

**Research Article****CONTRIBUTION OF DEAD WOOD AND FOREST SOIL TO CARBON SEQUESTRATION IN PARSA NATIONAL PARK, NEPAL****G. Kafle<sup>1\*</sup>, Y. P. Timilsina<sup>2</sup>, R. P. Sharma<sup>3</sup>, M. Rijal<sup>4</sup>, B. Bartaula<sup>5</sup>, B. Pokhrel<sup>1</sup>, and V. Thakur<sup>1</sup>**<sup>1</sup>Faculty of Forestry, Agriculture and Forestry University, Hetauda, Nepal<sup>2</sup>Institute of Forestry, Tribhuvan University, Pokhara, Nepal<sup>3</sup>Faculty of Forestry and Wood Sciences, Czech University of Life Sciences, Prague, Czech Republic<sup>4</sup>Central Department of Geology, Tribhuvan University, Kirtipur, Nepal<sup>5</sup>College of Business, Colorado State University, Fort Collins, Colorado, US

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**ABSTRACT**

Dead wood and forest soil contribute as a medium for carbon storage and suitable habitat for diverse flora and fauna species. This study was done with the objective to assess status of dead wood in Parsa National Park (PNP), and to analyze the role of dead wood and forest soil in carbon sequestration. Line transects and circular sample plots were randomly established; measurement of down dead wood, standing dead wood, and soil analysis were conducted using standard methods. Dead wood was categorized into three density class (sound, intermediate, and rotten) based on wood hardness. Total volume and biomass of dead wood were 39.83 m<sup>3</sup> ha<sup>-1</sup>, and 22.39 t ha<sup>-1</sup>, respectively, and total carbon stock in dead wood was 10.74 t ha<sup>-1</sup>. Total volume of dead wood was dominated by intermediate class (61%) in both standing and down dead woods, followed by sound (23%), and rotten (16%) density classes. Regarding total carbon stock for each dead wood class in the park, standing dead wood contributed almost two times more carbon stock than that of down dead wood. All three density classes were equally responsible in contributing carbon stock in PNP. Formulation and implementation of the localized plans for management of dead wood are necessary in PNP.

**Keywords:** Carbon storage, line transects, density class, soil organic carbon**INTRODUCTION**

Dead wood has been becoming a widely discussed issue in recent years (Merganicova & Merganic, 2010). The dead wood, which consists of both standing dead wood (snags) and material that has fallen to the ground (log) is a dynamic resource in forest ecosystem. Existence of dead wood stock in the forest stands has been emphasized in conjunction with functioning and productivity of the forest ecosystem (Humphrey et al., 2004); biodiversity enrichment (Schuck et al., 2004); storage of nutrients and water (Krankina et al., 1999); soil development and protection against soil erosion (Stevens, 1997); rock fall and avalanches (Kupferschmidt et al., 2003); natural regeneration (Ulbrichova et al., 2006); accumulation of greenhouse gases in the atmosphere and climate change (Zell et al., 2009). If there are enough of the right kinds of dead wood in a forest then it is likely to be natural (WWF, 2004). For the reasons, it was adopted as an indicator for sustainable forest management (SFM) by the Ministerial Conference (MCPFE, 2003) on the protection of forests in Europe (Butler & Schlaepfer, 2004). The volume of standing and fallen dead wood is one of the nine pan-European indicators for sustainable forest management (Criterion 4: maintenance, conservation and appropriate enhancement of biological diversity in forest ecosystems) (Christensen et al., 2005). Department of Environment and Climate Change also officially listed the removal of dead wood and dead trees as a key threatening process in Australia in 2008. Dead wood management has become an integral part of forest management policies and practices in European countries and further lobbying is in place (FCGB, 2002; WWF, 2004). Existence of a certain threshold amount of dead wood in a forest stand may therefore become a good basis of sustainable forest management. Erajja et al., (2010) found that fine wood debris and stumps of dead wood have a potentiality of high biodiversity enrichment in the managed forests, and thus they deserve more attention for biodiversity studies.

Soil is a potentially viable sink for atmospheric carbon (Lal et al., 2012). Land management exerts the least soil disturbance and contributes to increased accumulation of soil organic carbon, while intensive disturbance would result in lower soil organic carbon and consequently higher degradation of soil productivity (Post & Kwon, 2000). The loss of soil organic carbon pool through emission has a significant influence on the CO<sub>2</sub> concentration in the atmosphere, which leads to the global climate change driven by greenhouse effect (Genxu et al., 2002). Estimates soil organic carbon pools and soil carbon sequestration across a give geographical area are important requirements for understanding the role of soil in the global carbon cycle and for assessing potential biosphere responses to climate change (Lal et al., 2012).

In carbon sequestration studies, dead wood is recognized as an important component for conserving carbon stock. For example, in the USA 14% of the total forest carbon pool is stored in dead wood (Woodall et al., 2008). Delaney et al. (1998) found the amount of coarse woody debris is equivalent to approximately 10-20% of the above ground carbon biomass, indicating that dead wood can represent a significant amount of carbon in forests. In this context, dead wood helps enhancing SFM and mitigating the climate change impact (Bodegom et al., 2009) through offering the capacity to store carbon themselves (Randerson et al., 2002). In spite of recognition of the importance of dead wood for carbon sequestration, studies dealing with carbon stock in dead wood are still scarce (Sefidi et al., 2010). Sparse literature on dead wood, especially in the tropics (Chambers et al., 2000), suggests that wood debris dynamics are under-studied despite their significant contributions to the structure and function of forest ecosystem and the carbon cycle. There is a relative paucity of the information regarding dead wood in the tropical ecosystem and its role in the local and global carbon cycles (Nascimento & Laurance, 2002). This scenario also applies to Nepalese forest ecosystems as well. Accurate assessment of the total carbon stock of any forest is essential, which is possible only when carbon stock in dead wood is included.

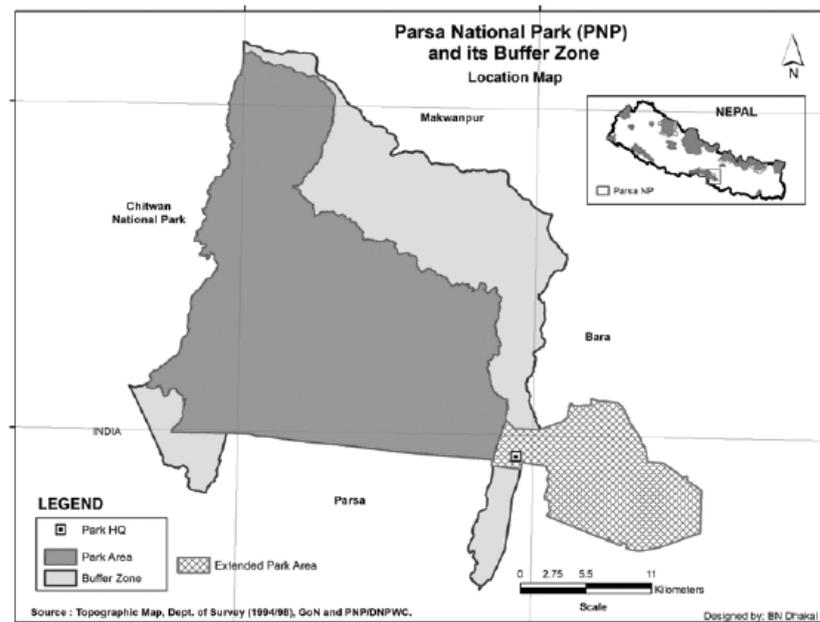
Site conditions such as site quality, stand structure, stand age, species composition, forest types (natural or plantation), and management objectives mainly influence dead wood stock in the forests. Old growth forests usually show larger carbon stock in decaying boles compared to young forests having the similar site conditions (IPCC, 2006). Silviculture and timber harvesting *per se*, other timber management, such as mechanical site preparation, broadcast burning, and fire prevention/suppression can significantly affect the quantity, quality, and dynamics of dead wood stock (Muller-Using & Bartsch, 2003). In managed forests, under sustainable wood production, dead trees are minimized to avoid pest problems and hazards. Thus, trees damaged by insects, diseases and fire are commonly harvested immediately after it if financial resource and accessibility allow to do so (Herrero et al., 2010). Moreover, dead wood is often rare in the managed forests because of silvicultural practice under clean management system (Harmon et al., 1986) and consequently, many species are either lost or reduced to the point of being endangered. The clean management system applied over the decades or centuries have caused the massive depletion of the habitat resources for micro fauna and flora and serious declines of removal of biodiversity (Atici et al., 2008). Debunking the myths about the negative impacts of dead wood is thus very crucial. Understanding dead wood dynamics is important to classify adequate density, size and amount into different decay classes and to make the decisions that include biodiversity and carbon budget in practical forestry (Herrero et al., 2010).

The carbon sequestration in the forest varies according to geographical location, tree species and stand age (Van Noordwijk et al., 1997). Estimates of the biomass contained within forests are critical in determining carbon loss associated with a wide range of land use and land-cover change processes. To assess the impact of deforestation and regrowth rate on the global carbon cycle, it is necessary to know the stock of carbon per unit area for different forest types. As mentioned earlier, elsewhere including protected areas, dead wood is a prominent medium for carbon sequestration or sink and suitable habitat for micro-flora and fauna species. The estimated carbon stocks in dead wood of forest stands would be useful for forest management or protected area management. However, information on the contribution of the dead wood to carbon sequestration in the forest is still lacking in Nepal, as none of the studies was conducted for quantifying carbon stocks of dead wood in the forests including protected areas. This study thus aimed to assess the status of dead wood in one of the protected areas in Nepal, i.e., Parsa National Park (PNP) and role of dead wood and forest soil in carbon sequestration. The specific objectives of this study were to determine the biomass of both standing and fallen dead wood in PNP; to assess the potential use of dead wood for carbon sequestration in PNP, and quantify carbon stock of forest soil in PNP.

## MATERIAL AND METHODS

### *Study area*

The Parsa National Park (PNP), located in the southern part of Nepal (Figure 1) was selected for our study. It is located in the Terai physiographic zone of Nepal with dense tropical forest containing diverse flora and fauna species. Under Nepal's National Park and Wildlife Conservation Act (2029), removal of any live and dead wood resource is strictly prohibited from protected areas. The park was initially declared as 'Parsa Wildlife Reserve' in 1984 with the aim of preserving Asian Wild Elephant (*Elephas maximus*) and their remaining habitat of historical Char-Koshe-Jhadi which was spread over Terai from east to west of Nepal.. Later, this reserve was named as a national park in 2017. The PNP also provides an extended habitat to the wildlife in the adjacent national park, named as Chitwan National Park (CNP). The PNP includes tropical and sub-tropical forests of *Churia* (Siwalik) and *Bhabar* physiographic region covering parts of three districts: Parsa, Makwanpur and Bara districts. Major portion of the PNP occupies *Churia* and *Bhabar* zone of the Parsa and Makwanpur districts. The geographical area of the PNP is 627.39 km<sup>2</sup> covering a small Terai-Bhawal area with 90% *Shorea robusta* forest and other mixed hardwood and riverine forest.



**Figure 1. Location of Parsa National Park (PNP) and its Buffer Zone**

#### Data

##### Down dead wood data

A total of 143 transect lines were randomly laid out for inventory of down dead wood following the method suggested by Harmon & Sexton (1996). The length of each transect line was 60 m. Diameters of all pieces of wood that intersected the transect line were measured and the density class noted. The down dead woods with minimum diameter 10 cm were measured. Based on the hardness of dead wood, collected wood samples were categorized into three density classes based on wood hardness: sound (very hard), intermediate (hard), and rotten (soft). The density class was determined in the field by striking the wood with a strong sharp blade. If the blade bounced off, it was considered sound, if it entered slightly; it was intermediate, if the wood felled apart, it was rotten (Pearson et al., 2007).

##### Data analysis

The volume of dead wood per unit forest area was calculated for each density class as below:

$$Volume (m^3 ha^{-1}) = \pi^2 \times \left[ \frac{d_1^2 + d_2^2 + \dots + d_n^2}{8L} \right] \quad (1)$$

where  $d_1, d_2, d_n$  = diameter (cm) of each of the  $n$  pieces intersecting the line, and  $L$  = the length of the line (i.e., 100 m)

Dry wood density of the sample dead wood for each density class was calculated by multiplying the standard undecomposed wood density and proportion factor for that density class. The average dry wood density of dead wood per unit forest area was calculated for each density class as below:

$$Density (t m^{-3}) = \text{average } \delta_n - \text{decomposed dry wood density for a density class} \times \text{proportion factor} \quad (2)$$

Average value was obtained for each density class. We used three classes of wood based on hardness of dead wood following the methods suggested by Heath and Chojnacky (Heath and Chojnacky, 2001), which calculated the proportion factors as 90% (sound), 70% (intermediate), and 40% (rotten) for sound, intermediate and rotten wood density classes, respectively.

$$Biomass\ stock (t\ ha^{-1}) = \sum (\text{average dry wood density} \times \text{volume } \delta \text{ dead wood for each density class}) \quad (3) \text{ (Harmon and Sexton, 1996; Pearson et al., 2007)}$$

$$Carbon\ stock\ \delta \text{ down dead wood } (t\ ha^{-1}) = \frac{Biomass\ stock}{2} \quad (4) \text{ (Pearson et al., 2007)}$$

##### Standing dead trees and stumps

Standing dead trees and stumps were measured as part of the tree inventory following the Nepal's community forest inventory guidelines (DoF, 2004). A total of 185 circular plots were randomly laid for inventory of standing dead trees and stumps. The area of each circular plot was 250 m<sup>2</sup>. Within plots delineated for live trees, diameter at breast height (dbh) and height of standing dead trees and stumps were measured. The decomposition state of

the dead tree was recorded. Decomposition classes for standing dead wood were defined practically as follows (MacDicken, 1997):

1. Tree with branches and twigs and resembles a live tree (except for leaves).
2. Tree with no twigs but with persistent small and large branches.
3. Tree with large branches only.
4. Bole (trunk) only, no branches.

The standing dead trees and stumps were categorized into three-density classes: sound, intermediate, and rotten. Again, Pearson et al., (2007) was followed to determine the density class of standing trees.

#### *Estimating biomass and carbon stock in dead trees and stumps*

The aboveground tree biomass of each dead tree or stump was calculated using the tree biomass-size relationship equation developed by Chave et al., (2005).

$$AGTB = 0.112 \times (\rho D^2 H)^{0.916} \quad (5)$$

Where, AGTB = above-ground tree biomass [kg];

$\rho$  = wood specific gravity [ $\text{g cm}^{-3}$ ];

D = tree diameter at breast height [cm]; and

H = tree height [m].

For decomposition class 1, the biomass of leaves (about 2–3% of aboveground biomass for hardwood/broadleaf species and 5–6% for softwood/conifer species) were subtracted from the total biomass.

After taking the sum of all the individual weights (kg) by sample plot and dividing a total weight by sample plot area (250 m<sup>2</sup>), the biomass stock density (kg m<sup>-2</sup>) was obtained. For tropical and subtropical region, the biomass stock density of a sampling plot was converted to carbon stock densities after multiplication with the Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2006) default carbon fraction of 0.47 (ANSAB et al., 2010).

To simplify the process for estimating belowground biomass of dead tree, root-to-shoot ratio value of 1:5 was used; that is, to estimate belowground biomass as 20% of aboveground tree biomass (MacDicken, 1997). Total carbon stock in dead wood in the forest was obtained by adding the carbon stocks of the standing and down dead wood.

The differences of average dead wood carbon stocks among three density classes of standing and down dead wood were analyzed using the parametric one way analysis of variance (ANOVA) based on F-test at 5% level of significance.

#### *Soil analysis*

For estimating bulk density, 40 soil samples (from 20 pits) of approximately 200 cm<sup>3</sup>, one each from two depths (0-10 cm, 10-20 cm) were collected with the help of a standardized 200 cm<sup>3</sup> metal soil sampling corers. Similarly, soil samples of approximately 100 gram, one each from two depths (0-10 cm, 10-20 cm) were collected for analysing organic carbon and total nitrogen. Soil samples were placed in sample bags, labelled and transported to the laboratory for further analysis. Overall, field measurement methods were based on the guidelines of ANSAB (ANSAB, 2010).

Bulk density of soil was determined using the soil core samples using Eq. 6 (Blake et al., 1986). The soil organic carbon (SOC) concentration was determined by dry combustion of oven-dry soil samples using Eq. 7 (Nelson and Sommers, 1982).

$$\text{Bulk density of soil} = \frac{\text{oven dry weight of soil in gram}}{\text{Volume of the soil in cm}^3} \quad (6)$$

$$\text{Soil organic carbon (tha}^{-1}\text{)} = \text{Organic carbon content \%} \times \text{soil bulk density (gm cm}^{-3}\text{)} \times \text{soil layer depth (cm)} \quad (7)$$

The differences of average soil organic carbon (SOC) of two soil depth layers were analyzed using the parametric *t* independent test at 5% level of significance.

## RESULTS

### *Status of volume and biomass of standing and down dead wood in PNP*

#### **Volume of dead wood**

Volumes of the standing and down dead wood were determined in Parsa National Park (PNP) for three density classes- sound, intermediate and rotten. Total volume of dead wood in PNP was 39.83 m<sup>3</sup> ha<sup>-1</sup>; where standing dead wood contributes to 25.88 m<sup>3</sup> ha<sup>-1</sup> and down dead wood contributes 13.95 m<sup>3</sup> ha<sup>-1</sup>. Total volume of dead wood was dominated by intermediate class (61%) in both dead wood categories (standing and down); and

followed by sound (23%) and rotten (16%) density classes.

The major statistics of the volume of dead wood category each with density classes in the PNP forest are presented in Table 1.

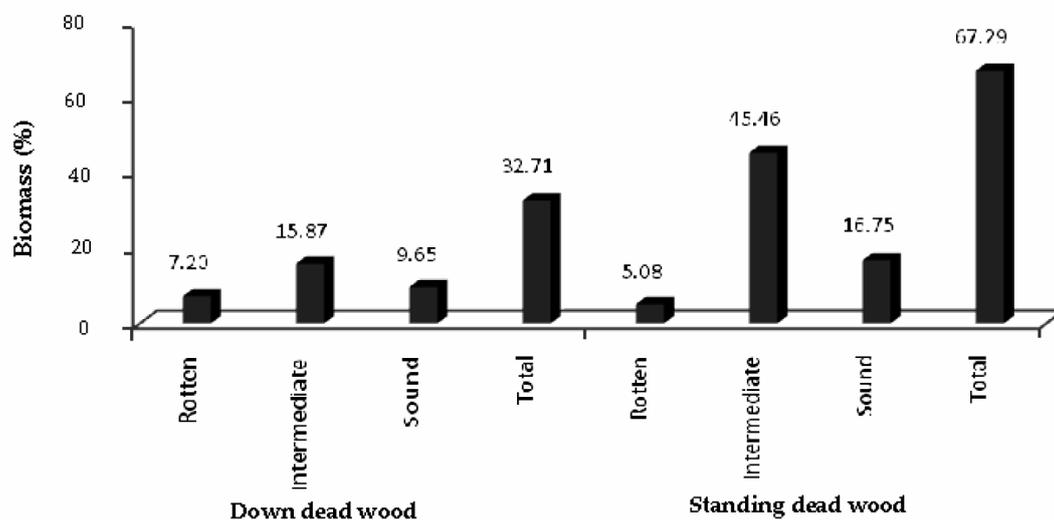
**Table 1. Volume of dead wood with respect to dead wood type and wood density hardness in PNP forest**

Dead wood types	Wood density hardness	Volume of dead wood ( $m^3 ha^{-1}$ )				
		Mean±SE	Min.	Max.	Total	% share
Standing	Rotten	0.201±0.065	0.01	1.04	3.41	8.56
	Intermediate	0.171±0.031	0.00	1.34	17.46	43.84
	Sound	0.077±0.019	0.00	0.76	5.00	12.56
	Total	0.141±0.019	0.00	1.34	25.87	64.97
Down	Rotten	0.088±0.020	0.02	0.57	3.06	7.70
	Intermediate	0.090±0.011	0.02	0.42	6.76	16.98
	Sound	0.125±0.023	0.02	0.59	4.11	10.33
	Total	0.098±0.009	0.02	0.59	13.94	35.02
Both	Rotten	0.125±0.026	0.01	1.04	6.47	16.26
	Intermediate	0.137±0.019	0.00	1.34	24.22	60.83
	Sound	0.093±0.015	0.00	0.76	9.12	22.90
	Total	0.122±0.012	0.00	1.34	39.82	100.00

### Biomass of dead wood

Total biomass of the dead wood in forests within PNP is  $22.39 t ha^{-1}$ . Total biomass in the intermediate density class of dead wood was 5 times higher than that of rotten and 2.3 times than that of sound density class. This means intermediate density class plays a vital role to increase the biomass of dead wood in PNP forest.

The majority (approx. 50%) of the biomass in dead wood was occupied by standing dead wood of intermediate density class as large density of this category was in the core as well as riverine area of park. Approx. 70% biomass contribution was provided by standing dead trees and stumps, which was higher amounts as compared to that of down dead wood lying on the ground (Figure 2). Biomass of standing dead trees in the rotten stage was substantially less due to dead trees' long standing capability stage.

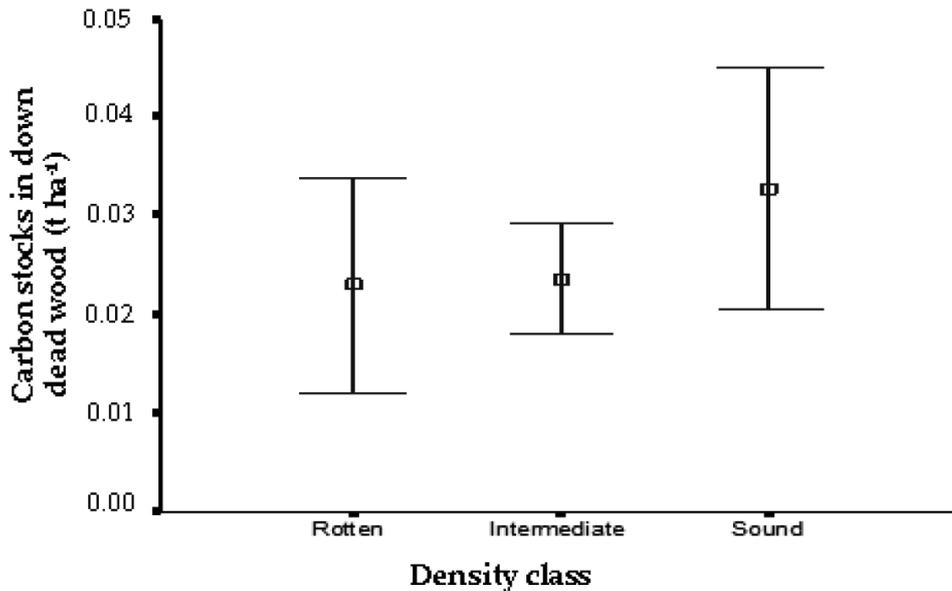


**Figure 2. Percentage share of biomass with respect to wood density class in PNP forest**

### Contribution of dead wood to carbon sequestration

#### Carbon stocks in down dead wood

The total carbon stock in down dead wood was 3.7 t ha<sup>-1</sup> in PNP forest. Within this category, about 50% was occupied by intermediate density class and followed by sound (29.5%) and rotten (22%), respectively. The average carbon stock in the down dead wood category was the highest in sound and almost the same average value in intermediate and rotten density classes. These average values were based on the numbers of dead wood in those classes. However, the total carbon stocks of intermediate density classes were 2.2 and 1.64 times higher than those of the rotten and sound density classes. The F-test in ANOVA showed no significant difference in the average carbon stock with respect to density classes in the down dead wood ( $p>0.05$ ). This indicated that average carbon stocks for all the density classes of down dead wood had equal contribution in the PNP forest (Figure 3).

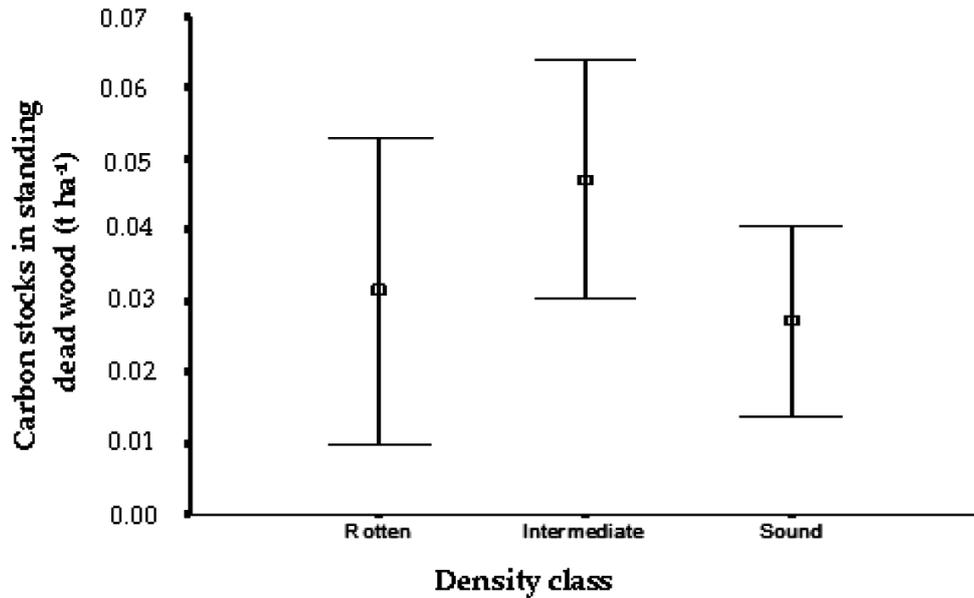


**Figure 3. Carbon stocks with respect to wood density class in down dead wood in PNP forest**

#### Carbon stocks in standing dead wood

The total carbon stock in standing dead tree/stumps in PNP forest was 7.1 t ha<sup>-1</sup>. Within this category, about 68% was occupied by intermediate density class and followed by sound (25%) and least by rotten (8%) respectively. The carbon stock in the rotten class within this category was the least due to the non-standing capability of rotten tree for long time.

Overall average carbon stock in the standing dead wood of all the density classes was 0.03 t ha<sup>-1</sup> with a range value of 0.36 t ha<sup>-1</sup>. Average carbon stock in this dead wood category was the highest in intermediate density class followed by rotten and sound density classes. Also, the total carbon stock of intermediate density class was 9 times higher than that of the rotten and 2.71 times than that of sound density classes. The ANOVA results showed that there was no significant difference in the average carbon stocks with respect to density classes in standing dead wood ( $p>0.05$ ). This indicated that average carbon stock of each density class of standing dead trees/stumps had approximately equal contributions in the PNP forest (Figure 4).

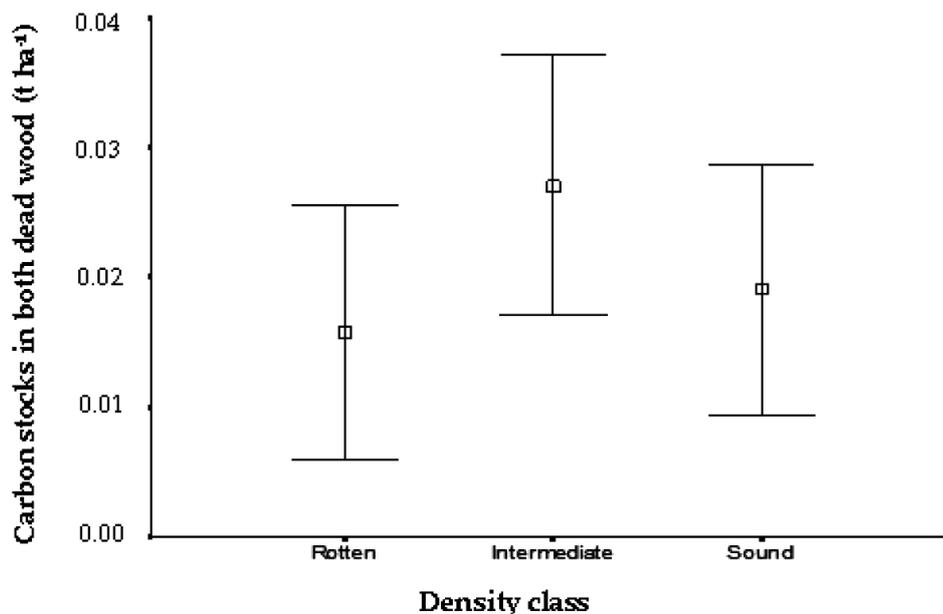


**Figure 4. Carbon stocks with respect to wood density class in standing dead wood in PNP forest**

#### **Total carbon stocks of dead wood in PNP forest**

The total carbon stock in dead wood was found  $10.741 \text{ t ha}^{-1}$  in PNP. Regarding total carbon stocks for each dead wood class, intermediate class had contributed 4.9 and 2.3 times more carbon stocks than that of rotten and sound categories, respectively.

Regarding total carbon stocks for each dead wood class, standing dead tree had contributed almost two times carbon stocks than that of the down dead wood. Regarding average carbon stocks per unit area in each density class, it was found maximum carbon stocks with value 0.03 ton in intermediate density class followed by sound with value 0.02 ton and rotten with value 0.02 ton, respectively (Figure 5).



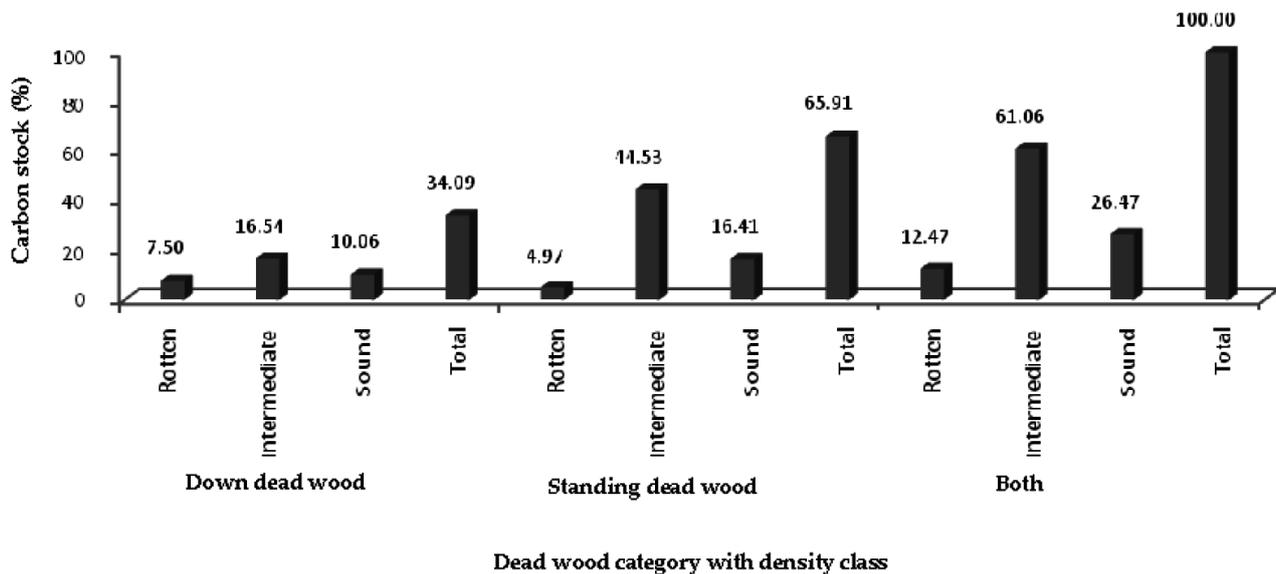
**Figure 5. Carbon stocks with respect to wood density class in PNP forest**

The one-way ANOVA results showed that there was no significant difference in the average carbon stock per ha with respect to density classes ( $p > 0.05$ ), suggesting that each density class was equally responsible to contribute the carbon stocks.

The percentage share of each dead wood category with respect to the total carbon stock increased from down to standing in PNP (Table 1). Similarly, the percentage share with respect to total carbon stock in each density

class increased from rotten, sound and intermediate class, respectively.

Within the dead wood category, 34% carbon stock was occupied by down dead wood and then reached the approximately double value as of 66% by standing dead tree/stumps in the PNP forest. Within density class, out of total dead wood carbon, about 61% was occupied by intermediate density class followed by sound (26.5%) and rotten (12.5%), respectively (Figure 6).



**Figure 6. Percentage share of carbon stock of dead wood in PNP forest**

#### *Soil organic carbon in PNP forest*

##### **Bulk density**

The average bulk density was 1.24 ( $\text{g cm}^{-3}$ ) throughout the whole study area. The lowest value of bulk density was found in 10-20 cm soil depth. The average bulk density in 0-10 cm soil depth was 1.26 ( $\text{g cm}^{-3}$ ) and average bulk density in 10-20 cm soil depth was 1.24 ( $\text{g cm}^{-3}$ ). The maximum bulk density in 0-10 cm soil depth was found 1.58 ( $\text{g cm}^{-3}$ ) whereas the minimum bulk density of 0-10 cm soil depth was found 1.01 ( $\text{g cm}^{-3}$ ). Similarly, the maximum bulk density of 10-20 cm soil depth was found 1.41 ( $\text{g cm}^{-3}$ ) whereas the minimum bulk density of 10-20 cm soil depth was found 1.08 ( $\text{g cm}^{-3}$ ). Table 2 shows the range of bulk density in soils of PNP forest on the 0-20 cm depth.

**Table 2. Bulk density and organic carbon (%) distribution according to soil depth in PNP forest**

	0-10 cm soil depth	10-20 cm soil depth
Organic carbon% min.	0.35	0.19
Organic carbon% max.	4.11	3.36
Bulk density min. ( $\text{g cm}^{-3}$ )	1.01	1.08
Bulk density max. ( $\text{g cm}^{-3}$ )	1.58	1.41
Organic carbon% avg.	2.64	1.91
Bulk density avg. ( $\text{g cm}^{-3}$ )	1.25	1.24

Organic carbon in soil was found to be 28.75  $\text{t ha}^{-1}$  in average throughout the whole study area. Amount of soil organic carbon was found to be highest in 0-10 cm soil depth with 33.21  $\text{t ha}^{-1}$  in average while amount of soil organic carbon was found to be the least in 10-20 cm soil depth with 24.30  $\text{t ha}^{-1}$ . The parametric independent t- test shows that there was significant difference in the average soil organic carbon between these two depths ( $p < 0.01$ ). The distribution of average soil organic carbon ( $\text{t ha}^{-1}$ ) in soil profiles in both soil depths is shown in the Table 3.

**Table 3. Depth wise soil organic carbon (t ha<sup>-1</sup>) in PNP forest**

Soil depth	Average soil organic carbon (t ha <sup>-1</sup> )	sd	p-value (t test)
0-10 cm	33.21	2.31	0.001*
10-20 cm	24.30	1.98	
Grand Total	28.75		

\* Significant at 5% level.

### DISCUSSION

In the forest of Parsa National Park (PNP), different types of dead wood were found with different wood density classes. The forest is found particularly dominated by an intermediate wood density class of standing dead wood as categorized by Pearson et al. (2007). The total volume of standing dead wood was approximately double than the amount of fallen dead wood (Table 1). Our result of down dead wood is about one-third less than that of volume obtained by Macmillan (1981) in old-grown temperate deciduous forest in the United States, which is dominated with *Quercus* mixed types. Our result is similar with the results of fallen dead wood that lie in the lowest range, <20 m<sup>3</sup> ha<sup>-1</sup> as obtained by Kirby et al. (1998) in British broadleaved forests. Generally, our results of total volume of dead wood lie within the range 0.3-139 m<sup>3</sup> ha<sup>-1</sup> that was also found in managed and unmanaged forests in Britain (Kirby et al., 1998). Stem volume of cull trees in Terai and Churia region of Nepal was estimated to be 17.88 m<sup>3</sup> ha<sup>-1</sup> and 17.83 m<sup>3</sup> ha<sup>-1</sup>, respectively DFRS (DFRS, 2015), which are lesser than our findings (28.87 m<sup>3</sup> ha<sup>-1</sup>) for standing dead wood. It might be because PNP is protected area while findings of the DFRS were average values from the national-level forest inventory.

The major part of carbon stock lies in the standing dead wood, which occupies 61.95% in the total carbon stock of 10.71 t ha<sup>-1</sup> out of which intermediate wood density class alone occupies 44.53% carbon stock. The collection of dead wood for buffer zone communities of PNP is limited since PNP forest has been protected legally. Therefore, this result depicts the amount of dead wood available in deciduous tropical/sub-tropical forests dominated with *Shorea robusta* in natural conditions without influence of any forest management practices.

The soil organic carbon was higher at the top layer than the lower layer. Our research quantified soil organic carbon stocks up to 20 cm depth, so lesser than the values by Chhabra et al., (2003). The higher organic carbon percentage in the top layer may be due to rapid decomposition of forest litter in a favorable environment. Soil organic carbon in Terai and Churia region of Nepal was estimated 33.66 t ha<sup>-1</sup> and 31.44 t ha<sup>-1</sup> respectively (DFRS, 2015) which are close to our findings (28.75 t ha<sup>-1</sup>). It might be due to similar physiographical location. Pandey & Bhusal (2016) reported that the soil organic carbon decreased with the increase in soil-depth in *Shorea robusta* forests of hills and Terai regions of Nepal. Chhabra et al., (2003) reported found 70 Mg ha<sup>-1</sup> soil organic carbon stock (1 m depth) in tropical deciduous forest, and 162 Mg ha<sup>-1</sup> in montane temperate forest in India.

It is clear from the study that dead wood can contribute to carbon sequestration. Carbon sequestration by dead wood needs to be considered in carbon accounting. Management of dead woods needs to be incorporated as an essential component in forest management planning.

### CONCLUSION

Both standing and down dead wood were prevailed in PNP where standing dead wood contributed more carbon stock than that of down dead wood. The range of organic carbon content and bulk density was higher in upper soil layers. The average carbon stock in down dead wood category is the highest in sound, and almost the same average value in intermediate, and rotten wood density classes. The total carbon stocks of intermediate wood density classes are higher than that of rotten and sound wood density classes.

In the national carbon accounting projects, consideration of dead wood carbon seems essential. Therefore, policy level provision on maintaining dead wood in managed forest is relevant in Nepalese context. It is required to understand the process of dead wood accumulation, the amount of dead wood and the total amount of live trees on per unit area basis in a naturally grown forest, which is not much affected from human management practices. The ratio of dead wood to live trees need to be taken into account, and a suitable ratio of dead wood to live trees is required to maintain in managed forest types, not only for maintaining forest biodiversity, but also for balancing soil carbon dynamics through carbon inputs from dead wood decay.

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