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Research Article

Are Sacred Groves of Kathmandu Valley Efficient in Sequestering Carbon?

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Ability of plant to fix atmospheric carbon dioxide and store it in biomass is contributing to global carbon cycle. Sacred groves, one of the regimes for forest management, play role in regulating climate by acting as sinks for carbon. Aiming to assess sequestrated carbon in tree the study was conducted in two sacred groves of Kathmandu valley, Nepal. Concentric circular plots of 20 m radius were used for data collection. Allometric equation having height, diameter, and specific gravity of tree was used to determine biomass. The calculated biomass of tree was converted to the carbon stock by using carbon fraction. Tree species of both sacred groves sequestered 15.08 metric tons of carbon. The carbon stock was high in *Quercus-Myrsine* forest and low in *Schima-Pyrus* forest.

1. Introduction

Carbon sequestration is the process of capturing and long-term storage of atmospheric carbon dioxide (CO_2) in the biosphere. Carbon is one of the essential elements of life and green plants have unique ability to assimilate it in the form of carbon dioxide as raw material for food preparation [1]. Thus, forests play a key role in climate change; both sinks and sources of carbon dioxide [2] and the rate of sequestration depend on the growing stages of tree. The rate is highest in young age of trees between 20 and 50 years [3]. Above-ground biomass of woody vegetation is one of the largest carbon pools. Above-ground biomass is determinant to the ecosystem's potential for carbon storage. Forest trees are contributing to reduce atmospheric CO_2 concentration by accumulating it as biomass [4]. This plays an important role in regulating the concentration of atmospheric CO_2 and global climate change [5].

Forest management regimes in Nepal include eleven different types and sacred groves, also called religious forest, which is one among them. Sacred groves are a patch of forest protecting rich biodiversity and conserved by local people based on their indigenous cultural, religious belief, and taboos [6]. In Nepal, there are culturally rich local societies of Kathmandu valley having traditionally managed sacred groves as a result of their strong belief and taboos associated with religion. Sacred groves, which are managed by the local communities, are also playing a significant role in the conservation of plant biodiversity. The study aims to analyze the efficiency of these forest trees in sequestering carbon. This will be a good basis to the incentive provisioned for Reducing Emission from Deforestation and Forest Degradation (REDD) mechanism.

In this study, two sacred groves of Kathmandu valley in midhill physiographic zone of Central Development Region of Nepal were selected. The first one is located in the oldest and most famous religious site of Hindu culture, called as Pashupati Sacred Grove (PSG), belonging to Lord Pashupatinath Temple. This site covers an area of 83.55 ha and is located in $27^\circ 42' 25''$–$27^\circ 42' 36''$N latitude and $85^\circ 20' 12''$–$85^\circ 21' 29''$E longitude at 1,300 m elevation. Pashupati Area Development Trust, a government organization, has undertaken the management responsibility of this grove. The second is Bajrabarahi Sacred Grove (BSG) located at southeast corner of Kathmandu valley, in Chapagaun Village Development Committee (VDC) of Lalitpur district. It is located at 1,440 m elevation between $27^\circ 36' 15.88''$–$27^\circ 36' 24.62''$N latitude and $85^\circ 19' 40.58''$–$85^\circ 19' 50.59''$E longitude covering 18.29 ha area.

Community based organization called Joytidaya Sangh is managing this grove. These areas are located in subtropical monsoonal climatic zone. The average annual temperature becomes maximum (31.9°C) during June and minimum during the months of December (2.0°C). The average relative humidity ranged between 70% and 86%. The average annual rainfall exceeds more than 1480.4 mm and about 80% of rainfall occurs during the monsoon season (June to September) [7]. The study area is characterized with 4 distinct seasons, spring (March–May), summer (June–August), autumn (September–November), and winter (December–February).

2. Materials and Methods

Data for tree level characteristics were collected from concentric circular plots [8] established in parallel transects of 150 m apart from each other traversing north-south direction, with the help of Google earth image. Tree level characteristics like height and diameter at breast height (DBH) of each tree inside the concentric circular plot were collected. Plots were constructed at 100 m interval within each transect and established 25 m inside the forest margin to reduce the edge effect.

Plot center of each CCP was identified by using Geographic Position System (GPS) incorporating already identified coordinates from Google Earth images. The CCP consists of four circular plots: plot with the radius of 20 m (area = 1257.1 m^2) all big size trees with DBH ≥30 cm were measured; plot with the radius 15 m (area = 707.1 m^2) trees with DBH 20.0–29.9 cm were measured; the third plot with the radius 8 m (area = 201.1 m^2) trees with DBH from 10.0 cm to 19.9 cm were measured; and fourth plot with the radius 4 m (area = 50.2 m^2) trees with DBH from 5.0 cm to 9.9 cm were measured. The height and DBH of trees (woody plant with single bole, ≥5 cm DBH and >1.3 m height) were measured with the help of Vertex IV with Transponder T3 and diameter tape, respectively.

Importance values index (IVI) of individual trees species recorded in the particular vegetation was calculated by adding the relative values of frequency, density, and dominance [9]. Name of each forest type was determined by ordering the importance values of recorded tree species. Maturity index [10] of forest community was calculated, which is the ratio of sum of frequencies of individual species in the habitat and total number of species in the habitat.

The Shannon-Weiner species diversity index [11] was calculated by using the following formula:

$$H = -\sum_{i=1}^{s} (p_i)(\log p_i), \tag{1}$$

where H is Shannon index of species diversity, p_i is proportion of total number of individual of species i, and s is number of species.

Evenness was calculated by dividing Shannon-Weiner diversity index with the log value of total number of species found in the area. Amount of carbon in tree species was calculated from the above-ground biomass. Above-ground biomass of trees was analyzed by using allometric equation which includes information about DBH in cm, tree height in m, and wood specific gravity in g cm^{-3} [12]. The climate of the study areas is moist, with 1480 mm average annual rainfall, and has subtropical evergreen forests; the following allometric equation developed by Chave et al. [13] was appropriate to use for the analysis of above-ground tree biomass (AGTB):

$$\mathrm{AGTB} = 0.0509 \rho D^2 H, \tag{2}$$

where AGTB is above-ground tree biomass (kg), ρ is wood specific gravity (g cm^{-3}), D is tree diameter at breast height (cm), and H is tree height (m).

The wood specific gravity was extracted from published literatures [14, 15]. The biomass stock densities were converted to carbon stock densities by using the IPCC (2006) [16] carbon fraction of 0.47. Root-to-shoot ratio value of 1 : 5 (20% of AGTB) was used to find below-ground biomass [17]. Total carbon stock density of tree in particular vegetation was calculated by summing up above-ground and below-ground carbon stock. Weight of carbon in the tree was multiplied by 3.67 to determine the weight of carbon dioxide sequestered [18]. Analysis of variance was conducted to determine the mean difference between species richness, diversity index, evenness, and maturity index. Paired t-tests were used to compare carbon with species richness, diversity index, evenness, and maturity index.

Table 1: Carbon stock density in the trees of different forests.

Forest type	Carbon stock (ton)
Schima-Pyrus forest (PSG)	113.98
Myrsine-Persea forest (PSG)	2,602.83
Quercus-Myrsine forest (PSG)	12,221.85
Neolitsea cuipala forest (BSG)	145.68
Total	**15,084.34**

3. Results

On the basis of importance value, three types of forest namely *Schima-Pyrus*, *Myrsine-Persea,* and *Quercus-Myrsine* were recorded in PSG, whereas single forest type, *Neolitsea cuipala*, was identified in BSG [19]. Trees species of PSG and BSG together sequestered 15,084.34 tons of carbon. The highest amount of average carbon (12,221.85 ton) was sequestered by *Quercus-Myrsine* forest followed by *Myrsine-Persea* (2602.83 ton) forest. The lowest carbon stock was recorded from *Schima-Pyrus* forest, 113.98 ton (Table 1).

3.1. Schima-Pyrus Forest. In this forest, *Schima wallichii* was found to be the most important tree species (IVI = 81.4) followed by *Pyrus pashia* (IVI = 51.5). There were 14 species of trees with the population of 319 individuals per hectare. Average tree height of this forest was 15.2 ± 7.8 m and average DBH was 40.9 ± 18.2 cm. Average carbon stock density of each species of tree in this forest was 5.45 ton ha^{-1}. This forest sequestrated 1595.75 tons of total carbon and *Schima wallichii* was the most (51.68 ton ha^{-1}) carbon sequestering tree followed by *Persea odoratissima* (10.41 ton ha^{-1}) and *Araucaria bidwillii* (3.59 ton ha^{-1}) (Table 2). The total carbon dioxide sequestration by this forest was 5.86 metric ton.

3.2. Myrsine-Persea Forest. The dominant tree of this forest was *Myrsine capitellata* (IVI = 142.0) followed by *Persea odoratissima* (IVI = 38.9). Eleven tree species were found in this forest; their average height and DBH were 11.7 ± 5.0 m and 30.7 ± 17.4 cm, respectively. This forest includes 603 individual trees per hectare. The total carbon stock density of the trees species in this forest was 28631.17 ton and average carbon stock density of each tree species in this forest was 115.68 ton ha^{-1}. In this forest *Schima wallichii* was the most carbon sequestrating (359.06 ton ha^{-1}) species followed by *Myrsine capitellata* (212.56 ton ha^{-1}) (Table 2). Total carbon dioxide sequestrated in this forest was 105.08 metric ton.

3.3. Quercus-Myrsine Forest. The dominant tree species of this forest was *Quercus glauca* (IVI = 138.5) followed by *Myrsine capitellata* (IVI = 56.2). In this forest five tree species were recorded; their average height and DBH were 12.6 ± 5.1 m and 28.5 ± 13.7 cm, respectively. The number of stems reported from this forest was 677 individuals per hectare. Average carbon stock density in the tree species of this forest was 304.78 ton ha^{-1} and carbon stock was 61109.27 ton. In this forest *Schima wallichii* was more carbon sequestrating tree species (821.52 ton ha^{-1}) followed by *Quercus glauca* (321.52 ton ha^{-1}) (Table 2). Total carbon dioxide sequestrated by the tree species of this forest was 224.27 metric ton.

3.4. Neolitsea Cuipala Forest. In this forest 18 tree species were recorded. Among the reported tree species *Neolitsea cuipala* was dominant tree (IVI = 111.3) followed by *Castanopsis indica* (IVI = 36.9). The average height and DBH of the reported trees in this forest were 18.6 ± 12.7 m and 36.6 ± 19.4 cm, respectively. This forest included 432 individual trees per hectare. Total carbon stock density of tree species in this forest was 143.37 ton ha^{-1} and the average carbon stock density of each tree species was 7.96 ton ha^{-1}. The higher carbon was sequestrated by *Neolitsea cuipala* (49.71 ton ha^{-1}) followed by *Castanopsis indica* (31.29 ton ha^{-1}) (Table 2). Total carbon dioxide sequestrated in this forest was 9.62 metric ton.

3.5. Species Richness and Carbon Stock. In *Neolitsea cuipala* forest of BSG, the number of tree species was higher (n = 18) but less than amount of carbon stock (143.37 ton ha^{-1}) in comparison to other forest types of PSG, whereas in *Quercus-Myrsine* forest of PSG the carbon stock was highest (1523.92 ton ha^{-1}) and the number of tree species was found to be lowest (n = 5). The lowest carbon stock was recorded from *Schima-Pyrus* forest (76.35 ton ha^{-1}) whereas the tree species richness was high (n = 14). In *Myrsine capitellata* forest the number of tree species was 11 with carbon stock density 1272.49 ton ha^{-1} (Table 3). The available number of tree species significantly affects the carbon sequestration of the forest of study area (t = 1.98, $p < 0.05$, df = 6).

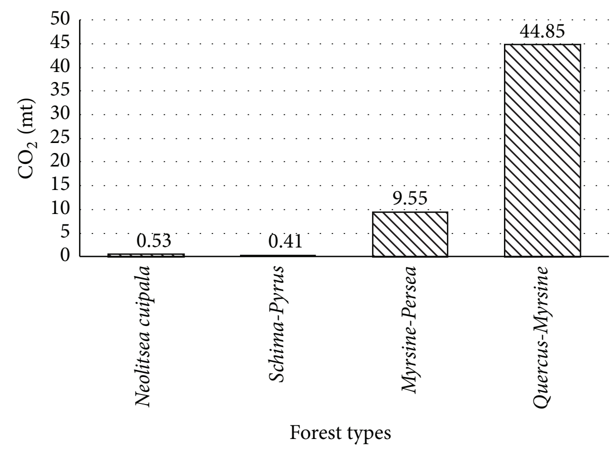

Figure 1: Total amount of carbon dioxide assimilation by trees in different forests.

3.6. Diversity, Evenness, and Carbon Stock. In both studied sites *Schima-Pyrus* forest was found to be more diverse than other forest types. In this forest Shannon-Wiener diversity index was found to be highest (1.84) but carbon stock was lowest (76.35 ton ha^{-1}). In *Quercus-Myrsine* forest carbon stock was found to be highest (1523.92 ton ha^{-1}) but the diversity index was found to be lowest (1.19). In *Neolitsea cuipala* forest the carbon stock was 143 ton ha^{-1} and diversity index was 1.80. Similarly, in *Myrsine-Persea* forest carbon stock was 1272.49 ton ha^{-1} and diversity index was 1.35 (Table 3). There was significant effect of diversity index in carbon stock of the forest in the study area (t = 2.00, $p < 0.05$, df = 6).

Evenness value indicates that the available tree species in *Quercus-Myrsine* forest were more evenly distributed (0.74) than other forest types. The carbon stock was found to be highest (1,523.92 ton ha^{-1}) in this forest. Tree species in *Myrsine-Persea* forest were less evenly distributed (0.56) but carbon stock was found to be high (1,272.49 ton ha^{-1}). In *Schima-Pyrus* forest the carbon stock was lowest (76.35 ton ha^{-1}) with high evenness value (0.70). In *Neolitsea cuipala* forest the carbon stock was found to be 143.37 ton ha^{-1} and evenness was 0.62 (Table 3). The evenness of tree species significantly affect the available carbon stock of the forest in the study area (t = 2.01, $p < 0.05$, df = 6).

3.7. Maturity and Carbon Stock. Maturity index of *Quercus-Myrsine* forest was found to be highest (80.0) with highest carbon stock (1523.92 ton ha^{-1}). Similarly, the maturity index of *Schima-Pyrus* forest was found to be lowest (29.4) with lowest carbon stock (76.35 ton ha^{-1}). The maturity indices in *Myrsine-Persea* and *Neolitsea cuipala* forests were 43.6 and 33.9 with their carbon stocks 1272.49 ton ha^{-1} and 143.37 ton ha^{-1}, respectively (Table 3). There were no significant effects of maturity index (t = 1.88, $p < 0.05$, df = 6) and carbon sequestration.

3.8. Carbon Dioxide Assimilation. It was found that the trees species of both study sites assimilate 55.34 metric tons of average carbon dioxide. The highest amount of carbon

Table 2: Carbon stock (per ha) of trees in different forests of the study area.

SN	Tree species	Forest types			
		Schima-Pyrus	*Myrsine-Persea*	*Quercus-Myrsine*	*Neolitsea cuipala*
1	*Albizia julibrissin* Durazz.	—	—	—	0.90
2	*Albizia lebbeck* (L.) Benth.	—	—	—	0.43
3	*Alnus nepalensis* D. Don	0.34	—	—	
4	*Areca catechu* L.	—	—	—	1.24
5	*Araucaria bidwillii* Hook.	3.59	—	—	
6	*Castanopsis indica* (Roxb.) Miq.	—	—	—	31.29
7	*Castanopsis tribuloides* (Sm.) A. DC.	0.09	139.74	—	5.37
8	*Cassia fistula* L.	—	—	—	3.45
9	*Celtis australis* L.	2.02	—	—	0.54
10	*Choerospondias axillaris* (Roxb.) Burtt & Hill.	—	64.63	—	13.74
11	*Eurya acuminate* DC.	0.11	—	—	
12	*Hymenodictyon excelsum* (Roxb.) Wall.	0.12	—	—	0.48
13	*Myrica esculenta* Buch.-Ham. ex D. Don	—	23.64	—	1.75
14	*Myrsine capitellata* Wall.	0.96	212.56	139.87	2.03
15	*Myrsine semiserrata* Wall.	—	8.44	—	0.73
16	*Neolitsea cuipala* (Buch.-Ham. ex D. Don) Kosterm.	—	—	—	49.71
17	*Persea odoratissima* (Ness) Kosterm.	10.41	198.40	220.39	0.52
18	*Pyrus pashia* Buch.-Ham. ex D. Don	2.24	21.96	—	
19	*Quercus glauca* Thunb.	2.28	38.62	321.52	
20	*Rhus succedanea* L.	—	—	—	0.64
21	*Sapium insigne* (Royle) Benth. ex Hook.f	—	—	—	0.57
22	*Schima wallichii* (DC.) Korth.	51.68	359.06	821.52	27.02
23	*Stranvaesia nussia* (D. Don) Decne.	0.36	30.07	—	
24	*Syzygium cumini* (L.) Skeels.	1.94	175.38	20.63	2.96
25	*Ziziphus incurva* Roxb.	0.22	—	—	

Table 3: Species richness, diversity, evenness, maturity, and carbon stock density in the trees of different forests.

Forest type	Number of species	Shannon diversity	Evenness	Maturity index	Carbon stock (ton ha^{-1})
Schima-Pyrus	14	1.84	0.70	29.4	76.35
Myrsine-Persea	11	1.35	0.56	43.6	1272.49
Quercus-Myrsine	5	1.19	0.74	80.0	1523.92
Neolitsea cuipala	18	1.80	0.62	33.9	143.37

dioxide was sequestrated in *Quercus-Myrsine* forest which sequestered 44.85 metric tons of carbon dioxide. The lowest sequestration of carbon dioxide was found in *Schima-Pyrus* forest. This forest sequestrated 0.41 metric ton of carbon dioxide in the trees (Figure 1).

4. Discussions

The sequestrated carbon in the forest varied according to the forest type and density of trees. Species composition of the forest also differs in the average amount of assimilated carbon in the particular forest type. Trees of PSG and BSG sequestrated 15,084.34 ton of carbon and 55.34 metric ton of carbon dioxide, respectively. The highest amount of carbon stock (12221.85 ton) and CO_2 (44.85 mt) was accumulated in *Quercus-Myrsine* forest due to having larger tree and higher density ($n = 677\,ha^{-1}$). In this study area *Schima wallichii* (821.52 ton ha^{-1}) was highest carbon sequestrating tree species (Table 2). Similar study conducted in the forest of Far Western Terai physiographic region of Nepal recorded average tree biomass of 186.6 ton ha^{-1} and *Shorea robusta* exhibited the highest biomass of 89.8 ton ha^{-1}, followed by *Terminalia tomentosa* 41.0 ton ha^{-1}, with one forest type *Shorea robusta* [20]. Similar kind of study was conducted in buffer zone community managed forest of Chitwan National Park at central lowland Nepal. Trees of that buffer zone community forest had sequestered 3333.7 tons of carbon and 12.1 metric ton carbon dioxide. The highest amount of carbon (1206.9 ton) and CO_2 (4.4 mt) was accumulated by *Dalbergia sissoo* forest. The highest carbon sequestrating tree was *Dalbergia sissoo* (262.5 t/ha) [18]. The difference found in the forest category and carbon stocks in between these studies were due to difference in physiographic region, species composition, and wood density of tree species. In the present study there is significant difference ($F = 13.42$, $\alpha = 0.05$, df = 3, 12) of the mean among species richness, diversity index, evenness, and maturity index of the studied forest.

Study about the carbon stock conducted in BSG with the sampling intensity of 0.6% recorded 1011 ton ha^{-1} of carbon stock. Among reported six major tree species, the average carbon stock was high in *Schima wallichii* (429.5 ton ha^{-1}) followed by *Castanopsis indica* (19 ton ha^{-1}) [21]. The present study conducted in same area with sampling intensity of 6.9% and recorded carbon stock density (143.37 ton ha^{-1}) was lower than that of previous study [21]. The reported tree species were found to be higher ($n = 18$) in current study.

Generally around the world there is positive relationship between biodiversity and carbon stock [2]. Similar result was reported in the collaborative forest of low land Terai region of Nepal [22]. The current study also showed significant effect of diversity index in carbon stock of the forest ($t = 2.00$, $p < 0.05$, df = 6).

The maturity index of forest community of the study area was higher in the *Quercus-Myrsine* forest. The largest girth sized and tallest *Schima wallichii* trees were the main carbon sink in this forest (Table 2). The amount (ton ha^{-1}) of assimilated carbon in the forest types of study area varied according to the girth size, height, and wood specific gravity of tree species. The more developed plant community has high maturity index [10]. The maturity index is an important indicator for the maturity of plant communities in a specific area and season [23]. In present study the result was based on one time data collection; thus there was no comparison of maturity index in different season. Though the maturity index of forest community has not significantly affected ($t = 1.88$, $p < 0.05$, df = 6) the carbon stock in the forest of study area, the carbon stock was found to be highest (1523.92 ton ha^{-1}) in the forest with higher maturity index in *Quercus-Myrsine* forest (MI = 80) than the *Schima-Pyrus* forest (MI = 29.4) of PSG. It showed that mature forest community sequestered higher carbon as indicated by the other study conducted in lowland area of Nepal [18]. However, other studies show that the old growth, mature forest with larger girth size, and taller trees are large carbon pool [24].

5. Conclusion

Sacred grove is one of the management regimes applied for the forest conservation in Nepal. In the studied sacred groves three forest types in PSG and one forest type in BSG were recognized based on IVI of tree species. Sequestrated carbon and carbon dioxide were found to be high in *Quercus-Myrsine* and low in *Schima-Pyrus* forests of PSG. Amount of carbon sequestration in the studied groves vary according to species composition, density of available trees, and wood specific gravity of tree species. Sacred groves offer safeguarding of forest ecosystems and are also contributing to mitigate climate change through carbon sequestration.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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