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Carbon Sequestration in *Pinus roxburghii*. Sarg Forest on Two Different Aspects in Daman Hill, Nepal

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ABSTRACT

By 2050 Nepal has committed to having net zero-CO2 emissions, and therefore, there is a need for improved effort to assess C accounting in energy, industry, and forestry sectors. Forests are critical to the global C cycle because they store large amounts of atmospheric C in biomass and soil. The estimation of the C sequestration potential of any forest is crucial since it significantly contributes to the mitigation of global climate change. In this context, we estimated the biomass and C sequestration on two contrasting aspects of *Pinus roxburghii*-Sarg forest in Daman hill in Makawanpur district, Nepal. The study found that tree density of 210 per ha in the southern aspect, while in the northern, it was found 180 per ha. Tree biomass estimated on the southern aspect was 434.68 t ha-1 and 426.16 t ha-1 on the north. Accordingly, on the southern forest, C stock was found to 204.30 t ha-1 as compared to 200.32 t ha-1 on the north. Both biomass increment and C sequestration rate was found to be higher on the southern aspect than the north. The study suggests that dbh classes, and aspects factors play a crucial role in biomass and C sequestration. *P. roxburghii* forests are important C sinks because of their capacity to store large amounts of C in biomass. Thus, conservation and sustainable management of these native forest ecosystems are suggested.

Keywords: aspect, biomass increment, carbon sequestration, dbh classes, tree density

INTRODUCTION

Climate change on Earth is one of the most pressing environmental issues that humankind is now facing. Earth's temperature has risen by 1 0C since the beginning of the industrial revolution, and various anthropogenic emissions are causing an additional 0.2 0C of warming on average per decade (IPCC, 2018). It is predicted that between 2030 and 2050, the average global temperature will rise by 1.5 0C if the same trend continues (IPCC, 2018). The primary reason for this concern is the increased emission of anthropogenic greenhouse gases (GHGs), mainly carbon-dioxide (CO2) (IPCC, 2007; Korkanc, 2014; Aryal et al., 2017). Forests contribute to the reduction of global climate change as it stores large amount of carbon (C) in biomass and soil (Houghton, 2007; Solomon, 2017). Therefore, increasing C sequestration by conserving C pools and increasing forest cover has been recommended as a viable means to reduce increased CO2 concentrations and increased C sink, which would help to combat the issue of global warming (Watson et al., 2000).

UNFCC defines 'C sequestration as the process of removing C from the atmosphere and storing it in a reservoir' (UNFCC, 2022). Forests are global C sinks, and offer varieties of other ecological services (Lal, 2005; Solomon, 2017; Zhao et al., 2019; Buchanan et al., 2021). Forest absorbs C through the natural process of photosynthesis from the atmosphere and stores the C in their stems, branches, leaves, bark, and roots. Globally, forest holds about 80% of terrestrial above-ground and below-ground biomass carbon of 40% which is very important to regulate the global C cycle and for regulation of climate and reducing climate instability (Kirschbaum, 1996; Aukland, 2002; Dogra & Chauhan, 2016). Therefore, estimating the ability of terrestrial forest ecosystems to store C is crucial to address the climate change issue caused by global warming. By conserving and safeguarding the C pools in the current forest ecosystem, the international goal of increasing the C sink and reducing C sources can be attained effectively (Brown et al., 1996; Hamburg, 2000).

The *Pinus roxburghii* (Chir pine) is an important conifer species is distributed in Nepal's mid-hill forests between 900 and 1950m (Jackson, 1994). The species currently represents about 9% of the total forest cover of the country, the third most important tree species in terms of stem volume coverage (DFRS, 2015). The species is also valued for multiple benefits such as timber, fuel and fodder, and other environmental services and local and national revenue generation. Conifer forests serve as a vital C reservoir among forest ecosystems (Gucinski et al., 1995; Pant & Tewari, 2014; Ghimire, 2022), and among conifer forests *Pinus roxburghii* sequester the most C (Negi et al., 2003; Afzal & Akhtar, 2013). Their ability to absorb CO2 from the atmosphere as well as their immense capacity for storage in biotic and abiotic components, is vital in contributing to the mitigation of climate change. The amount of C stored in a forest and its capacity to absorb CO2 are controlled by several variables, including the forest's age, type, size, density, and biomass, as well as its topography, climate, and land management (Zhang et al., 2011; Vayreda et al., 2012; Kushal & Baishya, 2021). Therefore, the estimation of biomass and C sequestration within the forest ecosystems is critical aspect as it allows us to forecast the long-term sequestration of C (Pant & Tiwari, 2013; Ghimire et al., 2018).

OBJECTIVES OF THE STUDY

This study focused on estimating the biomass and C sequestration in the P. roxburghii forest of Daman Hill of central Nepal on two contrasting aspects.

MATERIALS AND METHODS

Study Site

Two study sites: Deurali and Bagmara forest in the Makawanpur district of Nepal, located between 27o36’29” N and 85o05’39” E, were used for the study (Figure 1). The selected study sites had differences in terms of altitudes and aspects. The Deurali forest is situated on the southern part at 1350m amsl, whereas Baghmara forest is located on the northern part at 1100m *amsl*.

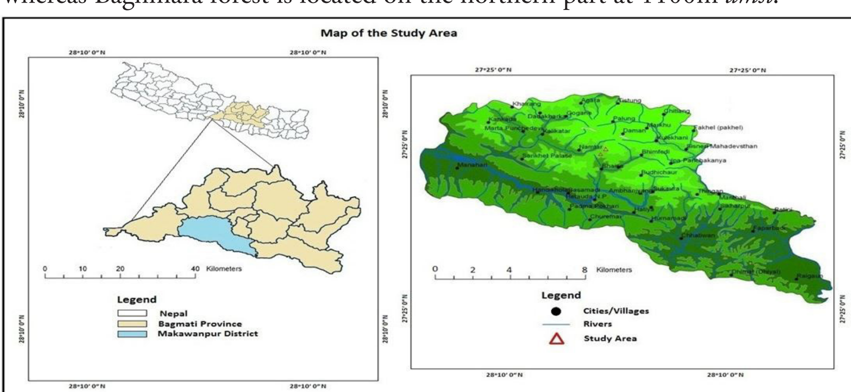

Figure 1. Map showing the study site.

For the study, 7 permanent rectangular plots of 15 *15 m2 were established on each aspect, and the study conducted from November 2015 and November 2016. The forest analysis was carried out in both aspects. We located, marked, and measured the diameter at breast height (dbh) and height of every tree or pole in the allocated plots. The diameter was measured with diameter tape (1.3 m from the ground level) and tree height with the Laser Rangefinder. Trees with dbh from 10-30 cm were considered poles, and individuals with dbh above 30cm were taken as trees. Further, the measured trees were classified into four different diameter classes concerning dbh as 10-30cm, 31-60cm, 61-90 cm, and >91cm.

Data Analysis

Forest data were analyzed for stand density, above-ground biomass, and carbon stock. Biomass accumulation of forests was estimated by already established allometric relationships for *P. roxburghii* forests Chave et al. (2005), and the carbon storage was calculated by the formula suggested by IPCC (2006).

Biomass Estimation

For the study, the allometric equation proposed by Chave et al. (2005) was used to determine the above-ground tree/pole biomass. This equation is based on forest stand types and climate, and the equation is a good fit for moist forest stands in Nepal (ANSAB, 2011).

AGTB =0.0509 * $\rho D^2 H$

Where,

AGTB =above -ground tree biomass (kg)

ρ = Specific wood density (gcm-3)

D= tree/pole diameter at breast height (cm)

H= tree/pole height (m)

The value of ρ for *Pinus roxburghii* is taken as 0.650 gcm-3 (Jackson, 1994).

Carbon Stock and Sequestration Rate Estimation

The stock method was used to estimate the total biomass carbon accumulation for the forest. This amount represents a standard C content for the forest species under investigation. The corresponding biomass was multiplied by the default C percentage of 0.47 to determine the carbon stock (IPCC, 2006). The biomass was calculated for the first year (B_1) and the second year (B_2), respectively. The annual biomass storage (ΔB) was calculated as follows: $\Delta B = B_2 - B_1$. The difference between carbon stocks measured in the first year (Y1) and the second year (*Y2*) was referred to as the carbon sequestration rate (IPCC, 2006; Tewari et al., 2008).

RESULTS AND DISCUSSION

Characteristics of Forest Stand

The characteristics of forest stand concerning two aspects are presented in Table 2. The study found that the southern aspect (210 per ha) of the *P. roxburghii* forest stand had higher tree density than the northern (184 per ha). The average dbh observed during the first year was 41.43cm in the southern aspect and 48.93cm in the northern. So, in the second year, it was reported that 42.15cm in the southern aspect and 49.06cm in the northern (Table 2). Similarly, the average height for the first year was 14.80m in the southern aspect and 18.38m in the northern. While in the second year, it was measured 15.04cm in the southern aspect and in the northern aspect it was reported 18.48cm. This study found that the northern aspect had a higher average dbh and height than the southern.

Table 1

Description of the study sites

S.N	Sites	Altitude (m)	Aspects	Forest species
1.	Deurali	1350	Southern	*Pinus roxburghii*
2.	Bagmara	1100	Nothern	*Pinus roxburghii*

Table 2

Forest stands characteristics with reference to aspects

Site	Density	Average diameter (cm)		Average height (m)	
	(number per ha)	Year 1	Year 2	Year 1	Year 2
Deurali forest	210	41.43	42.15	14.80	15.04
Bagmara forest	184	48.93	49.06	18.38	18.48

Forest Biomass and Carbon Sequestration

Table 3 below presents aspect-wise biomass and C stocks. The total biomass in the first year on the southern aspect was 427.83t ha^{-1} which increased to 434.68 t ha^{-1} in the second year. Similarly, biomass in the northern aspect was 423.25 t ha^{-1}

in the first year to 426.16 t ha^{-1} in the second. As a result, the total above-ground C stock on the southern aspect was 201.08 t ha^{-1} in the first year and 204.30 t ha^{-1} in the second year. While in the northern aspect, total above-ground C stock was 199.02 t ha^{-1} in the first year and 200.32 t ha^{-1} in the second year. The results found that the average annual biomass increment in the southern aspect was 6.85 t ha^{-1} and 2.71 t ha^{-1} in north. Accordingly, the average C sequestration rate in the southern aspect was 3.22 t ha^{-1} yr^{-1} and 1.30 t ha^{-1} yr^{-1} in north.

Table 3

Biomass and carbon stock regarding two aspects

Sites	Biomass (t ha^{-1})		Biomass increment (t ha^{-1}yr^{-1})	Carbon stock (t ha^{-1})		Carbon sequestration (t ha^{-1}yr^{-1})
	Year 1	Year 2		Year 1	Year 2	
Deurali	427.83	434.68	6.85	201.08	204.30	3.22
Bagmara	423.45	426.16	2.71	199.02	200.32	1.30

Biomass and Carbon Sequestration in Different Diameter Classes

Table 4 highlights the aspect-wise biomass and C sequestration rate of different diameter classes. The study found that the maximum above-ground biomass was accumulated in a diameter class of > 90cm in the southern aspect, while in the northern aspect, it was found in the 61-90cm diameter class. Accordingly, top C stock was observed in > 90 cm diameter class in the southern aspect, and in the northern aspect, it was reported in the 61-90 cm diameter class. The study found that the highest biomass increment was recorded in 31-60 cm diameter class in both aspects (Table 4). Accordingly, the highest C sequestration rate was reported in the diameter class of 31-60cm in both the southern (1.72 t ha^{-1} yr^{-1}) and northern aspects (0.51 t ha^{-1} yr^{-1}) (Table 4). Trees with a diameter class of >90cm contributed higher biomass and C stock accumulation in the southern aspect and by the 61-90cm class in northern part (Table 4).

Table 4

Biomass and carbon sequestration in different dbh classes

Site	Diameter class	Biomass ($t\ ha^{-1}$)		Biomass increment ($t\ ha^{-1}yr^{-1}$)	Carbon stock ($t\ ha^{-1}$)		Carbon sequestration ($t\ ha^{-1}yr^{-1}$)
		Year 1	Year 2		Year 1	Year 2	
Deurali forest	10-30	8.08	9.10	1.02	3.80	4.28	0.48
	31-60	63.40	67.07	3.67	29.80	31.52	1.72
	61-90	84.57	86.08	1.51	39.75	40.46	0.71
	>90	271.78	272.65	0.87	127.74	128.14	0.40
Bagmara forest	10-30	12.06	12.50	0.44	5.67	5.87	0.20
	31-60	64.57	65.65	1.08	30.35	30.86	0.51
	61-90	250.69	251.75	1.06	117.82	118.32	0.50
	>90	95.88	96.33	0.45	45.06	45.27	0.21

The present study highlights the first reporting of biomass and C sequestration rate in the *P. roxburghii* forest of Daman Hill on two contrasting aspects in Makawanpur district, Nepal. The reported tree density values in the study were about 210 per ha in the southern aspect, and 184 per ha in the north, which is in line with Sharma et al. (2020), who reported that the tree density for *P. roxburghii* forest was 339 trees per ha in the Kathmandu district, Nepal. Ghimire et al. (2018) also said a tree density of 107 per ha in a *P. roxburghii* forest in the Makawanpur district, Nepal. Similar tree densities have been observed in Pakistan's *P. roxburghii* forest (275-320 per ha) in Kashmir Himalaya (Shaheen et al., 2016) and India's *P. roxburghii* forest (380 per ha) in the Garhwal Himalaya (Ballabha et al., 2014). Slight variations should be attributed to differences in topography, climate, and land management modalities.

The findings show that in both aspects, trees of the dbh classes 61-90 cm and >90 cm contributed the most to forest biomass, while those in the dbh class 10-30 cm contributed the least (Table 4). As a result, the dbh classes 61-90cm and >90 cm had the maximum carbon stock accumulation. However, the dbh classes 11-60cm on both southern and northern aspects were reported to have higher rates of biomass and carbon sequestration (Table 4). The results is align with Adhikari (2011), who found higher biomass and C stock in the mature tree of higher dbh classes in a community forest of Salyan district, Nepal. Further, similar results were also reported by Pant and Tiwari (2013) in *P. roxburghii* in Kumaun Central Himalaya, India. Even though the average dbh and height of trees in the southern aspect were lower than those in the northern aspect (Table 4), the southern aspect had a more significant biomass increment and carbon sequestration rate. The presence of more mature trees (with higher dbh classes) could be the primary reason for higher biomass and carbon sequestration in the northern aspect. Overall, C sequestration rate in *P. roxburghii* reported in this study is 2.26 t $ha^{-1}yr^{-1}$. The C sequestration rate of 1.35 t $ha^{-1}yr^{-1}$ was reported in the pine forest of Lalitpur district (Baral et al., 2009). Therefore, importance should be given to the protection and sustainable management of these natural forests, which are better at storing large amounts of C and contribute significantly to reducing global warming.

CONCLUSIONS

This study reports the first study of biomass and C sequestration rate in the *P. roxburghii* forest in Bagmati Province, Nepal. It is well known that the *P. roxburghii* forest in Nepalese Himalaya is critical in providing multiple environmental services, including the production of timber, fuel, and food, as well as income generation. This study reported that dbh classes, and aspects play a significant role in biomass and C sequestration. Young trees had a profound role in biomass increment and C sequestration. The overall biomass and C sequestration rate in *P. roxburghii* forest was 4.78 t $ha^{-1}yr^{-1}$ and 2.26 t $ha^{-1}yr^{-1}$, respectively. These *P. roxburghii* forests are important C sinks because of their capacity to store large amounts of C. The potentiality of these forests in connection with C sequestration can contribute to the country earning C credits, minimize deforestation as well as to eradicate poverty in the long run. Therefore, conservation and sustainable management of these native forest ecosystems is recommended.

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