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Deadwood and Litter Carbon in Different Forest Types

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ဒေါက်တာယုယအေး

လက်ထောက်ညွှန်ကြားရေးမှူး

အကျဉ်းချုပ်

ကမ္ဘာ့ကုလသမဂ္ဂ ရာသီဥတုပြောင်းလဲမှု လျော့ချရေးအတွက် ဆောင်ရွက်နေသော နိုင်ငံများသည် မိမိတို့နိုင်ငံ သစ်တောကာဗွန်သိုလှောင်မှုများကို (သက်ရှိအပင်များ၊ သစ်/ သစ်ပင်သေ၊ သစ်ရွက်/သစ်ကိုင်းကြွေ၊ မြေဆီလွှာ) စောင့်ကြည့်တွက်ချက် တင်ပြရန် လိုအပ်ပါသည်။ သို့သော် သစ်တော ကာဗွန်တွက်ချက်လေ့လာမှုများသည် သက်ရှိအပင် များကိုသာ လေ့လာလေ့ရှိပြီး သစ်/ သစ်ပင်သေ၊ သစ်ရွက်/သစ်ကိုင်းကြွေ များ၏ ကာဗွန် သိုလှောင်မှုများကို လေ့လာသော သုသေသနမှာ အလွန်နည်းပါးလျက် ရှိပါသည်။ ထို့ကြောင့် တောအမျိုးအစား (၄)မျိုးမှ သစ်/ သစ်ပင်သေ၊ သစ်ရွက်/ သစ်ကိုင်းကြွေ များ၏ ကာဗွန်သိုလှောင်မှုများကို လေ့လာခဲ့ပါသည်။ တောတစ်မျိုးစီတွင် (၁)ဟက်တာ ဖြင့် စုစုပေါင်း(၄)ဟက်တာ နမူနာကွက်မှ တိုင်းတာချက်များအရ သစ်ပင်သေများ၏ ကာဗွန်သိုလှောင်မှုသည် တောအမျိုးအစား မူတည်၍ တစ်ဟက်တာလျှင် ၁၉.၁၅ တန်မှ ၄၇.၄၆ တန် သိုလှောင်နိုင်ပြီး၊ သစ်ရွက်/သစ်ကိုင်းကြွေ များသည် တစ်ဟက်တာလျှင် ၂.၁၅ တန်မှ ၁၆.၆ တန် အထိ သိုလှောင် နိုင်ပါသည်။ သစ်တောအတွင်း မြေပေါ်ပိုင်း စုစုပေါင်း ကာဗွန်သိုလှောင်မှု၏ (၁) ရာခိုင်နှုန်းမှ (၁၀) ရာခိုင်နှုန်း အထိ သစ်ရွက်/ သစ်ကိုင်းကြွေများမှ သိုလှောင်နိုင်ပြီး (၁၁) ရာခိုင်နှုန်းမှ (၃၂) ရာခိုင်နှုန်း အထိ သစ်/သစ်ပင်သေများမှ သိုလှောင်နိုင်ကြောင်း တွေ့ရှိရပါသည်။ ဤသုတေသနမှ သစ်တောအတွင်းရှိ သစ်/သစ်ပင်သေများနှင့် သစ်ရွက်/သစ်ကိုင်းကြွေများ၏ ကာဗွန် သိုလှောင်မှုကို သိရှိပြီး ကာဗွန်ထုတ်လွှတ်မှုကို လျော့နည်းစေသော သစ်တောစီမံ အုပ်ချုပ်မှုစနစ် ဖော်ဆောင်ရာတွင် အထောက်အကူ ပြုနိုင်မည် ဖြစ်ပါသည်။

Deadwood and litter carbon in different forest types

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Abstract

The United Nations framework convention on climate change (UNFCCC) commits signatory nations to monitor changes in all fluxes and sinks of carbon, including those related to vegetation, litter, deadwood and soil. However, much attention is focused on vegetation carbon only a handful of studies have been carried out to estimate carbon stocks in litter and deadwood in the natural forest. Thus, this study attempted to estimate deadwood carbon and litter layer carbon in four forest types, dry mixed deciduous forest, dry dipterocap Forest, dry Forest and dry hill forest. Based on 4 ha sample plots (1 ha in each forest type), it was found a wide range of carbon storage in deadwood carbon from 19.15 $tCha^{-1}$ to 47.46 Cha^{-1} and in the litter layer, from 2.15 to 16.6 $tCha^{-1}$. Deadwood occupied 11 % - 32% of total aboveground carbon while Litter layer carbon occupied 1 % - 10 % of total aboveground carbon. Not only this study provide information on carbon storage capacity of deadwood and litter but the information is important for designing forestry management systems that could result in carbon emission reductions.

Keywords: Climate Change, Carbon emission reduction, carbon storage, forest management

1. **Introduction**

Reducing Emissions from Deforestation and Forest Degradation (REDD) is a new initiative of United Nations Framework Convention in Climate Change (UNFCCC), led by forest-rich developing countries that calls for economic incentives to reduce the emissions of greenhouse gases from deforestation and forest degradation in developing countries (Gibbs et al., 2007). The developing countries need to have well-authenticated estimates of forest carbon stocks for successful implementation of mitigating policies to take advantage of the REDD programme (Saatchi et al., 2011; Salimon et al., 2011). Canadell and Raupach (2008) consider increasing the carbon density of existing forests also as an important option. Forests have five primary carbon pools - above-ground biomass, below-ground biomass, deadwood, litter, and soils – that simultaneously accumulate and release carbon (IPCC, 2006). However most of the studies focused more on aboveground biomass in living vegetation and a few studies account for deadwood and litter layer carbon. Deadwood and litter can account for a substantial fraction of the carbon stored in forests.

Deadwood is an important store of aboveground biomass, carbon and nutrients (Turner, Koerper, Harmon, & Lee, 1995). Large (>10 cm diameter) pieces of standing dead trees, stumps and fallen deadwood (coarse woody debris, CWD) comprise a significant fraction of the total stocks (Baker et al., 2007). Deadwood biomass plays a key role in the functioning and productivity of forest ecosystems (Harmon et al., 1986; Humphrey et al., 2004). Standing and fallen non-living wood pieces are special habitats for many species (mammals, birds, amphibians, insects, polypores and other saproxylic fungi, moss and lichen communities) (Nordén et al., 2004) and contribute to the structural and biological diversity of ecosystems, as many organisms (both directly and indirectly dependent) are adapted to utilize them as a resource (Aakala, 2010). Deadwood is also an important factor in nutrient cycles (N, P, Ca and Mg) (Laiho and Prescott, 1999; Holub et al., 2001) and a fundamental element in ecological, geomorphological and soil hydrological processes (Bragg and Kershner, 1999). Furthermore, non-living woody biomass is an important forest carbon pool (Ravindranath and Ostwald, 2008); it slows the release of carbon dioxide due to decomposition and in this way, it has the potential to moderate global warming by decreasing the build-up of carbon dioxide (Keller et al., 2004).

The IPCC Guidelines for National Greenhouse Gas Inventory (IPCC, 2003) stated that dead organic matter should be considered in future work on inventory methods because the quantity of carbon in dead organic matter is a significant reservoir in many of the world’s forests. Accordingly, the estimation of deadwood carbon stock changes is explicitly required for reporting under Tiers 2 or 3. Until recently, estimation of deadwood and litter were still rare (Delaney et al., 1998; Chojnacky and Heath, 2002;

Heath and Chojnacky, 2001; Woodall et al., 2008), although deadwood and litter biomass are required terrestrial carbon pools that are relevant for the estimation of carbon stocks and carbon stock changes under the UNFCCC and the Kyoto Protocol (IPCC Guidelines for National GHG Inventory). In Myanmar, only a handful of studies have been carried out to estimate carbon stocks in litter and deadwood in the natural forest. Thus, this study conduct to estimate deadwood carbon and litter layer carbon in four forest types, dry mixed deciduous forest (DMDF), Dry Dipterocap Forest (DDF), Dry Forest (DF) and Dry hill forest (DHF).

2. **Objectives**

The objectives of the study are

1. To estimate carbon storage capacity of deadwood and litter in different forest types
2. To assess the carbon stock among deadwood types and decay classes in different forest types

3. **Literature review**

In the early of 1970s, researchers and forest managers recognized the importance of deadwood in the ecology of a forest (Thomas, 2002). This triggered additional research to further expand knowledge about the role of deadwood in forest ecosystems. Nowadays, deadwood is of interests not only to ecologists, but also to mycologists, foresters, and fuel specialists (Rondeux & Sanchez, 2009). It is increasingly recognized as an important component in the functioning of forest ecosystems (Vandekerkhove et al., 2009) and is becoming an integrated part of forest management (Marage & Lemperiere, 2005).

As vary the definitions of deadwood between the studies, so do the types specified in individual works. While some authors (e.g. Atici et al., 2008; Fridman & Walheim, 2000; Christensen et al., 2005; Vacik et al., 2009) distinguish only two types of deadwood, namely standing and lying deadwood, other works use a more detailed classification with four or five deadwood components.

The basic classifications distinguish between standing and downed or fallen deadwood. Standing deadwood consists of standing dead trees, snags, and stumps. Snags are defined as vertical pieces of dead trees. There exists a discrepancy in the understanding of snags and stumps between some authors. For example, a snag is any vertical piece irrespective of its height resulting from natural processes only according to some others, while a snag is a height equal to or greater than 1.3 m in some study (Katarína, et., al 2012). Likewise, some researcher mentioned that a stump is a short vertical piece resulting from cutting but other author stated that stump is a piece shorter than 1.3 m irrespective of its origin (Katarína, *et., al* 2012). Lying deadwood includes downed dead trees, and lying deadwood pieces, which are often called logs. The specification of log parameters depends on a particular study.

The main attributes used for describing standing deadwood are diameter and height (Rondeux & Sanchez, 2009). In case of standing dead trees and snags with height 1.3 m or more, diameter at breast height is measured. In case of stumps and snags shorter than 1.3 m, diameter at the level where the tree was cut or where the stem was broken off is measured (Travaglini et al., 2007). For lying deadwood, a diameter in the middle of the log (a so called mid diameter) and its length are the main attributes (Rondeux & Sanchez, 2009). Alternatively, diameters at the top and bottom ends of the log (i.e. top and basal diameter, respectively) can be measured in order to produce more precise volume calculations (Harmon & Sexton, 1996).

The variability of minimum threshold diameter between coarse and fine woody detritus is large. In the context of forest management dead wood with diameter of more than 6-7 cm is generally accepted as "deadwood" (Atici et al. 2008), while smaller material is considered of lesser importance (Colak, 2002). Some authors (e.g. Debeljak, 2006; Travaglini et al. 2007; Vandekerkhove et al. 2009) use minimum threshold 5 or 7 cm, which equals the threshold diameter for living trees. Other authors (e.g. Atici et al., 2008; Fridman & Walheim, 2000; Nordén et al., 2004) use the diameter limit 10 cm as suggested by Harmon & Sexton (1996). However, Vandekerkhove et al. (2009) showed that the differences in diameter thresholds did not significantly affect the results, and concluded that unlike stand density, deadwood volume is less affected by size thresholds. So this study use 10 cm as a threshold and each piece of deadwood with a diameter ≥ 10 cm was measured on each plot. For standing dead trees, the diameter at breast height and the tree height were measured. For stumps (which are nearly all naturally occurring rather than a result of harvesting) and fallen trees, the length was measured along with two sets of orthogonal widths at either end.

Nowadays, deadwood is considered relevant for a number of different issues including nature conservation, forest certification, sustainable forest management, carbon sequestration, etc. Hence, deadwood is now assessed in many parts of the world within national forest inventories and various research activities. However, no harmonized methodology for deadwood inventory exists, as the objectives and the needs differ between the studies (Rondeux & Sanchez, 2009). In spite of these differences, simple, fast and accurate methods are required for both research and management purposes (Bütler, 2003).

In general, the survey can be accomplished either in the whole area of interest, or only on a portion of the given area. Although complete enumeration can provide us with the information about each individual, in large populations, such as forests, this survey is usually not economically and practically feasible. Hence, complete field inventory has been applied very scarcely. Because of high time and cost demands, sampling is often applied instead, while its main condition is that the selected sample represents the whole population. As Shiver & Borders (1996) pointed out, in most cases sampling can be more reliable than complete inventory, because more time can be taken to measurements, while sampling error could be kept small. There exist a great number of publications devoted to sampling techniques in general, e.g. Hush et al. (2003), Kish (1995), Shiver & Borders (1996), Thompson (2002), etc., presenting different sampling designs from simple random sampling, through systematic and stratified sampling, up to multi-stage or multi-phase sampling designs. Deadwood sampling methods present specific characteristics with regard to the spatial distribution and the variability of deadwood components (Rondeux & Sanchez, 2009). As already mentioned, deadwood consists of different types (standing/lying, aboveground/belowground, coarse/fine woody debris) several of which would ideally require their own survey method. Due to this complexity, the majority of studies usually account only for the selected components of deadwood. For example, Marage & Lemperiere (2005) studied standing dead trees only. Most often the aboveground coarse woody debris is the subject of interest, while belowground deadwood is conventionally excluded because its assessment and quantification is difficult (Rondeux & Sanchez, 2009). Thus, aboveground deadwood carbon was account for this study.

Standing deadwood is usually inventoried with the same methodology as living trees (Rondeux & Sanchez, 2009). The common approach is the plot-based sampling, while the plots can either be of fixed or variable area. Lying deadwood can also be assessed on the same sample plots as living trees or standing deadwood. In case of plot-based sampling, a common approach is to inventory only the deadwood inside the plot, i.e. if the log crosses the plot border, the part outside the plot is not accounted for in the inventory. The second widely used approach is the line intersects sampling for the inventory of deadwood. The principle of the method is that only the deadwood that crosses the line/transect is inventoried. Line intersect sampling is used by some author for assessing deadwood and debris following logging.

Both plot-based and line-based sampling techniques have some advantages and disadvantages. Line sampling is fast and accurate (Harmon & Sexton, 1996), easy to use, more time efficient and more economical than plot-based approach (Katarina, et., al 2012). However, plot-based sampling is applicable to all types of deadwood, while line intersect method includes only lying deadwood. Hence, if this method is to be used for the deadwood assessment, it must be coupled with another method to consider standing deadwood. Additionally, Oehmichen (2007) and Rondeux & Sanchez (2009) stated that line intersect sampling is not suitable for long-term monitoring. Full enumeration was the preferred method within the 20 m x 20 m plot, because some plots contained the majority of their CWD debris in a few large, misshapen and partially decayed logs. It was deemed more appropriate to carefully measure all logs than to marginally reduce within-plot measurement time, incurring the risk of not counting them, and increasing sampling error. Full enumeration also enables tracking of standing trees through time should they fall or be blown over. Plot sampling was selected for this study and full enumeration was done within the 20m x 20m plot.

4. **Materials and Methods**

4.1 Study Area

The research was carried out at Popa Mountain Park (PMP), the only prominent extinct volcano in central Myanmar and famous for high plant diversity, medicinal plant. PMP is located in the central dry zone of Myanmar between 25° 56´ N and 95° 16´ E (Figure-1). The peak of Mount Popa is in the north of the park and reaches about 1,500 m above sea level. A range of small hills gradually declines in altitude for a distance of about 12 km to the south. The peaks of the small hills are range from 450 to 600 m above sea level. The surrounding plains are about 300 m above the sea level. Due to its comparatively high elevation, PMP has lower temperatures and higher rainfall than the rest of the central dry zone of Myanmar. Mean maximum and minimum monthly temperatures were 31.30°C and 8.52°C, respectively, and the mean annual rainfall was about 1170 mm (Popa Forest Department office, 2013, unpublished data).

The area was legally classified as a forest reserve in 1902. During the Second World War, villagers in the area surrounding the reserve gradually encroached and cleared large areas for cultivation. Within 1955-1972, the Forest Department conducted extensive reforestation and illegal cultivators were removed from the reserve. Reforestation work consisted of establishing plantations and encouraging natural regeneration of the native tree species. The vegetation gradually recovered in reclaimed areas (Naing Zaw Htun 2011)**.** Between 1981 and 1984, the Nature Conservation National Park Project was conducted and Popa Reserve was proposed as a protected area (PAs). Afterward, the area was declared a Protected Area in 1989. The park covers an area of about 100 km^2 of which 88.7 % is covered by forest (N Z Htun, Mizoue, and Yoshida 2011). All forests in PMP are second or third growth after cutting and clearing for agriculture in the early twentieth century (FD 1981). Elevation ranges from about 300 to 1500 m asl. The PMP includes a diverse range of vegetation types such as dry mixed deciduous forest, and dry dipterocarp forest (scrub indaing forest), dry forest (Than-dahat forest) and dry hill forest (N Z Htun, Mizoue, and Yoshida 2011) (Figure-2). Moreover, in some areas there are *Pinus insularis* plantation, Eucalypus (*Eucalyptus camadulensis*) and *Xylia xylocarpa* plantations. These plantations were established during the period 1955–1972.

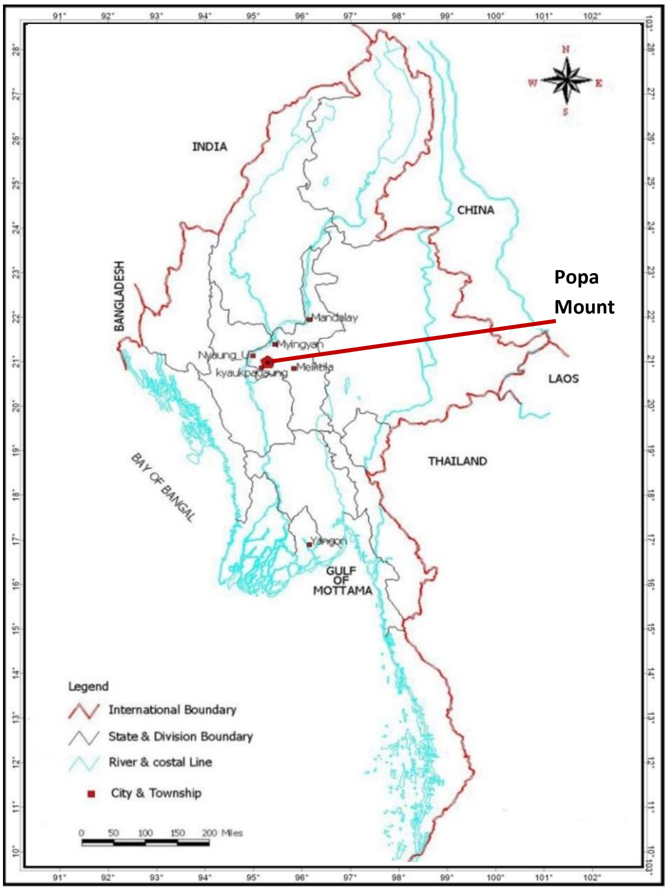
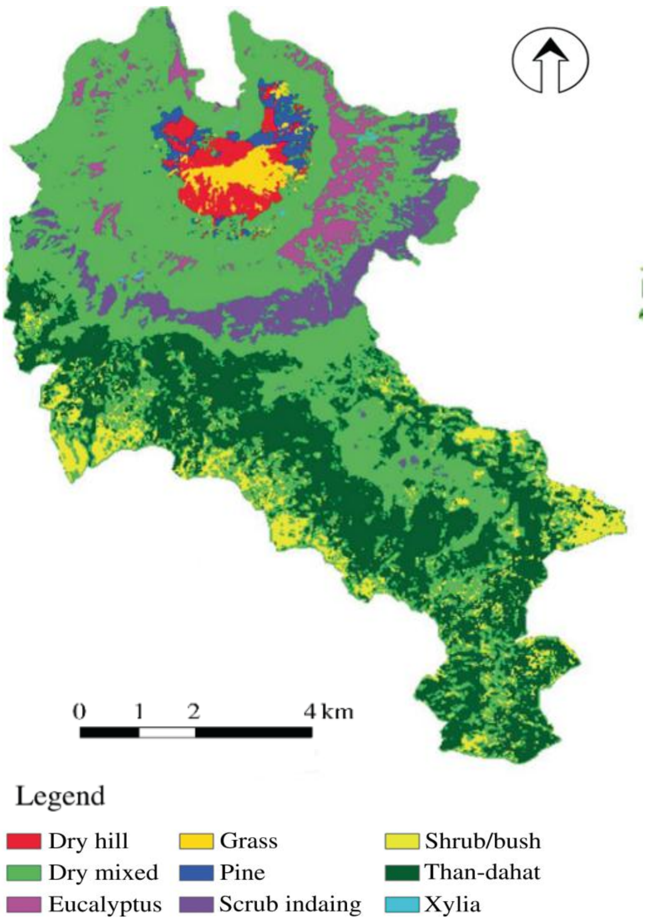


Figure 1. Location of Popa Mountain Park.

Figure 2. Land Cover Status map of Popa Mountain Park



4.2 Measurement of deadwood carbon

All fallen logs and standing dead trees greater than 10 cm diameter were measured within the 20 m x 20 m plots. For standing dead trees, the diameter at breast height and the tree height were measured. For stumps (which are nearly all naturally occurring and a result of harvesting) and fallen trees, the length was measured along with two sets of orthogonal widths at either end.

Each piece of deadwood was measured and classified decay stages according to decomposition classes by following (Coomes et al. 2002): 1) Stage I, bark largely intact; 2) Stage II, bark and twig lost, but shape of trunk remaining intact; and 3) Stage III, shape no longer maintained, and trunk sinking into the ground. The carbon stock of standing dead trees and coarse wood debris (CWD) was estimated by multiplying the log volume by the deadwood density (fresh-wood density × decay stage modifier) according to Coomes (Coomes et al. 2002). As it was difficult to identify these logs to species a mean fresh-wood density (490 kg/m^3) and decay stage modifiers: Stage I, 0.82; Stage II, 0.66; Stage III, 0.47 were used (Coomes et al. 2002). The biomass of all CWD biomass (CWD-B) in the plot was derived using Equation (4) and carbon content of each CWD was calculated as 47% of dry weight (biomass).

$$\text{CWD-B} = \sum \text{LV} \times \text{FWD} \times \text{DSM}$$

where, LV is log volume of dead tree (m^3), FWD is fresh-wood density (kgm^{-3}), DSM is decay-stage modifier (DSM is defined as a deadwood density as a proportion of fresh-wood density).

The volume (LV, m^3) of stumps and fallen logs was estimated using the two pairs of orthogonal widths (a and b, and c and d, cm) and the length of the stump or log (l, m)

$$\text{LV} = \frac{\pi \times l}{32}\left[(a+b)^2 + (c+d)^2\right]$$

4.3 Measurement of litter carbon

Litter layer were collected from each plot. Four subplots having size of 30 cm x 30cm for litter layer (Korea Forest Service 2007) were randomly established in each sample plot (20m x 20 m). All litters inside the frame were collected and weighed. The litters were mixed thoroughly and a sample that is representative of the materials found in the litter was collected. Samples (approximately 200 to 300 g) were collected in each plot. Collected samples were oven-dried (80^{o}C) until constant weights were obtained (Kenzo et al. 2009). The biomass of each sub-plot was calculated by the ratio of dry and fresh weight of the sample. A carbon content default value of 0.47 was used to estimate the carbon content of tree biomass as proposed by the IPCC (IPCC 2006).

$$\text{Biomass (kg)} = \frac{\text{Sample dry weight}}{\text{Sample fresh weight}} \text{ X Total fresh weight}$$

5. **Results**

5.1 Deadwood Carbon

Deadwood is an important store of aboveground biomass, carbon and nutrients (Turner, Koerper, Harmon, & Lee, 1995). Full enumeration (>10cm diameter of standing and fallen deadwood) was done within the 20m x 20m plot and these measurements converted to per-hectare C-stocks. Large (>10 cm diameter) pieces of standing dead trees, stumps and fallen deadwood (coarse woody debris, CWD) comprise a significant fraction of the total stocks (Baker et al., 2007).

In Dry mixed deciduous forest, mean deadwood carbon was 28.3 ± 5.3 $tCha^{-1}$ (Table 1). Fallen logs account for 53% of total deadwood carbon with the standing dead tree being a remainder. Each piece of deadwood was classified into one of three broad decay classes and 25 % of deadwood was fallen logs of the intermediate decay class. In Dry Dipterocap forest, mean deadwood was 47.46 ± 7.52 $tCha^{-1}$. The proportion of the carbon accumulation was 14% in fallen log, 22 % in standing dead tree and 64% in stump. Partially decayed (decay class II) stump was the greatest contributor to total deadwood biomass (28%). In Dry Forest, mean deadwood was 19.15 ± 5.62 $tCha^{-1}$. Fallen logs account for 25% of total deadwood carbon, 52 % for standing dead tree and 23 % in stump. According to decay classes identification, 33 % of deadwood was accumulated in stump of stage I decay class (Bark largely intact) in Dry forest. In Dry Hill Forest, deadwood stored 27.21 ± 6.23 $tCha^{-1}$. Among them, 31 % of total deadwood was accumulated in fallen log, 53 % in standing dead tree and 16 % in stump (Figure 3). In term of decay class, 42% of deadwood was accumulated in standing dead tree of intermediate decay class (Figure 4).

Table 1. Deadwood and Litter carbon in DMDF, DDF, DF and DHF

	DMDF	**DDF**	**DF**	**DHF**
Standing deadwood carbon ($tCha^{-1}$)	13.2	40.8	14.3	28.7
Fallen deadwood ($tCha^{-1}$)	15.1	6.6	4.8	8.5
Deadwood carbon ($tCha^{-1}$)	28.3	47.4	19.1	27.2

Deadwood carbon varied 19.1 to 47.4 among forest types and was greatest in Dry Dipterocarp Forest. Variation among forest types was determined more by variation in the standing pool than the fallen pool. Fallen deadwood was more consistent across forest types (4.8, 6.6, 8.5 and 15.1) than standing dead tree carbon.

Normally deadwood was classified as standing deadwood and fallen deadwood. Standing deadwood (standing dead tree and stump) was more abundant than fallen deadwood in most of the forest types. Fallen deadwood is dominant in dry mixed deciduous forest (53% of total deadwood carbon) while standing deadwood was dominant in dry dipterocap forest (86 % of total deadwood carbon), dry forest (75 % of total deadwood carbon) and dry hill forest (69% of total deadwood carbon).

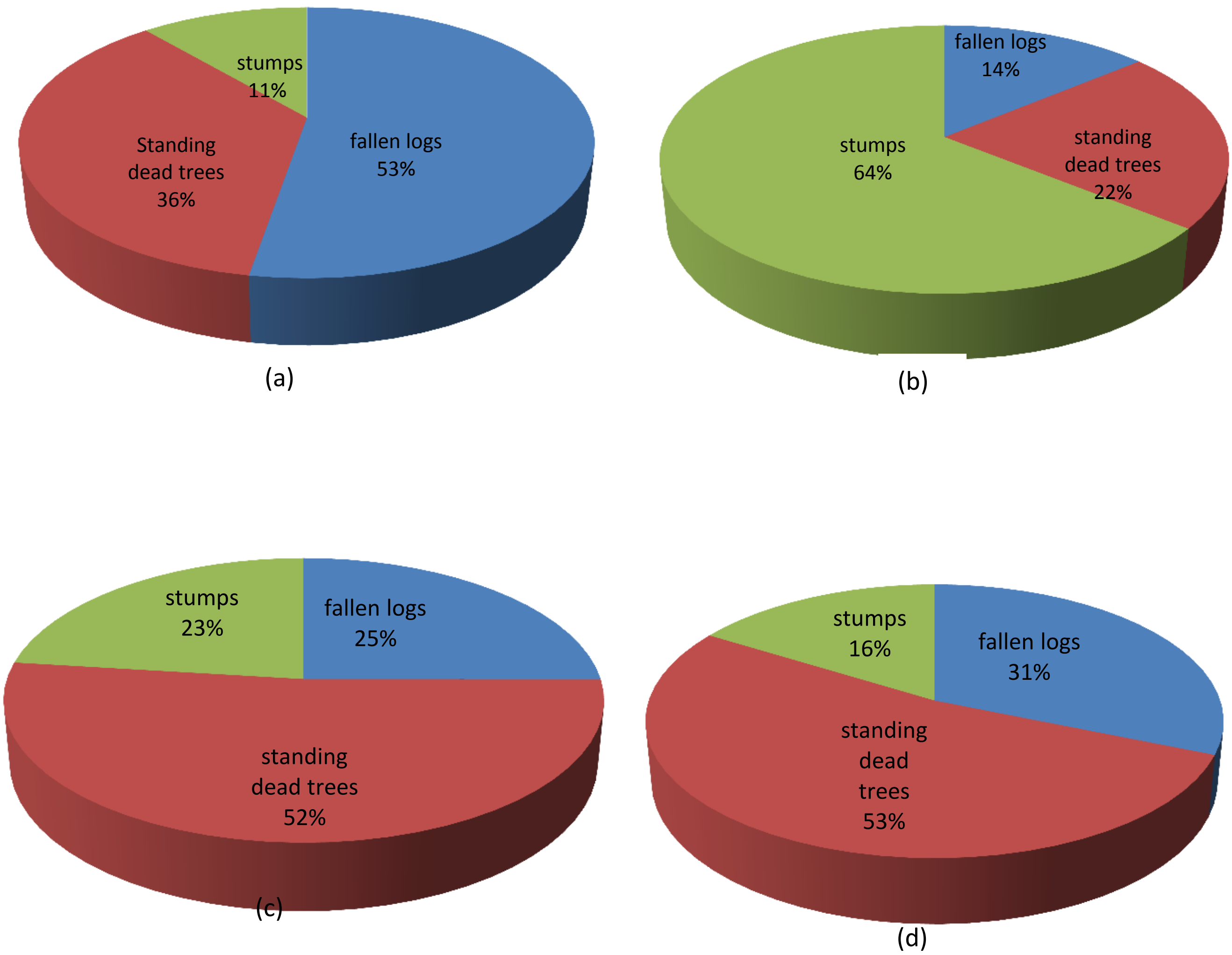


Figure 3. Carbon content of different component of deadwood in (a) DMDF (b) DDF (c) DF (d) DHF

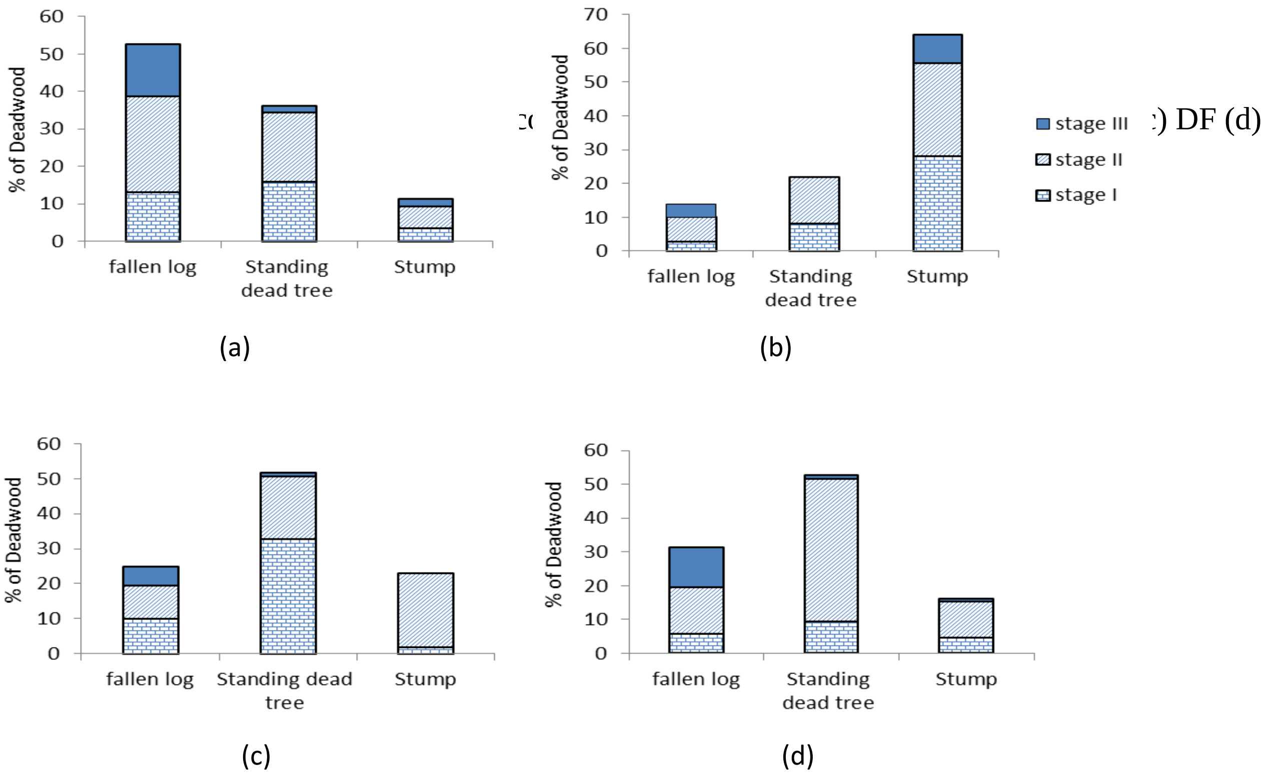


Figure 5. Distribution of deadwood carbon among fallen and standing pools in three ordinary decay classes (a) DMDF (b) DDF (c) DF (d) DHF

Each piece of deadwood was measured and classified decay stages according to decomposition classes: Stage I, bark largely intact; Stage II, bark and twig lost, but shape of trunk remaining intact; and Stage III, shape no longer maintained, and trunk sinking into the ground. According to the classification of decay classes, fallen logs of the partially decay class (stage II) was the greatest contributor to total deadwood carbon (25%) in dry mixed deciduous forest while partially decayed (stage II) stump was abundant in dry dipterocap forest (28%). But in dry forest, stump (stage I) was abundant and 33 % of deadwood was accumulated in decay stage I stump. In dry hill forest, standing dead tree of intermediate decay class was plentiful and 42% of deadwood was occupies in standing dead tree of intermediate decay class (Figure 4).

In DMDF, 24 % of total plots had no deadwood while 16% of sample plots in DDF had no deadwood. (Figure 5). Half of sample plots (52% of sample plots) in DF and almost half (40 % of sample plots) in DHF could not found deadwood within sample plot (Figure 5).

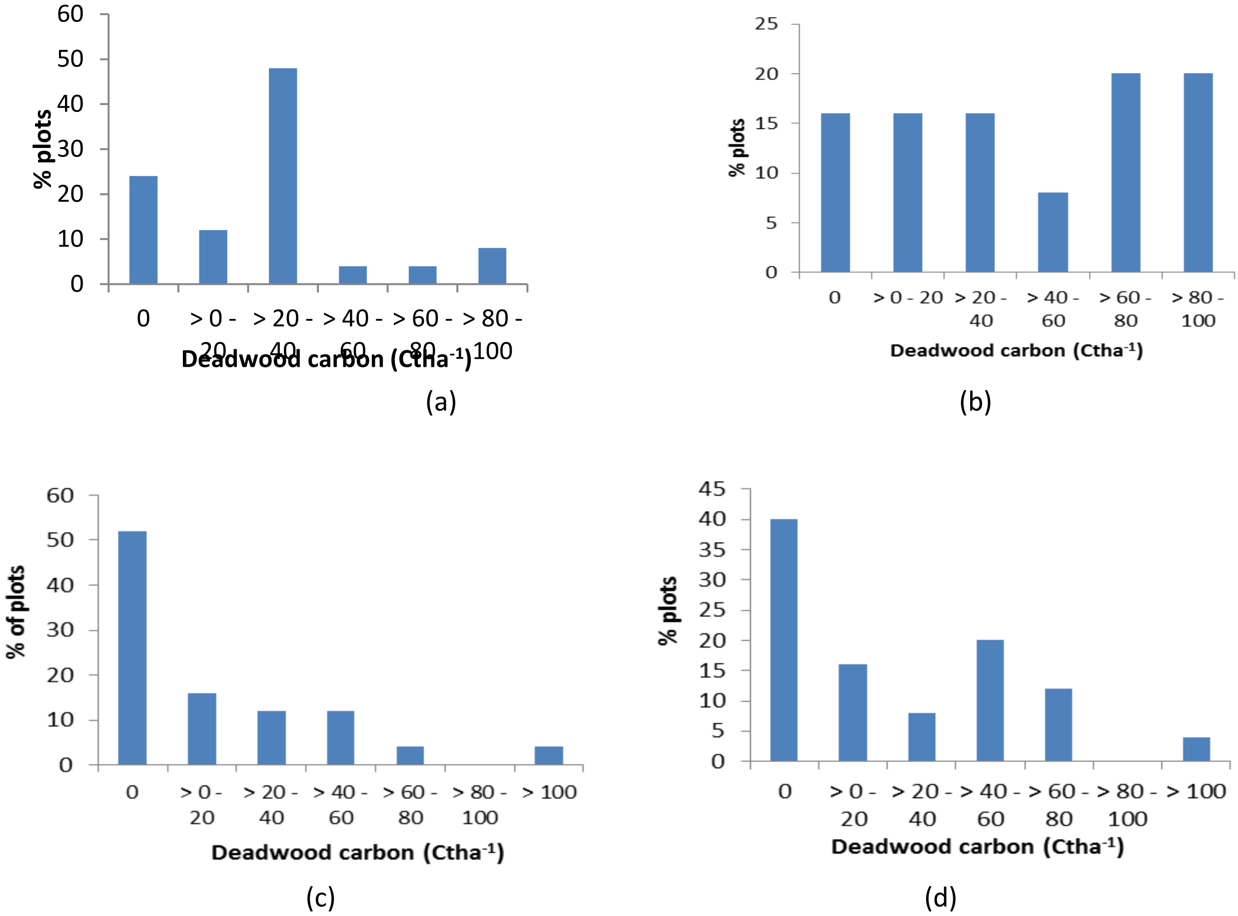


Figure 6. Deadwood carbon (tCha-1) in 100 plots across Popa Mountain Park (a) DMDF (b) DDF (c) DF (d) DHF

5.2 Litter caron

Litter is defined as all detached and dead leaves, flowers, fruits, seeds, bark fragments, and deadwood less than 2.5 cm in diameter (Jaramilo, 2003). Based on 100 sub-sample plots in each forest, it was found that litter layer carbon in the DMDF, 16.6 ± 2.8 t Cha^{-1}, was higher than in other forests in PMP. The litter layer carbon stock was amount to 8.62 ± 1.18 $tCha^{-1}$ in the DDF, 2.15±0.77 $tCha^{-1}$ in the DF and 10.77 ± 1.34 $tCha^{-1}$ in the DHEF (Table 14). The carbon accumulation in the DMDF litter layer was significantly higher than in the DDF and the DF ($P<0.05$). However, litter layer carbon in the DHEF was not significantly different to the DMDF and DDF. Among the four forest types, the litter carbon in the DF was lowest in PMP. The DF litter carbon accumulation was significantly different to litter carbon of the DMDF, DDF and DHF ($P<0.05$).

The DMDF was the highest followed by the DHF, however, there is no significant differences between these two forests. It may be due to high species diversity in the DMDF and no single species dominance, thus, the rate of litter production might be different among different tree species. Likewise, the DHF was found in high elevation and have many large trees. It might be that less light penetration to forest floor stimulates decomposition. Therefore, a lot of litter is accumulated on the forest floor due to less decomposition in the DHF.

The carbon accumulation of litter in the DF was the lowest among all forest in PMP. It might be the DF is affected by annual fire, because the dominant species in the DF was *Tectona hanatoniani* (more than 50 % of total stand density). The leaves of *Tectona hanatoniani* are large and the decomposition rate is slower than for small leaves, thus, they compile on the forest floor. Because of the strong heat in the DF area, it is easy for there to be forest fire. When annual fires happen, most of the areas of the DF litter layer are destroyed. Therefore, the DF accumulates the lowest amount of carbon in the litter layer while the DMDF has the highest.

5.3 Deadwood and litter carbon content in total aboveground carbon

Live tree carbon accumulation was highest in the DHF (200.22 ± 31.23 $tCha^{-1}$) followed by DF (126.87 ± 12.06 $tCha^{-1}$), DMDF (116.64 ± 11.34 $tCha^{-1}$) and DDF (91.28 ± 5.0 $tCha^{-1}$). In term of total aboveground carbon stock (living tree, litter and deadwood), DHF (274.63 tC ha^{-1}) is higher than other forests DMDF (180.00 tC ha^{-1}), DDF (162.03 tC ha^{-1}) and DF (166.71 tC ha^{-1}).

The proportion of total aboveground carbon (AGB, Litter and CWD) as deadwood varied from 11% to 32% across all forest (Figure 6). These results were higher than Houghton who found that deadwood biomass averaged 9% of aboveground biomass (range 1% - 17%) (R. A. Houghton et al., 2001) and 10.4 % in Nascimento's study (Nascimento & Laurance, 2002). Jaramillo reported that deadwood (standing + downed combined) comprised 27% - 29 % of aboveground in tropical dry forest (Jaramillo, Kauffman, Renteria-Rodriguez, Cummings, & Ellingson, 2003) which was close to this study's result. But lower than Clark's findings in the fallen and standing CWD of the tropical rain forest at La Selva, 3.3 % of ABG live woody biomass or carbon. This is because CWD carbon allocation was affected by rising global temperature (Cochrane, 1999) and fire frequency (Clark et al., 2002). CWD pool is more labile than the live wood pool (Clark et al., 2002) and the magnitude of the CWD pool would vary as a function of the relationship between inputs and outputs (Clark et al., 2002).

The proportion of deadwood carbon is varied from 11 % of total aboveground carbon (AGB, Litter and CWD) in DHF to 32 % of total aboveground carbon in DDF. And there were no relationships between live tree carbon and deadwood carbon (Figure 7). This findings correspond well with the Nascimento's study (Nascimento & Laurance, 2002). He mentioned that there are no significant correlations between live and/or dead biomass components. In terms of percentage, litter layer occupied 10.26 % of total aboveground carbon (aboveground, Litter, deadwood) in the DMDF, 5.84 % in the DDF, 1.45% in the DF and 4.52% in the DHF.

The carbon stock in all components of total aboveground carbon in four forest types can be summarized as follows:

Living tree carbon stock: DHF > DF > DMDF >DF.

Litter carbon: DMDF > DHF > DDF > DF

Deadwood carbon: DDF > DMDF > DHF > DF

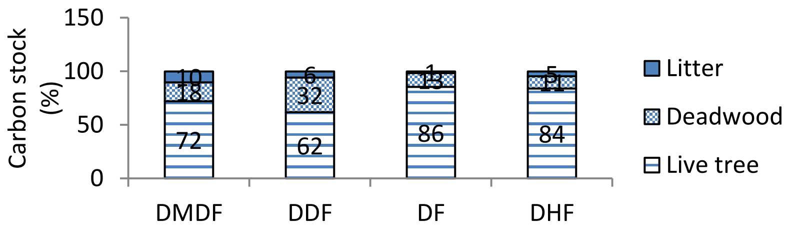


Figure 7. Live tree carbon, deadwood carbon and litter carbon allocation in DMDF, DDF, DF and DHF

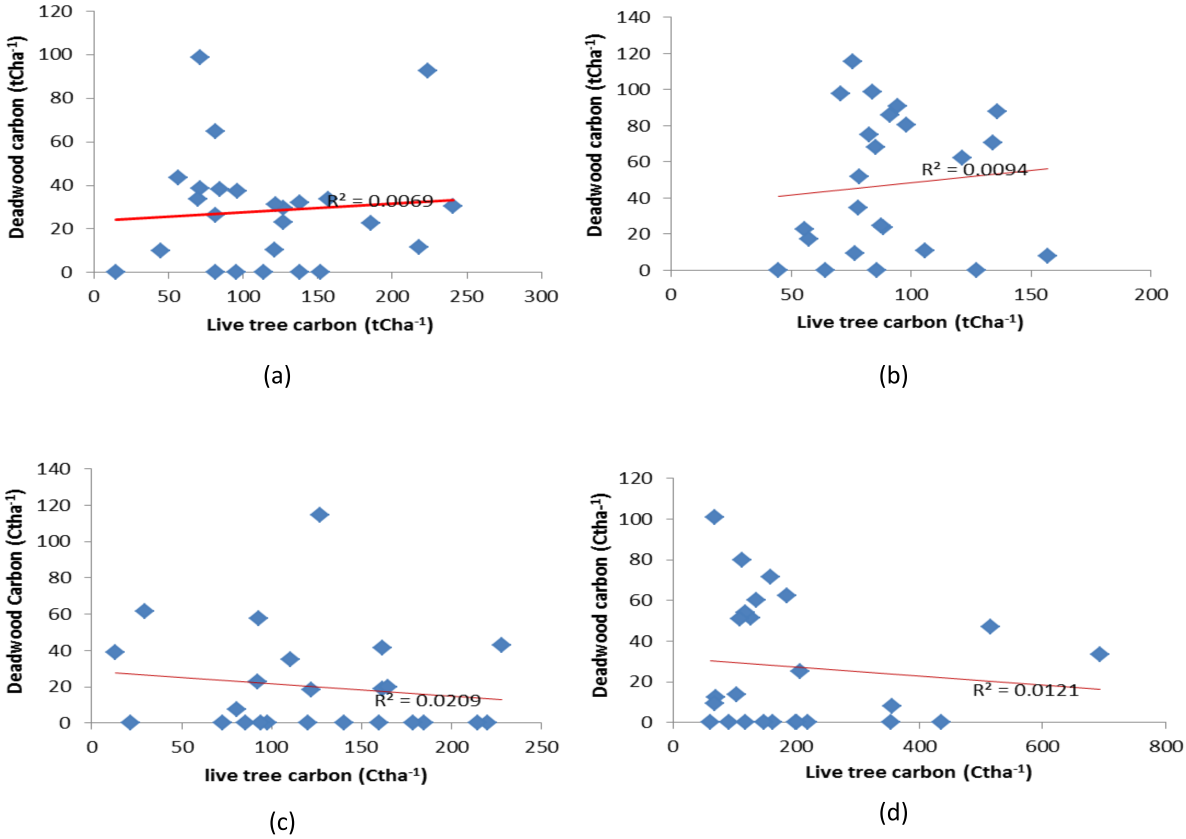


Figure 8. Relationship between live tree carbon and deadwood carbon (a) DMDF (b) DDF (c) DF (d) DHF

6. **Discussion**

Based on the 25 sample plots in each forest, the trend of deadwood carbon storage in PMP is DDF > DMDF > DHEF > DF, 47.46 ± 7.52 $tCha^{-1}$, 28.3 ± 5.3 $tCha^{-1}$, 27.21 ± 6.23 $tCha^{-1}$ and 19.15 ± 5.62 $tCha^{-1}$, respectively. Deadwood carbon stock in this study was close to the deadwood of the watershed area in New Zealand, 30.2 ± 27.6$tCha^{-1}$, (Staley, 2010) and similar with South Island forests in New Zealand, 29.0 $tCha^{-1}$ (Coomes et al., 2002) and indigenous forest in New Zealand, 27.00 6$tCha^{-1}$ (S. J. Richardson et al., 2009). It is because stand age and disturbance history strongly affect the amount of coarse wood debris in a forest (Harmon, Franklin, Swanson, Sollins, et al., 1986). Also, variation among forest types is determined by ecological factors that include rates of tree mortality and the effects of natural disturbance (Carmona, Armesto, Aravena, & Pérez, 2002; Harmon, Franklin, Swanson, Sollins, et al., 1986), management history and depletion of the live tree biomass pool (Jönsson & Jonsson, 2007) and climate (Kennedy, Spies, & Gregory, 2008). This finding was close with CWD carbon, 25.4 $tCha^{-1}$, in the tropical rain forest at la Selva (Clark, Clark, Brown, Oberbauer, & Veldkamp, 2002).

Among four forest types, the range of deadwood carbon was very wide from 19.15 $tCha^{-1}$ to 47.46 Cha^{-1}. This finding was in line with Clark (Clark et al., 2002) who mentioned that the estimates of CWD stocks in tropical forest were from 0 to > 60 $tCha^{-1}$ in term of biomass, 0 to > 30 $tCha^{-1}$ in term of carbon. In addition, these findings were comparable to other estimates from the forest in Oregon (Nonaka, Spies, Wimberly, & Ohmann, 2007) ranging from 50 – 200 $tCha^{-1}$ in biomass, 25 – 100 $tCha^{-1}$. This finding was within the range of 18-413 $tCha^{-1}$ in biomass, 9-206.5 $tCha^{-1}$ in carbon, with a recently disturbed and old growth forest having the largest value (Carmona et al., 2002). Dead wood patterns and dynamics vary with biophysical factors, disturbance history and management practices (Kennedy et al., 2008). Microclimate conditions also influence decomposition rates of dead wood (Harmon, Franklin, Swanson, Sollins, P.Gregory, et al., 1986). The amount of deadwood in forests varies greatly around the world most range from 30 to 200 Mg ha^{-1} (Baker et al., 2007; Carmona et al., 2002; Harmon, Franklin, Swanson, Sollins, et al., 1986; Jönsson & Jonsson, 2007; Tyrrell & Crow, 1994)

Deadwood carbon stock in each forest type is DDF (47.46 $tCha^{-1}$), DMDF (28.3 $tCha^{-1}$), DHF (27.21 $tCha^{-1}$) and DF (19.15 $tCha^{-1}$). It was expected that the dry evergreen forest would have a large amount of deadwood carbon because of the large trees found in that type of forest. This was also explained in Richardson's study who stated that large, slow-growing tree species support the greatest volumes and biomass of deadwood (S. J. Richardson et al., 2009). The potential importance of topography to amounts of dead wood was mentioned and discusses in both Gale (Gale, 2000) and Muller (Muller, 2003), who indicated that higher topographic positions have been shown to have higher potential for tree death and therefore higher mass and volume of dead wood. However, the results in PMP are contrary to their findings. The DHF was found at the highest elevation, with many large trees and was the more mature forest among all the natural forests in PMP. The deadwood carbon stock in the DHF was lower than in the DDF and DMDF which are located at lower elevations and have higher stand density with small trees. This study enumerate all standing dead trees, stumps and felled dead trees (above 10 cm diameter and higher than 1.3 m long) in all sample plots. Many dry stumps and coppices are found in the DDF and the DMDF. If dead stump are higher than 1.3 m and larger than 10 cm, this study counted as deadwood. Due to the large numbers of stems are found in the DDF, the mean deadwood carbon storage is the highest in the DDF, 47.46 $tCha^{-1}$. Aboveground carbon stock is lowest in the DDF, however, deadwood carbon stock is highest in the DDF. This findings support the Nascimento's study (Nascimento & Laurance, 2002). He found that there are no significant correlations between large tree biomass and that of any other live or dead biomass components.

In the study deadwood include standing dead tree, stump and fallen deadwood. Each piece of deadwood was measured and classified decay stages according to decomposition. Partially decayed (stage II) stump abundant in DDF (28% of deadwood carbon in DF) and stage I stump was abundant in DF (33 % of deadwood carbon in DF). In DMDF, 25 % of total deadwood is allocated in partially decayed fallen logs. In dry hill forest, standing dead tree of intermediate decay class was plentiful and 42% of deadwood was occupies in standing dead tree of intermediate decay class. According to the identification of decay class and deadwood types, many stumps are found in DDF and DF. It might be the result of human disturbance since these two forest located in more accessible area. Although plenty of deadwood in all forests, some plots had no deadwood. Almost half of the sample plots in Dry forest had no deadwood. It might be frequency of fire in dry forest. Further studies on disturbance in the PMP are recommended.

There is a wide range of carbon storage in the litter layer among the forest types, from 2.15 to16.6 $tCha^{-1}$. This is a greater range than that found in Indian forests, which is between 0.16 and 3.26 $tCha^{-1}$ (Mohanraj, 2011). Watershed areas in New Zealand have carbon storage of 0.6 ± 2 $tCha^{-1}$ and the tropical lowland Dipterocarp rainforest in Sabah in Malaysia measures 0.7 $tCha^{-1}$(Saner, Loh, Ong, & Hector, 2012; Staley, 2010). The carbon stock in the litter layer is also comparative with the deciduous forest in Alaungdaw Kathapa National Park in Myanmar (3.8 $tCha^{-1}$) and natural secondary forest in China (3 $tCha^{-1}$) (Oo, 2009; Zheng et al., 2007). As the current study was undertaken with all data collected during the dry season, when the deciduous trees have shed their leaves, the litter mass is at its maximum.

7. **Conclusion**

This study designed to estimate non-living tree carbon storage capacity in different forest types, especially deadwood and litter carbon. Forest inventory data from 100 sample plots were used to assess deadwood carbon and 400 sub-sample plots were used to estimate the litter carbon in Popa Mountain Park. Inventory was conducted in four forest types, namely dry mixed deciduous forest, dry dipterocarp forest, dry forest and dry hill forest. It was found that litter layer carbon in the DMDF, 16.6 ± 2.8 t Cha^{-1}, was higher than in other forests in PMP. The litter layer carbon stock was amount to 8.62±1.18 $tCha^{-1}$ in the DDF, 2.15±0.77 $tCha^{-1}$ in the DF and 10.77±1.34 $tCha^{-1}$ in the DHF. Mean deadwood carbon varied 19.15 $tCha^{-1}$ to 47.46 $tCha^{-1}$ among forest types and was greatest in Dry Dipterocarp Forest. The proportion of total aboveground carbon (AGB, Litter and CWD) as deadwood varied from 11% to 32% across all forest. Variation among forest types was determined more by variation in the standing pool than the fallen pool. Broad differences among forest types provide initial cautionary guidelines for maintaining deadwood in forests. Although plenty of deadwood in all forests, some plots had no deadwood. Almost half of the sample plots in DF had no deadwood. It might be frequency of fire in DF. According to the identification of decay classes and deadwood types, many stumps (Partially decayed (stage II) stumps in DF and stage I stumps in DDF) are found. The fallen logs were abundant in DMDF and standing dead tree of intermediate decay class was plentiful in DHF. It might be the result of human disturbance since these two forests (DDF and DF) located in more accessible area.

Our study findings identified that deadwood store carbon in 10 % - 32% of total aboveground carbon (living tree, deadwood and litter) but many stumps were found in accessible forests. Most of the naturally dead standing trees are observed in DHF. This was due to less population pressure and limited access to this forest. Considering the occurrence of stump more accessible area, the PMP has human disturbance although it is a designated protected area by the government. Management interventions should take into account the need of local people who stay in and around the PMP. Law enforcement mechanism is also important to ensure that government regulation and policies regarding protected area are not violated or punished otherwise. It is also fairly necessary to provide incentives to forest dependent communities for their activities to protect this protected area. Forest-dependent communities should be allowed to participate in all decision making processes for sound management of protected areas. Implementing activities on the ground such as restoring degraded forests and protecting the park require participation from both government agency and local communities. Deadwood and litter carbon might affect by human disturbance and frequencies of fire in PMP, further studies on these variables by forest types are important. This study provides an important step for estimation non-living tree carbon for designing low carbon emission forest management systems.

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