Nature Environment and Pollution Technology
An International Quarterly Scientific Journal
p-ISSN: 0972-6268
(Print copies up to 2016)
e-ISSN: 2395-3454
Vol. 21 | No. 1 | pp. 175-181 | 2022
Original Research Paper
https://doi.org/10.46488/NEPT.2022.v21i01.019
Open Access Journal

# Terrestrial Biomass and Carbon Stock in Broad-leaved Forests of Punakha District, Western Bhutan

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**Nat. Env. & Poll. Tech.**
**Website: www.neptjournal.com**

*Received:* 16-04-2021
*Revised:* 27-05-2021
*Accepted:* 06-06-2021

**Key Words:**
Carbon stock
Terrestrial biomass
Broad-leaved forest
Volumetric equation

## ABSTRACT

The present study assessed the terrestrial biomass of broad-leaved forests to determine the carbon storage potential of each tree species in Punakha. The assessment was based on a woody stem having a minimum of 10 cm diameter at breast height (DBH) and tree height. Biomass was estimated using volumetric equations and carbon stock by multiplying the constant factor 0.5 to biomass. The study covered 41 sampling plots of 31.62 m × 31.62 m and recorded a total of 24 tree species. Total biomass was 274.68 $Mg.ha^{-1}$ with AGTB 196.36 $Mg.ha^{-1}$, BGTB 51.07 $Mg.ha^{-1}$ and DOM 27.22 $Mg.ha^{-1}$. The total carbon stock estimated was 137.34 $MgC.ha^{-1}$. The present study used a non-destructive approach to assess the carbon storage potential of each broad-leaved tree species and concludes that Punakha broad-leaved forest has the potential to accumulate more biomass and carbon stock, as DBH class-wise biomass and carbon distribution showed right-skewed trend indicating young forest stands.

## INTRODUCTION

Bhutan today has a total forest coverage of 2,730,889 ha which constitutes 71% of the total geographical area of the country (Amatya et al. 2018, Forest Resources Management Division [FRMD] 2016a). The present study area alone contributes 79,316 ha (72%) of forest cover of the total area of 109,878 ha of the Punakha District (FRMD 2016a). The total biomass of Bhutan's forests was estimated to be about 1109 million tonnes and forest carbon stock 709 million tonnes including 188 million tonnes of soil organic carbon (Forest Resources Management Division [FRMD] 2016b). Bhutan's rich forest cover and its high Green House Gas (GHG) sequestration potential were reinforced by a constitutional mandate that a minimum of 60% of the country's total land be maintained under forest cover for all times (Ministry of Agriculture 2009).

The importance of forests have attracted considerable attention in the recent past especially after the inception of the Kyoto Protocol as it provides ecosystem services as significant terrestrial carbon (C) sink (FRMD 2016b, Rabha 2014, Wellbrock et al. 2017). Forests are one of the vital components in the socio-economic system especially for forest-dependent households (Sahu et al. 2015, Salunkhe et al. 2018). Furthermore, forests have led to estimate global carbon budget and the estimation of carbon (C) stocks to better understand their function in the global carbon cycle as a mitigation measure or a source of carbon in response to climate change (Malhi et al. 1998, Murthy et al. 2015, Nakai et al. 2009).

Aboveground tree biomass (AGTB), belowground tree biomass (BGTB), deadwood, litter, and soil organic matter (SOM) are five carbon pools in the forest ecosystem (FRMD 2016b). Biomass can be measured either in terms of fresh weight or dry weight and it can be both dead and living components. The amount of C sequestrated by broad-leaved forests can be inferred from total biomass accumulated as approximately 50% of forest dry biomass is C (Beets et al. 2012, Cairns et al. 2003, Justine et al. 2015, Vashum & Jayakumar 2012, Wolf et al. 2011). Forest ecosystem which covers about 4.1 billion ha globally store about 80% of aboveground terrestrial C and 40% of belowground C to mitigate global climate change (Ahmad et al. 2015, Lal 2005, Sahu et al. 2015, Wellbrock et al. 2017).

To understand the carbon storage potential of Punakha broad-leaved forests (PBFr), volumetric equations and specific wood density with variables DBH and tree height were used to calculate biomass accumulation and C stock following a non-destructive approach. The present study found out that PBFr plays a vital role as C sinks. Carbon storage potential in different tree species differ depending upon management practices, disturbances, and age of the trees (Mendoza-Ponce & Galicia 2010).

## MATERIALS AND METHODS

### Study Area

The study was carried out in Punakha District (Fig. 1) approximately located between latitude 27°39'59.99" N and longitude 89°49'59.99" E with elevation ranging from 1200 to above 4500 meters above sea level. It is bordered by Thimphu, Gasa, and Wangdue Phodrang Districts. Temperature varies approximately from minus 4°C to 35°C. The District consists of 79,316 ha (72%) of forest cover of a total area of 109,878 ha (FRMD 2016a). Natural mixed forests of broad-leaved evergreen and coniferous trees covered the study area. Dominant tree species recorded were *Quercus lanata, Castanopsis tribuloides* and *Rhododendron arboretum.*

Forests are under threat as a result of increased developmental activities, limiting carbon sequestration capability. Furthermore, only a few studies carried out concentrating on the value of individual broad-leaved tree species' carbon stock potential. In this study, floristic composition and importance level of specific broad-leaved tree species in connection to their carbon storage potential were investigated using a total of 41 sampling sites.

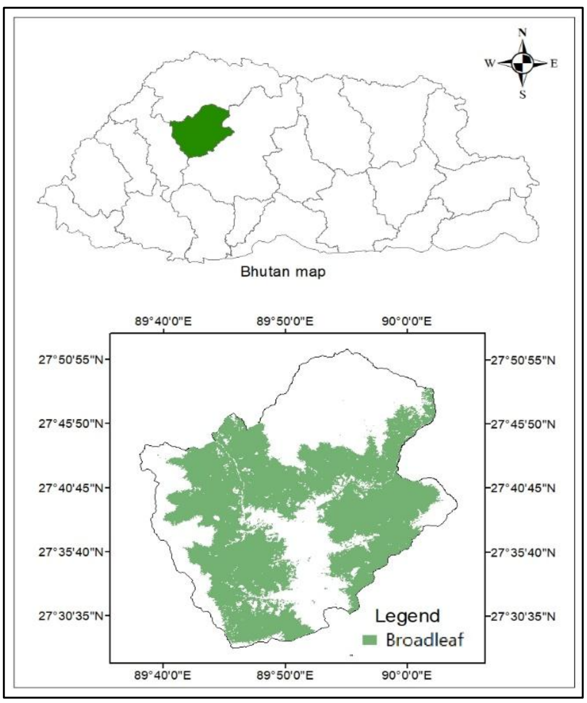


Fig.1: Map of Bhutan showing the study area.

### Tree Height and DBH Measurement

The Forest Survey of India (FSI) (2015) and Tshering (2019) methodologies were used to lay a quadrat measuring 31.62 m × 31.62 m and recorded a total of 24 tree species. For the enumeration, trees were defined as circumferences with a minimum diameter of 10 cm at breast height (DBH), i.e. 1.37 m above the ground (Borah et al. 2013, FRMD 2016a, FRMD 2016b, Mani & Parthasarathy 2009, Rabha 2014, Salunkhe et al. 2016, Shahid & Joshi 2015). The height and DBH of the trees were measured using a non-destructive approach (Pragasan 2015, Tshering 2019). Clinometer and diameter tape were used to measure the tree height and DBH, respectively. Non-broad-leaved tree species such as conifer species sampled in the same quadrats were excluded as it was not the focus of the current study.

### Terrestrial Tree Biomass Estimation

Non-destructive estimation of biomass was carried out using a volumetric equation (Forest Survey of India [FSI] 1996). The following procedures were considered for the current study. (1) Bole biomass was calculated using the formula V × WD (where, V=volume of trees [v: $m^3.tree^{-1}$], WD=wood specific density [$Mg.m^{-3}$]) (Ahmad et al. 2014, Mandal & Joshi 2015). (2) Aboveground tree biomass (AGTB) was derived by using the formula BB × BEF (where, BB=bole biomass [$Mg.ha^{-1}$], BEF=biomass extension factor 1.59) (Khan et al. 2015, Mandal & Joshi 2015). (3) Belowground tree biomass (BGTB) was calculated by AGB × 0.26 (where, 0.26=constant root-shoot ratio) (Joshi et al. 2020, Shahid & Joshi 2015, Srinivas & Sundarapandian 2019, Subashree & Sundarapandian 2017, Mandal & Joshi 2015, Sahu et al. 2015). (4) The dead woods and leaf litter in the form of dead organic matter (DOM) were calculated, (AGTB + BGTB) × 0.11 (where 0.11 = default factor) (Joshi et al. 2020, Sahu et al. 2015). The total biomass ($Mg.ha^{-1}$) was obtained by adding aboveground and belowground tree biomass including dead woods and leaf litter biomass (DOM).

### Total Carbon Stock

Carbon values for each forest carbon pool were summed to estimate total forest carbon stock (Joshi et al. 2020). Total carbon stock ($MgC.ha^{-1}$) of the broad-leaved forests of Punakha District was then converted into tonnes of $CO_2$ equivalent by multiplying with constant conversion factor 0.5 following the methods of Borah et al. (2013), Chaudahury & Upadhaya (2016), Shahid & Joshi (2015), Sun et al. (2016), Terakunpisut et al. (2007) and Tshering (2019).

The following equation was used to calculate the total forest carbon stock:

TC=C (AGTB) + C (BGTB) + C (DOM)

Where, TC=Total carbon stock (CMg.$ha^{-1}$), C (AGTB)=Carbon stock in aboveground tree biomass, C (BGTB)=Carbon stock in belowground tree biomass, and C (DOM)=Carbon stock in dead woods and leaf litter in the form of dead organic matter.

## RESULTS AND DISCUSSION

### Biomass and Carbon

Total biomass and C stock accumulations were 274.68 Mg.$ha^{-1}$ and 137.33 MgC.$ha^{-1}$ respectively (Table 1) and it is within the range of the standing biomass of different forest types of Western Himalaya ranging from 123.89±26.33 to 537.77±56.34 Mg.$ha^{-1}$ (Singh & Verma 2018). Values reported in the present results were lower than the values of tropical evergreen and deciduous forests of Uttara Kannada District with 344-417 MgC.$ha^{-1}$ (Murthy et al. 2015). Further, total biomass (54±19 million tonnes) and C stock (25±9 million tonnes) reported for the whole Punakha District by FRMD (2016b) was much higher than the values reported in the present results. This was owing to the fact that the previous study included total biomass estimates of trees (all forest types), saplings, shrubs, and herbs, as well as soil carbon, but the current study only included biomass and C estimates of trees (of the broad-leaved forest). However, the C stock of the study area was found comparable to tropical rain

Table 1: Species-wise tree density (count.$ha^{-1}$), biomass (Mg.$ha^{-1}$), and carbon (MgC.$ha^{-1}$).

| Sl. No. | Species | Tree density | Biomass | | | Total biomass | Total carbon |
|---|---|---|---|---|---|---|---|
| | | | AGTB | BGTB | DOM | | |
| 1 | *Quercus lamellosa* | 43.44 | 0.2 | 0.05 | 0.03 | 0.28 | 0.14 |
| 2 | *Michelia doltsopa* | 19.59 | 1.85 | 0.48 | 0.26 | 2.59 | 1.30 |
| 3 | *Myrsine semiserrata* | 14.48 | 2.11 | 0.55 | 0.29 | 2.95 | 1.48 |
| 4 | *Lindera pulcherrima* | 15.33 | 1.15 | 0.3 | 0.16 | 1.61 | 0.81 |
| 5 | *Quercus Glauca* | 27.26 | 8.34 | 2.17 | 1.16 | 11.67 | 5.84 |
| 6 | *Quercus oxyodon* | 29.81 | 16.33 | 4.25 | 2.26 | 22.84 | 11.42 |
| 7 | *Symplocos glomerata* | 19.59 | 6.83 | 1.78 | 0.95 | 9.56 | 4.78 |
| 8 | *Symplocos ramosissima* | 30.66 | 3.91 | 1.02 | 0.54 | 5.47 | 2.74 |
| 9 | *Rhododendron arboreum* | 115.84 | 6.65 | 1.73 | 0.92 | 9.30 | 4.65 |
| 10 | *Quercus semecarpifolia* | 11.93 | 6.97 | 1.81 | 0.97 | 9.75 | 4.88 |
| 11 | *Lyonia ovalifolia* | 102.21 | 0.29 | 0.07 | 0.04 | 0.40 | 0.20 |
| 12 | *Castanopsis tribuloides* | 118.40 | 76.86 | 19.98 | 10.65 | 107.49 | 53.75 |
| 13 | *Quercus griffithii* | 58.77 | 10.29 | 2.68 | 1.43 | 14.40 | 7.20 |
| 14 | *Quercus lanata* | 120.95 | 11.98 | 3.12 | 1.66 | 16.76 | 8.38 |
| 15 | *Schima wallichii* | 34.07 | 5.16 | 1.34 | 0.71 | 7.21 | 3.61 |
| 16 | *Michelia champaca* | 12.78 | 8.08 | 2.1 | 1.12 | 11.30 | 5.65 |
| 17 | *Daphniphyllum chartaceum* | 52.81 | 4.8 | 1.25 | 0.66 | 6.71 | 3.36 |
| 18 | *Myrica esculenta* | 14.48 | 0.99 | 0.26 | 0.14 | 1.39 | 0.70 |
| 19 | *Toona ciliata* | 20.44 | 0.06 | 0.02 | 0.01 | 0.09 | 0.05 |
| 20 | *Ilex dipyrena* | 31.52 | 18.14 | 4.72 | 2.51 | 25.37 | 12.69 |
| 21 | *Albizia lebbeck* | 28.11 | 5.27 | 1.37 | 0.73 | 7.37 | 3.69 |
| 22 | *Eurya acuminata* | 15.33 | 0.05 | 0.01 | 0.01 | 0.07 | 0.04 |
| 23 | *Cinnamomum glaunduliferum* | 13.63 | 0.04 | 0.01 | 0.01 | 0.06 | 0.03 |
| 24 | *Juglans regia* | 48.55 | 0.014 | 0.004 | 0.002 | 0.02 | 0.01 |
| | Poll biomass | – | 196.36 | 51.07 | 27.22 | – | – |
| | Pool carbon | – | 98.18 | 25.54 | 13.61 | – | – |
| | Total | 999.98 | 196.36 | 51.07 | 27.22 | 274.68 | 137.33 |
| | *Mean* | 41.67 | 8.18 | 2.13 | 1.13 | 11.44 | 5.72 |

forest (Ton Mai Yak station) (137.73±48.07 tonne.C.ha$^{-1}$), dry evergreen forest (KP 27 station) (70.29±7.38 tonneC.ha$^{-1}$), and mixed deciduous forest (Pong Phu Ron station) 48.14±16.72 tonneC.ha$^{-1}$ of Thong Pha Phum National Forest (Terakunpisut et al. 2007).

The AGTB score of the present study (196.36 Mg.ha$^{-1}$) was found lower than the tropical forest of Nagathol forest (261.64 Mg.ha$^{-1}$) and higher than that of Monbel forest (166.94 Mg.ha$^{-1}$), Rose Kandy (144.01 Mg.ha$^{-1}$), Bhuban hill (116.8 Mg.ha$^{-1}$) and Dolu forest (99.10 Mg.ha$^{-1}$) (Borah et al. 2013). However, the present AGTB score falls within the biomass range of temperate forests of Kashmir Himalaya (Dar & Sundarapandian 2015) and tropical dry forest of East Godavari region, Andhra Pradesh (58.04 to 368.39 Mg.ha$^{-1}$) (Srinivas & Sundarapandian 2019). The variation in the distribution of biomass and C stocks in forest ecosystems could be due to geographical regions and their locality factors (Joshi et al. 2020), forest types, species composition, vegetation management pattern, and stand age (Chaudhury & Upadhaya 2016, Singh & Verma 2018).

Biomass accumulation and C stock potential varied among the tree species of Punakha Broad-leaved Forests (PBFr). The *Castanopsis tribuloides* had the highest biomass accumulation and C stock (107.49 Mg.ha$^{-1}$ and 53.75 MgC.ha$^{-1}$ respectively) whereas the lowest value was recorded in *Juglans regia* (0.02 Mg.ha$^{-1}$ and 0.01 MgC.ha$^{-1}$ respectively) among 24 tree species studied (Table 1). The *Castanopsis* sp was also reported by FRMD (2016b) as one of the 28 major trees to be an important source of biomass in Bhutan. Punakha broadleaf forest was dominated by *Quercus lanata, Castanopsis tribuloides,* and *Rhododendron arboreum* with a tree density of 120.95 count.ha$^{-1}$, 118.40 count.ha$^{-1}$, 115.84 count.ha$^{-1}$ respectively and the least in *Quercus semecarpifolia* with 11.93 count.ha$^{-1}$ of the total 999.98 count.ha$^{-1}$. The considerable variation in tree density could be due to variation in species richness, DBH size, different anthropogenic activities, and environmental factors affecting plant growth (Chaudhury & Upadhaya 2016, Rabha 2014, Tshering, 2019).

## Biomass and Carbon Estimates by DBH Class

The distribution of biomass and carbon stock in different DBH classes is shown in Fig. 2. The maximum biomass accumulation and carbon stock were observed in 10-19.9

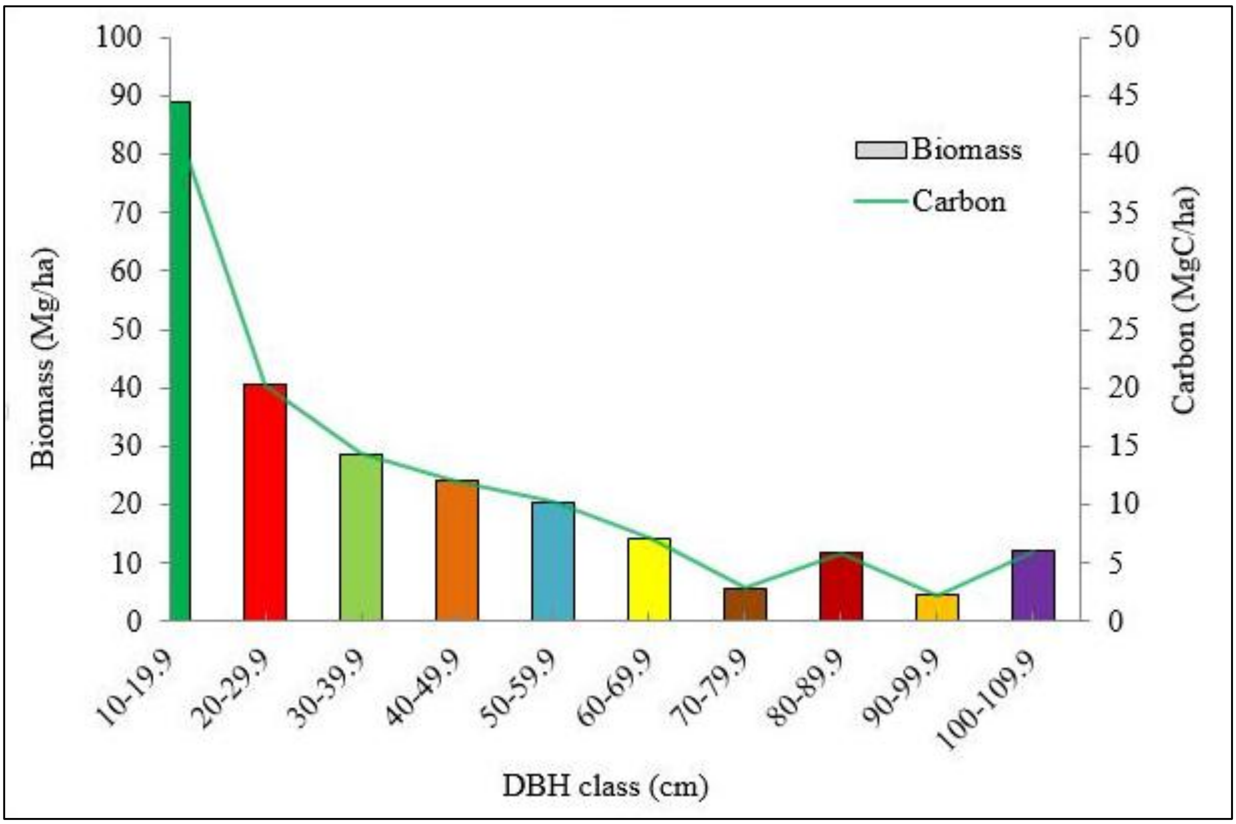


Fig. 2: Biomass and carbon storage in different DBH classes.

Table 2: Biomass (Mg.ha$^{-1}$) and carbon stock (MgC.ha$^{-1}$) in different tree families.

| Sl.No. | Family | BB | AGTB | BGTB | DOM | TB | TC |
|---|---|---|---|---|---|---|---|
| 1 | Fagaceae | 77.62 | 123.42 | 32.09 | 17.11 | 172.62 | 86.31 |
| 2 | Magnoliaceae | 5.95 | 9.46 | 2.46 | 11.92 | 23.85 | 11.92 |
| 3 | Myrsinaceae | 1.33 | 2.11 | 0.55 | 0.29 | 2.96 | 1.48 |
| 4 | Lauraceae | 1.98 | 3.15 | 0.82 | 0.44 | 4.40 | 2.20 |
| 5 | Symplocaceae | 5.15 | 8.18 | 2.13 | 1.13 | 11.45 | 5.72 |
| 6 | Ericaceae | 4.36 | 6.94 | 1.80 | 0.96 | 9.70 | 4.85 |
| 7 | Juglandaceae | 2.71 | 4.31 | 1.12 | 0.60 | 6.03 | 3.01 |
| 8 | Theaceae | 2.60 | 4.13 | 1.07 | 0.57 | 5.78 | 2.89 |
| 9 | Daphniphyllaceae | 3.02 | 4.80 | 1.25 | 0.66 | 6.71 | 3.35 |
| 10 | Myricaceae | 0.62 | 0.99 | 0.26 | 0.14 | 1.39 | 0.69 |
| 11 | Meliaceae | 1.99 | 3.16 | 0.82 | 0.44 | 4.43 | 2.21 |
| 12 | Aquifoliaceae | 11.41 | 18.14 | 4.72 | 2.51 | 25.37 | 12.69 |
| | Total | 118.74 | 188.79 | 49.09 | 36.76 | 274.68 | 137.33 |
| | Mean | 9.90 | 15.73 | 4.09 | 3.06 | 22.89 | 11.44 |

cm (88.94 Mg.ha$^{-1}$ and 44.47 MgC.ha$^{-1}$ respectively) followed by 20-29.9 cm (40.54 Mg.ha$^{-1}$ and 20.27 MgC.ha$^{-1}$ respectively) contrasting the findings of FRMD (2016b), where total aboveground biomass and carbon increased with increasing diameter class peaking at DBH class of 60-70 cm with 59±3 and 28±2 million tonnes, though the gradual decrease of biomass accumulation and carbon stock were observed in higher DBH class after picking at mid. However, current findings are similar to the dominant size class at ≥4.5-20 cm where it potentially provided greater carbon sequestration in the tropical rain forest and dry evergreen forest (Terakunpisut et al. 2007). The least was in 90-99.9 cm with total biomass 4.49 Mg.ha$^{-1}$ and carbon 2.24 MgC.ha$^{-1}$, contradicting the findings of Singh and Verma (2018), where individuals lying in DBH class >150 cm contributed significantly to carbon stocks.

Variation of different biomass accumulation and carbon stock potential at different DBH classes could be due to the greater number of individuals recorded at lower diameter class (≥10-19.9 and 20-29.9 cm DBH) showing a right-skewed trend indicating young forest stands (Fig. 2). Maximum tree count in the DBH class of 10-20 cm and minimum in 90-100 cm DBH were also reported during the National Forest Inventory of Bhutan by Amatya et al. (2018). Additionally, similar findings were reported by Srinivas and Sundarapandian (2019) in the tropical dry forest of the East Godavari region and by Dar and Sundarapandian (2015) in temperate forests of Kashmir Himalaya.

## Tree Family-wise Carbon Stock and Biomass Accumulation

Fagaceae had a maximum biomass accumulation of 172.62 Mg.ha$^{-1}$ sequestering carbon 86.31 MgC.ha$^{-1}$ followed by Aquifoliaceae with biomass 25.37 Mg.ha$^{-1}$ and carbon 12.69 MgC.ha$^{-1}$. The reason for the highest value of biomass and carbon stock in Fagaceae and Aquifoliaceae could be due to higher number of individuals unlike the lowest value estimated in Myricaceae with biomass 1.39 Mg.ha$^{-1}$ and carbon 0.69 MgC.ha$^{-1}$. Singh and Verma (2018) found that a larger number of people has a similar effect on biomass and carbon density in diverse forest types in the Western Himalaya. Other reasons for biomass and carbon distribution variation in different tree families could be higher DBH size, age, and environmental factors (Chaudhury & Upadhaya 2016, Rabha 2014, Tshering 2019, Zhang et al. 2019). Biomass accumulation and carbon sequestration potential variation of different tree families were shown in Table 2.

The *Castanopsis tribuloides* and *Quercus lamellose* under family Fagaceae, and *Lyonia ovalifolia* and *Rhododendron arboretum* belonging to Ericaceae were found with greater biomass storage and carbon sequestration potential. Species that have high carbon sequestration potential should be planted that might be capable of reducing the carbon emitted due to deforestation and other anthropogenic activities. If the carbon problem is to be managed through forest management, trees with low biomass and carbon sequestration capacity must be eliminated or replaced with other tree species that store more carbon.

## CONCLUSIONS

The study pertaining to estimation of carbon stock in broad-leaved forests of Punakha District covered 41 sampling plots of 31.62 m x 31.62 m and recorded a total of 24 tree species. Total biomass and carbon stock estimated were 274.68 $Mg.ha^{-1}$ and 137.33 $MgC.ha^{-1}$ respectively. Biomass accumulation and carbon stock distribution in different DBH classes showed a right-skewed trend indicating young forests for huge carbon sequestration potential in the future if it's conserved sustainably. The present study covered only broad-leaved forests, so we recommend future researchers to carry out similar studies on conifer tree species.

## ACKNOWLEDGEMENT

We are thankful to the College of Natural Resources (CNR) for providing financial support. We are grateful to Mr. Karma Sherub from the Department of Forest Science in College of Natural Resources and Mr. Chetenla from Thimphu Forest Division under Department of Forests and Park Services for their support during fieldwork and analysis.

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