Spatial Variation in Carbon Stock of Fragmented Moist Temperate Forest of Buner District (Pakistan)

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Abstract

Forest fragmentation is the breaking of forested areas into fragments/patches for different human purposes. The forests of Malakand division especially in district Buner, Khyber-Pakhtunkhwa had been extensively fragmented recently. Therefore, this study was designed to assess the vegetation as well as soil carbon in both interior and exterior fragmented forest on the basis of elevation. Stratified random sampling method was used for field inventory in which 20 plots of size 0.5 ha were laid out on elevation basis, according to the nature of study area. Sample plots were taken in forest interior and forest exterior. The plot-to-plot distance of interior and exterior plots were 100m. Moreover, three sub-plots in each plot were taken for soil sample collection at three depths i.e. (0-10 cm,10-20 cm,20-30 cm). The overall results showed that biomass carbon in interior of the forest fragment is greater than the exterior of the forest fragment. The total carbon in interior and exterior fragmented forest was recorded at 266.94±27 t/ha and 134.43±15 t/ha respectively. The results further showed that vegetation carbon as well as soil carbon increases with an altitude. This study elaborated that there is 50% decrease in carbon density from forest interior towards exterior which recommends that the carbon density in forest exterior required afforestation of Pinus roxburghii species based on silviculture requirements that will capture more carbon and combat with climate change.

Keywords: Edge Effect; Forest Carbon; Fragmentation; Carbon Interior and Exterior.

Introduction

Forest fragmentation is the process of splitting vast, complete forest patches into smaller, isolated, and geometrically uneven portions over time (Das et al., 2017). Forest fragmentation is the breaking of forested areas into patches for different human purposes (Ethier and Fahrig, 2011). Fragmentation is a vigorous process in which an organism's habitation is gradually decreased into smaller sections that become increasingly remote and subject to edge effects (Echeverria et al., 2008). Forest fragmentation is a common occurrence, and it is one of the most common ways humans change ecosystem and biodiversity practices (Gonzalez et al., 2011). While forest

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fragmentation can have a variety of consequences, one of the most common ways for fragmentation, to alter the richness and aim of a forest land scape, is through edge effects (Ziter et al., 2014). Fragmentation diminishes the size of forest patches and promotes habitat isolation and edge effects (Tapia-Armijosetal.,2015). Traditional patch metrics are used to estimate landscape fragmentation (Kadıoğulları, 2013). Fragmented forest loss, have variety of negative environmental and ecological repercussions, have grown commonplace around the world (Das et al., 2017). According to numerous studies, forest ecosystems have been extensively reduced in several parts of the world as a result of human disruption (Shafique and Behera, 2017). Fragmented forest loss, which have a variety of negative ecological and environmental repercussions, have grown common place around the world (Das et al., 2017). Naturally as well as semi-naturally fragmented forest are major extinction hazards because they diminish the attainability of appropriate habitat of many species, as well as causing a biodiversity regime shift (Pardini et al., 2010). The spatial and temporal shift of land use by human activities have become a more major proximate component in the regions of fragmented forest since the latter few decades of the twentieth century (Abdullah & Nakagoshi, 2007). In the tropical rainforest of north-eastern Australia, certain microclimatic edge effects were recorded around linear clearings for power lines and unpaved roads (Pohlman et al.,2009). Forest ecosystems are often degraded as a result of forest loss and fragmentation (Dasetal.,2017). The causes of forest clearing and fragmentation in the Chiapas highlands, Mexico, were linked to human density, rising demand for arable areas, and timber. (Rueff, 2014). The goal of this study was to examine the spatio-temporal variation of the fragmented (Land Structure) in the (Hindu Kush Himalaya) region in order to determine the occurrence of variation in the patterns of elevational gradients while taking into account the effects of human population, as human caused fragmentation can be managed through various actions (Das et al., 2017). The Forest edge has become the main aspects in (L.S) all over the world as a result of forest fragmentation. Forest edges are subjected to different microclimatic conditions than the forest interior in term of wind, light, temperature, and soil moisture and have a larger capacity to collect atmospheric deposition (Remy et al., 2016). Researchers, policymakers, conservationists, and resource managers all need to know how large a disturbance is on a particular scale for a certain area of interest (Buma et al., 2017). On the human population the pressure was increased on high economic development, are two important underlying rivers that have resulted in these conditions. (Uusivuori et al., 2002). Pakistan is a densely populated Asian country with only around 2.5 percent of its territory covered in forest (Qasim et al., 2013). The majority of the country's forest has been destroyed, and recent deforestation statistics show a high incidence of 1.65% (Qamer et al., 2016). which had previously been recorded at 0.6 percent from 1981 to 1990 and 1.5 % from 1991 to 2010 (Qamer et al., 2016). The current research was conducted out in the Hindu Kush regions, Kumrat valley. These activities exacerbate deterioration, soil erosion, slope destabilization, rock falls, and rock slides, all of which are already prevalent in the Karakoram mountains (Ali et al., 2017). Traditional inventories, which lack vital scientific knowledge on carbon stock density and temporal land cover variation are being used to manage these forests (Khan et al., 2020). The moist temperate forest of Malakand division is fragmented in Buner region which need to be quantify for carbon dynamics and climate change mitigation measures. Therefore, this study was carried out to estimate the forest edge effect in terms of carbon density in interior forest and exterior of fragmented Forest. Uptil now, no study has been carried out on forest edge effects on carbon accumulation in fragmented forest. This study is an attempt to bridge the Gap of How much is the carbon stock in the biomass of both interior and exterior of fragmented forest? How much is the spatial variation of carbon stock in forest fragment?

Material and Methods

The study was conducted in fragmented moist temperate forest of buner district, that is largely hilly area. The boarder of swat is on the north side, Malakand by the west, on the east side is Shangla, and on the south is Swabi and Mardan. It is located between 34°-09' and 34°-43' degrees north latitude, and 72°-10' and 72°-47' degrees east longitude. Buner's hilly areas, Mahaban and Malka, are generally surrounded by verdant pine trees.
Summers are pleasant, but winters are harsh; the optimal temperature in summer is around 10-15°C for roughly7months of the year, while winter temperatures are considerably below freezing (Ali et al., 2016). Buner receives 235 mm of rain per month in the summer and 116 mm in the winter, with a mean annual rainfall of 1068 mm (Rahman et al., 2022). The climate in the district is mild. In the summer, the top parts (Gadezai and Gokand) are pleasant, while the lower parts (Khadukhel) are hot, with temperatures reaching 40° C. Snow falls occurs at higher elevations in winter. This region was known for its huge forests, which were dominated by Pinus roxburghii, Olea ferruginea, Acacia modesta, and Quercus incana during 926–1969. Celtis australis, Monotheca buxifolia, Berberis lyceum, Dodonaea viscosa, Melia azedarach and Eucalyptus camaldulensis.

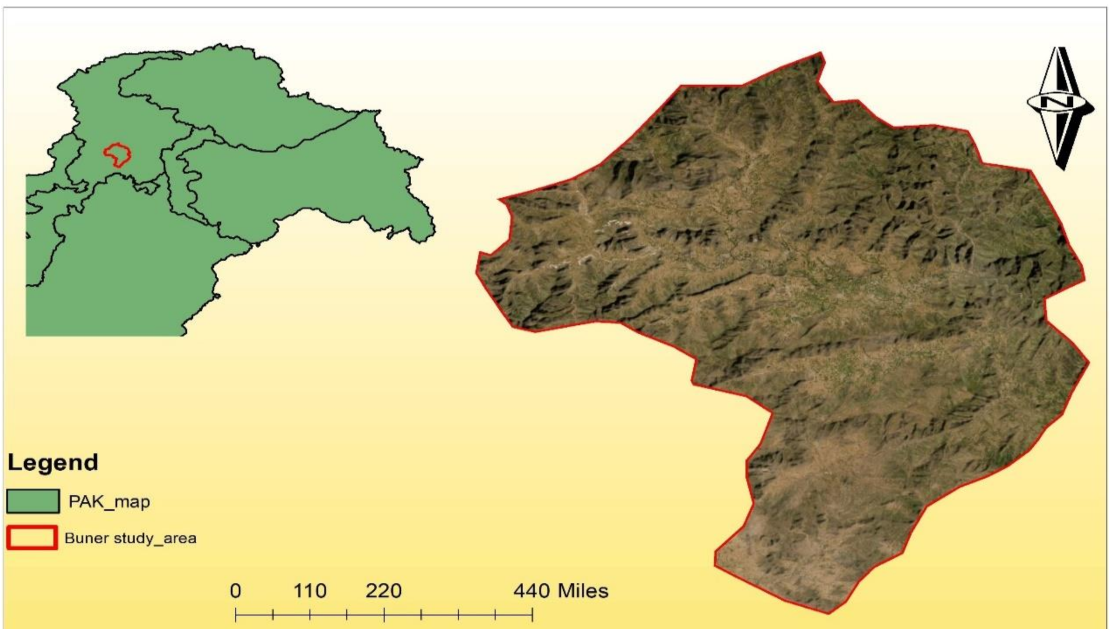


Figure 1.1 Map of the study area

Study Design

Stratified sampling was used for data collection during field inventory. The basis for stratification was elevational. The Himalayan moist temperate forest of the Buner district elevation are ranges from 700 to 1500 and 1500 m to 3000 m. The study area was divided into five elevation classes. The difference of elevation between two classes were 200 m. At each elevation five sample plots were taken at forest exterior and five at forest interior. The forest's interior plots were laid out at a distance of 100 m from the forest exterior. The size of the plot was 0.5 ha-1. Overall, 20 plots were laid out. A non-destructive method of sampling was used for assessing tree biomass carbon. The diameter tape was used to measure the tree diameter within each plot at 1.3 m standard above the ground level. Similarly, for the measurement of standing tree height, Abney level was used. To calculate the carbon of detritus and herbs in each plot, 4 sub-plots of 2 m2 were laid out. Similarly, for the estimation of shrub carbon in each plot, four sub-plots of 6 m2 were taken. Fresh weight of understory vegetation was taken at the spot & brought to the lab for further analysis. For soil carbon in each plot, soil samples were collected using soil auger and soil core within 3 sub-plots of 1 m2, at three depth levels, 0-10cm, 10-20cm, 20-30 cm. The samples were transferred to the lab for further analysis.

Statistical Analysis

MS Excel was used for data processing of the ecosystems carbon including tree carbon, soil carbon, and understory vegetation. Two-way ANOVA and Least significant differences were used to test the variation in carbon density. Statistics version 8.1 were used for data analysis. Sigma Plot 12.5 and SPSS 25 version were used to get the relationship between carbon density and basal area at both forest edges and forest interior.

Bulk Density

Bulk density refers to the dry weight of a unit volume of soil. Bulk density is calculated using both solid particles and pore spaces, and is impacted by parameters such as degree of compaction, particle consolidation, and the amount of organic matter present.

Low soil bulk density is caused by a high quantity of organic matter (Alietal.,2020). The wet weights of the samples were measured on the spot with a digital balance. Samples were wrapped in plastic zip bags and transferred to the University of Haripur. The soil samples were air dried then retained for 24 hours in oven at about 105 °C. The diameter and length of soil auger was determined for the purpose of volume measurement. By using the following equation, the bulk density of soil was calculated.

Bulk Density (gm/cm) = WS /VC.

WS is weight of soil sample in grams. VC is the volume of the core in cm3.

Soil Organic Carbon

The soil was kept into room temperature for removing the moisture and grind the soil then filtered the soil from200mm sieve. 5 g of soil was taken into a conical flask of 500 ml volume. The potassium dichromate solution of 10 ml was added. Then 20 ml of Sulphuric Acid was added the solution was left for 40 minutes. Then add 10ml of Ortho-Phosphoric Acid and also added 200ml of distilled water. Some drops of indicator were added to change the color of the solution and the reading was noted. The total organic carbon was calculated by the following formula.

Percentage Oxidable organic carbon = (Bv)- (Av) X 0.3 X M/Wt of soil (gm).

Where,

M = Mortality of ferrous ammonium sulphate

0.3 = 31 x 0-3 x 100, where 3 represents carbon equivalent weight.

By is the volume of ferrous ammonium sulphate solution used to titrate the bank (ml), and

Av is the volume of ferrous ammonium sulphate solution used to titrate the sample (ml)

Wt = Weight of air-dry soil(gm).

Biomass Calculation

Stem biomass into (kg) was calculated from the density of wood (m3) of the trees and volume (m3). Basic wood density of the tree's species was sourced from literature.

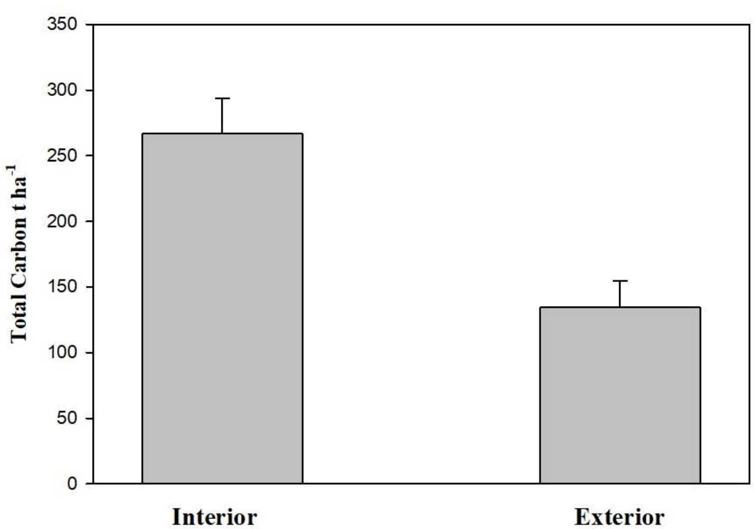
Stem biomass (kg) was calculated as,
Biomass (kg) = Volume (m3) x Basic wood density (kg/m3).
Biomass of twigs, roots, branches, and leaves was calculated by using Allometric equation.

Determination of Carbon Stock in Forest Land
Total carbon stocks (t ha-1) in the study area were determined by the total biomass. Total biomass of the respective tree species is multiplied with 0.5 and this conversion factor is widely used int he world (Nizami, 2012)

Statistical Analysis
The variation in the carbon stock both in interior and exterior of the forest fragment was determined statistically. For each species the regression analysis was carried out and the relationship between diameter (m) and Avg. C (t ha-1) was determined. The regression equation was developed with co-efficient of determination (R2) value. All the statistical analysis was carried out on the software Sigma plot ver12.5.

Results
As per goal of this study variation in biomass, carbon density in interior and exterior of the fragmented forest as well as dynamics of carbon in soil of both exterior and interior of the forest fragments were determined.

Biomass in interior and exterior of the fragments.
The total carbon determined in interior vegetation biomass was 266.94±27 t ha-1 while in exterior of the forest it was 134.43±15 t ha-1 (Figure No: 4.1).
Figure 3.1. Total carbon recorded at interior and exterior fragments in the study areas.
The calculation of the species wise carbon in interior and exterior of the forest fragments revealed



that the average carbon in interior of the forest fragment for Pinus roxburghii was 26.99 t ha-1. The maximum Carbon 51.82 t ha-1 for Pinus roxburghii was recorded in diameter of 0.85m while minimum carbon 1.03 ton ha-1 was recorded at 0.05 m diameter. A linear relationship was statistically between diameter (m) and the average C (t ha-1) with R2 =0.99 (Figure No. 4.2).

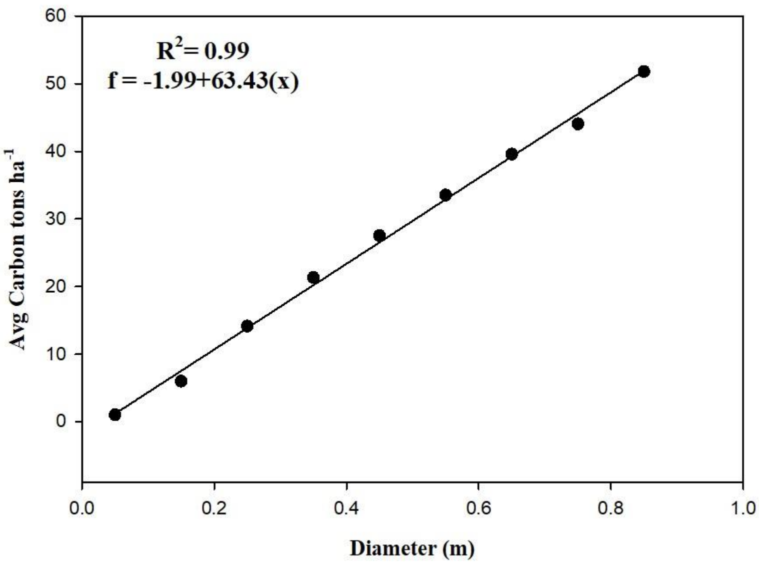


Figure No 3.2. Average carbon stocks (t ha-1) for Pinus roxburghii in interior of the fragment.

Similarly, the average carbon in exterior site for Pinus roxburghii was 17.86 t ha-1. The maximum Carbon 34.86 t ha-1 for Pinus roxburghii was recorded in diameter of 0.85m while minimum carbon 0.57 t ha-1 was recorded at 0.05 m dia. The Figure No. 3.3 shows the average biomass and different diameter classes (m). The regression analysis showed there is Cubic relationship exist between biomass (t ha-1) and diameter (m) of Pinus roxburghii (R2 = 0.99).

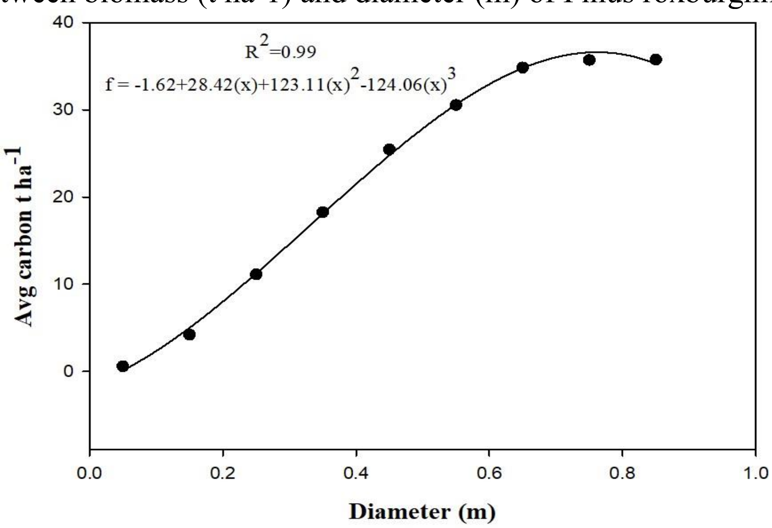
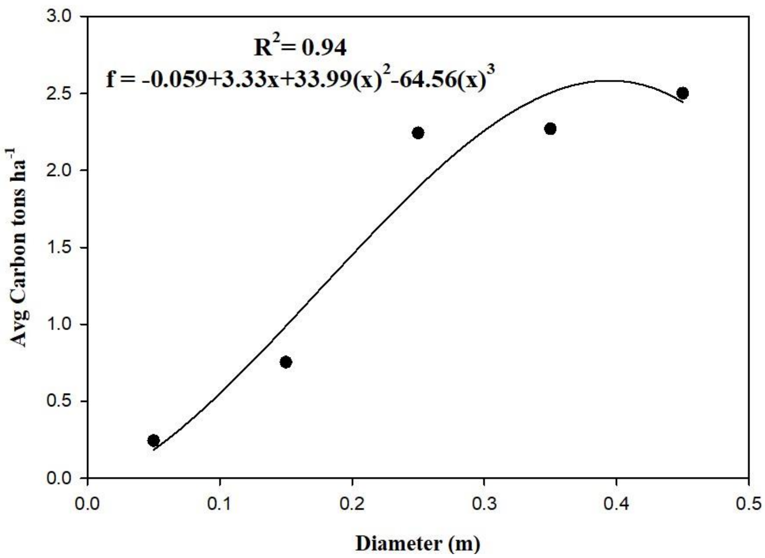


Figure No: 3.3. Average carbon stocks (t ha-1) recorded for Pinus roxburghii in exterior of the fragment.

Similarly, the average carbon in interior site for Olea ferrugenia was enumerated 1.6 t ha-1. The maximum Carbon 2.5 t ha-1 for Olea ferrugenia was recorded in diameter of 0.45m while minimum carbon 0.24 t ha-1 was recorded at 0.05 m dia. The Fig No: 3.4 shows the average biomass and different diameter classes (m). The regression analysis showed there is cubic relationship exist between biomass (t ha-1) and diameter (m) of Olea ferrugenia (R2 = 0.94).

Figure No: 3.4. Average carbon stocks (t ha-1) recorded for Olea ferrugenia in interior of the fragment.

The average carbon in exterior site for Olea ferrugenia was enumerated 0.92 t ha-1. The maximum Carbon 2.5 t ha-1 for Olea ferrugenia was recorded in diameter of 0.45m while minimum carbon



0.03 t ha-1 was recorded at 0.05 m dia. The Figure No: 3.5 shows the average biomass and different diameter classes (m). The regression analysis showed there is quadratic relationship exist between biomass (t ha-1) and diameter (m) of Olea ferrugenia (R2 = 0.99).

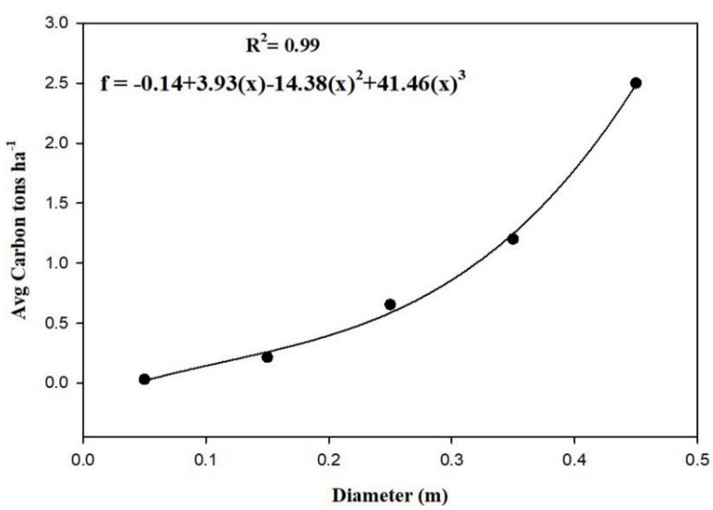


Figure No 3.5: Average carbon stocks (t ha-1) recorded for Olea ferrugenia in exterior of the fragment.

Likewise, the average carbon in interior site for Melia azadarach was enumerated 0.64 t ha-1. The maximum Carbon 1.44 t ha-1 for Melia azadarach was recorded in diameter of 0.35m while minimum carbon 0.04 t ha-1 was recorded at 0.05 m dia. The Fig 3.6 shows the average biomass and different diameter classes (m). The regression analysis showed there is quadratic relationship exist between biomass (t ha-1) and diameter (m) of Melia azadarach (R2 = 0.99).

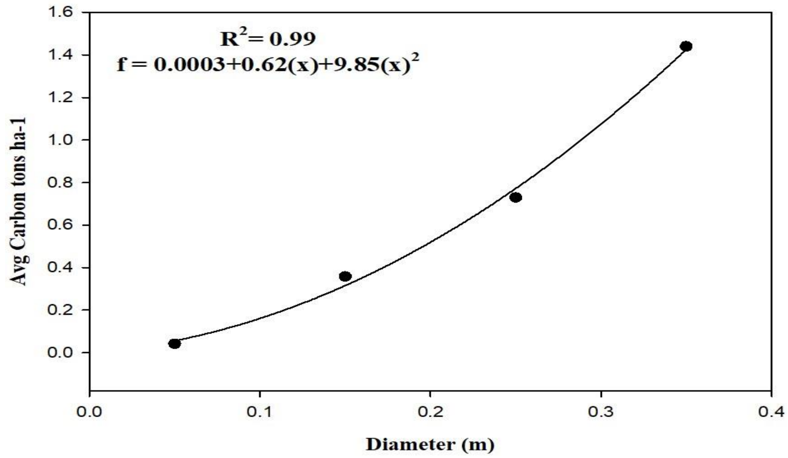


Figure No 3.6: Average carbon stocks (t ha-1) recorded for Melia azadarach in interior of the fragment.

Similarly, the average carbon in exterior site for Melia azadarach was enumerated 0.62 t ha-1. The maximum Carbon 1.22 t ha-1 for Melia azadarch was recorded in diameter of 0.45m while minimum carbon 0.02 t ha-1 was recorded at 0.05 m dia. The Fig 3.7 shows the average biomass and different diameter classes (m). The regression analysis showed there is cubic relationship exist between biomass (t ha-1) and diameter (m) of Melia azadarach (R2 = 0.97).

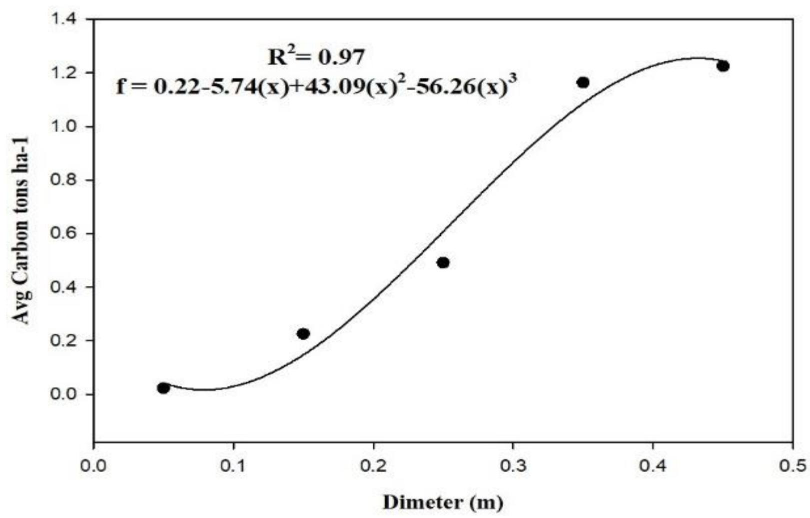


Figure 3.7. Average carbon stocks (t ha-1) recorded for Melia azadarach in exterior of the fragment.

Also the average carbon in interior site for Eucalyptus camaldulensis was enumerated 3.47 t ha-1. The maximum Carbon 7.02 t ha-1 for Eucalyptus camaldulensis was recorded in diameter of 0.45m while minimum carbon 0.33 t ha-1 was recorded at 0.05 m dia. The Fig 3.8 shows the average biomass and different diameter classes (m). The regression analysis showed there is quadratic relationship exist between biomass (t ha-1) and diameter (m) of Eucalyptus camaldulensis (R2 = 0.99).

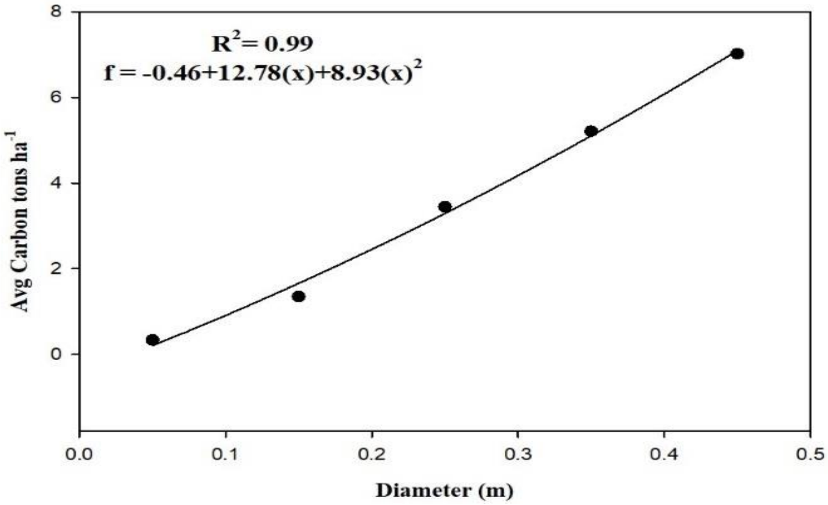


Figure 3.8. Average carbon stocks (t ha-1) recorded for Eucalyptus camaldulensis in interior of the fragment.

Soil carbon in interior and exterior of the fragments.

For soil carbon estimation, three samples were taken at depth of 0-10. 10-20 and 20-30cm were collected from both interior and exterior forest fragment at different elevations.

The study revealed that the total carbon in interior at an elevation of 700m was 44.1±4.1 t ha-1 and in exterior it was 30.1±3.1 t ha-1. Similarly, the total carbon in interior at an elevation of 900m, 1100m, 1309m and 1500m were 48.1±5.2, 49.4±5.3, 56.2±5.6 and 58.8±5.8 t ha-1 respectively.

Moreover, the total carbon in exterior at an elevation of 900m, 1100m, 1309m and 1500m were 34.4±3.2, 36.9±4, 40.7±5.1 and 41.3±5.3 t ha-1 respectively as shown in Figure No 3.9.

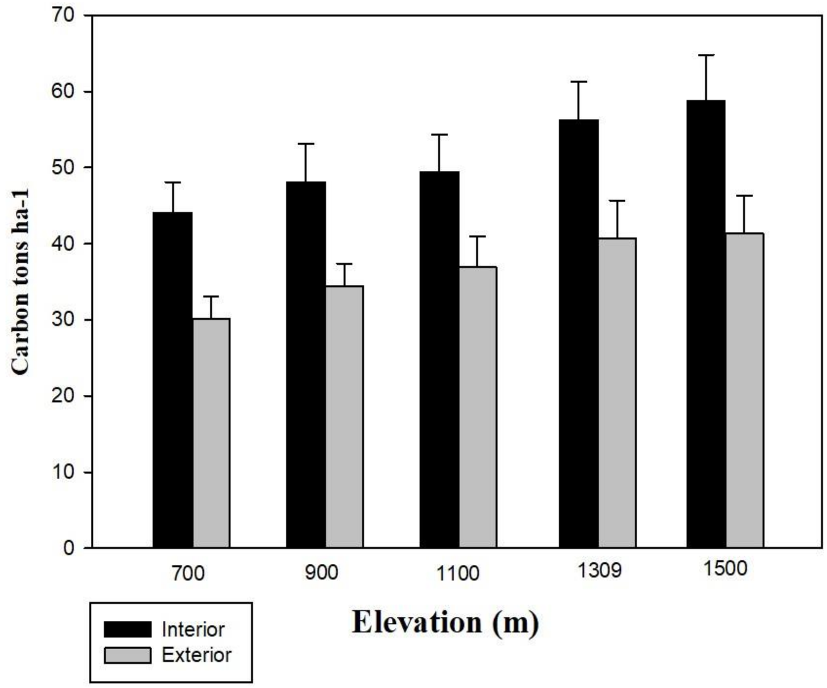


Figure No 3.9. Soil Carbon (t ha-1) in interior and exterior of the forest fragments.

Spatial variation of above ground biomass.

The study revealed that the spatial variation of carbon stock in vegetation of interior and exterior of the forest fragments in t ha-1. The total carbon in interior at an elevation of 700m, 900m, 1100m, 1309m and 1500m were 37.38±1, 47.95±2, 48.46±3, 63.37±3 and 71.89±4 carbon t ha-1. The statistical analysis showed significant (P<0.005) variation in C density along the elevation between 700m to 1500m.

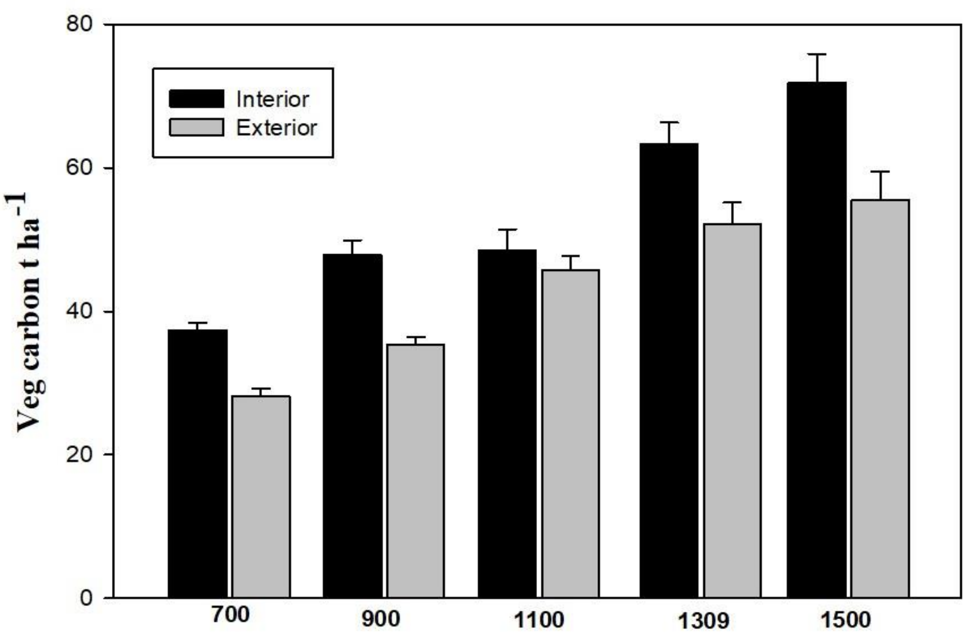


Figure 3.10. Shows vegetation carbon in interior and exterior of the forest fragments.

The figure shows the spatial variation of carbon stock in vegetation of exterior forest in t ha-1. The total carbon in exterior forest at an elevation of 700m, 900m, 1100m, 1309m and 1500m were

28.17±1, 35.42±1, 45.73±2, 52.18±3 and 55.54±4 carbon t ha-1 respectively. The statistical analysis showed significant ($P<0.005$) variation in C density along the elevation between 700m to 1500m.

Summary

The study was carried out to find the spatial variation in vegetation as well as soil carbon in the both interior and exterior of the forest fragments on the basis of elevation in Malakand division of district Buner Khyber-Pakhtunkhwa.

In this study overall 30 circular plots of size r=17.84m (1/10th ha) were laid out along the 3 transects. The transects were laid out at an elevational difference from 700-1500m. At each elevational distance of 200m, overall 5 sample plots were taken inside and 5 outside the forest fragment. For measuring the vegetation biomass carbon in the trees a non-destructive method of sampling was used. In this method the trees diameter measured (dbh) at 4.5 feet above the ground and the diameter of each tree within each plot was measured by using dia tape (Metric Diameter Tape) and for measuring tree height (H), a (haga altimeter) was used. Stem biomass (kg) was calculated from wood density into (m3) of the respective trees and volume (m3). The basic wood density of the various tree species was derived from literature. Using the Allometric equation, the contribution of roots, twigs, branches, and leaves to total biomass was estimated. The research area's total carbon stocks (t ha-1) were determined using the total biomass. Total biomass of the respective tree species multiplied by a conversion factor of 0.5, which is a frequently used conversion factor around the world. Soil samples were taken from the three 1 m2 sub-plots within each plot at three depth increments in the Centre of the subplot (0–10cm, 10–20cm, and 20–30cm) and stored individually in zip bags. A soil auger was used to extract soil core samples with a volume of 72.22 cm3. The samples' moist weights were measured on the spot with an electric balance. The samples were wrapped in plastic bags and sent to the University of Haripur, where they were air-dried before being baked for 24 hours at 105°C. The weight of the soil sample (gm) was then multiplied by the volume of the core (cm3). In a 500 mL glass beaker, 10 g of air-dried soil was mixed with 50 mL distilled water to determine the pH of the soil. Following the titration, the materials were combined and set aside for an hour. Filter these mixtures from filter paper and after this, the soil pH was calculated by using soil pH meter and EC was measured by (electrical conductivity meter). Moreover, 5 g of soil was taken from the sample into a conical flask of 500 ml volume. Then added potassium dichromate solution of 10 ml. After that 20 ml of Sulphuric Acid was mixed and left these solutions for 40 minutes. Then added 10 ml of Ortho Phosphoric Acid and also 200ml of distal water. Later added some drops of indicator for to change the colour of the solution and the reading was noted.

Total carbon vegetation biomass was calculated in interior and exterior of the forest fragments and the result showed that, the total carbon recorded in interior vegetation biomass was 266.94±27 t ha-1 while in exterior of the forest it was 134.43±15 t ha-1. Species wise carbon was also calculated in interior and exterior of the forest fragments and the result showed that, the average carbon in interior site for Pinus roxburghii was enumerated 26.99 t ha-1. The maximum Carbon 51.82 t ha-1 for Pinus roxburghii was recorded in diameter of 0.85m while minimum carbon 1.03 t ha-1 was recorded at 0.05 m dia. Likewise the average carbon in exterior site for Pinus roxburghii was enumerated 17.86 t ha-1. The maximum Carbon 23.86 t ha-1 for Pinus roxburghii was recorded in diameter of 0.85m while minimum carbon 0.57 t ha-1 was recorded at 0.05 m dia. The average carbon in interior site for Olea ferrugenia was enumerated 6.12 t ha-1. The maximum Carbon 2.5 t ha-1 for Olea ferrugenia was recorded in diameter of 0.45m while minimum carbon 0.24 t ha-1

was recorded at 0.05 m dia. The average carbon in exterior site for Olea ferrugenia was enumerated 0.92 t ha-1. The maximum Carbon 2.5 t ha-1 for Olea ferrugenia was recorded in diameter of 0.45m while minimum carbon 0.03 t ha-1 was recorded at 0.05 m dia. The average carbon in interior site for Melia azadarach was enumerated 0.64 t ha-1. The maximum Carbon 1.44 t ha-1 for Melia azadarach was recorded in diameter of 0.35m while minimum carbon 0.04 t ha-1 was recorded at 0.05 m dia. The average carbon in exterior site for Melia azadarach was enumerated 0.62 t ha-1. The maximum Carbon 1.22 t ha-1 for Melia azadarch was recorded in diameter of 0.45m while minimum carbon 0.02 t ha-1 was recorded at 0.05 m dia. The average carbon in interior site for Eucalyptus camaldulensis was enumerated 3.47 t ha-1. The maximum Carbon 7.02 t ha-1 for Eucalyptus camaldulensis was recorded in diameter of 0.45m while minimum carbon 0.33 t ha-1 was recorded at 0.05 m.

For soil carbon estimation, three samples were taken at different depths from both interior forest and exterior fragment at different elevations in each sample plot. The total carbon stored in soil of interior and exterior forest fragment in t ha-1. The total carbon in interior at elevation of 700m was 44.1±4.1 t ha-1 and in exterior was 30.1±3.1 t ha-1. Similarly, the total carbon in interior at elevation of 900m, 1100m, 1309m and 1500m were 48.1±5.2, 49.4±5.3 , 56.2±5.6 and 58.8±5.8 t ha-1 respectively. Moreover, the total carbon in exterior at elevation of 900m, 1100m, 1309m and 1500m were 34.4±3.2, 36.9±4, 40.7±5.1 and 41.3±5.3 t ha-1 respectively.

The spatial variation of carbon stock in vegetation of interior and exterior of the forest fragments in t ha-1. The total carbon in interior at an elevation of 700m, 900m, 1100m, 1309m and 1500m were 37.38±1, 47.95±2, 48.46±3, 63.37±3 and 71.89±4 carbon t ha-1. The spatial variation of carbon stock in vegetation of exterior forest in t ha-1. The total carbon in exterior at an elevation of 700m, 900m, 1100m, 1309m and 1500m were 28.17±1, 35.42±1, 45.73±2, 52.18±3 and 55.54±4 carbon t ha_1 respectively.

Conclusion and Recommendations

The findings of this study showed that more amount of carbon is stored in interior than exterior of the edge /fragment and this is consistent with the study conducted by (Sajjad et al., 2019) in which the carbon was more in interior forest than forest edge. The carbon calculated in interior forest was 266.94±27 t ha-1 and in exterior was 134.43±15 t ha-1. (Sajjad et al., 2019) reported carbon in interior forest as 320 Mg C ha-1 and 265 Mg C ha-1 in exterior of the fragment. Moreover, (Paula et al., 2011) studied the forest fragmentation and estimated carbon in forest interior as 202.8 tons' ha-1 in Atlantic forests. In the present study, the soil organic carbon assessed in forest interior was higher than forest exterior and is related to the study carried by Barros and Fearnside, (2016) in which the soil carbon was high in edges. However, the results of the study conducted by Ahmad and Nizami, (2015) showed higher carbon concentration in vegetation biomass and soil of forests in moist temperate forests.

The carbon density was revealed in Pinus roxburghii is highest therefore the department must consider the artificial regeneration in Pinus roxburghii in the exterior of the forest fragments in the Malakand division. The regression model prepared for biomass 98% (average basis) suitable for measuring biomass in future. As the carbon density in exterior and interior is dependent on biomass, the need for enhancing biomass in exterior can be enhanced by afforestation. However, the carbon density in exterior required afforestation of Pinus roxburghii species based on silvicultural requirements.

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