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Corrigendum

Corrigendum to "Are Sacred Groves of Kathmandu Valley Efficient in Sequestering Carbon?"

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In the article titled "Are Sacred Groves of Kathmandu Valley Efficient in Sequestering Carbon?" [1], a mistake occurred during the calculation of carbon in two forest types of PSG-Quercus-Myrsine forest and Myrsine-Persea forest. While using the following formula: AGTB = 0.0509 ρ D2 H, the authors forgot to multiply the value by 0.0509, which affects many parts of the article. The corrected article is as follows.

Abstract

The ability of plants to fix atmospheric carbon dioxide and store it in biomass is an important process contributing to the global carbon cycle. Sacred groves, one of the regimes for forest management in Nepal, play an important role in regulating local climate by acting as sinks for carbon. Aiming to assess sequestrated carbon in trees, this study was conducted in two sacred groves of Kathmandu valley, Nepal. Concentric circular plots of 20 m radius were used for data collection. An allometric equation involving the height, diameter, and specific gravity of trees was used to determine biomass. The calculated biomasses of trees were converted to the carbon stock using the carbon fraction. Tree species in both sacred groves sequestered 1014.23 metric tons of carbon, but the carbon stock was found to be the highest in *Quercus-Myrsine* forest and lowest 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 a unique ability to assimilate it in the form of carbon dioxide as a raw material for photosynthesis [1]. Thus, forests play a key role in climate change, and both sinks and sources of carbon dioxide [2], as well as the rate of sequestration, depend on the growing stages of trees. The rate is the highest in young trees that are between 20 and 50 years old [3]. Above-ground biomass of woody vegetation is one of the largest carbon pools and determines the ecosystem's potential for carbon storage. Forest trees contribute towards reducing 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].

Current forest management regimes in Nepal include eleven different forest types and sacred grove (religious forest) is one among them. Sacred groves are patches of forest that protect rich biodiversity and are conserved by local people based on their indigenous cultural and religious beliefs and taboos [6]. Culturally and religiously rich local communities of Kathmandu valley have traditionally managed sacred groves as a result of their strong beliefs and taboos associated with religion. Such sacred groves have been proven to have a significant role in the conservation of plant biodiversity. This study aimed to analyze the efficiency of the trees of these groves in sequestering carbon. This will serve as a good basis for incentive provision by the Reducing Emission from Deforestation and Forest Degradation (REDD) mechanism.

In this study, two sacred groves of Kathmandu valley in the midhills physiographic zone in Province No. 3 of

Central Nepal were selected. The first one, called Pashupati Sacred Grove (PSG), is located in the oldest and famous religious site of Hindu culture, and it belongs to Lord Pashupatinath Temple. This site covers an area of 83.55 ha and is located at 27°42′25″–27°42′36″ N latitude and 85°20′12″–85°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 the south-east corner of Kathmandu valley, in Chapagaun of Lalitpur district. It is located at 1,440 m elevation between 27°36′15.88″–27°36′24.62″N latitude and 85°19′40.58″–85°19′50.59″E longitude covering 18.29 ha area. A community based organization called Joytidaya Sangh is managing this grove. These groves are located in the subtropical monsoonal climatic zone. The average annual maximum temperature of the valley reaches 32°C in June and drops to a minimum of 2.0°C in December. The average relative humidity varies between 70% and 86%. The average annual rainfall exceeds 1480.4 mm; about 80% of the rainfall occurs during the monsoon season (June to September) [7]. The study area is characterized by four 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 (CCPs) [8] established in parallel transects of 150 m intervals traversing a north–south direction, with the help of Google Earth images. Tree height and DBH of each tree inside the concentric circular plot were measured. Plots were constructed at 100 m interval along each transect and were established 25 m inside the forest margin to reduce the edge effect.

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

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

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

$$H = -\sum_{i=1}^{s} (\text{pi})(\log \text{pi}) \quad (1)$$

where

H = Shannon index of species diversity

Pi = proportion of total number of individuals of species i

S = number of species

Evenness was calculated by dividing the Shannon-Weiner diversity index with the log value of total number of species found in the area. The amount of carbon in tree species was calculated from the above-ground biomass. Above-ground biomass of trees was calculated using the allometric equation considering DBH in centimeters, tree height in meters, and wood-specific gravity in gram per cubic centimeter [12]. The allometric equation developed by Chave *et al.* [13] was used for the calculation of above-ground tree biomass (AGTB).

$$\text{AGTB} = 0.0509\rho D^2 H \quad (2)$$

where

AGTB = above-ground tree biomass (kg)

ρ= wood specific gravity (g cm^{-3})

D = tree diameter at breast height (cm)

H = tree height (m)

The specific gravity of wood was extracted from published literature [14, 15]. The biomass stock densities were converted to carbon stock densities 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 trees in a particular vegetation was calculated by summing the above-ground and below-ground carbon stock. The weight of carbon in a 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.

3. Results

On the basis of the importance value, three types of forests, namely, *Schima-Pyrus*, *Myrsine-Persea*, and *Quercus-Myrsine* were recorded in PSG, whereas a single forest type, *Neolitsea cuipala*, was identified in BSG [19]. The total average carbon stock for the combined tree species of PSG and BSG was 1014.23 metric tons. The highest amount of average carbon stock (622.09 metric tons) was found in the *Quercus-Myrsine* forest followed by the *Neolitsea cuipala* (145.68 metric tons) forest. The lowest carbon stock was recorded in the *Schima-Pyrus* forest (113.98 metric tons) (Table 1).

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

Forest type	**Carbon stock (metric ton)**
Schima-Pyrus Forest (PSG)	113.98
Myrsine-Persea Forest (PSG)	132.48
Quercus-Myrsine Forest (PSG)	622.09
Neolitsea cuipala Forest (BSG)	145.68
Total	**1014.23**

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	7.11	-	5.37
8	*Cassia fistula* L.	-	-	-	3.45
9	*Celtis australis* L.	2.02	-	-	0.54
10	*Choerospondias axillaris* (Roxb.) Burtt & Hill.	-	3.28	-	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.	-	1.20	-	1.75
14	*Myrsine capitellata* Wall.	0.96	10,81	7.12	2.03
15	*Myrsine semiserrata* Wall.	-	0.42	-	0.73
16	*Neolitsea cuipala* (Buch.-Ham. ex D. Don.) Kosterm.	-	-	-	49.71
17	*Persea odoratissima* (Ness) Kosterm.	10.41	10.09	11.22	0.52
18	*Pyrus pashia* Buch-Ham. ex. D. Don.	2.24	1.11	-	
19	*Quercus glauca* Thunb.	2.28	1.96	16.37	
20	*Rhus succedanea* L.	-	-	-	0.64
21	*Sapium insigne* (Royle) Benth. ex. Hook. F.	-	-	-	0.57
22	*Schima wallichii* (DC.) Korth.	51.68	18.27	41.82	27.02
23	*Stranvaesia nussia* (D. Don.) Decne.	0.36	1.53	-	
24	*Syzygium cumini* (L.) Skeels.	1.94	8.92	1.05	2.96
25	*Ziziphus incurva* Roxb.	0.22	-	-	

3.1. Schima-Pyrus Forest. In this forest, *Schima wallichii* was found to be the most dominant species (IVI = 81.4) followed by *Pyrus pashia* (IVI = 51.5). Fourteen tree species with a population of 319 individuals per hectare were recorded in this forest. 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 metric ton ha^{-1}. The calculated amount of total carbon sequestrated was 1595.75 metric tons. Among tree species, *Schima wallichii* was most efficient (51.68 metric ton ha^{-1}) in sequestering carbon, followed by *Persea odoratissima* (10.41 metric ton ha^{-1}) and *Araucaria bidwillii* (3.59 metric ton ha^{-1}) (Table 2). The total amount of carbon dioxide sequestrated by this forest was calculated as 5860 metric tons.

3.2. Myrsine-Persea Forest. *Myrsine capitellata* (IVI = 142.0) was found to be the dominant tree species in this forest type, followed by *Persea odoratissima* (IVI = 38.9). A total of 11 tree species were found in this forest and 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 tree species in this forest was 1457.33 metric tons and average carbon stock density of each tree species in this forest was 5.89 metric ton ha^{-1}. *Schima wallichii* was the most efficient in sequestrating carbon (18.27 metric ton ha^{-1}), followed by *Myrsine capitellata* (10.81 metric ton ha^{-1}) (Table 2). Total carbon dioxide sequestrated in this forest was 5350 metric tons.

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

Forest type	No. of Species	Shannon diversity	Evenness	Maturity Index	Carbon stock (metric ton ha^{-1})
Schima-Pyrus	14	1.84	0.70	29.4	76.35
Myrsine-Persea	11	1.35	0.56	43.6	64.77
Quercus-Myrsine	5	1.19	0.74	80.0	77.57
Neolitsea cuipala	18	1.80	0.62	33.9	143.37

3.3. Quercus-Myrsine Forest. *Quercus glauca* (IVI = 138.5) was the dominant tree species in this forest, followed by *Myrsine capitellata* (IVI = 56.2). Five tree species were recorded to have average height and DBH of 12.6±5.1 m and 28.5±13.7 cm, respectively. The number of stems found in this forest was 677 individuals per hectare. Average carbon stock density of the tree species of this forest was 15.51 metric ton ha^{-1} and total carbon stock was 3110.46 metric tons. In this forest, *Schima wallichii* was the most competent in sequestrating carbon (41.82 metric ton ha^{-1}), followed by *Quercus glauca* (16.37 metric ton ha^{-1}) (Table 2). Total carbon dioxide sequestrated by the tree species in this forest was 11420 metric tons.

3.4. Neolitsea Cuipala Forest. In all, 18 tree species were recorded in this forest type. *Neolitsea cuipala* was the dominant tree species (IVI=111.3), followed by *Castanopsis indica* (IVI=36.9). The average height and DBH of the trees in this forest was 18.6±12.7 m and 36.6±19.4 cm, respectively. This forest had a population of 432 individuals per hectare. The total carbon stock density of tree species in this forest was calculated to be 143.37 metric ton ha^{-1}, whereas the average carbon stock density of each tree species was 7.96 metric ton ha^{-1}. The highest amount of carbon was sequestrated by *Neolitsea cuipala* (49.71 metric ton ha^{-1}) followed by *Castanopsis indica* (31.29 metric ton ha^{-1}) (Table 2). The total carbon dioxide sequestrated in this forest was 9620 metric tons.

3.5. Species Richness and Carbon Stock. In the *Neolitsea cuipala* forest of BSG, the number of tree species was the highest (n=18) and the amount of carbon stock (143.37 metric ton ha^{-1}) was also the highest in comparison to other forest types of PSG. In the *Quercus-Myrsine* forest of PSG, the carbon stock was 77.57 metric ton ha^{-1} and the number of tree species was found to be the lowest (n=5). The lowest carbon stock was recorded in the *Myrsine-Persea* forest (64.77 metric ton ha^{-1}), whereas the tree species richness was high (n=11). In the *Schima-Pyrus* forest, the number of tree species was 14 and the carbon stock was recorded to be 76.35 metric ton ha^{-1} (Table 3). There is a strong positive correlation (r = 0.69) between the number of species and carbon stock. The available number of tree species significantly affects the carbon stock of the forest of the study area (t = 4.88, p<0.05, df = 6).

3.6. Diversity, Evenness, and Carbon Stock. In both studied sites, the *Schima-Pyrus* forest was found to be more diverse than other forest types. In this forest, the Shannon-Winner diversity index was found to be the highest (1.84), but the carbon stock was low (76.35 metric ton ha^{-1}) in comparison to other forest types. In the *Quercus-Myrsine* forest, the carbon stock was 77.57 metric ton ha^{-1} and the diversity index was found to be the lowest (1.19). In the *Neolitsea cuipala* forest, the carbon stock was the highest (143 metric ton ha^{-1}), and the diversity index was 1.80. Similarly, in the *Myrsine-Persea* forest, the carbon stock was the lowest (64.77 metric ton ha^{-1}) and the diversity index was 1.35 (Table 3). There was significant effect of diversity index on the carbon stock of the forest in the study area (t = 5.01, p<0.05, df = 6).

The evenness value indicates that the available tree species in the *Quercus-Myrsine* forest were more evenly distributed (0.74) than other forest types. The carbon stock was found to be 77.57 metric ton ha^{-1} in this forest. On the other hand, tree species in the *Myrsine-Persea* forest were the least evenly distributed (0.56), and carbon stock was found to be low (64.77 metric ton ha^{-1}). In the *Schima-Pyrus* forest, the carbon stock was found to be 76.35 metric ton ha^{-1} with a high evenness value (0.70). In the *Neolitsea cuipala* forest, the carbon stock was found to be the highest (143.37 metric ton ha^{-1}) and evenness was 0.62 (Table 3). The evenness of tree species significantly affects the available carbon stock of the forest in the study area (t = 5.03, p<0.05, df = 6).

3.7. Maturity and Carbon Stock. The carbon stock (143.37 metric ton ha^{-1}) was found to be the highest in the *Neolitsea cuipala* forest compared to the other forests of the study area. The maturity index of the *Quercus-Myrsine* forest was found to be the highest (80.0) with a carbon stock of 77.56 metric ton ha^{-1}. Similarly, the maturity index of the *Schima-Pyrus* forest was found to be the lowest (29.4) with a carbon stock of 76.35 metric ton ha^{-1}. The maturity indices of the *Myrsine-Persea* and *Neolitsea cuipala* forests were 43.6 and 33.9 with carbon stocks of 64.77 metric ton ha^{-1} and 143.37 metric ton ha^{-1}, respectively (Table 3). There was a negative correlation (r = - 0.32) between the maturity index and carbon stock. There were no significant effects of maturity index (t = 1.88, p<0.05, df = 6) on the tree carbon stock of the study sites.

3.8. Carbon Dioxide Assimilation. The trees species of both study sites were found to have assimilated 3700 metric tons of carbon dioxide in average. The highest amount of carbon dioxide (2280 metric tons) was sequestrated by the *Quercus-Myrsine* and the lowest by the *Schima-Pyrus* forest (420 metric tons) (Figure 1).

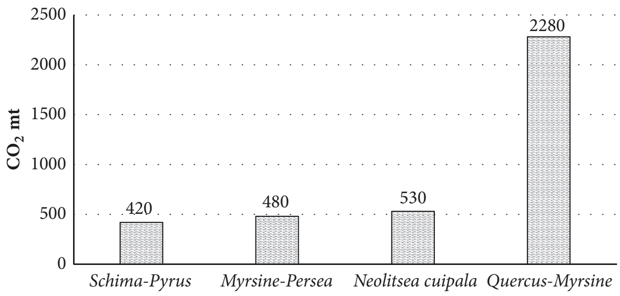

Figure 1: Total amount of carbon dioxide accommodated by trees in different forests.

4. Discussions

The amount of sequestrated carbon in forests varied according to the forest type and density of trees. Species composition of the forests also determines the average amount of assimilated carbon in the particular forest type. Trees of PSG and BSG sequestrated 1014.23 metric tons of carbon and 3700 metric tons of carbon dioxide, respectively. The highest amount of carbon stock (622.09 metric tons) and CO_2 (2280 metric tons) was accumulated in *Quercus-Myrsine* forest because the trees are larger in size and have the highest number (677) of individuals per hectare. *Schima wallichii* (41.82 metric ton ha^{-1}) was the highest carbon sequestrating tree species (Table 2). A similar study conducted in the forest of the Far Western Terai physiographic region of Nepal recorded an average tree biomass of 186.6 metric ton ha^{-1}, and *Shorea robusta* exhibited the highest biomass of 89.8 metric ton ha^{-1}, followed by *Terminalia tomentosa* 41.0 metric ton ha^{-1}, in one forest type of *Shorea robusta* [20]. The results of the present study show the same pattern in carbon sequestration as that of a study conducted in a buffer zone community managed forest of Chitwan National Park in central lowland Nepal. Trees of that buffer zone community forest sequestered 3333.7 metric tons of carbon and 12100 metric tons of carbon dioxide. The highest amount of carbon (1206.9 metric tons) and CO_2 (4400 metric tons) was accumulated by a *Dalbergia sissoo* forest. The highest carbon sequestrating tree was *Dalbergia sissoo* (262.5 metric ton ha^{-1}) [18]. The difference in the forest category and carbon stocks between these studies can be attributed to the difference in the physiographic region, species composition, and wood density of tree species. In the present study, there is a 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 forests.

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

Generally, there is a worldwide positive relationship between biodiversity and carbon stock [2]. A similar result has been reported from the collaborative forest of lowland Terai region of Nepal [22]. The current study also showed significant effect of diversity index in carbon stock of the forest ($t = 5.01$, $p<0.05$, df = 6).

The maturity index of the forest community of PSG was higher for the *Quercus-Myrsine* forest. *Schima wallichii* trees with the largest girth size and tallest height were the main carbon sink in this forest (Table 2). The amount (metric ton ha^{-1}) of assimilated carbon in all forest types of the study area varied according to the girth size, height, and wood specific gravity of the tree species. More developed plant communities have 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 the present study, the result was based on one time data collection. Therefore, maturity index in different seasons was not compared. Although the maturity index of forest community does not significantly affect ($t = 1.88$, $p<0.05$, df = 6) the carbon stock in the forest of the present study area, the carbon stock was found to be the highest (622 metric tons) in the forest with higher maturity index, that is, the *Quercus-Myrsine* forest (MI=80), rather than the *Schima-Pyrus* forest (MI=29.4) of PSG. It showed that the mature forest community sequestered more carbon as indicated by other studies conducted in lowland areas of Nepal [18]. However, other studies show that old growth, mature forests with larger girth size and taller trees are large carbon pools [24].

5. Conclusion

Sacred groves are one of the management regimes practiced for forest conservation in Nepal. In the studied sacred groves, three forest types in PSG and one forest type in BSG were recognized based on the IVI of tree species. Sequestrated carbon and carbon dioxide were found to be the highest in *Quercus-Myrsine* and the lowest in *Schima-Pyrus* forests of PSG. The amount of carbon sequestrated in the studied groves varied according to species composition, density, and wood specific gravity of tree species. Sacred groves offer safeguarding of forest ecosystems and also contribute towards mitigating climate change through carbon sequestration.

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