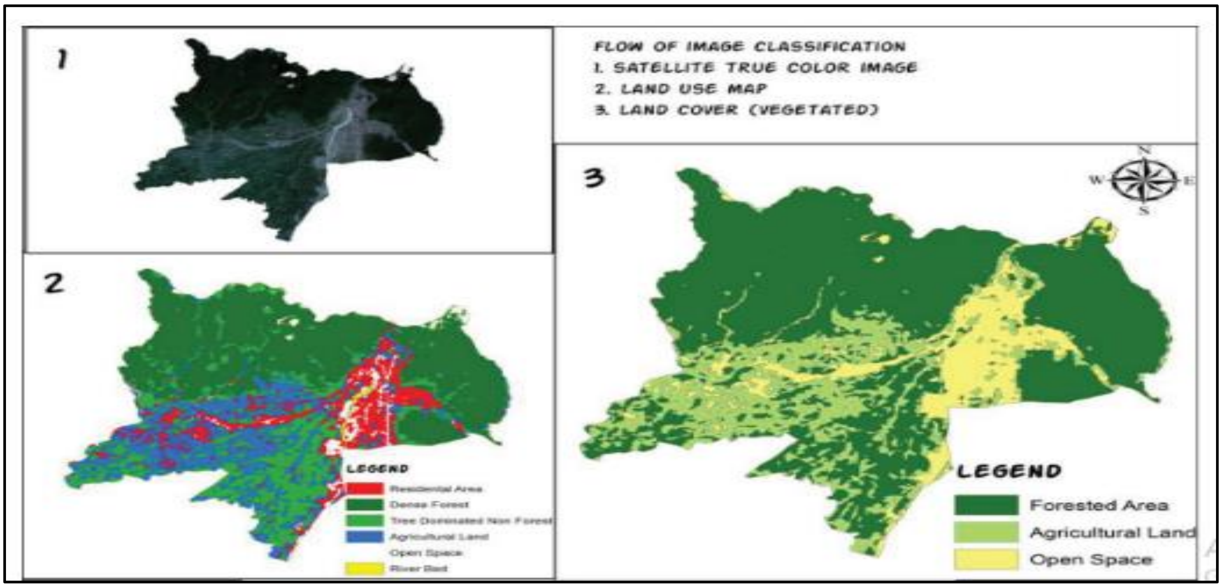


Figure 4: Land cover statistics of Butwal Sub-Metropolitan City. Source:(DFO, 2013)

3.2 Methods

Historical ground fire data in conjunction with satellite remote sensing and department of forest and environment department (geoapps.icimod.org) was used for delineation and identification of fire affected areas.

3.2.1 Vegetation sampling

The trees and saplings were analyzed by systematic random sampling method lying 60 quadrats of size 10 m radius (Jhariya *et al.*, 2012) (Figure 5). The diameter at breast height (i.e., 1.37 m above the ground) of all the trees and saplings in each quadrat was measured and recorded individually and converted into Grith Base Height (GBH) to study regeneration status. For tree species, the individuals >31.5 cm GBH are categorized as tree, between (<31.5 cm >10cm) categorized as sapling and <10 cm as seedlings. (Jhariya *et al.*, 2012)

In each of these quadrats, a sub quadrat of 5m radius size was randomly laid within the main quadrats for measuring saplings and shrubs. Similarly, another sub quadrat of 1m radius size in 10m radius, quadrat was laid for measuring herbs and seedlings (Jhariya *et al.*, 2012) (Figure 5). All understory bushes, grasses and herbaceous plants were measured by species number and canopy coverage. Plants were identified by using local name, photographs, and consulting literatures like Polunin and Stainton, 1997).

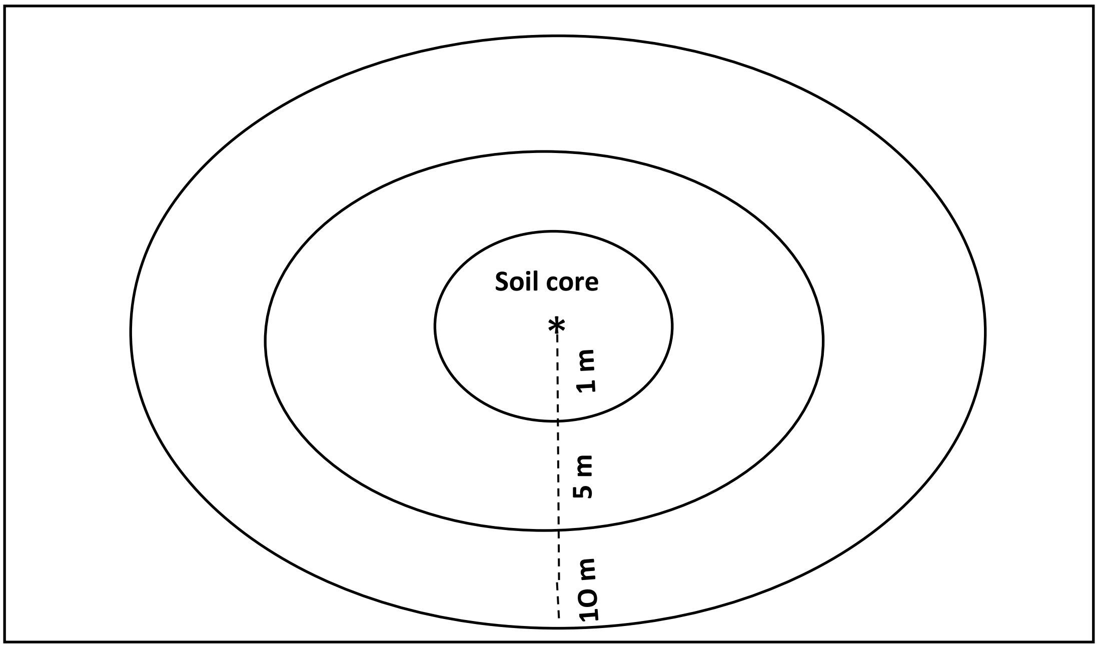


Figure 5: Showing plot design: soil core: 10 m and 5 m circular plot for trees and sapling and shrub respectively, 1m circular plot for herbaceous species and seedlings.

3.2.2 Vegetation analysis

The field data was used to calculate frequency, density, basal area and importance percentage of tree species following the method described by Zobel *et al.* (1987) with minor modification. Diversity parameters for tree, sapling, seedling, shrub, and herb layers were determined from the Shannon-Weiner information function (Shannon and Weaver, 1963). Concentration of dominance was measured following Simpson's index method (Simpson, 1949). Vegetations were also measured for species richness (Marglef, 1958), equitability (Pielou, 1966) and Beta diversity (Whittaker, 1962).

Frequency (F):

Frequency is the proportion of sampling units containing the species.

$$\text{Frequency (\%)} = \frac{\text{No.of quadrat in which an individual species occured}}{\text{Total no.of quadrat sampled}} \text{ x } 100\%$$

Relative frequency (RF):

Relative frequency can be obtained by comparing the frequency of occurrences of all the species present.

$$\text{Relative Frequency (\%)} = \frac{\text{Frequency of individual species}}{\text{Sum of the frequency of all species}} \text{ x } 100\%$$

Density (D):

Density is the number of individuals per unit area.

$$\text{Density(stem/ha)} = \frac{\text{Total no.ofindividual of a species in all plots}}{\text{Total no.of plot studied}} \text{ x } \frac{10000}{\text{size of the plot}}$$

Relative density (RD)

Relative density can be obtained by comparing the density of occurrences of all the species present.

$$\text{Relative Density} = \frac{\text{Density of individual species}}{\text{Total density of all species}} \text{ X } 100\%$$

Basal Area (BA):

Basal area is one of the characters which determine dominance. Basal area cover indicates the amount of ground occupied by the stems.:

$$\text{Basal area of a species } (m^2/ha) = \frac{\text{Total basal area of species x 10000}}{\text{Size of the plot } (m^2)}$$

Relative Basal Area (RBA):

Relative basal area can be obtained by comparing the basal area of occurrences of all the species present.

$$\text{Relative Basal Area } (\%) = \frac{\text{Basal area of individual species x 100}}{\text{Total basal area of all species}}$$

Importance Value Index:

Relative frequency, relative density, and relative basal area each indicate a different aspect of the importance of a species in a community. Therefore, the sum of these three values should give a good overall estimate of the importance of a species. This sum is called the importance value index.

IVI = RFi + RDi + RBAi

Where,

IVI = Importance Value Index of Species i

RFi = Relative Frequency of Species i

RDi = Relative Density of Species i

RBAi = Relative Basal Area of Species i

Species Diversity Index (H)

The Shannon-wiener index (Shannon-wiener index, 1949) is one of the most employed variables for the estimation of species diversity: for its determination is employed the formulation:

$$(\mathbf{H}) = -\sum \mathbf{Pi.\ln(\ Pi})$$

$$\textbf{Equitability} = \frac{\boldsymbol{H}}{\boldsymbol{H_{max}}} = \frac{\boldsymbol{H}}{\boldsymbol{Ln\ N}}$$

Where,

H = Species Diversity Index

Pi = Proportion of the species

Pi = ni /N

N = Sum of total density of all species

ni = Density of a species

Beta (β) Diversity:

The Whittaker's Beta (β) Diversity was calculated using the following formula (Magurran, 2004).

$$\text{Beta diversity } (\beta) = \frac{S}{\bar{\alpha}} - 1$$

Where S= total no. of species found in both forest

$\bar{\alpha}$ =Average of total no. of species found in both forest

Concentration of dominance:

The Simpson's concentration of dominance (Simpson, 1949) was measured as

$$CD = \sum Pi^2$$

where Σ Pi = Σ ni/n

n = Sum of total density of all species

ni = Density of a species

Species Richness:

Margalef's species richness Index is calculated by: (Margalef, 1958)

$$Species\ richness = \frac{(S-1)}{\ln N}$$

Where, S = number of species.

N = total number of individuals.

Berger-parker dominance:

Berger-Parker dominance index is determined by the equation (Berger

and Parker, 1970).

$$D = \frac{N_{max}}{N}$$

Where,

N_{max} = Number of individuals of the most abundant

species, N = Total number of individuals in the forest

3.2.3 Regeneration Status

Regeneration status of tree species, the population structures were developed based on different tree grith classes in addition to seedlings and saplings. The total numbers of individuals belonging to following grith classes were calculated for each species on each forest according to and Jhariya *et al.,* (2012). Diameter at breast height (DBH) of each tree within each plot was measured using DBH tape and converted into Grith Breast Height (GBH) for the calculation of regeneration pattern. In addition to seedling (A) as <10 cm GBH and 10-31.5 cm GBH as sapling (B) classes, three more size classes (based on GBH) i.e., 31.5-70.0 cm (C); 70.1-110.0 cm (D) and >110 (E) were arbitrarily established for each tree species (Jhariya *et al.,* 2012). The total number of individuals belonging to these size classes were calculated for each species on each stand.

3.2.4 Carbon stock

Diameter at breast height (DBH) of each tree within each plot was measured using DBH tape, and height of each tree was calculated using Clinometer.

3.2.4.1 Above ground biomass

The above ground biomass of the tree includes the wood, branches, leaves, barks, were measured. Volume of the trees were calculated by πr^2 x h, (Jhariya *et al.* 2012,) Where r = radius = (dbh/2), h/2 = height of the tree (Tamrakar, 2000). The biomass of pole (kg) was calculated (Chaturvedi and Khanna, 1982). The lists of specific wood density were used from MPFSN, (1988). Above ground carbon like wood, branch and foliage carbon were calculated according to Negi *et al.*, (2003).

3.2.4.2 Below ground biomass

The below ground biomass includes all biomass of underground parts. The below ground biomass has been calculated following Oli and Shrestha, (2009); MPFSN, (1988). The below ground carbon has been calculated by using the default factor of 0.5 (Oli and Shrestha, 2009).

3.2.5 Soil sample collection and analysis

Soil cores were used for the collection of soil sample from different depths such as 0-2cm, 2-10cm, 10-30cm and >30cm at the center of the main sampling plot. Altogether twelve random samples were collected six representing unburnt forest and six in burnt forest. Soil cores representing four different layers were collected from each soil depth for the estimation of bulk density, soil pH, SCS and SOC content as according to Aryal *et al.*, (2016/18). Fresh weights of soil samples in the field were taken in the field and oven dried until constant weight was weighted.

3.2.6 Soil bulk density

Soil bulk density was determined using core sampling methods (Blake and Hartge, 1986).

Soil bulk density (g/cm^3) = oven dry weight of soil (g)/volume of the soil (cm^3).

3.2.7 Soil pH

Soil pH was determined with a 1:2 soil water suspension using pH meter in laboratory of Botany department, Amrit Campus (Aryal *et al.*, (2016/18).

3.2.8 Soil charcoal stock (SCS)

Air-dried soil samples were sorted (e.g., charcoal, roots, coarse mineral fraction, barks, twigs, grass stems, seeds, and rocks) separately. Charcoal which could be seen by naked eyes was sorted and weights were measured separately from different soil depths. Percentage of SCS was calculated for various depths (Aryal *et al.*, 2016/18).

3.2.9 Soil organic carbon (SOC)

Soil organic carbon (%) was analyzed by Walky and Black method in laboratory of Botany department, Amrit Campus. SOC (t/ha) was calculated by (Awasthi *et al.,* 2005).

3.3 Statistical data Analysis

The significance of differences in diameter, basal area, height, diameter at breast height, above ground carbon and below ground carbon stock between burnt and unburnt forest were evaluated by independent sample t-test. Similarly, Soil pH, bulk density, soil organic carbon between the forest and soil depths were analyzed by independent sample t-test test by using IBM SPSS statistics software Version 25 Inc., Chicago, IL, USA. One-way ANOVA and Duncan's multiple range test were performed after testing normality of collected data to test the significance of Bulk density, Soil pH and soil organic carbon throughout the four soil depths of soil profile between burnt and unburnt forest.

CHAPTER 4: RESULTS

4.1 Species composition

A total 74 species. (41 trees, 19 shrubs and 33 herbs, grasses species) belonging to 72 genera and 43 families were recorded in both burnt and unburnt forest (Appendix II). The largest percentages (44%) recorded are herbaceous plant species followed by trees (30%) and shrubs (26%) species (Figure 6). Among them, shrub species belonging to family Fabaceae was dominated representing 3 genera with 3 species (appendix I). Similarly, herbaceous species belonging to families Fabaceae and Poaceae were co-dominated representing 4 genera with 4 species and 3 genera with 3 species respectively.

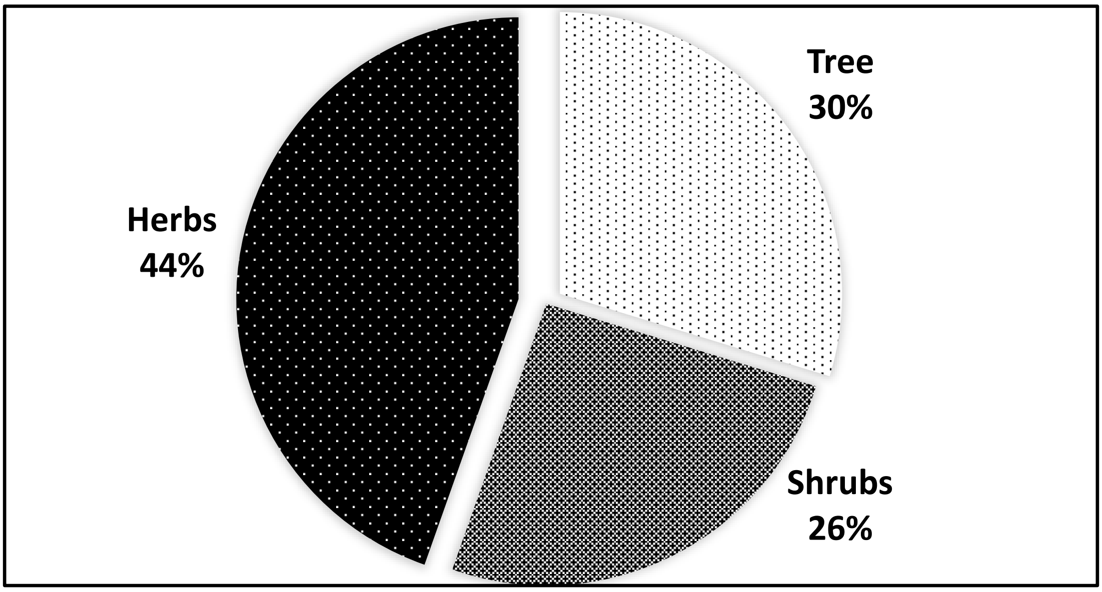


Figure 6: The growth forms of collected plant species.

A total of 22 and 19 species of trees were recorded in unburnt and burnt forest respectively (Appendix II). In unburnt forest *T. grandis, M. philippensis and F. semicordata* in the tree layer were found similarly in burnt forest *S. robusta, L. Parviflora* were found. In shrub layer, 19 species were recorded in unburnt forest and 18 species in burnt forest. *Bauhinia vahlii* was recorded only in unburnt forest. Similarly, 30 species of herb was recorded in unburnt forest and 32 species was recorded in burnt forest whereas *Mucuna pruriens* was recorded in unburnt forest only and *Calotropis gigantea*, *Capillipedium assimile* and *Heliotropium indicum* were recorded only in burnt forest (Appendix II).

4.1.1 Vegetation in herb layer

A total of 33 species belonging to 24 families was collected in both forest in which 30 species were recorded in unburnt forest and 32 species were recorded in burnt forest (Appendix V). In burnt forest herb layer was dominated by *Imperata cylindrica*, *Eranthemum pulchellum Cassia tora*, *Eragrostis tenella*, *Capillipedium assimile*, *Blumea lacera* including other herbeceous species (Figure 7). The importance value index (IVI) of *I. cylindrica,* and *E. pulchellum* were found 49.19 and 46.42 respectively in unburnt forest (Figure 7). Similarly, the IVI of some other herbaceous species recorded in burnt forest are listed in Appendix V.

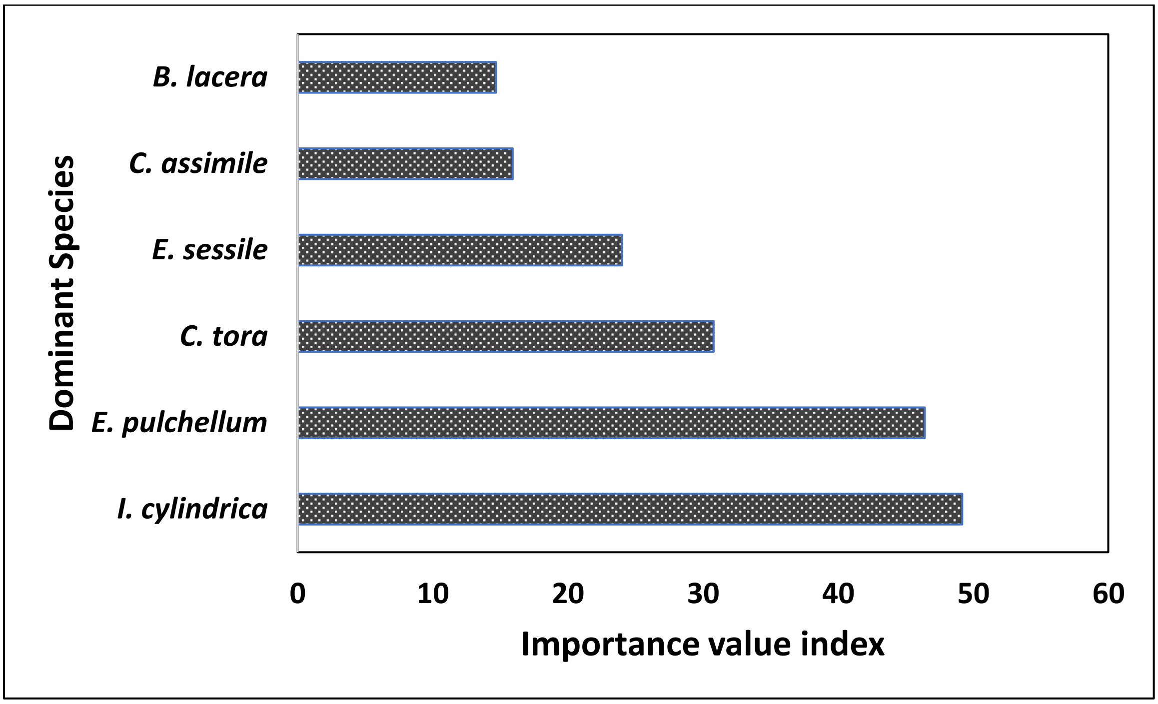


Figure 7: Importance value index of dominant herbaceous species of burnt forest.

Similarly, in unburnt forest, herb layer was dominated by *Boehmeria platyphylla, Dryopteris filix-mas, Triumfetta pilosa, Stellaria media, lepidium sativum, Achyranthus aspera* including other herbeceous species (Figure 8, Appendix V). Dominated herbaceous species were found different in both study forest (Figure 7 and 8). The IVI of *Boehmeria platyphylla* and *Dryopteris filix-mas* were found 39.37 and 19.76 respectively in unburnt forest whereas the IVI of some other herbaceous species recorded in unburnt forest are listed in Appendix V.

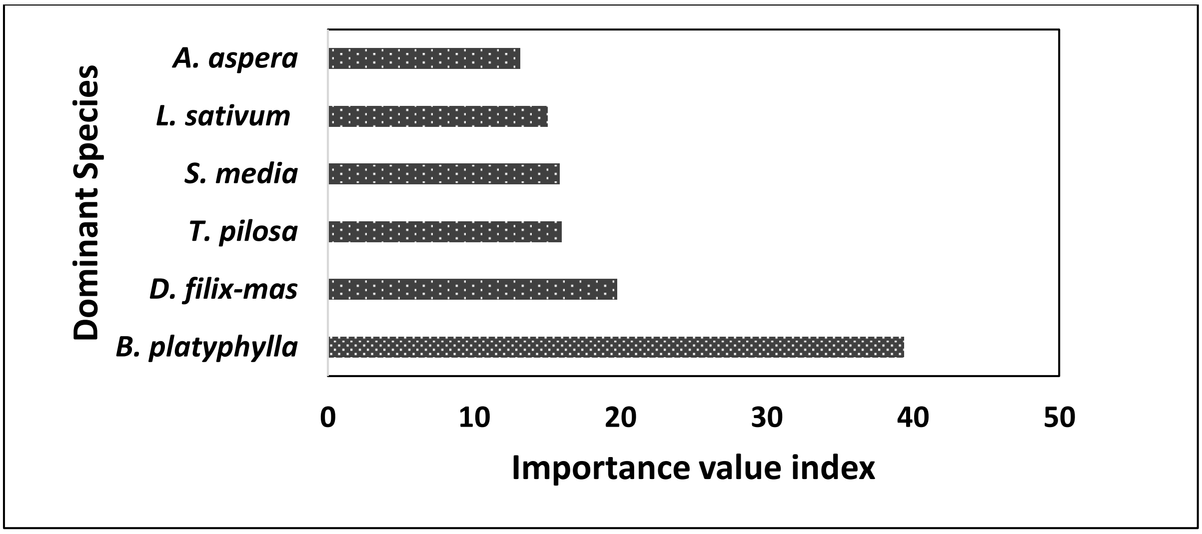


Figure 8: Importance value index of dominant herbaceous species of unburnt forest.

4.1.2 Vegetation in Shrub layer

Shrub layer was mainly dominated by *Tephrosia purpurea* with IVI 54.72, *Jasminum dispermum* with 28.33, *Colebrookea oppositifolia, Cassia occidentalis, Maesa macrophylla, Pogostemon bengalensis* including other shrub species (Figure 9, Appendix IV) in burnt forest.

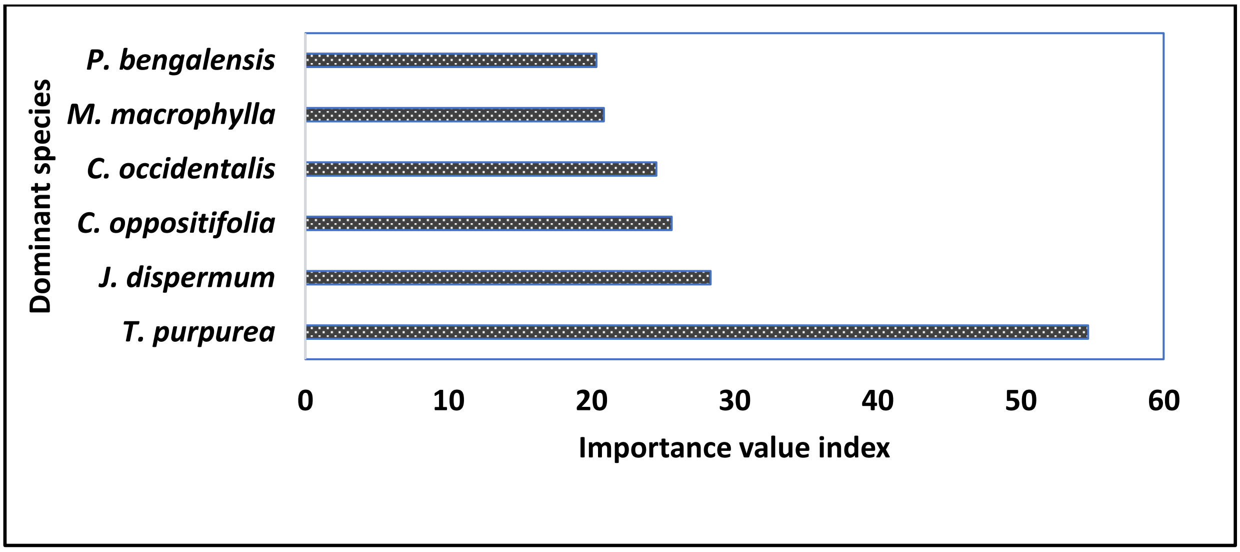


Figure 9: Importance value index of dominant shrub species of burnt forest.

Shrub layer was mainly dominated by *T. purpurea, Elatostoma sessile, J. dispermum, Cassia occidentalis, P. bengalensis, Bauhinia vahlii* and including shrub species (Figure 10, Appendix IV) in unburnt forest. The IVI of *T. purpurea* and *E. sessile* in unburnt forest were 49.52 and 34.12 respectively. Among 6 dominated shrub species, 4 shrub species like *T. purpurea, J. dispermum, C. occidentalis* and *P. bengalensis* were found similar in both study forest remaining 2 were different (see Figure 9 and 10).

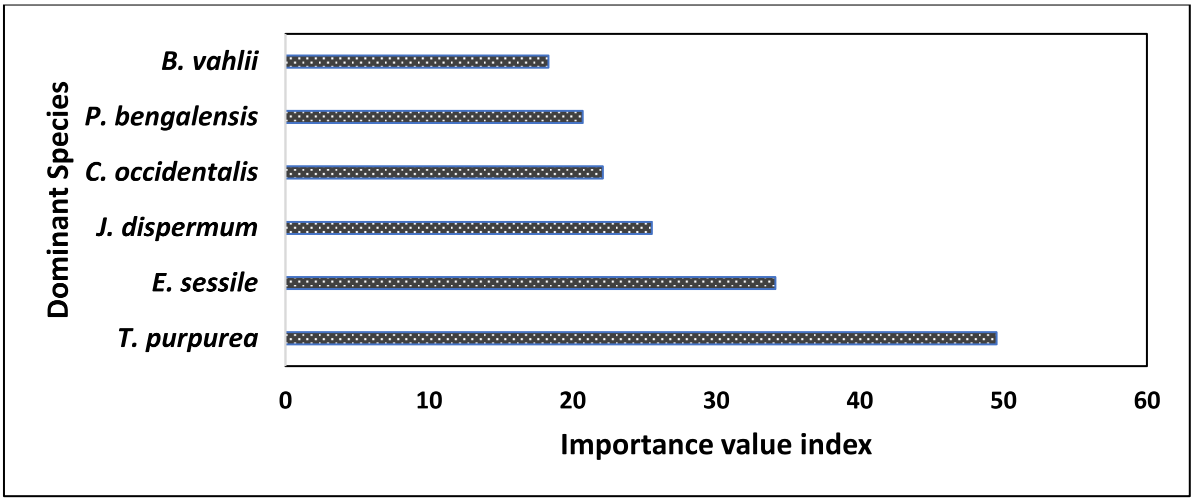


Figure 10: Importance value index of dominant shrub species of unburnt forest.

4.1.3 Vegetation in tree layer

Total of 22 species of tree belonging to 14 families was recorded in unburnt forest whereas 19 species of tree belonging to 11 families was recorded in burnt forest and 22 species in unburnt forest. (Appendix III). Three tree species like *M. Philippensis*, *T. grandis and F. semicordata* were only recorded in unburnt forest. The importance value index of *S. robusta* and *L. parviflora* were found 130.64 and 19.03 respectively in unburnt forest whereas the Importance value index of *S. robusta* and *Lagerstroemia parviflora* were found 126.80 and 36.98 respectively in burnt forest (Figure 11). Similarly, the importance value index of other tree species recorded in both burnt and unburnt forest were listed in (Appendix III).

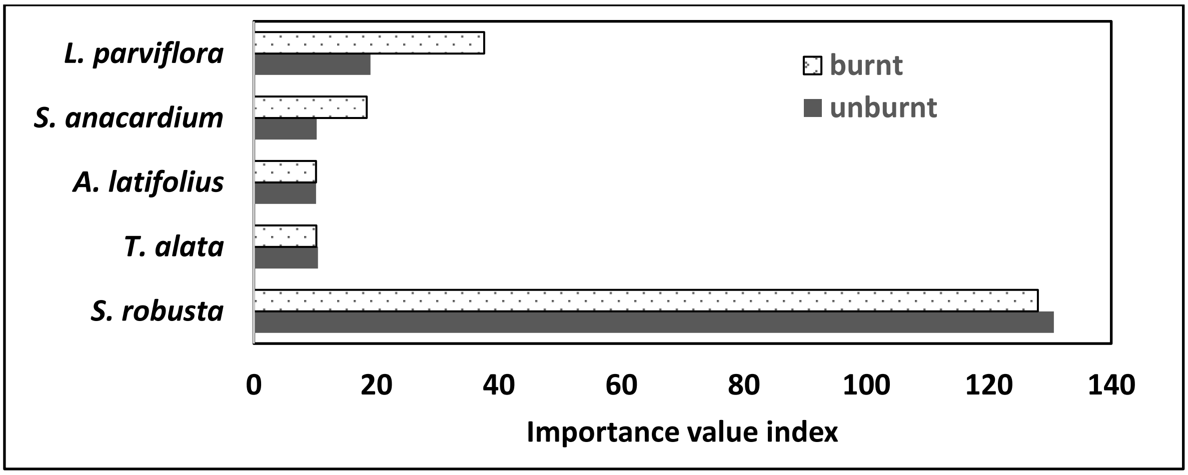


Figure 11: Importance value index of dominant tree species of both burnt and unburnt forest.

4.2 Diversity indices

Across the forest burnt and unburnt the value of Shannon-Wiener diversity index (H) of tree layer (1.43 and 1.80) respectively (Table 1). Similarly, Margalef's species richness index of trees layers of burnt (2.34) and unburnt (2.94) forest were calculated. Shannon-Wiener diversity index value for sapling (2.61), seedling (1.08) and herb layer (3.11) were higher in the unburnt forest while shrubs layer (2.35) value was found less (2.35) in unburnt forest (Table 1). Margalef's species richness index was recorded higher in unburnt forest for tree (2.94), sapling (2.72), seedling (2.29) and shrubs layer (2.45) while in herb layer (3.81) the value was higher in burnt forest. The value of equitability, concentration of dominance (CD) and Berger Parker dominance for tree, sapling, seedling, and shrubs were shown in table 1.

The values of equitability were higher in unburnt forest for tree layer (0.58), sapling (0.85), seedling (0.35) and herb layer (0.91) whereas it was recorded lower for shrubs layer (0.79). Concentration of dominance (CD) was inscribed higher for tree (0.44), sapling (0.28), seedling (0.78), and herb layer (0.13) in burnt forest whereas it was inscribed equal value in both burnt and unburnt for shrub layer (0.08). Similarly, Berger-Parker dominance was recorded higher for tree (0.64), sapling (0.51), seedlings (0.88), and herb layer (0.24) in burnt forest whereas it was recorded lower for shrubs layer (0.17) in burnt forest (Table 1).

Table 1: Diversity indices as per growth form

		Burnt			
Life form	Shannon-Wiener index	Equitability	Concentration of Dominance	Species richness	Berger-Parker
Tree	1.43	0.49	0.44	2.34	0.64
Sapling	1.65	0.58	0.28	2.51	0.51
Seedling	0.55	0.19	0.78	2.05	0.88
Shrubs	2.62	0.90	0.08	2.44	0.17
Herbs	2.41	0.69	0.13	3.81	0.24
		Unburnt			
Life form	Shannon-Wiener index	Equitability	CD	Species richness	Berger-Parker
Tree	1.80	0.58	0.38	2.94	0.61
Sapling	2.61	0.85	0.11	2.72	0.27
Seedling	1.08	0.35	0.62	2.29	0.79
Shrubs	2.35	0.79	0.08	2.45	0.18
Herbs	3.11	0.91	0.05	3.76	0.09

4.2.1 Beta (β) diversity

The beta (β) diversity for tree, sapling, seedling, shrubs, and herb layer between two forest burnt and unburnt were shown in Table 2, Beta (β) diversity index was recorded highest in seedlings (0.18) and lowest in shrubs layer (0.027) (Table 2). Between burnt and unburnt forest, higher dissimilarity of species was observed in saplings and seedlings than in trees, shrubs, and herbs.

Table 2: Beta (β) diversity between burnt and unburnt forest

Life form	**Beta diversity index**
Tree	0.078
Sapling	0.1176
Seedling	0.1875
Shrubs	0.027
Herbs	0.066

4.3 Comparison of height and DBH of *S. robusta*

The average height of *S. robusta* was recorded 19.16±0.24m and 16.289±0.21m for unburnt and burnt forest respectively whereas average DBH was 0.41±0.11m and 0.37±0.16m respectively. (Figure 12).

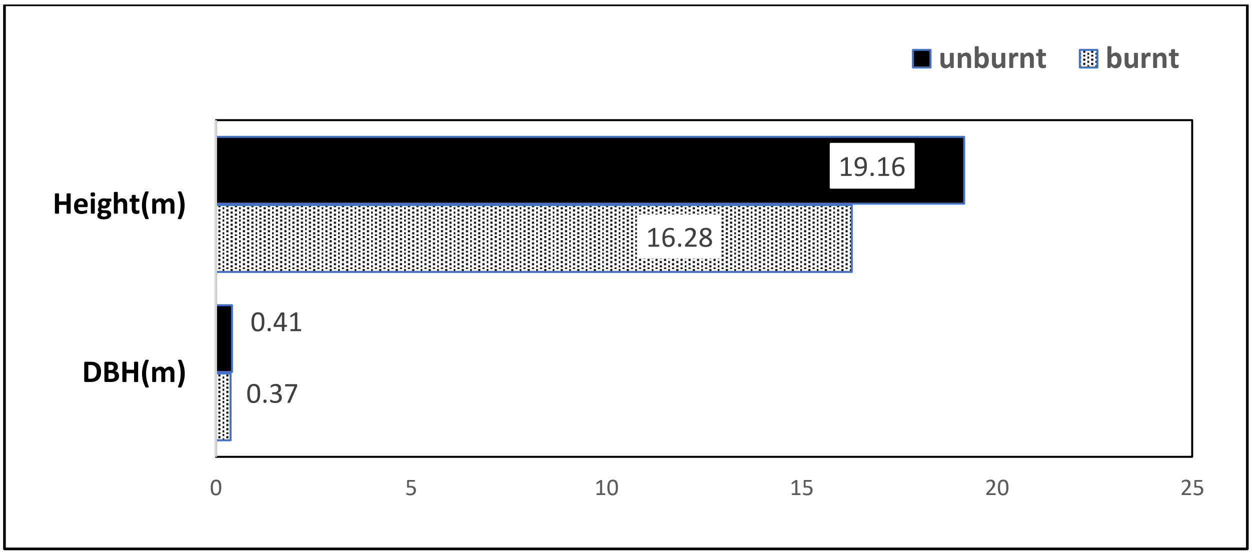


Figure 12: Average DBH and height of *S. robusta* across the burnt and unburnt forest. (N=30).

Independent sample t test to compare average height *(p=0.02)* and average DBH *(p=0.03)* of *S. robusta* between burnt and unburnt forest showed significant difference (Table 3).

Table 3: Comparing DBH and height of *S. robusta* of burnt and unburnt forest (t- test analysis)

Parameters	**Mean value in Unburnt**	**Mean Value in Burnt**	**T value**	**Significance**
DBH of *S. robusta*	0.41±0.11m	0.37±0.16m	2.68	0.03
Height of *S. robusta*	19.16±0.24m	16.289±0.21m	8.78	0.02

4.3.2 Comparison of density of dominant tree species

The calculated density of dominant tree species of forest burnt and unburnt are shown in the Figure 13. The average density of *S. robusta* were calculated as 749.71±25.15 (Individuals/hectares) and 1031.79±36.284 In/ha for unburnt and burnt forest, respectively. The highest density of S. *robust*a was 1439.71 (In/ha) was calculated in burnt forest whereas the lowest density of *S. robusta* was 504.01 (In/ha) was calculated in unburnt forest. Similarly, the average density of *L. parviflora* was calculated as 42.68±1.787 (In/ ha) and 165.21±10.6 (In/ha) for unburnt and burnt forest, respectively. Also, the average density of *S. anacardium* were calculated as 28.04±1.69 (In/ha) and 83.08±7.55 (In/ha) for unburnt and burnt forest, respectively (Figure 13).

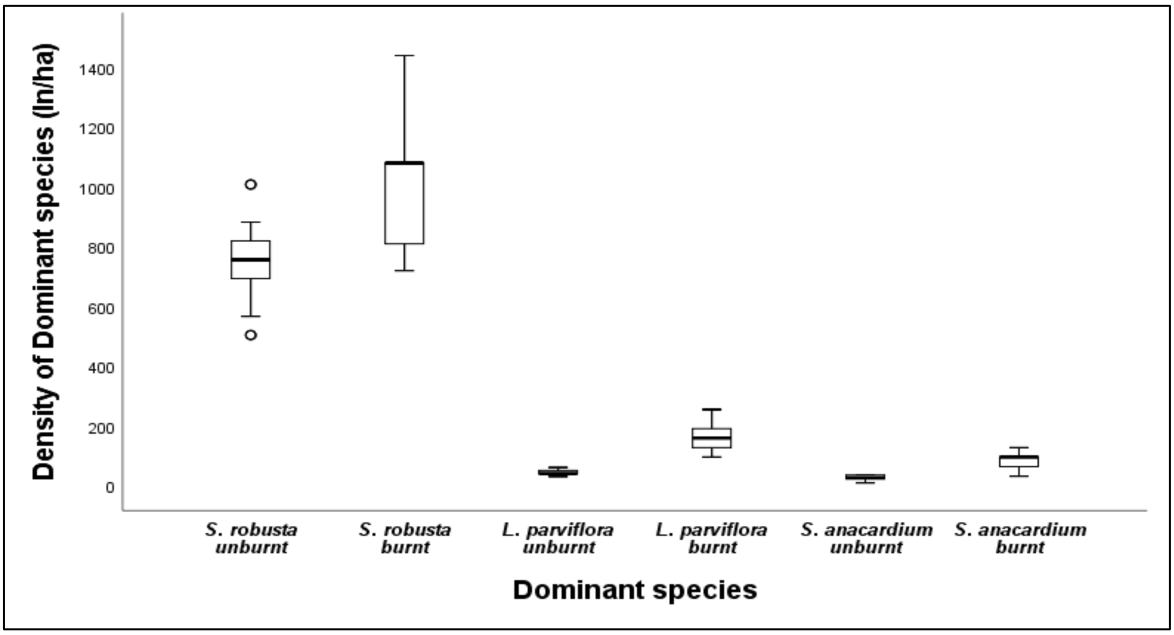


Figure: 13: Comparison of densities of dominant tree species of burnt and unburnt forest. The box plots show the median, and 25 to 75 percentiles. Whiskers indicate maximum and minimum values.

4.3.3 Comparison of basal Area of dominant tree species

The average basal area of *S. robusta* were calculated as 1.72±0.06 sq. m and 1.00±0.09 sq. m for unburnt and burnt forest, respectively. The highest basal area of S. *robust*a was 2.28 sq. m was calculated in unburnt forest whereas the lowest basal area of *S. robusta* was, 0.80 sq. m was recorded in burnt forest. Similarly, the average basal area of *L. parviflora* were calculated as 0.25±0.01 sq. m and 0.43±0.02 sq. m for unburnt and burnt forest, respectively. Also, the average basal area of *S. anacardium* were calculated as 0.06±0.00 sq. m and 0.245±0.03 sq. m for unburnt and burnt forest, respectively (Figure 14).

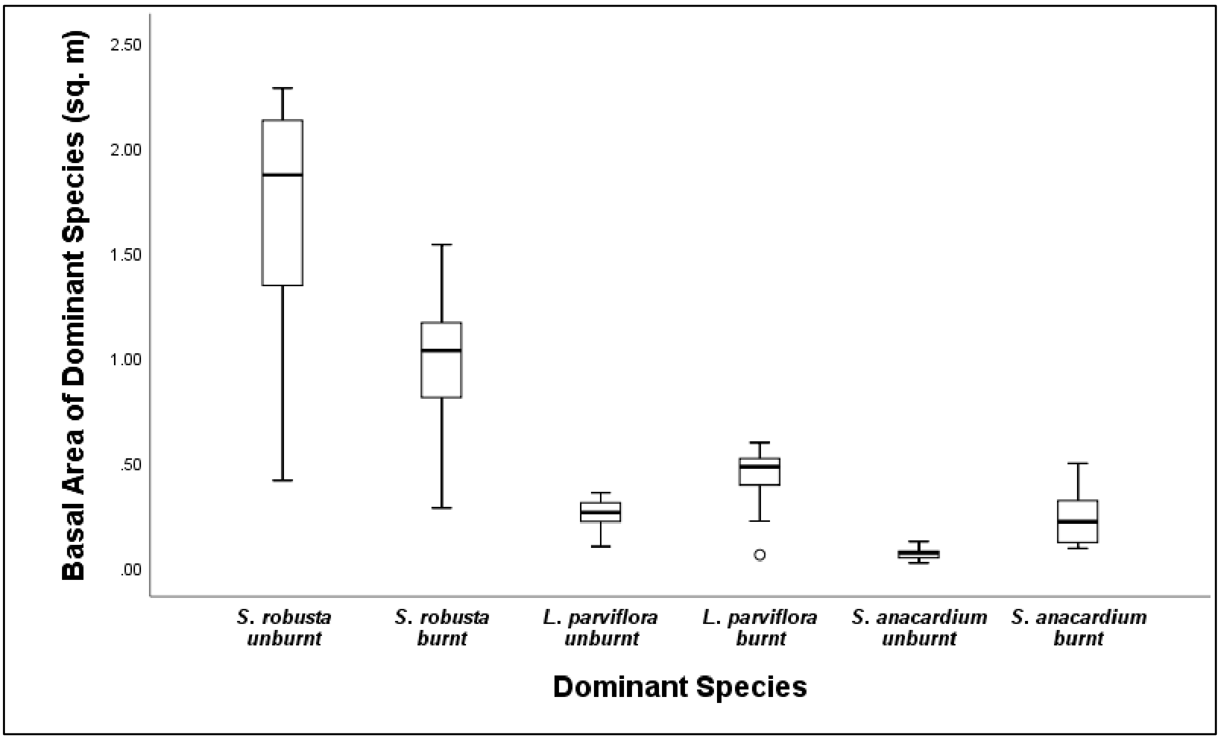


Figure: 14: Basal area (Sq. m) of dominant tree species in burnt and unburnt forest. Box plots show the median (line inside the box) and upper and lower quartiles (75%, 25%) and maximum and minimum values.

Results of independent sample t test to compare density and basal area of major tree species between burnt and unburnt forest are given in table 4. P value for the comparison of basal area of *S. robusta (p=0.04) L. Parviflora (p=0.01)* and *S. anacardium (p=0.00)* were, P value for the comparison of basal area and density of *S. robusta (p=0.03) L. parviflora (p=0.00)* and *S. anacardium (p=0.00).* This analysis indicates basal area and density of *S. robusta*, *L. parviflora* and *S. anacardium* were highly significant difference between forest (Table 4).

Table 4: Comparing Density and basal area of dominant tree of burnt and unburnt forest by t-test analysis.

Parameters	**Mean value in Unburnt**	**Mean Value in Burnt**	**T value**	**Sig.**
Basal Area of *S. robusta*	1.72±0.06 sq. m	1.00±0.09 sq. m	6.290	0.04
Density of *S. robusta*	749.71±25.15 (In/ha)	1031.79±36.28 (In/ha)	6.389	0.03
Basal Area of *L. parviflora*	0.25±0.01 sq. m	0.43±0.02 sq. m	6.489	0.01
Density of *L. parviflora*	42.68±1.787 (In/ha)	165.21±10.6 (In/ha)	11.41	0.00
Basal Area of *S. anacardium*	0.06±0.00 sq. m	0.245±0.03 sq. m	6.554	0.00
Density of *S. anacardium*	28.04±1.69 (In/ha)	83.08±7.55 (In/ha)	8.720	0.00

4.4 Regeneration status

Population structures of tree, seedling and sapling layer across burnt and unburnt forest were shown in the Figure 15. The relative density of seedling (68.13%) and tree with grith class C were higher in unburnt forest (17.68%) likewise relative density of saplings (19%) and tree with grith class D were higher in burnt forest (11%) (Figure 15).

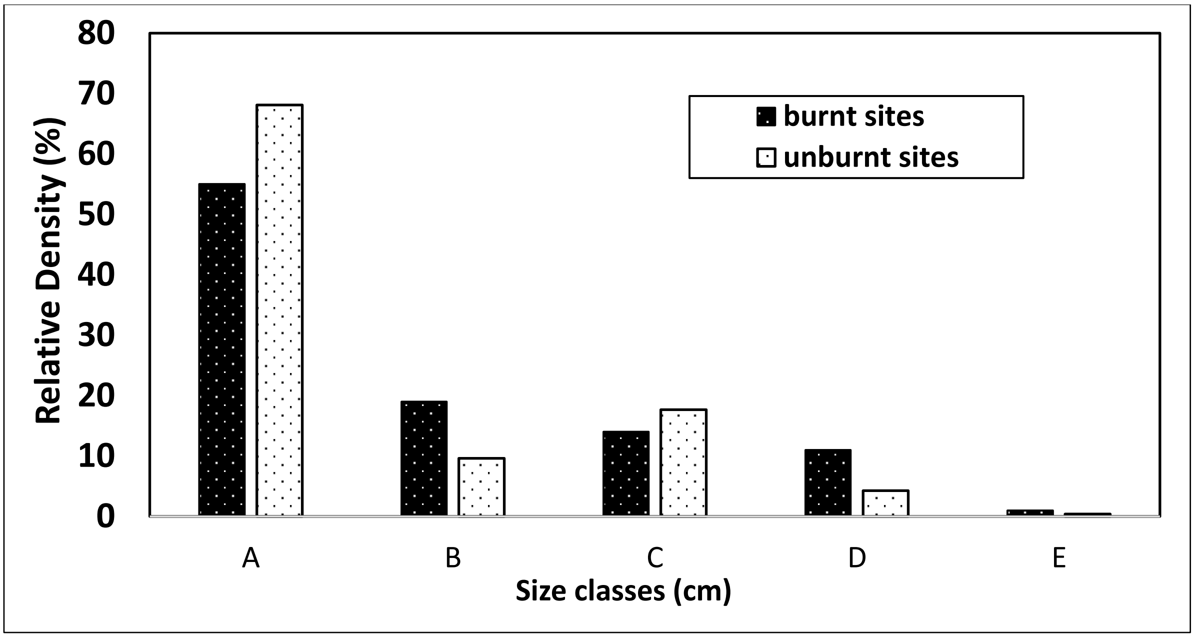


Figure 15: Total average of relative density of tree species in burnt forest and unburnt forest. A=Seedling, B=Sapling, Tree species with different GBH classes (C=31.5-70cm, D=70-110cm, E=>110cm).

Relative density of seedlings, saplings, and tree species with different GBH of dominant tree species were shown in Figure 16. The relative density of seedlings of *S. robusta* (79.84%) was higher followed by tree with grith class C (8.09%) in unburnt forest. Similarly relative density of saplings of *l. parviflora* (50%), *D. sissoo* (44%), *S. anacardium* (53%), *T. indica (38%)* and *S. oleosa* (43%) were higher followed by relative density of seedlings. (Figure 16).

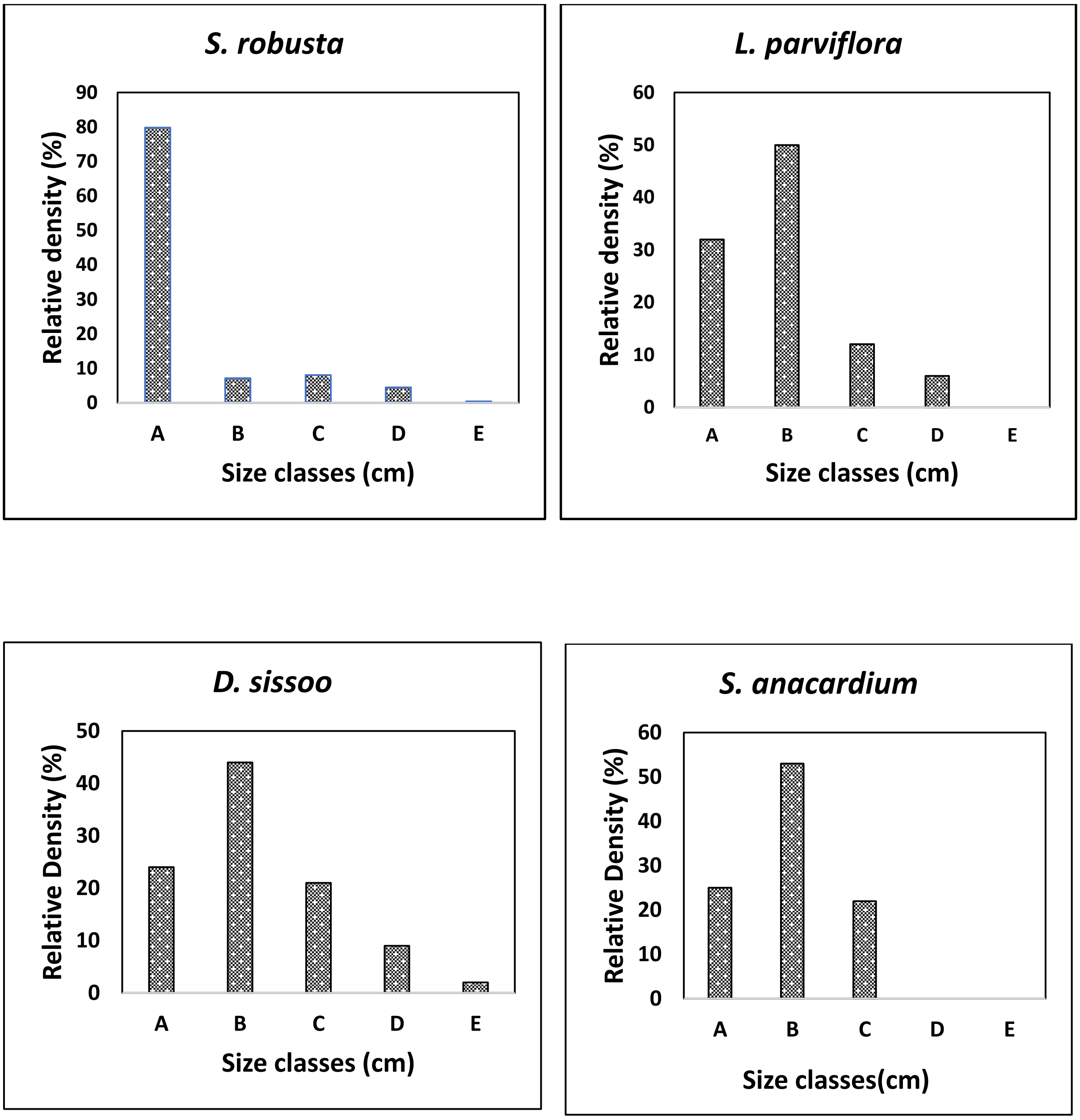


Figure 16: Relative density of dominant tree species in unburnt forest. A=Seedling, B=Sapling, Tree species with different GBH classes (C=31.5-70cm, D=70-110cm, E=>110cm). (Continued…….)

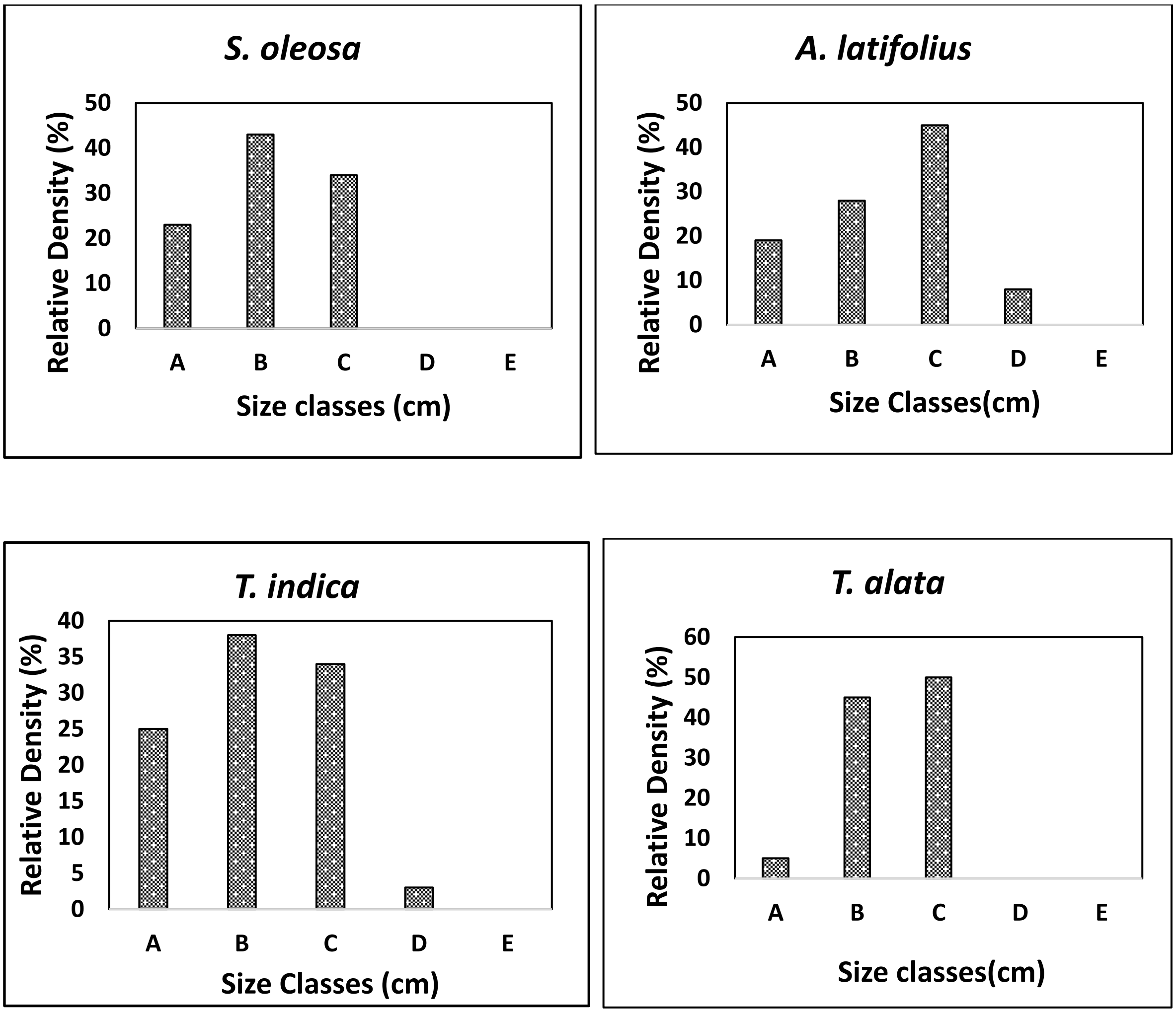


Figure 16: Relative density of dominant tree species in unburnt forest. A=Seedling, B=Sapling, Tree species with different GBH classes (C=31.5-70cm, D=70-110cm, E=>110cm).

Relative density of Seedlings, saplings, and tree species with different GBH of dominant tree species of burnt forest were shown in Figure 17. The relative density of seedlings of *S. robusta* (64.21%), *l. parviflora* (57.34%) and *C. fistula* (85%) were higher followed by relative density of saplings in burnt forest. Similarly relative density of saplings of *S. anacardium* (75%), and *A. latifolia* (70%) were higher. (Figure 18). Relative density of seedlings, saplings, and tree with different grith classes of Species like *A. latifolia* and *C. fistula* were dominant in burnt forest. (Figure 16 and 17). Regeneration status of *A. latifolia* and *C. fistula* were found enhanced after fire.

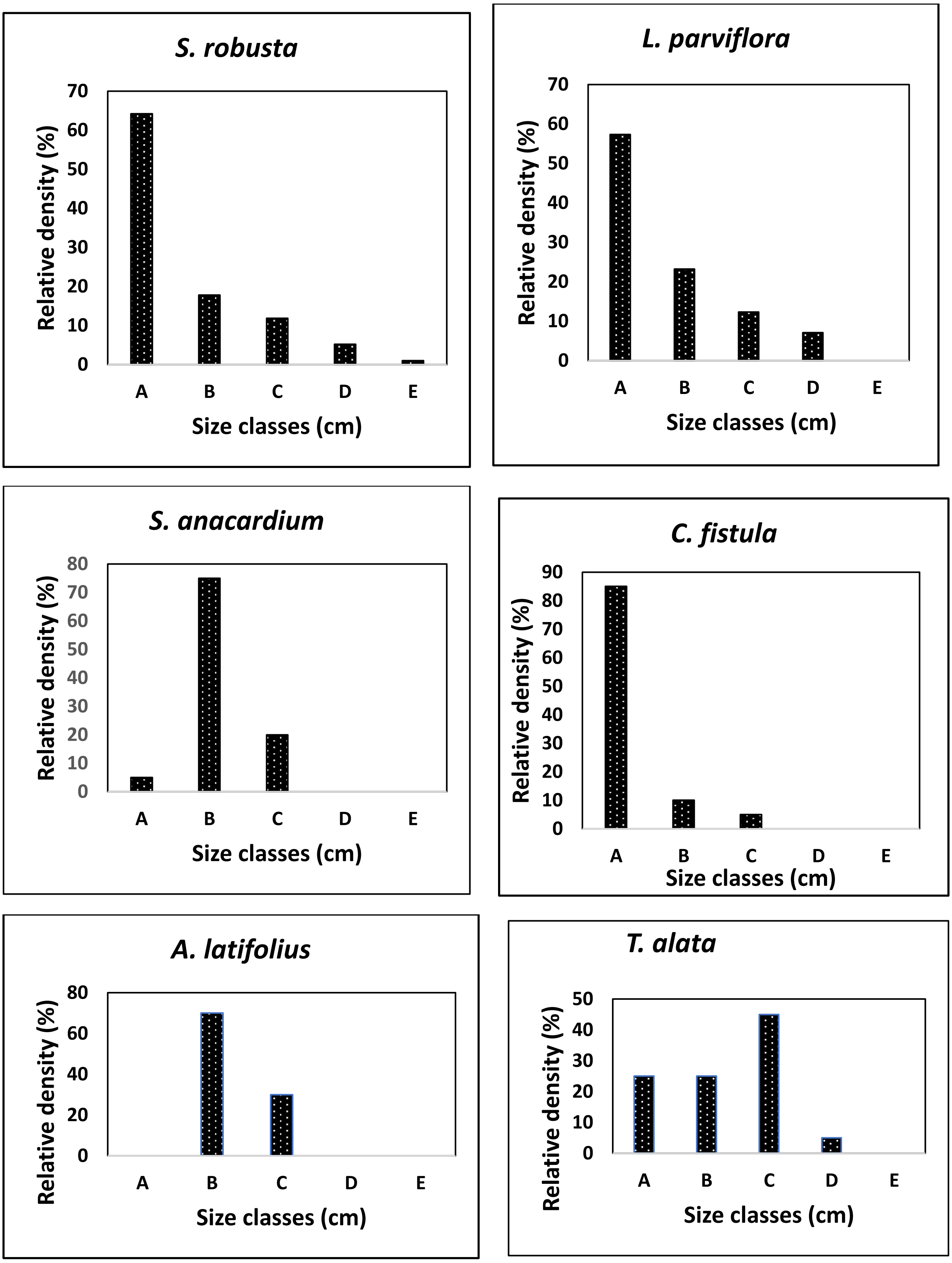


Figure 17: Relative density of dominant tree species in burnt forest. A=Seedling, B=Sapling, Tree species with different GBH classes (C=31.5-70cm, D=70-110cm, E=>110cm).

4.5 Carbon stock

Between two forest, the total tree carbon stocks were 200.38±22.69 t/ha and 233.72±29.63 t/ha in burnt and unburnt forest, respectively (Figure 18). The value of above ground carbon stock (AGC) between burnt and unburnt forest were 161.71±18.09 t/ha and 189.176±23.84 respectively. Also, the below ground carbon stocks (BGC) were 39.67±4.60 t/ha and 45.60±5.79 t/ha in burnt and unburnt forest, respectively (Figure 18).

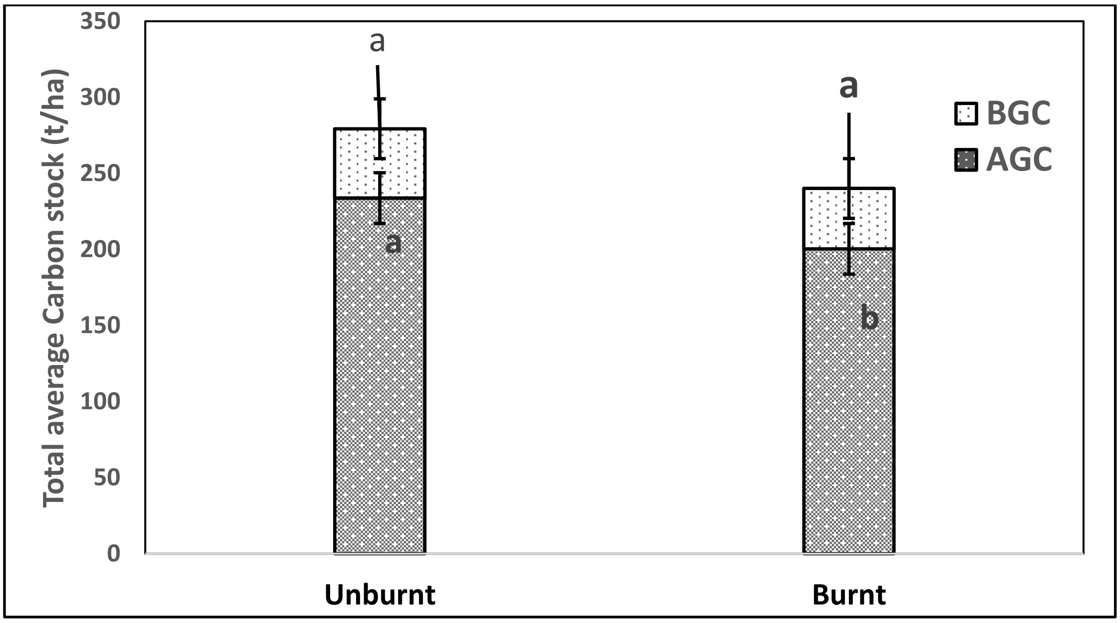


Figure 18: Total average vegetation carbon stock (t/ha) of burnt and unburnt forest. Same letters indicate insignificant difference tested by Duncan multiple range tests. Error bar showed ±SE (N=30).

4.5.1 Above Ground Carbon stock of dominant species (t/ha)

The calculated above ground tree carbon (AGC) stocks of dominant tree species between the forest burnt and unburnt were shown in the Figure 19. The average above ground carbon stock of *S. robusta was* calculated as 515.20±51.62 (t/ha) and 344.61±41.01 (t/ha) for unburnt and burnt forest, respectively. Similarly, the average AGC stock of *L. Parviflora* were calculated as 56.13±5.37 (t/ha) and 74.65±6.48 (t/ha) for unburnt and burnt forest, respectively. Also, the average AGC stock of *S. anacardium* were calculated as 28.68±3.66 (t/ha) and 39.83±11.35 (t/ha) for unburnt and burnt forest, respectively. The average AGC stock of *D. sissoo* were calculated as 120.60±17.57 (t/ha) and 123.88±15.13 (t/ha) for unburnt and burnt forest, respectively.

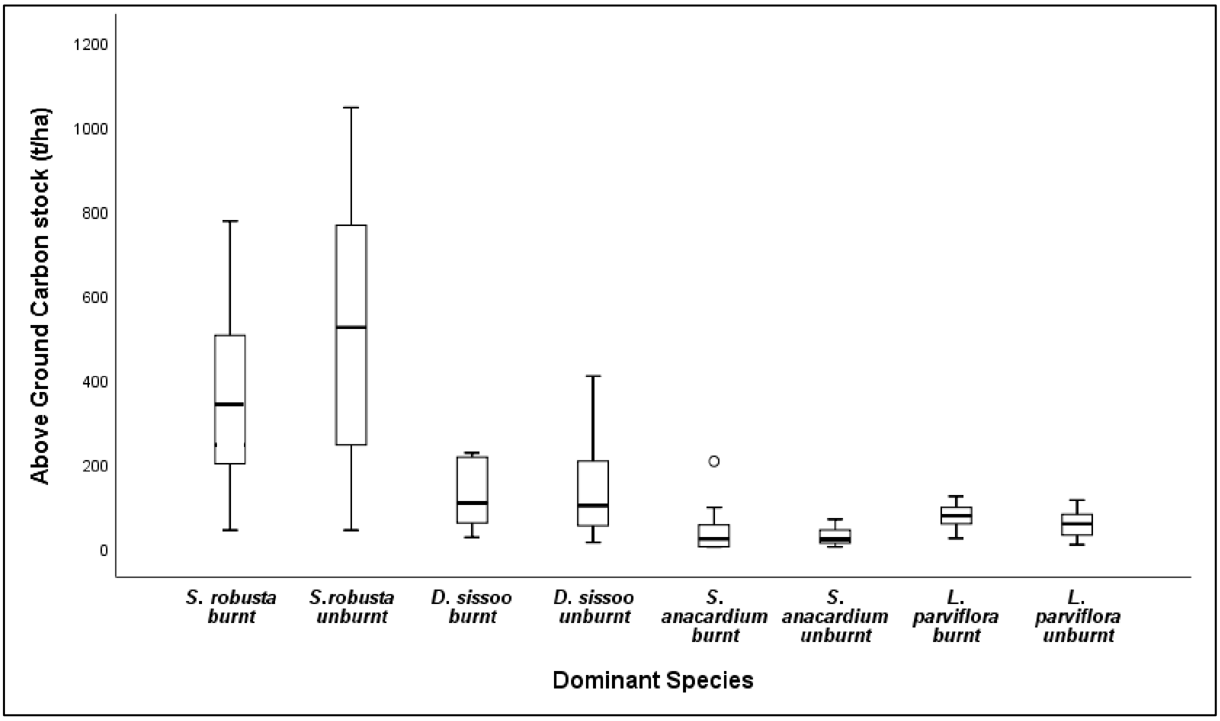


Figure 19: Above ground carbon stock of dominant tree species between burnt and unburnt forest. The box plots show the median, and 25 to 75 percentiles. Whiskers indicate maximum and minimum values.

1.5.2 Below Ground Carbon stock of dominant species

The average BGC stock of *S. robusta was* calculated as 126.08±12.19 (t/ha) and 86.73±10.32 (t/ha) for unburnt and burnt forest, respectively (Figure 20). Similarly, the average BGC stock of *L. parviflora was* calculated as 12.54±1.27 (t/ha) and 16.29±1.49 (t/ha) for unburnt and burnt forest, respectively. Also, the average BGC stock of *S. anacardium was* calculated as 8.72±2.52 (t/ha) and 6.22±0.79 (t/ha) for unburnt and burnt forest, respectively. The average BGC stock of *D. sissoo was* calculated as 28.64±4.06 (t/ha) and 26.54±3.51 (t/ha) for unburnt and burnt forest, respectively.

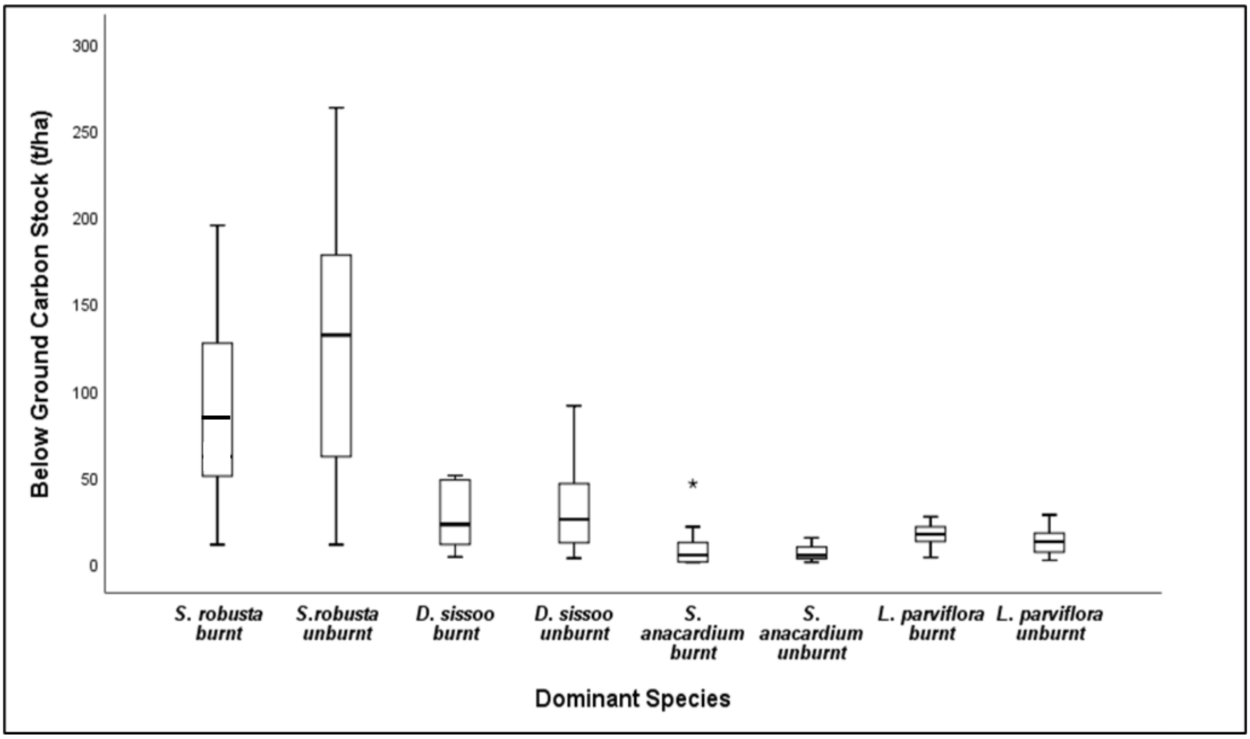


Figure 20: Below ground carbon stock of major dominant tree species between burnt and unburnt forest. Box plots show the median (line inside the box) and upper and lower quartiles (75 %, 25 %) and maximum and minimum values.

Results of independent sample t test to compare AGC stock, BGC stock and total carbon stock of tree species between burnt and unburnt forest were given in table 5. P value for the comparison of AGC *(p= 0.006)*, BGC *(p= 0.013)* and total carbon stock *(p= 0.007)* were highly significant difference between forest. (Table 5)

Table 5: Comparing above ground carbon stock, below ground carbon stock and total carbon stock of dominant tree species between burnt and unburnt forest (t- test analysis)

Parameters	**Mean value in Unburnt**	**Mean Value in Burnt**	**T value**	**Significance**
Above Ground Carbon Stock	189.176±23.84 (t/ha)	161.71±18.09(t/ha)	0.899	0.006
Below Ground Carbon stock	45.60±5.79 (t/ha)	39.67±4.60 (t/ha)	0.920	0.013
Total Carbon stock	233.72±29.63 (t/ha)	200.38±22.69(t/ha)	0.876	0.007

4.6 Soil pH

Mean soil pH of burnt forest was ranges from (6.02 to 6.13) and unburnt forest ranges from (5.05 to 5.53) Figure 21 and Appendix IV. Highest value (6.13) measured in burnt forest at topsoil (0-2cm). Lowest values 5.05 measured in unburnt forest at the depths of 0-2cm (Appendix VI). Independent t test analysis of soil pH showed insignificant difference ($p=0.726$) between forest (Appendix VI). One-way ANOVA analysis of soil pH between burnt and unburnt forest were insignificantly different. But, between various soil depths of the burnt and unburnt forest were significantly difference (Figure 21, Appendix VI).

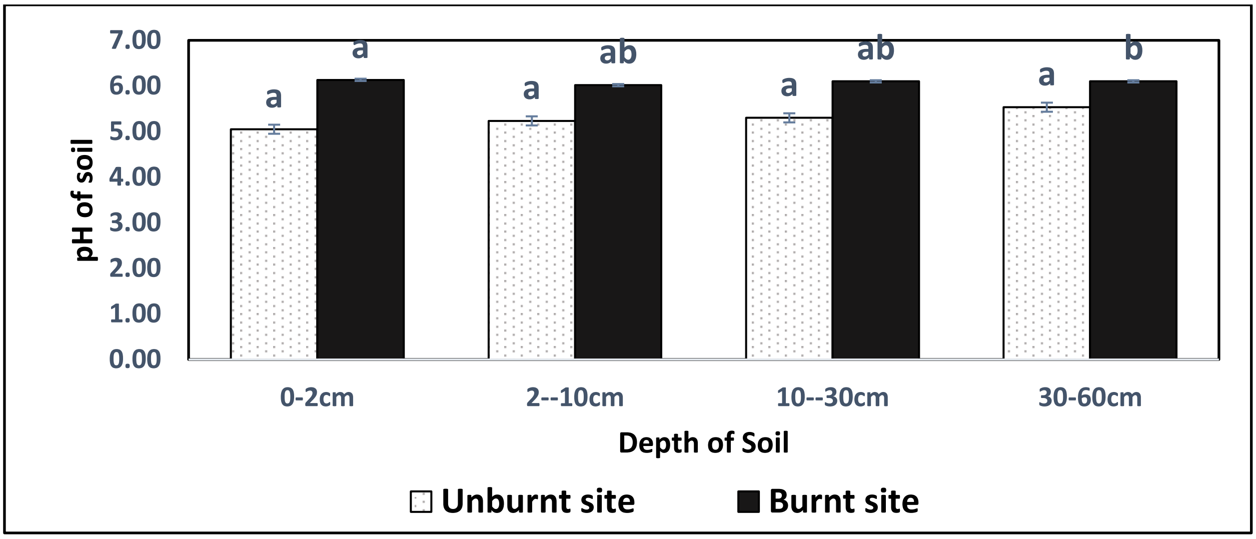


Figure 21: pH of soil at different soil depth of burnt and unburnt forest. Different letter showed significant different between soil depths tested by Duncan multiple range test at *($P<0.05$)*. Error bar showed ±SE (N=12).

4.7 Soil bulk Density

There was increase in the bulk density with the increasing soil depths. Mean minimum value (0.85±0.03g/cm^3) was calculated in topsoil of burnt forest. Similarly, mean maximum value (1.05±0.01g/cm^3) was calculated in unburnt forest at the depths of 30 cm above, followed by unburnt forest (1.04±0.01g/cm^3) at the depths of 10-30cm (Figure 22). Independent t test analysis of bulk density showed significant difference ($P=0.000$) between forest (Apendix VI). were significant difference, Similarly, One-way ANOVA analysis of BD between burnt and unburnt forest across various soil depths were significantly difference (Figure 22, Appendix VI).

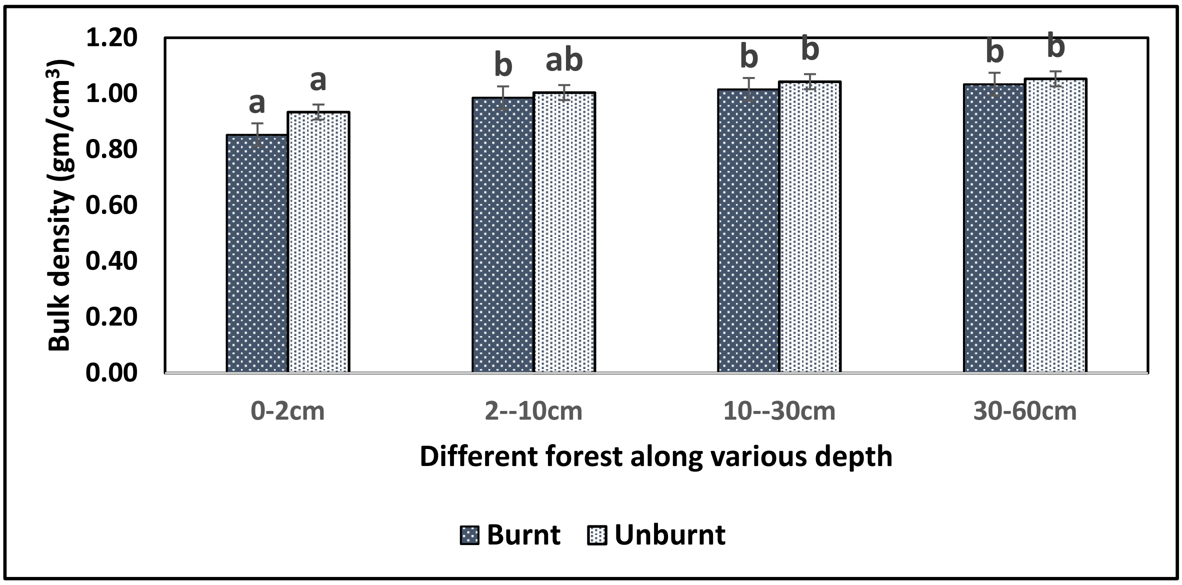


Figure 22: Bulk density between burnt and unburnt forest at various depth. Different letter showed highly significantly different between soil depths tested by Duncan multiple range test. at *(P<0.05)*. Error bar showed ±SE (N=12).

4.8 Soil Charcoal stock

Total weight of soil charcoal stock (%) was decreased with increasing depths of the soil of all six-soil sample of burnt forest (Figure 23). Total soil charcoal stock (SCS) was higher value values (35%) in the topsoil and lower (2%) in >30cm depth were recorded (Figure 23). There were no charcoals reported in all depths of unburnt forest (data not shown).

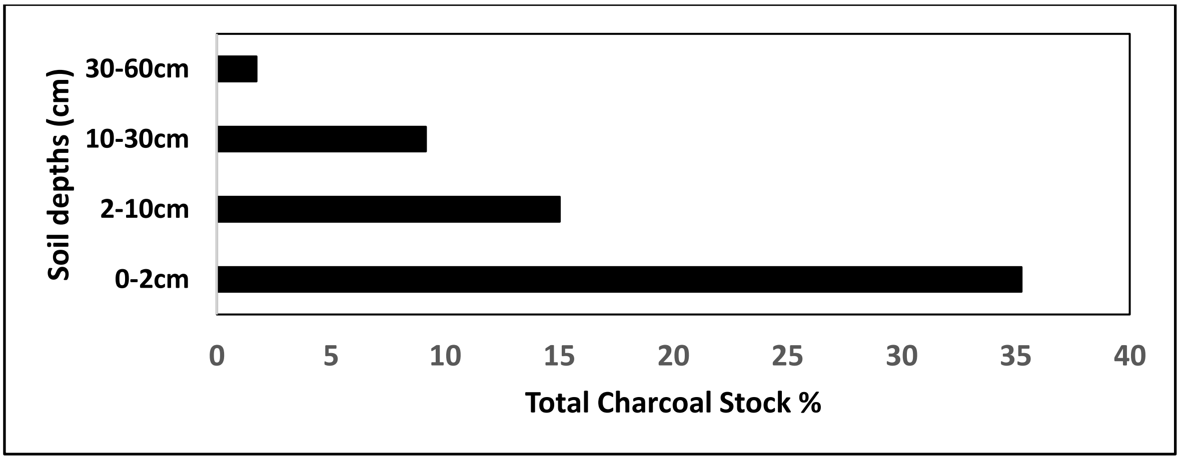


Figure 23: Total weight of soil charcoal stock (%) of different depths of all six burnt forest.

4.9 Soil Organic Carbon (t/ha)

The measurements showed that fire increased the amount of soil organic carbon compared to unburnt forest, (Figure 24). However, compared with SOC in different depths, SOC stock was gently decreased with increasing soil depths except soil with depth 2-10cm of burnt forest. The SOC was highest (251.90±10.73t/ha) at 2-10cm of burnt forest followed by (226.52±8.53t/ha) at 0-2cm depths of burnt forest. Similarly, the SOC was lowest (56.64±6.84t/ha) at unburnt forest of soil depth 30 cm above (Figure 24). Independent t test analysis of SOC showed significant difference (*P=0.000*) between forest (Appendix VI). One-way ANOVA analysis of SOC between burnt forest and unburnt forest were significant difference, Similarly, between various soil depths of the burnt and unburnt forest were insignificantly difference (Figure 24, Appendix VI).

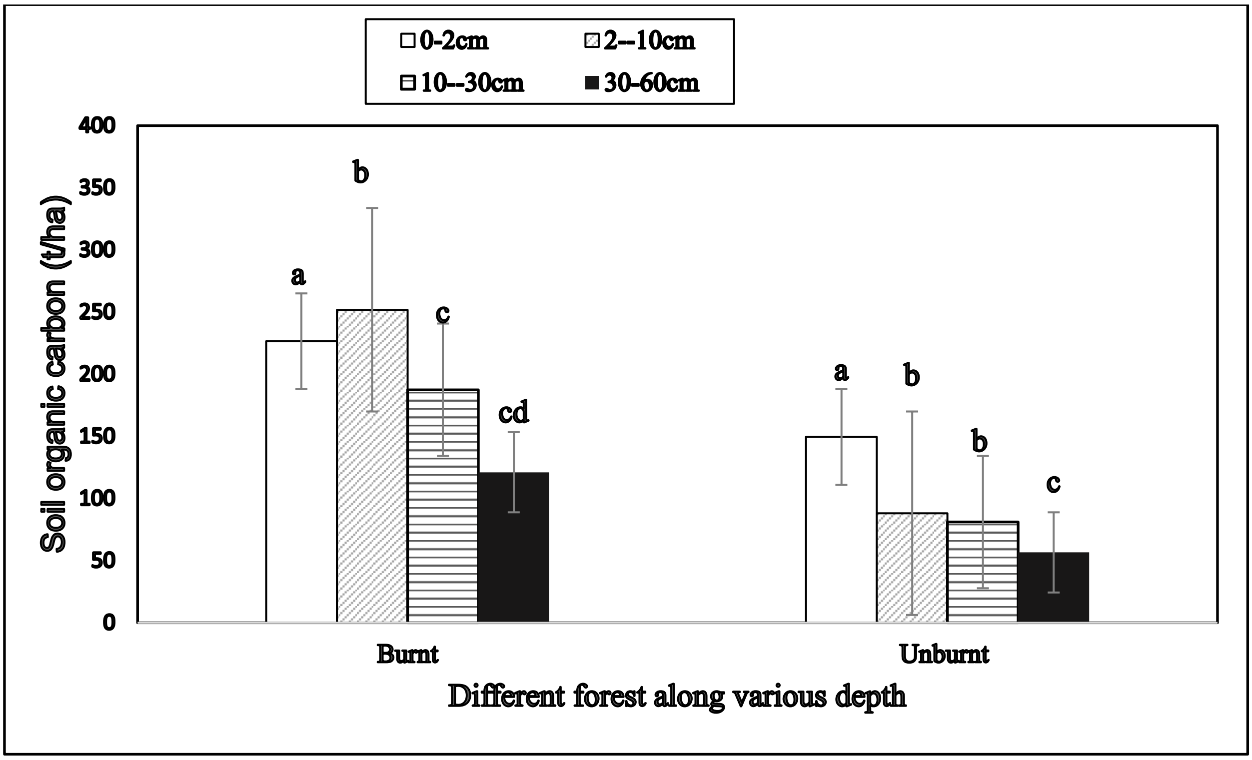


Figure 24: Mean total SOC from all forest and soil depths. Different letter indicate significant difference between soil depths tested by Duncan multiple range test at *($p<0.05$)*. Error bar showed ±SE (N=12).

CHAPTER 5: DISCUSSION

5.1. Species composition

The role of fire in maintaining species diversity is probably the most recent development in the understanding of ecosystems events like changes in species composition, successional stages, forest types, regeneration status (Rawat and Agarwal., 2015). Fire has long been considered as one of the main factors affecting (beneficially or injuriously) vegetation depending on the forest type and local climatic situation as well as anthropogenic disturbances.

In the present study, Sal Forest has dominant species like *S. robusta, L. parviflora* with tree associates like *D. sissoo, T. alata, A. latifolia, F. semicordata*. Similarly, in shrubs layer species like *T. purpurea, E. sessile, J. dispermum, C. occidentalis, P. bengalensis, B. vahlii*, etc. were prominently found. Also, *I. cylindrica, E. pulchellum, C. tora, E. tenella, C. assimile, B. lacera* etc. were in herb layer reported from both burnt and unburnt forest.

In burnt forest, *S. robusta, L. parviflora, S. anacardium, C. fistula* were dominant, with *T. alata, C. arborea, D. sissoo,* as associates' species in tree layer. Similarly, T. *purpurea, C. oppsitifolia, I. cylindrica, E. pulchellum*. etc were dominant in herb and shrub layer. Bakshi, (1957), also reported that Sal tree did not change significantly after fire compared to other fire intolerant species (*T. grandis, M. philippensis, F. semicordata, M. azederach* and *A. latifolius*). Most studies indicated that Sal trees can resist fire once they have passed the sapling stage (Bakshi 1957; Kumar and Thakur, 2008). Controlled burning or grazing is necessary to maintain pure Sal Forest that prevents the wet Sal Forest from becoming mixed broadleaved forest. (Suman 1984).

Similarly, Domination of vegetation after burning in *L. parviflora* can be corelated to the adaptation characteristics of this species. This species was sunlight demander, drought resistant and fire-resistant species (Orwa *et al.,* 2009). Some shrub species like *Viburnum mullaha, Sarissa opaca, Urena lobata* also attracted additional grazing by reducing the height in fire (Maithani *et al.,* 1986), and together these factors negatively affect vegetation regeneration and successional pathways (Lehmkuhl, 1994).

I. cylindrica, was dominant herbaceous species in the present study of burnt forest. Similar results were obtained by some previous researchers: according to Brook (1989) fire promoted *I. cylindrica,* rapidly colonized in disturbed forest. Seth (1970) also described *I. cylindrica* dominated grasslands form a fire climax community. *I. cylindrica* species have high root-rhizome: shoot ratio provides a source of dry matter for regeneration after cutting or burning (Ramakrishnan *et al.,* 1983).

Climatic conditions of local area affect the annual fire behavior in *S. robusta* forest of Chure range of Butwal along with various climatic agents like temperature, relative humidity, and precipitation affect fuel moisture on the forest floor. The long, hot, and dry summers that last from February until May convert the Sal under-story into a continuous sheet of dry and highly inflammable fuel mass (IFFN, 2005). The rainfall during the dry season is very low and range between 10.5 to 28.5 mm (Figure 3). During the dry season the temperature fluctuates from 11.3°C to 36.5°C increasing the risk of ignition to high levels.

In unburnt forest of present study, dominant species in tree layer were *S. robusta*, *A. latifolia, T. alata, D. sissooo* with *F. semicordata, T. grandis, M. azedarach, M. philippensis* etc. as associates. *T. purpurea, E. sessile, B. vahlii, B. platyphylla, D. filix;mas, T. Pilosa* etc. were dominant in shrub and herb layer. Species like *B. platyphylla* was dominating the herb layer as it mostly found in moist and damp places ((Maithani *et al.*, 1986). Similarly in unburnt forest, *B. platyphylla* was dominating the herb layer as it mostly found in moist and damp places. In all these instances, fire increased the number of herbs and shrubs, especially palatable plants.

5.2. Diversity pattern

In the tree, sapling and seedling layer, results of diversity parameters revealed that Shannon index value, Equitability, and species richness higher in unburnt forest, under the tree layer vegetation. In the present study burnt forest showed lowest diversity compared to unburnt forest. This showed that after forest fire the species diversity was decreased. Similar findings were reported by Kafle (2006) in tropical deciduous forest in Thailand, Collins and Stephens (2010) in mixed Conifers forest of California and Harner and Harper (1976) in Juniper forest of Mexico Contrast results were obtained in National forest land of California by Safford and Stevens (2014), and in yellow Pine Forest of California by Shive *et al*., (2018).

Present data were comparable with the several studies which ranged from 1.9 to 4.0 (Reddy *et al*., 2008). Slightly different data were reported by various authors; diversity parameters in the tropical dry forest communities of the Vindhayan region had ranges of 0.68 to 2.02 (Shannon index), 0.75 to 1.75 (equitability) (Jha and Singh 1990). Pandey (1992) studied in Sal and teak forests of Madhya Pradesh found species diversity varying from 0.32 to 3.76 and concentration of dominance from 0.07 to 0.63 at different habitation in Madhya Pradesh. The results obtained by Pandey (1992) also supports the findings made by Naidu and Sribasuki (1994), they reported young plants were more badly affected by fires than mature one. At the present study burnt forest have less diversity. These results supports the findings of Kodandapani (2001), who also reported the lesser diversity in the burnt forest occurring dry deciduous forest leading to nonspecific forests, frequent fires could also lead to stand where most trees are even aged. Contrasting results were obtained by Kafle (2006) which explains the protected area supports greater number of ground flora species. However, the burnt area contained higher species diversity and evenness indices than the protected area in total. In shrub layer the Shannon index value, equitability, and species richness higher in burnt forest whereas in herb layer, these diversity parameters are higher in unburnt forest at present study. The decline of species richness in time after forest fire disturbance might be caused primarily by the elimination of some early species which were over topped and shaded out by rapidly growing woody plants, especially resprouts (Miller, 2000). Concerning the species richness, a high number of species results with in higher community stability or rather resilience (Guo, 2001). This wide diversity takes the advantage of heterogeneity and increases their diversity. The level of heterogeneity created, obliviously would depend on the height and architecture of the woody species (Pandey *et al.*, 2008). The fire affected areas support more herbaceous vegetation as compared to unburnt area because of reduction in competition for space and resources. Keith *et al.,* (2010) have reported the similar results and stated that the herb species increase immediately after fire because of a general reduction in the tree cover that brings more light to the soil. It suggested that the total diversity of *S. robusta* forest of the Butwal has mainly positively influenced by forest fire.

5.3. Height, Density and Basal area

The smallest sized individuals are mostly affected by fire, since they have a thinner bark than the better developed plants, lack underground reserve organs, and are exposed to higher temperatures in the zone where the fire is fueled most intensely by available dry biomass (Miranda *et al.*, 2007). Thus, individual size can be a key factor for fire survival.

The present study suggests that woody vegetation on the burnt forest was being transformed into a lower woodland community scattered with a low density of large trees but high density of short and small plants, together with significant Basal area changes in this study, the burnt forest had a mean height and DBH of woody stems shorter than that of the unburnt forest, suggesting negative effects of repeated burning including top kill of woody plants. Similar findings were obtained by Enslin *et al.*, (2000) ; Gandiwa and Kativu, (2009). Although the burnt and unburnt forest had almost the same number of woody species, these species were basically different, and fewer in the burnt forest. In this study, various species like *T. grandis, M. philippensis* and *F. semicordata* were not observed in burnt forest. Similarly, the density and abundance of species like *M. azederach* and *A. latifolius* found decreasing significantly after fire whereas species like *L. parviflora, S. oleosa* and *S. anacardium* showed increase in the frequency and density with the forest fire. Thus, this fact showed that some species were lost to burning and replaced by some relatively fire tolerant species (*L. parviflora, S. oleosa* and *S. anacardium*).

The fire tolerant species are adapted to burning by prolific production of coppices hence the higher values of multi stemming in burnt forest as compared to the unburnt forest. In addition, the present study showed significant differences in height of between burnt and unburnt forest. The results support findings of Trapnell (1959), Strang (1974), Gandiwa (2006) and Gandiwa *et al*, (2011). However, the results, contradict those of Tafangenyasha (2001), which showed that burnt forest have relatively taller woody plants than unburnt forest, probably due to differences in woody species and soil conditions in the study areas. It has been suggested that vegetation respond variably to long-term burning (Higgins *et al*., 2007).

The results of this study seem to suggest that fire had little effect on density of stems between the burnt and unburnt forest. However, some species like *S. robusta, T. grandis, M. philippensis, F. semicordata, L. parviflora, S. oleosa, S. anacardium, M. azederach* and *A. latifolius,* fire influenced the tree density. Similar findings were recorded by Strang (1974), Trollope (1982), Van Wyk (1971) and Tafangenyasha (2001). In addition, Higgins *et al*. (2007)

found that fire did not influence tree density but influenced the size structure and biomass of tree populations in Savanna of Africa. Prior *et al.* (2009) suggests that an increase in the frequency or severity of fires is likely to change the tree density and basal area of savannas in North Australia. Another factor that could affect the impact of fires on the density of trees is tree clustering. Groen *et al.,* (2008) found that clustering reduces the damaging effect of fire on trees in African savannas. Thus, repeated fires may have reduced densities of fire intolerant plants and failed to do so for fire tolerant species. The number of stems per plant in present study was not statistically significant different between the burnt and unburnt forest.

There was higher number of stems per plant on the burnt forest as compared to the unburnt forest at present study, might be due to the adaptation of plants to withstand fires possibly by having underground unaffected portion with food resources and regeneration parts. This trend in the number of stems per plant was support also by findings of San Jose and Farinas (1983), Scholes and Walker (1993) and Enslin *et al.,* (2000) who recorded the greatest number of stems per plant on the burnt forest as compared to the unburnt forest. Tchie and Gakahn (1989) mentioned that the number of stems per plant is species specific and in this present study, the same species, which had higher number of stems per plant, were found on both the burnt and unburnt forest, thus suggesting the in-significance difference between the burnt and unburnt forest.

It has been reported that fires can change plant communities by reducing dominance of some plants while enhancing the abundance of others (Pyke *et al.*, 2010). However, in present study species like *T. grandis, M. philippensis* and *F. semicordata* displayed trend of woody plant species loss and the species like *L. parviflora, S. oleosa and S. anacardium* were dominant in plant community after fire.

Although the unburnt forest had slightly more species than the burnt forest, the differences in number of species between the two forests were not significant. Elsewhere, Enslin *et al.,* (2000) and Govender *et al.,* (2006) found that changes in woody vegetation after burning did not involve a marked decrease in species composition. However, woody species were shown to be generally negatively affected by frequent fires. (Heinl,2005). Similarly, O'Connor (1985) suggests that reduced species diversity has been recorded in several fire experiments, mostly in mesic savannas. At present study the proportion of dead stems was found to be significantly different between the burnt and unburnt forest. The presence of dead stems on the unburnt forest might be due to other contributory factors such as drought, wind, insects, disease and/or age. Since, both study forest was in the same environmental setup, the results also indicate that the dry season annual hot fires caused additional mortality on plants in the present study, particularly in the burnt forest. A significant difference was recorded in basal areas between the burnt and unburnt forest. Woody plants on the unburnt forest were significantly larger, i.e., had higher basal areas and heights, as compared to those on the burnt forest. The dry season annual hot fires probably produced more extreme top kill, resulting in basal coppicing, i.e., the killing above ground surface parts of plants and generation of smaller plants with narrower basal areas, on the burnt forest (Enslin *et al.*, 2000).

5.4. Regeneration Status

Forest fire effects on patterns of species diversity and regeneration in tropical and subtropical forests (Jhariya *et al.,* 2012). The presence of good regeneration potential shows suitability of a species to the environment. The density values of seedlings and saplings were considered as regeneration potential of the species (Joshi, 1990). In the present study significant differences in the relative density of seedlings, trees and total population were observed among burnt and unburnt forest. The unburnt forest supported higher seedlings and tree density. Although there were no environmental differences (soil, topography, and climate) among the unburnt and burnt forest, the unburnt forest supported higher seedlings and tree density. Kodandapani *et al*., (2008) have also reported the similar trend while comparing the spatial, temporal, and ecological characteristics (density, DBH, Soil properties) of forest fires in the dry tropical ecosystem in the Western Ghats. Higher values of seedling density on burnt forest as compared to unburnt forest was also reported by Joshi (1990). According to Kodandapani (2001) fire enhances the productivity of ecosystems by releasing chemicals and nutrients locked up in old herbages which ultimately helped the regeneration of seedlings after forest fire.

In this study, the hump in the middle size classes may indicate comparatively fast growth or less mortality in individuals once they successfully cross the sapling layer and attain the first tree size class (C), as exemplified by *A. latifolius, T. alata* in unburnt forest, and *S. anacardium* and *T. alata* in burnt forest. West *et al.,* (1981) also reported similar pattern of regeneration which explained heavy exploitation of older individuals and greater mortality among young individuals due to repeated forest fires.

The seedling of species *S. robusta* were dominant, followed by saplings class (B) and small trees (C) in both unburnt and burnt forest whereas dominant seedlings were exemplified by *L. Parviflora* and *C. fistula* in burnt forest only in the present study. Compared to present study, Saha (2002) also reported similar regeneration status of *S. robusta* in Central India. Current result could be correlated to the effects of fire on juvenile die back of *S. robusta.* In the pre-monsoon period dying back of the Sal seedlings were observed to take place from March onwards (West *et al.,* 1981). Moisture and root competition at the peak of the growing season are indicated to be the limiting factors responsible for the dying hack of the whippy Sal seedlings. During long drought and forest fire, Sal roots remains under the ground with minimum effects of fire and regeneration continues due to its die back nature (West *et al.,* 1981). Several juveniles escaped from fire did not undergo stem die back, they exhibit height and growth patterns like unburnt seedlings (Saha, 2002). The regeneration of Sal occurs through fertile seeds, coppicing or sprouting from root suckers (Gautam *et al.* 2006). In current study GBH of *S. robusta* tree from 60 to 90cm were recorded higher in burnt forest compared to unburnt. Similar results were observed by Yadav *et al.*, (1986), Sal trees with middle-grith class (80-90cm) at breast height as the best size to produce good-quality fertile seeds.

In the present study, domination of seedlings after burning in *L. Parviflora* and *C. fistula* could be correlated to the study by Orwa *et al.*, (2009). They also observed these plant species (*L. Parviflora* and *C. fistula)* to be well adapted to fire. These species were sunlight demanding, drought resistant, non-browsable and fire-resistant species (Orwa *et al*., 2009). Similarly, no seedlings of *A. latifolius* in burnt forest were recorded which contrasts with the findings of Kumar *et al.,* (2008) as he reported *A. latifolius* seedlings were abundantly grew in burnt forest.

5.5. Tree carbon stock

Carbon sequestration is a biological process, in which photosynthetic organisms especially plants, plays a vital role to balance atmospheric CO_2. However, the capacity of capturing and storing carbon varies according to the nature of the plants. The observations of Negi *et al.,* (2003) revealed that the wood, which constitutes maximum portion of total biomass, stored maximum amount of carbon. While comparing the different life forms, it was observed that the maximum carbon is stored in the order of conifers > deciduous > evergreen > bamboos. Thus, it can be said that the conifers can store largest amount of carbon and was more efficient in carbon sequestration (Negi *et al.,* 2003).

It was observed that maximum mean value of C stock was calculated in unburnt forest. Minimum mean value observed in burnt forest. Highest C value in unburnt forest could be because of the higher value of height and DBH of *S. robusta, L. parviflora* in this forest than burnt forest. In burnt forest, fungal infection appears in the wound caused by fire ultimately stunted growth occur in *S. robusta species.* Similar results were observed by Bakshi (1957) in

Kashmir, he reported older *S. robusta* trees were resistant to fire but younger trees become unhealthy due to fungi infection in the wound from fire. There was significant difference of total mean carbon stocks (AGC+BGC) in *S robusta* forest of burnt and unburnt forest were observed in the present study. Similar results were obtained in *P. roxburghii* forest of Langtang National Park, Central Nepal (Aryal *et al*, 2017) in deciduous forest, Champadevi Community Forest of Central Nepal (Panthi, 2011) and sub-tropical forest of Garhwal Himalaya (Kumar, 2010). By contrast weak or negligible effect of fire in carbon stock in forest of New Zealand was observed by (Gordon *et al*., 2018). Aryal *et al*., (2017) studied impact of surface fire on Carbon sequestration of *P. roxburghii* forest in Langtang National Park, Nepal. They measured total carbon stock and CO_2 mitigation of unburned and burned forest of different intensities namely: high frequency and high intensity (HFHI), high frequency and moderate intensity (HFMI), high frequency and low intensity (HFLI). They found, total CO_2 mitigation in HFMI (3346.27) forest were highest than others.

In present study the average total carbon stock (AGC+BGC) of species like *D. sissoo, S. anacardium* and *L. parviflora* were higher in burnt forest whereas average carbon stock *of S. robusta* species were lower in burnt forest compared to unburnt forest. Bakshi (1957) reported that older trees of *S. robusta* were resistant to fire, but sal trees between 15- and 35-years age were infected due to fire causing the wounds which ultimately become prone to heart rot due to fungi. The species like *D. sissoo, S. anacardium* and *L. parviflora* had several fire-adaptive characters that were able to survive on low intensity of surface fires (Orwa *et al*. 2009; Semwal and Mehta, 1996). The overall results of tree carbon stock suggested that fire can changes the total carbon stock in the forest.

5.6. Soil pH

Soil pH in different forest types were significantly differs generally acidic in pine forests (Aryal *et al*., 2016/18; Shrestha 1992) also, Sal Forest of terai region of Nepal (Paudel *et, al.*, 2003). In the present study high to low pH value of the soil was recorded in burnt and unburnt forest respectively. It was observed that in *S. robusta* forest soil pH increased after burnt. The result suggested that soil pH was less significant between the burnt and unburnt forest whereas it was significant across the soil depth Soil pH was slightly higher in layer 0-2cm and above 30cm soil depth.

Burning of accumulated litter, fresh plants parts or slash increases soil nutrients. Soil pH increased towards alkaline levels after burning, supporting the observation that burning forest residue has a liming effect on the soil. These results supported previous work done by Iglesias (2010) in pine forest of southern France, reported that pH of soil was not altered after the fire while Ulery *et al.,* (1995) in pine and chapparal and De Marco *et al*., (2004) in Mediterranean forest of southern Italy, reported increase in pH of soil due to fire in forest as litter were converted into ash. The result suggested that soil pH increases after fire in *S. robusta* forest of Chure region Butwal.

5.7. Bulk density

Bulk density of soil is highly correlated to Soil organic carbon (Leifeld *et al.,* 2004) and depends on several factors such as compression, combination, and amount of Soil Organic Carbon present in the soil. The low value of BD explains less compacted soil with high pore space compared to other soil depths suitable for vegetation growth, however, high BD value make the soil unfit for vegetation growth. Soil BD less than 1.5 g/cm^3 has an optimum movement of air and water for similar soil types and is good soil for plant growth (Hunt and Gilkes 1992). In our present study BD significantly differed between burnt and unburnt forest suggesting that it remains altered after fire, similar with the observation by several researchers that burning increases bulk density and reduces moisture content (Hubbert *et al.,* 2006; Boerner *et al.,* 2009; Xue *et al.,* 2014). It was observed that mean minimum value (0.85±0.03g/cm^3) was calculated in topsoil of burnt forest. Similarly, at the depths of 30 cm above mean maximum value (1.05±0.01g/cm^3) was calculated in unburnt forest, followed by unburnt forest (1.04±0.01g/cm^3) at the depths of 10-30cm. There were significantly differences between BD at different soil depths i.e., low values calculated even in depths (30-60cm). The possible reasons of low BD throughout the soil depth might be due to decomposition of biomass, less anthropogenic disturbances, and the remains of burnt product including charcoal, ashes and leaching of organic content up to depths of 60cm.

5.8. Soil organic carbon

The storage of carbon under the ground is called soil carbon. In fact, its amount depends on the above ground input received from leaf litter and on the decomposition of fine roots below ground (Rasse *et al.*, 2006). The present study showed that fire increased the amount of soil organic carbon compared to unburnt forest. However, compared with SOC in different depths, SOC stock was slightly decreased with increasing soil depths except 2-10cm of burnt forest. The findings of this study suggested that the SOC stock significantly increased after fire was similar with the results from studies conducted by other researchers (Kara and Bolat, 2009: Black Pine plantation forest in Turkey; Pardini *et al.,* 2004: Brushland, Mediterranean environments in NE Spain). However, contrasting results; decreased SOC after fire had also been reported (Sitlhou and Singh 2015: Subtropical Forest in Manipur, Kumar *et al.*, 2013: in *P. roxburghii* forest in Gharwal Himalaya, India). The effect of fire on SOC abundance in an ecosystem depends on the type and frequency of fire (Zhao *et al.*, 2012), time and season of the burn (Zhao *et al.,* 2012), the availability of fuel mass, vegetation type, topography, and post fire climate conditions of the forest (Semwal and Mehta, 1996). SOC stock was gradually decreased with increasing soil depths (Awasthi *et al.*, 2005; Smith *et al.*, 2000).

These results showed highest SOC stock at burnt forest in soil layer 2-10cm, however, the amount was significantly different among the four soil layer forest in burnt forest. Ansley *et al.*, (2006) also reported that the increase SOC was largely due to increased aboveground production (biomass) and very fine roots of grasses that may have passed through sieve in fire treatment soils. The higher values of SOC in soil layer 2-10cm was probably due to the topography of the forest (gentle slope) which retards surface washed off charcoal and other burnt plant parts and enhance leaching. Similarly, soil depths >10 cm in fired forest with high SOC value suggested continuous leaching of char after annual seasonal fire than in unburnt forest. Awasthi *et al.,* (2005) and Smith *et al*. (2000) also reported low SOC at the top layer of steep slopes and high deposition in deep layers up to 15 cm due to leaching. The high SOC value in burnt forest probably due to conversion of plants parts like leaves, branches, flower, fruit etc. to charcoal and ashes. This might be increased SOC in different soil depths after leaching.

5.9 Soil charcoal Stock

Presence of charcoal particles along the soil vertical profile across soil depths indicated fire disturbances in forest. In present study, the total percentage of charcoal stock in four different soil layers i.e., 0-2, 2-10, 10-30 and above 30cm depths showed gradual decrease from top to downwards. Total soil charcoal stock (SCS) was higher value (35%) in the topsoil and lower (2%) in >30cm depth were recorded. Amount of charcoal in soil profile was greatest near the surface and decreased gradually with increased depths like the findings reported in *Pinus roxburghii* forest of Langtang National Park by Aryal et al (2016/18), in mixed Hardwood Forest of U.S. Hart et al., 2008) and in Amazonian seasonal forest in Brazil. Turcios *et al*., (2015) Similar results were also obtained by Suman (1984) that charcoal leaching was one of the excellent examples of long-term C pool and past fire condition. Surface charcoal can be washed away by monsoon but charcoal in the soil depths were deposited in long term. Similar types of findings were recorded in previous works including charcoal deposition (Horn and Underwood, 2014) and relationship between fire, climate, and human activity to document past fires (Berg and Anderson, 2006). There were no charcoals reported in all depths of unburnt forest. However, the negligible amount of charcoal accumulation in unburnt forest recorded might be due to possible by wind, water, landslides etc. from surrounding burnt areas ecosystems. The expected highest value of SCS in burnt forest suggests possibility i.e. due to gentle slope which supports accumulation on the top layer as well as leaching in course of time which retardates surface runoff.

CHAPTER 6: CONCLUSION AND RECOMMENDATION

6.1 Conclusion

- Altogether 74 species are recorded from the study forest (69 in burnt and 71 in unburnt), among them, *Calotropis gigantea*, *Capillipedium assimile* and *Heliotropium indicum* are uncommon which are recorded only in burnt forest. The uncommon species found in burnt forest may be fire preferring species.

- Higher number of saplings and lower number of seedlings in burnt forest suggested that the fire event has different impacts on different aged groups i.e., seedlings are more sensitive to fire.

- Total tree carbon stock in unburnt forest is comparatively higher than that of burnt forest which is in accordance with the data obtained for density of the species in both forests i.e., higher the tree density higher the carbon stock.

- Among the soil parameters, high soil pH, soil organic carbon (SOC) and soil charcsoal stock (SCS) in burnt forest is positively related with the fire event. More specifically, presence of high amount of SOC and SCS in burnt forest indicates moderate type of fire event which supports existence of plant life.

- Among the plants species the dominant ones like *Shorea* (tree) and *Imperata* (grass) shows higher tolerance potential than others. In case of *Imperata*, the underground root-rhizome supports its perennially even after fire. These events support to conclude that plant are of two types based on their tolerance potential against fire. Some plants have aerial parts that can tolerate fire and others that have underground perennial structures.

6.2Recommendations

Following recommendations have been suggested based on the results of present study:

- In present study, higher number of saplings in burnt forest may suggest that fire has positive role in growth and development of *S. robusta*. However, as the study was not focused to analyze the intensity of past fire, it is recommended for the future researchers to starts research work with complete information of past fire events.

- Similarly, lower number of seedlings of *Shorea* in burnt forest suggested the fire tolerant potential of this species, although artificial fire experiment is recommended to plan for scientific verification of present result.

- As the extensive fire events are always destructive, local peoples should be encouraged by the governmental authorities for the collection of dry matter from forest floor. This minimizes the accumulation of fuel mass on the forest floor ultimately reduces the chance of severe fire.

- The information came out from the study is believed to be useful for the governmental agencies like department of forest resources, President Chure Conservation Project, Butwal Sub-metropolitan, to maintain the *S. robusta* forest of this region.

References

Almendros G., Knicker H., Gonza´lez-Vila, J.F., (2003). Rearrangement of carbon and nitrogen forms in peat after progressive isothermal heating as determined by solid-state 13C- and 15N-NMR spectroscopy, *Organic Geochemistry* 34: 1559–1568.

Aryal B., Bhattarai BP., Pandey M. and Giri A. (2017). Carbon sequestration & CO_2 mitigation in a burned ecosystem of *Pinus roxburghii* forest in Langtang National Park, Nepal. *Tropical Plant Research,* 4: 297–306.

Aryal B., Bhattarai BP., Pandey M and Giri A (2016/18). Impact of forest floor fire on soil carbon sequestration of *Pinus roxburghii* forest in Langtang National Park, Nepal. *Journal of Natural History Museum,* 30:148-163.

Awasthi K.D., Singh B.R. and Sitaula B.K. (2005). Profile carbon and nutrient levels and management effect on soil quality indicators in the Mardi watershed of Nepal. *Acta agriculture Scandinavia, Section B-soil, and Plant,* 55:192-204.

Bajracharya, R.M., R. Lal, and J.M. Kimle. (1998). Soil process and the carbon cycle: long term tillage effect on soil organic carbon distribution in aggregates and primary particles fractions of two Ohio soils. *Soil Process and the carbon cycle, CRC Press, Boca, Raton, FL, USA,* :353-368.

Bakshi, B. K., Arora, K.K., & Singh, S. (1957). Root diseases of shisham (Dalbergia sissoo Roxb.) V. Incidence of diseases in relation to soil pH and soil texture. Indian Forester 83, 555-558.

Balch J.K., Massad, T.J., Brando, P.M., Nepstad, D.C., and Curran, L.M., (2013). Effects of high frequency under story fires on woody plant regeneration in southeastern Amazonian forests. *Philosophical Transactions of The Royal Society: Biological Science* 368 (1619).

Baldocchi, D., (2008). ‘Breathing of the terrestrial biosphere: lessons learned from a global network of carbon dioxide flux measurement systems. *Australian Journal of Botany* 56: 1– 26

Barbour, M.G., Burk, J.H., and W.D. Pitts. (1987). Terrestrial plant ecology. *Benjamin Cummins Publishing Company Menlo Park, CA.*, 2: 191-193.

Beer, C., Reichstein, M., Tomelleri, E., Ciais, P., Jung, M., Carvalhais, N., Rodenbeck, C., Arain, M.A., Baldocchi, D., and Bonan, G.B., (2010). Terrestrial gross carbon dioxide uptake: global distribution and covariation with climate. *Science,* 329: 834.

Berenguer, E., Ferreira, J., Gardner, T. A., Aragão, L. E. O. C., De Camargo, P. B., Cerri, C. E. and Barlow, J. (2014). A large-scale field assessment of carbon stocks in human-modified tropical forests. *Global Change Biology,* 20: 3713-372.

Berg, E.E. and R.S. Anderson (2006). Fire history of white and Lutz spruce forests on the Kenai Peninsula, Alaska, over the last two millennia as determined from soil charcoal. *Forest Ecology and Management*, 227:275–283.

Berger, W. H. and F. L. Parker(1970). Diversity of planktonic foraminifera in deep sea sediments. *Science*, 168: 1345-1347.

Bhandari, B. S., Mehta, J. P. & Semwal, R. L. (2012). Forest fire in Uttarakhand Himalaya: An Overview. *GlimPses of Forestry Research in the Indian Himalayan Region, SPecial Issue on International Year of Forests*, 45(1): 167–175

Bhujel, K.B., Maskey B. and Gautam R. (2017). Fire-induced carbon emissions from tropical mixed broad-leaved forests of the Terai–Siwalik region, central Nepal. *Journal of Forestry Research.* 32(6):2557-2565.

Blake, G.R. and K.H. Hartge. (1986). Bulk density. In: Methods of soil analysis. *ASA and SSSA, Madison, WI.* 1: 363–375.

Boerner RE., Huang J. and Hart SC (2009). Impacts of Fire and Fire Surrogate treatments on forest soil properties: a meta-analytical approach. *Ecological Application,* 19:338–358.

Bond WJ. and Van Wilgen BW (1996). Fire and Plants. *PoPulation and Community Biology* Series 14.

Bond W.J. and Keeley J.E (2005), Fire as a global “herbivore”: The ecology and evolution of flammable ecosystems. *Trends in Ecology and Evolution,* 20: 387 394.

Boyce MS. (1992). Population viability analysis. *Annual Review of Ecology and Systematics,* 23: 481-506.

Brook, R.M. (1989). Review of literature on *Imperata cylindrica* (L.) Rauscher with reference to Southeast Asia. *Tropical Pest Management*, 35:12–25.

Campbell, J., Alberti, G., Martin, J. and Law, B.E., (2008). Carbon dynamics of a ponderosa pine plantation following a thinning treatment in the northern Sierra Nevada. *Forest Ecology Management*, 257: 453–463.

CBS, 2002. Population of Nepal: Village Development Committees/ Municipalities' population census 2001. Ramshah Path, Thapathali Kathmandu, Nepal.

Cerdà, A. and Doerr, S., (2005). Influence of vegetation recovery on soil hydrology and erodibility following fire: an 11-year investigation. *International Journal of Wildland Fire*, 14:423–437.

Certini, G. (2005). Effects of Fire on Properties of Forest Soils: *A Review. Oecologia*, 143: 1-10.

Chaturvedi, A.N. and Khanna L.S. (1982). *Forest Mensuration: International Book Distributors, Dehra Dun, India*.408 pp.

Collins, B. M., and S. L. Stephens. (2010). Stand-replacing patches within a "mixed severity" fire regime: quantitative characterization using recent fires in a long-established natural fire area. *LandscaPe Ecology* 25:927–939.

Denman, K.L., Brasseur, G., Chidthaisong, A., Ciais, P., Cox, P.M., Dickinson, R.E., Hauglustaine, D., Heinze, C., Holland, E., Jacob, D., Lohmann, U., Ramachandran, S., da Silva Dias, P.L., Wofsy, S.C., Zhang, X., (2007). Couplings between changes in the climate system and biogeochemistry. In: Climate change 2007: *The Physical science basis. Contribution of working grouP I to the fourth assessment rePort of the intergovernmental Panel on climate change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.*

De Marco, A., A.E. Gentile, C. Arena and A. De Santo. (2004). Nutrient content and biological activity in burned and unburned soils of a Mediterrabean maquis area of southern Italy. *GeoPhysical Research* Abstract, Vol. 6:14(4)

DFO (2013). *District Forest Office: An introduction*. District Forest office, DFO, Rupandehi.

Druffel, E.R.M. (2004). Comments on the importance of black carbon in the global carbon cycle. *Marine Chemistry* 92:197-200.

Elliott, J. K., M. V. James, and L. H. Ronald (2009). Long-Term Effects of High Intensity Prescribed Fire on Vegetation Dynamics in the Wine Spring Creek Watershed, Western North Carolina, USA. *Fire Ecology*, 5: 66-85.

Enslin B.W., Potgieter A.L.F., Biggs H.C. and Biggs R (2000). Long term effects of fire frequency and season on the woody vegetation dynamics of the Sclerocarya birrea/Acacia nigrescens savanna of the Kruger National Park, *Koedoe, Conservation Biology* 43: 2737.

Fearnside, P.M., P.M.L.A. Graca, and F.J.A. Rodrigues. (2001). Burning of Amazonian Rainforest: burning efficiency and charcoal formation in forest cleared for cattle pasture near Manaus, Brazil. *Forest Ecology and Management*, 146:115-128.

Foereid, B., J.Lehmann, and J.Major.(2011). Modeling black carbon degradation and movement in soil. *Plant and Soil*, 345: 223–236.

Furley P.A., Rees R.M., Ryan C.M. and Saiz, G (2008), Savanna burning and the assessment of long-term fire experiments with reference to Zimbabwe. *Progress in Physical Geography*, 32: 611-634.

Galdos M. V, C.C. Cerri, C.E.P. Cerri, 2009 Soil carbon stocks under burned and unburned sugarcane in Brazil: Geoderma 153; 347–352

Gandiwa, E (2004), The ecological effects of fire on woody plants at the National University of Science and Technology Campus, Zimbabwe, BSc Thesis, National University of Science and Technology, Bulawayo, 61p.

Gandiwa, E (2006), Influence of fire frequency on woody vegetation structure and composition in northern Gonarezhou National Park, Zimbabwe, MSc Thesis, University of Zimbabwe, Harare, 120p.

Gandiwa E. and Kativu S (2009), Influence of fire frequency on Colophospermum mopane and Combretum apiculatum woodland structure and composition in northern Gonarezhou National Park, Zimbabwe, Koedoe, Conservation Biology, 1: 13

Gandiwa E., Chikorowondo G., Zisadza Gandiwa P., and Muvengwi J (2011a), Structure and composition of Androstachys johnsonii woodland across various strata in Gonarezhou National Park, southeast Zimbabwe, *TroPical Conservation Science*, 4: 218-229.

González-Pérez, J.A., González-Vila, F.J., Almendros, G., Knicker, H., (2004). The effect of fire on soil organic matter. *Environment International* 30: 855–870.

Govender N., Trollope W.S.W. and Van Wilgen B.W (2006), The effect of fire season, fire frequency, rainfall and management on fire intensity in savanna vegetation in South Africa, *Journal of APPlied Ecology*, 43: 748-758.

Groen T.A., Van Langevelde F., Van De Vijver C.A.D.M., Govender N. and Prins, H.H.T (2008), Soil clay content and fire frequency affect clustering in trees in South African savannas, *Journal of TroPical Ecology*, 24: 269-279.

Guo Q (2001). Early post-fire succession in California chaparral: Changes in diversity, density, cover and biomass. *Ecology research* ,16: 471-485.

Hansen D. and Jerram F. (2019). Results of mixing calculations, fractionation calculations and partial melting calculations in association with a petrological study of selected basaltic rocks of the Faroe Islands.", Mendeley Data, VI

Harner, R. F., and K. T. Harper. (1976). The role of area, heterogeneity, and favorability in plant species diversity of pinyon-juniper ecosystems. *Ecology* 57: 1254–1263.

Hart, J.L., S.P.Horn and H.D. Grissino-Mayer (2008). Fire history from soil charcoal in a mixed hardwood forest on the Cumberland Plateau. *Journal of the Torrey Botanical Society*. 135: 401–410.

Heinl, M (2005), Fire regime and vegetation response in the Okavango Delta, Botswana, *Dissertation at the Chair of Vegetation Ecology, Technische Universität München, Freising WeihenstePhan, Germany,* 133p.

Higgins S.I., Bond W.J, February E.C., Bronn A., EustonBrown D.I.W., Enslin B., Govender N., Rademan L., O'regan S., Potgieter A.L.F., Scheiter S., Sowry R., and Robertson F (1987), The ecological effects of fire in savannas. *B.H. Walker, (ed.), Determinants of troPical savannas. IUBS MonograPh Series,* 3: 93-140.

Hillel, D. (1982) Introduction to Soil Physics. Academic Press, San Diego.

Horn, S.P., K.H. Orvis, L.M. Kennedy and G.M. Clark, (2000). Prehistoric fires in the highlands of the Dominican Republic evidence from charcoal in soils and sediments. *Caribbean Journal of Science*, 36:10–18.

Horn, S.P. and C.A. Underwood. (2014). Methods for the study of soil charcoal as an indicator of fire and forest History in the Appalachian Region. In:Proceedings of Wildland fire in the Appalachians, *US DePartment of Agriculture Forest Service, Southern Research Station, U.S.A.*, 104-110.

Hoffmann W.A., Adasme R., Haridasan M., De Carvalho M.T., Geiger E.L., Pereira M.A.B., Gotsch S.G., and Franco A.C (2009). Tree top kill, not mortality, governs the dynamics of savanna forest boundaries under frequent fire in central Brazil, *Ecology*, 90: 1326-1337.

Holden SR, and Treseder KK (2013). A meta-analysis of soil microbial biomass responses to forest disturbances. *Forest Microbiol*, 4:163.

Holdo R.M (2007), Elephants, fire, and frost can determine community structure and composition in Kalahari woodlands, *Ecological Applications*, 17: 558-568.

Hubbert KR, Preisler HK, Wohlgemuth PM, Graham RC and Narog MG (2006). Prescribed burning effects on soil physical properties and soil water repellency in a steep chaparral watershed, southern California, USA. *Geoderma* 130: 284–298.

Hunt N. and Gilkes B (1992). Farm monitoring handbook. The University of Western Australia, Newlands, 1–280.

Iglesias, M.T. (2010). Effects of fire frequency on nutrient levels in soils of Aleppo Pine Forest in southern France. *Lazaroa* 31:147-152.

IFFN (2005) https://gfmc.online/iffn/country/country.html.

Ingerson, A.L., (2007). Us forest carbon and climate change. *The Wilderness Society Washington, DC.*

IPCC, 2000.Special report on land use: In: land-use change, and forestry. (*Eds. R.T. Watson, I.R. Noble, B. Bolin, N.H. Ravindranath, D.J. Verardo& D.J. Dokken) IPCC, Cambridge, University Press, Cambridge, UK*, 377.

Jakson, W. J. and P. F. Moore (1998). The role of indigenous use of fire in forest management and conservation. International Seminar on cultivating forests; alternative forest management practices and techniques for community forestry. Regional community forestry training centre, Bangkok, Thailand.

Jhariya MK, Bargali SS, Swamy SL and Kittur B. (2012). Vegetational structure, diversity and fuel load in fire affected areas of tropical dry deciduous forests in Chhattisgarh. *Vegetos,* **25**: 210–224.

Johnson, D. and Curtis, P. (2001). Effects of forest management on soil C and N storage: meta-analysis. *Forest Ecology and Management* 140: 227–238.

Joshi, N.K. (1990). Effect of fire on vegetation composition, forest floor, litter fall, litter decomposition and nutrient return in pure and mixed Sal Forest of Garhwal Himalaya. Ph.D. Thesis, H.N.B. Garhwal University Srinagar. 344.

Kafle, S.K. (2006). Effects of forest fire protection on plant diversity in a tropical deciduous Dipterocarp-Oak Forest, Thailand. Proceedings of the second international symposium on fire economics, planning, and policy: *A Global View*, 465-472.

Kanagaraj R, Wiegand T, Comita LS (2011) Tropical tree species assemblages in topographical habitats change in time and with life stage. *J Ecol* 99 : 1441 –52.

Kara, O. and I. Bolat. (2009). Short-term effects of wildfire on microbial biomass and abundance in black pine plantation soils in Turkey. *Ecological Indicators,* 9: 1151–1155.

Kashian, D.M., Romme, W.H., Tinker, D.B., Turner, M.G., Ryan, M.G., (2006). Carbon storage on landscapes with stand-replacing fires. *Bioscience* 56: 598–606.

Keeley, J.E., Pausas, J.G., Rundel, P.W., Bond, W.J. and Bradstock, R.A., (2011). Fire as an evolutionary pressure shaping plant traits. *Trends Plant Sci*ence, 16: 406–411.

Keeling, C.D., S.C. Piper and M. Heimann. (1989). A three-dimensional model of atmospheric CO_2 transport based on observed winds: 4 Mean annual gradients and inter annual variations, *American GeoPhysical Union, USA,* 305-363.

Keith R P, Thomas T V, Tania L S and Rosemary L S (2010). Understory vegetation indicates historic fire regimes in ponderosa pine-dominated ecosystems in the Colorado Front Range. *Journal of Vegetational Science,* 21: 488-499.

Kirshbaum, M.U.F. (2000). Will changes in soils organic carbon act as a positive or negative feedback on global warming? *Biogeochemistry.* 48:21-51.

Kittur, B. and Jhariya, M.K. (2012). Assessment of Population Structure of Major Tree Species in Fire Affected Areas of Achanakmar Amarkantak Biosphere Reserve. *Journal of Plant DeveloPment Sciences*. 4: 341-343.

Kodandapani, N. (2001). Forest fires: Origins and Ecological Paradoxes. *Resonance*, 6: 34-41.

Kodandapani, N.; Cochrane, M. and Sukumar, R. (2008). A comparative analysis of spatial, temporal, and ecological characteristics of forest fires in seasonally dry tropical ecosystems in the Western Ghats, India. *Forest Ecology and Management*, 256: 607-617.

Kraaij T. and Ward D (2006), Effects of rain, nitrogen, fire and grazing on tree recruitment and early survival in bush encroached savanna, South Africa. *Plant Ecology,* 186: 235-246.

Kuhlbusch, T. and P.J. Crutzen. (1995). Toward a global estimate of black carbon in residues of vegetation fires representing a sink of atmospheric CO_2 and a source of O_2. *Global Biogeochemical Cycles,* 9:491–501.

Kumar R and Thakur V (2008). Effect of forest fire on trees, shrubs, and regeneration behavior in Chir pin forest in northern aspects under Solan forest division. Himachal Pradesh. *Indian Journal of Forestry* 31: 19-27.

Kumar, M., M.A.Sheikh, J.A. Bhat and R.W. Bussmann.(2013). Effect of fire on soil nutrients and under story vegetation in Chir pine forest in Garhwal Himalaya, India. *Acta Ecologica Sinica* 33: 59-63.

Ramakrishnan, P.S, Kushawa, S.P.S.,. & Tripathi, R.S. (1983). Population dynamics of *ImPerata cylindrica* (L.) Beauv. var. major related to slash and burn agriculture (jhum) in Northeastern India. *Proceedings of the Indian Academy of Sciences (Plant Sciences),* 92: 313–321.

Lal, R. J.M. Kimble and B.A. Stewart. (1995). World soils as a source or sink for relatively active gases. *Soil Management and Green House effect. (Eds. R. Lal, J. Kimble, E. Levine &B.A. Stewart). Lewis Publisher, Boca Raton, Florida, USA*, 1-8.

Lal, R. and J.M. Kimble. (1997). Conservation tillage for carbon sequestration. *Nutrient Cycling in Agroecosystems* 49:243-253.

Lal, R., J.M. Kimble, R.F. Follett, and C.V. Cole. (1998). The potential of US Cropland to Sequester Carbon and Mitigate the Greenhouse Effect. *Ann Arbor Press. Chelsea MI*, 128.

Lavorel S., Lambin E.F., Flannigan M. and Scholes M (2001). Fires in the earth system: The need for integrated research, *IGBP Global Change Newsletter*, 48: 710.

Lehmkuhl JF (1994). A classifcation of subtropical riverine grassland and forest in Chitwan National Park, Nepal. Vegetation.;111:29–43.

Leifeld, J., Bassin, S. and Fuhrer, J. (2004). Carbon stock in Swiss agriculture soils predicted by land use soil characteristics, and altitude. *Agriculture, Ecosystem and Environment.* 105:255-266.

Mackenzie, M.D. and T.H. Deluca. (2006). Resin adsorption of carbon and nitrogen as influenced by season and time since fire. *Soil Science Society of America Journal*, 70: 2122–2129.

Magurran, A.E. (2004) Measuring Biological Diversity. Blackwell Publishing, Oxford, 256 p.

Maithani G. P., V. K. Bahuguna , Pyare Lal (1986) Effect of Forest Fires on the Ground Vegetation of a Moist Deciduous Sal (*Shorea robusta*) forest

Mangan, S.A., S.A. Schnitzer, E.A. Herre, K.M.L. Mack, M.C. Valencia, E.I. Sanchez, and J.D. Bever (2010). Negative plant–soil feedback predicts tree-species relative abundance in a tropical forest. *Nature*, 466: 752-756.

Marschall, J. M. (2013). *Timber product value loss due to prescribed fire caused injuries in red oak trees.* M.S. Dissertation Thesis, Columbia, USA: University of Missouri-Columbia.

Margalef, D. R. (1958). Information theory in ecology. *General System Bulletin*, 3: 36-71.

Marrinan M.J., Edwards W. and Landsberg J (2005), Resprouting of saplings following a fire impacts on carbon uptake, storage, and emission: the role of burn severity in the eastern cascades, oregon. Ecosystems 12, 1246–1267.

Matt Hansen and Rhett A. Butler (2019). The year rainforests burned; Mongabay, University of Maryland.

Mataix-Solera, J., Gómez, I., Navarro-Pedreno, J., Guerrero, C. and Moral, R., (2002). Soil organic matter and aggregates affected by wildfires in a Pinus Forest in a Mediterranean environment. *International Journal of Wildland Fire*, 11:107–114.

Mataix-Solera, J., Cerdà, A., Arceneguy, V., Jordán, A., and Zavala, L.M. (2011). Fire effects on soil aggregation: a review. *Earth-Science Reviews* 109: 44–60.

MFSC. 2010. Forest Fire Management Strategy 2010. Ministry of Forests and Soil Conservation,Government of Nepal, Kathmandu, Nepal.

Meigs, G.W., Donato, D.C., Campbell, J.L., Martin, J.G. and Law, B.E., (2009). Forest fire impacts on carbon uptake, storage, and emission: the role of burn severity in the eastern cascades, oregon. *Ecosystems* 12: 1246–1267.

Miller,M., (2000). Wildland Fire in Ecosystems: Effects of Fire on Flora, tropical rainforest fire in northeast Queensland, Australia, *Austral Ecology*, 30: 817-826.

Miranda, S.C., Silva-Júnior, M.C., Salles, L.A., (2007). A comunidade lenhosa do cerrado rupestre na Serra Dourada, Goiás. *Heringeriana* 1: 43–53.

MPFSN, (Master Plan for the Forestry sector Nepal) (1988). Forest resources information status and development plan Master plan for the forestry sector project of HMGN/ADB/FINNIDA, 232.

M.V. Galdos, C.C. Cerri, and C.E.P. Cerri, (2009). Soil carbon stocks under burned and unburned sugarcane in Brazil: *Geoderma* 153: 347–352.

Naidu C V and Srivasuki K P (1994). Effect of Forest fire on Tree Species on different areas of Aeshachalam Hills. *Journal of TroPical Forestry*, 10 (III).

Negi, J.D.S., R.K. Manhas and P.S. Chauhan. (2003). Carbon allocation in different components of some tree species of India: A new approach for carbon estimation. *Current science,* 85:1528-1531.

Oli, B.N. and K. Shrestha. (2009). Carbon status in Forest of Nepal: An overview. Journal of Forest and livelihood, 8:63-67.

Orwa C, Mutua A, Kindt R, Jamnadass R. and Simons A. (2009). Agroforestry Database: a tree reference and selection guide: http://www.worldagroforestry.org/af/treedb/

O'Connor T.G (1985), A synthesis of field experiments concerning the grass layer in the savanna regions of Southern Africa. *Council for Scientific and Industrial Research, National Scientific Programmes Unit, Southern African National Scientific Programmes* Report No. 144.

Parajuli A., Chand D.B., Rayamajhi B., Khanal R., Baral S., Malla Y. and Poudel Y. (2015) Spatial and temporal distribution of forest fires in Nepal:

Pardini, G., M.Gispert, and G.Dunjó. (2004). Relative influence of wildfire on soil properties and erosion processes in different Mediterranean environments in NE Spain. *Science of the Total Environment* 328:237–246.

Pan, Y., Birdsey, R.A., Fang, J., Houghton, R., Kauppi, P.E., Kurz, W.A., Phillips, O.L. Shvidenko, A., Lewis, S.L. and Canadell, J.G., (2011). A large and persistent carbon sink in the world's forests. *Science* 333: 988–993.

Patterson, W.A., K.J. Edwards, and D.J. Maguire. (1987). Microscopic charcoal as an indicator of fire. *Quaternary Science Review* 6:3-23.

Paudel S. and Sah JP. (2003). Physiochemical characteristics of soil in tropical Sal (*Shorea robusta* Gaertn.) forests in eastern Nepal. *Himalayan Journal of Science*. 1: 107-110

Paudyal, D. (2008). Sustainable Resin Tapping in Nepal: Challenges and opportunities (A case from Salyan districts). *The initiation* 2:172-179.

Pausas, J. and Verdu´, M., (2005). Plant persistence traits in fire prone ecosystems of the Mediterranean Basin: a phylogenetic approach. *Oikos* 109: 196–202.

Pielou, E.C. (1966) The Measurement of Diversity in Different Types of Biological Collections. Journal of Theoretical Biology, 13, 131-144.

Pitman N C A, Terborgh J W, Silman M R, Percy N V, Neill D A, Ceron C E, Palacios W A and Aulestia M (2002). A comparison of tree species diversity in two upper Amazonian forests. *Ecology* 83: 3210-3224.

Polunin, O. and Stainton, A. (1997). Flowers of the Himalaya. Oxford University Press, India. 580.

Prior L.D., Murphy B.P. and Russell Smith J (2009), environmental and demographic correlates of tree recruitment and mortality in North Australian, *Forest Ecology and Management*, 257: 66-74.

Pyke D.A., Brooks M.L. and D'Antonio C (2010), Fire as a restoration tool: A decision framework for predicting the control or enhancement of plants using fire. Restoration Ecology, 18: 274-284.

Rasse, D.P., J. Mulder, C. Moni, and C. Chenu, (2006). Carbon turnover kinetics with depth in a French loamy soil. *Soil Science Society of American Journal* 70:2097-2105.

Rawat U. S .and Agarwal N.K. 2015; Biodiversity: Concept, threats and conservation. Environment Conservation Journal 16: 19-28.

Reddy C S, Babar S, Giriraj A, Reddy K N and Rao J T (2008). Structure and Floristic Composition of Tree Diversity in Tropical Dry Deciduous Forest of Eastern Ghats, Southern Andhra Pradesh, India. *Asian Journal of Science Research* 1: 57-64.

Robichaud, P.R., (2009). Post-fire stabilization and rehabilitation. In: Cerdà, A., Robichaud, P.R. (Eds.), Fire effects on soils and restoration strategies. Science Publishers, Enfield 299–320.

Romanya, J, P. Casals, and V.R. Vallejo. (2001). Short term effects of fire on soil nitrogen availability in Mediterranean grasslands and shrublands growing in old fields. *Forest Ecology Management*, 147:39-53.

Ryan, C.M. and Williams, M (2011), How does fire intensity and frequency affect miombo woodland tree populations and biomass? *Ecological APPlications*, 21: 48-60.

Safford, H. D., and Van de Water K. P. (2014). *Using Fire Return Interval DeParture (FRID) analysis to maP sPatial and temPoral changes in fire frequency on National Forest lands in California*. PSW-RP-266. USDA Forest Service, Pacific Southwest Research Station, Albany, California, USA.

Saha S (2002). Anthropogenic fire regime in a deciduous forest of central India. *Current Science* 82: 1144-1147.

San Jose J.J. and Farinas M.R (1983), Changes in tree density and species composition in a protected Trachypogon savanna, Venezuela, *Ecology*, 64: 447-453.

Sanford, J.R. and R.L. Horn, S.P. 2000. Holocene rain-forest wilderness: a neotropical perspective on humans as an exotic, invasive species. In: Proceedings RMRS P-15-Vol-3. Ogden, UT: U.S. Department of Agriculture Forest Service, Rocky Mountain Research Station:2000. (Eds. D.N. Cole, S.F. McCool, W.T. Borrie, O'Loughlin & J., comps). Volume 3: 168–173.

Santín, C., Knicker, H., Fernández, S., Menéndez-Duarte, R., Álvarez, M.Á., 2008. Wildfires influence on soil organic matter in an Atlantic mountainous region (NW of Spain). Catena 74, 286–295.

Scholes R.J. and Walker B.H (1993), An African savanna: synthesis of the Nylsvley study, Cambridge University Press, Cambridge.

Seth, A.K. (1970). Chemical control of *ImPerata cylindrica* (L.) Beauv. in Malaysia. *Weed Research*, 10: 87–93.

Simpson, E. H. (1949). The measurement of diversity. *Nature*, 163-88.

Shannon, C. E. and W. Wiener (1963). The Mathematical Theory of Communication. University of Illinois Press, Urbana, USA, 117.

Shive, K., H. Preisler, K. Welch, H. Safford, R. J. Butz, K. O'Hara, and S. L. Stephens. (2018). Scaling stand-scale measurements to landscape-scale predictions of forest regeneration after disturbance: the importance of spatial pattern. *Ecological Applications* 28:1626–1639.

Shrestha A. (1992). Physical and chemical properties of soil in Nepal. *NePal Journal Online, 3*: 27-29.

Smit I.P.J., Asner G.P., Govender N., Kennedy Bowdoin T., Knapp D.E. and Jacobson, J (2010), Effects of fire on woody vegetation structure in African savanna. *Ecological APPlications*, 20: 1865-1875.

Smith P., D.S. Powlson, J.U. Smith, P. Falloon and K.Coleman. (2000). Meeting Europes. Climate change commitments: Quantitative estimates of the potentials for carbon mitigation by agriculture. *Global Climate Change* 6:525-539.

Strang R.M (1974), Some manmade changes in successional trends on the Rhodesian Highveld, *Journal of APPlied Ecology*, 11: 249-263.

Suman, D.O. (1984). The production and transport of charcoal formed during agricultural burning in central Panama. *Interciencia* 9: 311–313.

Tafangenyasha C (2001), Decline of the mountain acacia, Brachystegia glaucescens in Gonarezhou National Park, Southeast Zimbabwe. *Journal of Environmental Management*, 63: 3750.

Tamrakar, P. R. (2000). Biomass and volume tables with species description for community forest management. ministry of forests and soil conservation, Kathmandu, Nepal.

Tchie N. and Gakahn G.C (1989), Responses in important woody species of Kenya's rangeland to prescribed burning, *African Journal of Ecology*, 27: 119-128.

Terefe, T., Mariscal-Sancho, I., Peregrina, F. and Espejo, R., (2008). Influence of heating on various properties of six Mediterranean soils. A laboratory studies. *Geoderma* 143: 273–280.

The Convention about Life on Earth (2014) XIV WORLD FORESTRY CONGRESS, Durban, South Africa, 7-11

Tilman, D., F. Isbell, and J.M. Cowles 2014. Biodiversity and Ecosystem Functioning. *Annual Review of Ecology Evolution and Sysematics*, 45: 471-493.

Trapnell C.G (1959), Ecological results of woodland burning experiments in northern Rhodesia, *Journal of Ecology*, 47: 129-168.

Trollope W.S.W (1982), Ecological effects of fire in South African savannas. In: Ecology of tropical savannas, *SPringer Verlag, Berlin*.

Turcios, M.M., M.M.A. Jaramillo,J.Dovalejr, P.M. Fearnside and R.I. Barbosa. (2016). Soil charcoal as long-term Pyrogenic carbon storage in Amazonian seasonal forests. *Global change Biology*, 22:190-197.

Ulery, A.L., R.C. Graham,O.A. Chadwick and H.B. Wood.(1995). Decadescales changes of soil carbon, nitrogen exchangeable cations under chaparral and pine. *Geoderma* 65: 121-134.

Van Wyk P (1971), Veld burning in Kruger National Park. An interim report of some aspects of research. Proceedings Tall Timbers Fire. *Ecology Conference*, 11: 931.

Van Wilgen B.W. and Scholes R.J (1997), The vegetation and fire regimes of southern hemisphere Africa, In: Fire in southern African savannas: Ecological and atmospheric perspectives, Witwatersrand University Press, Johannesburg.

Vega**.** Jose´ A. Cristina Ferna´ ndez, Pedro Pe´ rez-Gorostiaga, Teresa Fonturbel (2008). The influence of fire severity, serenity, and post-fire management on Pinus pinaster Aid. recruitment in three burnt areas in Galicia (NW Spain): *Forest Ecology and Management*, 256: 1596–1603.

Weber, M. G. and M. D. Flannigan (1997). Canadian boreal forest ecosystem structure and function in changing climate, Impact on fire regimes. *Environment Reviews*, 145- 166

West DC, Shugart HH. and Ranney JW. 1981. Population structure of forest cover in a large area in the boreal Swedish forest. *Forest Science*, 27: 701–710.

West O (1965). Fire in vegetation and its use in pasture management with special reference to tropical and subtropical Africa, Commonwealth Agricultural Bureau, Farnham Royal, England

Whittaker, R. H. (1972). Evolution and measurement of species diversity. Taxon., 21(2/3) : 213-251.

Whitlock, C. and C.Larsen, (2001). Charcoal as a fire proxy. In: Tracking environmental change using lake sediments (Eds. J.P., Smol, H.J.B.,Birks, & W.M., Last).Terrestrial, algal, and siliceous indicators. Dordrecht, The Netherlands, *Kluwer Academic Press: Volume* 3: 75–97.

Wiedinmyer, C. and Neff, J.C. (2007). Estimates of CO_2 from fires in the United States: implications for carbon management. *Carbon Balance Management* 2: 10.

www.geoapps.icimod.org retrieved 2020/8/25

Xiang X, Shi Y and Yang J. (2014). Rapid recovery of soil bacterial communities after wildfire in a Chinese boreal forest. *Science RePorts*, 4: 3829.

Xue L, Li Q, Chen H (2014) Effects of a wildfire on selected physical, chemical, and biochemical soil properties in a Pinus Forest in south China. *Forests*, 5:2947–2966.

Zhao, H., D.Q. Tong, Q. Lin and G.Wang. (2012). Effect of fires on soil organic carbon pool and mineralization in a Northeastern China wetland. *Geoderma*, 189-190:532-539

Zobel, D.B., Behan, M.J., Jha, P.K. and Yadav, U.R.K. (1987) A Practical Manual for Ecology. Ratna Book Distributors, Kathmandu.

APPENDICES

Appendix I: List of Fire data along with geographical Co-ordinates and date of fire.

संकलन मिति	प्रदेश	जिल्ला	नगरपालिका	वडा नं.	विश्वषनियता	अक्षांश	देशान्तर
१३/४/२०१८	प्रदेश-५	रुपन्देही	बुटवल	७	७४	२७.४२९	८३.४८३
१३/४/२०१८	प्रदेश-५	रुपन्देही	बुटवल	७	७३	२७.६९५	८३.४८९
१३/४/२०१८	प्रदेश-५	रुपन्देही	बुटवल	६	६३	२७.६९७	८३.४८४
१३/४/२०१८	प्रदेश-५	रुपन्देही	बुटवल	७	८७	२७.६९	८३.४८५
१३/४/२०१८	प्रदेश-५	रुपन्देही	बुटवल	७	८४	२७.६९४	८३.४८६
१४/४/२०१८	प्रदेश-५	रुपन्देही	बुटवल	६	८७	२७.७	८३.४८७
१४/४/२०१८	प्रदेश-५	रुपन्देही	बुटवल	६	३२	२७.७	८३.४९१
१४/४/२०१८	प्रदेश-५	रुपन्देही	बुटवल	२	५३	२७.६९९	८३.४४७
१४/४/२०१८	प्रदेश-५	रुपन्देही	बुटवल	६	३६	२७.६९७	८३.४७८
१४/४/२०१८	प्रदेश-५	रुपन्देही	बुटवल	४	३५	२७.७०१	८३.४७९
१४/४/२०१८	प्रदेश-५	रुपन्देही	बुटवल	६	१००	२७.७०४	८३.४८३
१४/४/२०१८	प्रदेश-५	रुपन्देही	बुटवल	६	७७	२७.७०१	८३.४८१
१४/४/२०१८	प्रदेश-५	रुपन्देही	बुटवल	४	५७	२७.७०५	८३.४८२
१५/४/२०१८	प्रदेश-५	रुपन्देही	बुटवल	६	२७	२७.७	८३.४७३
१५/४/२०१८	प्रदेश-५	रुपन्देही	बुटवल	७	४६	२७.६८८	८३.४८८
२०/४/२०१८	प्रदेश-५	रुपन्देही	बुटवल	७	५६	२७.६८४	८३.४८८
२०/४/२०१८	प्रदेश-५	रुपन्देही	बुटवल	७	४८	२७.६८६	८३.४९६
२३/४/२०१८	प्रदेश-५	रुपन्देही	बुटवल	३	५३	२७.७१८	८३.४६९
२३/४/२०१८	प्रदेश-५	रुपन्देही	बुटवल	३	६६	२७.७२	८३.४८५
२३/३/२०१९	प्रदेश-५	रुपन्देही	बुटवल	६	८०	२७.७०१	८३.४८१
२३/३/२०१९	प्रदेश-५	रुपन्देही	बुटवल	६	९६	२७.६९७	८३.४८२
२३/३/२०१९	प्रदेश-५	रुपन्देही	बुटवल	४	९२	२७.७०३	८३.४८
२८/३/२०१९	प्रदेश-५	रुपन्देही	बुटवल	६	५२	२७.७०१	८३.४८९
३१/३/२०१९	प्रदेश-५	रुपन्देही	बुटवल	२	४८	२७.७०९	८३.४४९
०४/०४/२०१९	प्रदेश-५	रुपन्देही	बुटवल	२	५२	२७.७०३	८३.४४९

१९/४/२०१९	प्रदेश-५	रुपन्देही	बुटवल	७	८२	२७.६८७	८३.५
१९/४/२०१९	प्रदेश-५	रुपन्देही	बुटवल	७	५१	२७.६८१	८३.४९५
२०/४/२०१९	प्रदेश-५	रुपन्देही	बुटवल	४	९१	२७.७१६	८३.४८३
२०/४/२०१९	प्रदेश-५	रुपन्देही	बुटवल	४	९६	२७.७१	८३.४८१
२०/४/२०१९	प्रदेश-५	रुपन्देही	बुटवल	४	७३	२७.७१	८३.४८६
२०/४/२०१९	प्रदेश-५	रुपन्देही	बुटवल	२	७३	२७.६९५	८३.४४७
२१/४/२०१९	प्रदेश-५	रुपन्देही	बुटवल	७	७४	२७.६८८	८३.४८९
१९/५/२०१९	प्रदेश-५	रुपन्देही	बुटवल	६	४३	२७.६९७	८३.४८४
१९/५/२०१९	प्रदेश-५	रुपन्देही	बुटवल	२	२७	२७.७०४	८३.४४४
२०/५/२०१९	प्रदेश-५	रुपन्देही	बुटवल	३	३९	२७.७१६	८३.४७२
२७/५/२०१९	प्रदेश-५	रुपन्देही	बुटवल	७	७८	२७.६७५	८३.४९५

(Source: www.geoapps.icimod.org)

Appendix II: Checklist of herb, Shrubs and tree species found in studied forest.

Scientific name	Local name	Family	Habit	Forest
Shorea robusta Gaertn.	Sal	Dipterocarpaceae	Tree	Both
Bauhinia purpurea L.	Koiralo	Fabaceae	Tree	Both
Terminalia chebula Retz.	Harro	Combertaceae	Tree	Both
Terminalia alata Heyne ex. Roth	Saj	Combertaceae	Tree	Both
Anogeissus latifolius (Roxb. Ex DC.) Bedd.	Banjee	Combertaceae	Tree	Both
Cassia fistula L.	Rasbrishka	Fabaceae	Tree	Both
Semicarpus anacardium L. f.	Bhalayo	Anacardiaceae	Tree	Both
Dalbergia sissoo Roxb.	Sissau	Leguminosae	Tree	Both
Melia azedarach L.	Bakaino	Meliaceae	Tree	Both
Lagerstroemia parviflora Roxb.	Botdhayera	Lythraceae	Tree	Both
Mallotus philippensis (Lam.) Muell.-Arg.	Rohidi	Euphorbiaceae	Tree	Unburnt only.
Schleichera oleosa (Lour.) Oken	Kusum	Sapindaceae	Tree	Both
Careya arborea Roxb.	Kumli	Lecythidaceae	Tree	Both
Wendlandia coriacea DC.	Tilka	Rubiaceae	Tree	Both
Delonex regia (Bojer ex Hook.) Raf.	Gulmohar	Leguminosae	Tree	Both
Eucalyptus citriodora Hook.	Masala	Myrtaceae	Tree	Both
Euphorbia pulcherrima Wild ex Klotzsh.	Lalupate	Euphorbiaceae	Tree	Both
Bombax ceiba L	Simal	Leguminosae	Tree	Both
Grewia elastica Royle.	Syal fusre	Tiliaceae	Tree	Both
Tamarindus indica L.	Imli	Leguminosae	Tree	Both
Tectona grandis L. f	Sagvan	Verbenaceae	Tree	Unburnt only
Ficus semicordata Buch. – Ham ex Sm.	Khanayo	Moraceae	Tree	Unburnt only
Thysanolaena maxima (Roxb.) O. Kuntze	Amriso	Gramineae	Shrub	Both
Tephrosia purpurea (L.) Pers.	Sakinu	Leguminosae	Shrub	Both
Cassia occidentalis L.	Thulo tapre	Leguminosae	Shrub	Both

Pogostemon bengalensis (Burm. F.) Kuntze	Rudilo	Libiatae	Shrub	Both
Justica adhatoda L	Asuro	Acanthaceae	Shrub	Both
Smilax ovalifolia Roxb.	Kukurdaino	Liliaceae	Shrub	Both
Chlerodendrum indicum (L.) Kuntze	Chinde	Verbenaceae	Shrub	Both
Asparagus racemosus Willd.	Kurilo	Liliaceae	Shrub	Both
Colebrookea oppositifolia Sm.	Dhusure	Lamiaceae	Shrub	Both
Vitex negundo L.	simali	Verbenaceae	Shrub	Both
Nerium indicum Miller	Karbir	Apocynaceae	Shrub	Both
Rungia parviflora Nees.	Pindee	Acanthaceae	Shrub	Both
Jasminum dispermum Wall.	Lahare jai	Oleaceae	Shrub	Both
Ricinus communis L.	Ader	Euphorbiaceae	Shrub	Both
Maesa macrophylla (Wall.) A.DC.	Bhogate	Myrsinaceae	Shrub	Both
Bauhinia vahlii Benth.	Bhorla	Fabaceae	Shrub	Unburnt only
Viscum album L.	Hadchure	Loranthaceae	Shrub	Both
Melastoma falcata L.		Melastomataceae	Shrub	Both
Elatostoma sessile J.R. Forst	Gaglato	Urticaceae	Shrub	Both
Eranthemum pulchellum Andrews	Nilgathe	Acanthaceae	Herb	Both
Achyranthus aspera L.	Datiwan	Amaranthaceae	Herb	Both
Argemone maxicana L.	Thakal	Papaveraceae	Herb	Both
Blumea lacera (Burm.f.) DC.	Kukure	Compositae	Herb	Both
Alocasia macrorrhiza Schott.	Tarul	Araceae	Herb	Both
Boehmeria platyphylla D. Don.	Khasreto	Urticaceae	Herb	Both
Cassia tora L	Tapre	Fabaceae	Herb	Both
Imperata cylindrica (L.)	Siru	Cyperaceae	Herb	Both
Saccharum spontaneum L.	Daddi	Graminae	Herb	Both
Curcuma aromatica Salisb.	Ban halido	Zingiberaceae	Herb	Both
Musa superba Roxb.	Ban kera	Musaceae	Herb	Both
Zingiber officinale Rosc.	Aduwa	Zingiberaceae	Herb	Both
Chromolaena odorata L.	Seto Banmara	Asteraceae	Herb	Both

Calotropis gigantea (L.) Dryand.	Aank	Asclepadaceae	Herb	Burnt only
Dryopteris filix-mas (L.) Schott.	Uniu	Dryopteridaceae	Herb	Both
Capillipedium assimile (Steud.) A. Camus	Musikhare	Poaceae	Herb	Burnt only
Phyllanthus urinaria L.	Bhui amala	Euphorbiaceae	Herb	Both
Heliotropium indicum L.	Mrigi raj	Boraginaceae	Herb	Burnt only
Murraya koenigii (L.) Spreng.	kari patta	Rutaceae	Herb	Both
Urtica dioica L.	Sisnu	Urticaceae	Herb	Both
Stellaria media Kurz.	Boksi jhar	Caryophyllaceae	Herb	Both
Flemingia macrophylla (Willd.) Merr.	Bhatwasi	Fabaceae	Herb	Both
Lygodium flexuosum (L.) Sm.	Janai lahara	Lygodiaceae	Herb	Both
Eragrostis tenella (L.)Beauvois ex Roem. & Sch.	Banso	Poaceae	Herb	Both
Adiantum capillus-veneris L.	Kani uneu	Pteridaceae	Herb	Both
Triumfetta pilosa Roth.	Dalle kuro	Malvaceae	Herb	Both
Ageratina adenophora (Spreng.)	Kalo Banmara	Asteraceae	Herb	Both
Mimosa pudica L.	Lajalu jhar	Fabaceae	Herb	Both
Cynodon dactylon (L.) Pers.	Dubo	Poaceae	Herb	Both
Cuscuta reflexa Roxb.	Akash beli	Convolvulaceae	Herb	Both
Mucuna pruriens (L.) DC.	Kauso	Fabaceae	Herb	Unburnt only
Artemisia indica Willd.	Titepati	Asteraceae	Herb	Both
lePidium sativum L.	chamsur	Brassicaceae	Herb	Both

Appendix III: Importance value index of tree Species.

A = Unburnt forest B= Burnt Forest

(A)

Name of tree Species	F (%)	RF (%)	D (In/h)	RD (%)	BA (sq. m)	RBA (%)	IVI
Shorea robusta	100.00	10.14	823.64	61.79	50.9	58.71	130.6
Bauhinia purpurea	56.67	5.74	22.73	1.71	0.96	1.10	8.55
Terminalia chebula	33.33	3.38	17.30	1.30	1.56	1.80	6.48
Terminalia alata	60.00	6.08	20.28	1.52	2.50	2.88	10.49

Anogeissus latifolius	63.33	6.42	42.56	3.19	0.47	0.54	10.16
Cassia fistula	26.67	2.70	22.50	1.69	0.45	0.52	4.92
Semicarpus anacardium	56.67	5.74	32.65	2.45	1.81	2.08	10.28
Dalbergia sissoo	66.67	6.76	44.11	3.31	5.83	6.73	16.79
Melia azedarach	26.67	2.70	22.83	1.71	0.43	0.49	4.91
Lagerstroemia parviflora	76.67	7.77	40.02	3.00	7.16	8.25	19.03
Mallotus philippensis	56.67	5.74	25.32	1.90	0.96	1.11	8.75
Schleichera oleosa	43.33	4.39	19.73	1.48	1.68	1.93	7.80
Careya arborea	40.00	4.05	20.91	1.57	1.93	2.22	7.85
Wendlandia coriacea	26.67	2.70	19.77	1.48	1.24	1.43	5.62
Delonex regia	23.33	2.36	19.09	1.43	0.16	0.18	3.98
Eucalyptus citriodora	10.00	1.01	14.32	1.07	0.44	0.50	2.59
Euphorbia pulcherrima	40.00	4.05	22.27	1.67	0.36	0.41	6.14
Bombax ceiba	46.67	4.73	16.36	1.23	3.30	3.81	9.77
Grewia elastica	40.00	4.05	21.00	1.58	0.30	0.35	5.97
Tamarindus indica	46.67	4.73	30.55	2.29	1.79	2.06	9.08
Tectona grandis	36.67	3.72	19.09	1.43	2.31	2.67	7.81
Ficus semicordata	10.00	1.01	15.91	1.19	0.18	0.21	2.41

(B)

Name of tree Species	F (%)	RF (%)	D (In/h)	RD (%)	BA (sq. m)	RBA (%)	IVI
Shorea robusta	100.00	20.00	962.86	64.50	43.68	42.30	126.80
Bauhinia purpurea	13.33	2.67	10.61	0.71	1.60	1.55	4.92
Terminalia chebula	26.67	5.33	25.45	1.71	1.78	1.73	8.77
Terminalia alata	30.00	6.00	28.63	1.92	2.14	2.07	9.99
Anogeissus latifolius	16.67	3.33	9.63	0.65	0.27	0.26	4.24
Cassia fistula	36.67	7.33	73.32	4.91	4.53	4.38	16.63
Semicarpus anacardium	40.00	8.00	84.85	5.68	4.57	4.42	18.11
Dalbergia sissoo	30.00	6.00	19.09	1.28	4.71	4.57	11.84
Melia azedarach	3.33	0.67	1.06	0.07	0.94	0.91	1.65
Lagerstroemia parviflora	76.67	15.33	164.99	11.05	10.94	10.60	36.98

Schleichera oleosa	26.67	5.33	24.39	1.63	5.23	5.06	12.03
Careya arborea	13.33	2.67	12.73	0.85	3.34	3.24	6.75
Wendlandia coriacea	10.00	2.00	11.63	0.78	2.19	2.12	4.90
Delonex regia	13.33	2.67	9.63	0.65	2.65	2.56	5.87
Eucalyptus citriodora	16.67	3.33	8.62	0.58	3.39	3.29	7.20
Euphorbia pulcherrima	10.00	2.00	8.36	0.56	3.74	3.62	6.18
Bombax ceiba	6.67	1.33	6.06	0.41	1.27	1.23	2.97
Grewia elastica	10.00	2.00	8.57	0.57	2.10	2.03	4.61
Tamarindus indica	20.00	4.00	22.27	1.49	4.19	4.06	9.55

Appendix IV: Importance value index of Shrub species.

A = Unburnt forest B= Burnt forest

(A)

Name of shrub species	F (%)	RF (%)	D (In/h)	RD (%)	C (%)	RC (%)	IVI
Thysanolaena maxima	23.33	3.93	0.02	5.75	193	4.95	14.64
Tephrosia purpurea	80	13.48	0.07	15.11	814	20.9	49.51
Cassia occidentalis	43.33	7.30	0.04	7.88	267	6.86	22.05
Pogostemon bengalensis	43.33	7.30	0.02	5.17	320	8.22	20.70
Justica adhatoda	13.33	2.24	0.00	1.56	134	3.42	7.25
Smilax ovalifolia	13.33	2.24	0.01	2.46	90	2.31	7.024
Chlerodendrum indicum	26.66	4.49	0.01	2.54	128	3.28	10.33
Asparagus racemosus	23.33	3.93	0.01	2.46	100	2.56	8.96
Colebrookea oppositifolia	26.66	4.49	0.02	4.60	202	5.19	14.28
Vitex negundo	33.33	5.61	0.02	5.42	198	5.08	16.12
Nerium indicum	6.66	1.12	0.00	0.49	15	0.38	2.00
Rungia parviflora	23.33	3.93	0.02	4.35	148	3.80	12.09

Jasminum dispermum	43.33	7.30	0.04	9.12	354	9.09	25.51
Ricinus communis	16.66	2.80	0.00	0.98	31	0.79	4.59
Maesa macrophylla	40	6.74	0.01	3.20	230	5.90	15.85
Bauhinia vahlii	46.66	7.86	0.02	4.84	218	5.60	18.31
Viscum album	16.66	2.80	0.02	4.10	62	1.59	8.51
Melastoma falcata	13.33	2.24	0.01	2.62	125	3.21	8.08
Elatostoma sessile	60	10.11	0.08	17.25	263	6.75	34.12

(B)

Name of shrub species	F (%)	RF (%)	D (In/h)	RD (%)	C (%)	RC (%)	IVI
Thysanolaena maxima	10	1.89	0.04	7.93	183.00	5.00	14.82
Tephrosia purpurea	80	15.09	0.08	17.37	814.00	22.24	54.72
Cassia occidentalis	43.33	8.18	0.04	9.07	267.00	7.29	24.54
Pogostemon bengalensis	30	5.66	0.03	5.95	320.00	8.74	20.35
Justica adhatoda	13.33	2.52	0.01	1.79	134.00	3.66	7.97
Smilax ovalifolia	13.33	2.52	0.01	2.83	90.00	2.45	7.81
Chlerodendrum indicum	26.66	5.03	0.01	2.93	128.00	3.49	11.46
Asparagus racemosus	23.33	4.40	0.01	2.83	100.00	2.73	9.97
Colebrookea oppositifolia	40	7.55	0.04	8.50	350.00	9.56	25.61
Vitex negundo	33.33	6.29	0.03	6.23	198.00	5.41	17.93
Nerium indicum	6.667	1.26	0.00	0.57	15.00	0.40	2.23
Rungia parviflora	23.33	4.40	0.02	5.00	148.00	4.04	13.45
Jasminum dispermum	43.33	8.18	0.05	10.48	354.00	9.67	28.33
Ricinus communis	16.66	3.14	0.01	1.13	31	0.84	5.13
Maesa macrophylla	53.33	10.06	0.02	4.25	240.00	6.55	20.87
Viscum album	26.66	5.03	0.03	7.74	96	2.62	15.40

Melastoma falcata	40	7.55	0.02	4.53	159	4.34	16.43
Elatostoma sessile	6.66	1.26	0.00	0.849	32	0.87	2.98

Appendix V: Importance value index of herb species.

A = Unburnt forest B= Burnt Forest

A

Name of herb species	F (%)	RF (%)	D (In/h)	RD (%)	C (%)	RC (%)	IVI
Eranthemum pulchellum	16.66	1.84	0.6	0.81	61	1.32	3.97
Achyranthus aspera	46.66	5.15	1.93	2.61	249	5.38	13.15
Argemone maxicana	16.66	1.84	0.5	0.68	31	0.67	3.18
Blumea lacera	30	3.31	2.73	3.70	93	2.01	9.02
Alocasia macrorrhiza	30	3.31	0.9	1.22	45	0.97	5.50
Boehmeria platyphylla	90	9.93	6.93	9.37	928	20.07	39.37
Cassia tora	30	3.31	1.26	1.71	78	1.69	6.71
Imperata cylindrica	33.33	3.68	3.2	4.33	138	2.98	10.99
Saccharum spontaneum	16.66	1.84	2.23	3.02	143	3.09	7.95
Curcuma aromatica	23.33	2.57	1.6	2.16	131	2.83	7.57
Musa superba	33.33	3.68	2.33	3.15	113	2.44	9.27
Zingiber officinale	16.66	1.84	0.8	1.08	32	0.69	3.61
Chromolaena odorata	43.33	4.78	2.9	3.92	173	3.74	12.44
Calotropis gigantea	0	0.00	0	0.00	0	0.00	0.00
Dryopteris filix-mas	60	6.62	4.66	6.31	316	6.83	19.76
Capillipedium assimile	0	0.00	0	0.00	0	0.00	0.00
Phyllanthus	36.66	4.04	2.2	2.97	128	2.77	9.79
Heliotropium indicum	0	0.00	0	0.00	0	0.00	0.00
Murraya koenigii	46.66	5.15	2.4	3.24	173	3.74	12.13
Urtica dioica	20	2.21	1.16	1.58	105	2.27	6.05
Stellaria media	50	5.51	3.5	4.73	258	5.58	15.83
Flemingia macrophylla	36.66	4.04	2.16	2.93	185	4.00	10.97
Lygodium flexuosum	30	3.30	2.5	3.37	165	3.56	10.26
Eragrostis tenella	26.66	2.94	4.5	6.08	110	2.37	11.40
Adiantum capillus-veneris	33.33	3.67	4.3	5.81	160	3.46	12.95
Triumfetta pilosa	30	3.30	6	8.11	210	4.54	15.96
Ageratina Adenophora	20	2.20	2.6	3.51	128	2.76	8.49
Mimosa pudica	13.33	1.47	0.26	0.36	40	0.86	2.70
Cynodon dactylon	6.66	0.73	0.33	0.45	25	0.54	1.73
Cuscuta reflexa	3.33	0.36	0.03	0.04	5	0.10	0.52

Mucuna pruriens	13.33	1.47	0.36	0.49	85	1.83	3.80
Artemisia indica	26.66	2.94	2.03	2.74	195	4.21	9.91
lepidium sativum	26.66	2.94	7	9.46	121	2.61	15.02

B

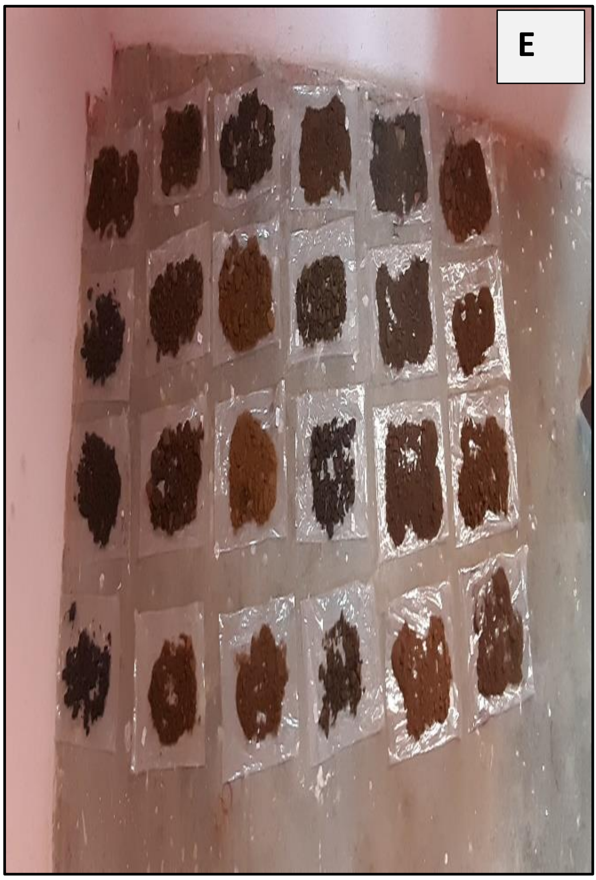
Name of herb species	F (%)	RF (%)	D (In/h)	RD (%)	C (%)	RC (%)	IVI
Eranthemum pulchellum	80.00	11.11	22.73	20.02	579	15.29	46.42
Achyranthus aspera	40.00	5.56	7.00	6.17	78	2.06	13.78
Argemone maxicana	20.00	2.78	1.80	1.59	29	0.77	5.13
Blumea lacera	50.00	6.94	4.57	4.02	141	3.72	14.69
Alocasia macrorrhiza	6.67	0.93	0.10	0.09	6	0.16	1.17
Boehmeria platyphylla	30.00	4.17	1.20	1.06	93	2.46	7.68
Cassia tora	60.00	8.33	15.00	13.21	350	9.24	30.79
Imperata cylindrica	43.33	6.02	28.33	24.96	690	18.22	49.19
Saccharum spontaneum	10.00	1.39	0.97	0.85	53	1.40	3.64
Curcuma aromatica	16.67	2.31	0.73	0.65	58	1.53	4.49
Musa superba	6.67	0.93	0.33	0.29	90	2.38	3.60
Zingiber officinale	13.33	1.85	0.40	0.35	26	0.69	2.89
Chromolaena odorata	10.00	1.39	0.47	0.41	23	0.61	2.41
Calotropis gigantea	20.00	2.78	0.40	0.35	29	0.77	3.90
Dryopteris filix-mas	6.67	0.93	0.43	0.38	30	0.79	2.10
Capillipedium assimile	43.33	6.02	3.73	3.29	251	6.63	15.93
Phyllanthus urinaria	10.00	1.39	0.40	0.35	28	0.74	2.48
Heliotropium indicum	13.33	1.85	0.77	0.68	54	1.43	3.95
Murraya koenigii	23.33	3.24	1.77	1.56	63	1.66	6.46
Urtica dioica	20.00	2.78	0.70	0.62	60	1.58	4.98
Stellaria media	30.00	4.17	2.13	1.88	173	4.57	10.61
Flemingia macrophylla	23.33	3.24	1.20	1.06	125	3.30	7.60

Lygodium flexuosum	13.33	1.85	0.87	0.76	60	1.58	4.20
Eragrostis tenella	46.67	6.48	11.67	10.28	275	7.26	24.02
Adiantum capillus-veneris	13.33	1.85	0.33	0.29	68	1.80	3.94
Triumfetta pilosa	10.00	1.39	0.50	0.44	80	2.11	3.94
Ageratina Adenophora	10.00	1.39	1.83	1.61	90	2.38	5.38
Mimosa pudica	6.67	0.93	0.13	0.12	10	0.26	1.31
Cynodon dactylon	13.33	1.85	2.33	2.06	95	2.51	6.42
Cuscuta reflexa	13.33	1.85	0.13	0.12	30	0.79	2.76
Mucuna pruriens	0.00	0.00	0.00	0.00	0	0.00	0.00
Artemisia indica	13.33	1.85	0.50	0.44	45	1.19	3.48
lepidium sativum	3.33	0.46	0.07	0.06	5	0.13	0.65

Appendix VI: ANNOVA table for the analysis of pH, Bulk density and SOC.

ANOVA					
Dependent variable: pH					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	0.358	3	0.119	0.439	0.726
Within Groups	11.968	44	0.272		
Total	12.327	47			
Dependent variable: Bulk density					
	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	0.12	3	0.04	11.128	0.00
Within Groups	0.072	20	0.004		
Total	0.192	23			
Dependent Variable: SOC					
	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	28068.144	3	9356.048	61.406	0.000
Within Groups	3047.297	20	152.365		
Total	31115.441	23			

Appendix VII: Selected Photo plates.


E


F


G


H

A= Landscape of Burnt forest, B= Landscape of unburnt forest, C= Measuring DBH, D= Soil collection through soil borer, E= Drying of soil before analysis, F= Lab Analysis, G = Example of disturbance and H, I = Burnt wood after fire.