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Carbon Storage and its Links to Diversity and Structural Drivers of Forests in Bago Yoma Region, Myanmar

Inkyin Khaine (Ph.D), Assistant Director, Training and Research Development Division, Forest Department

Nay Aung, Range Officer, Forest Research Institute

Aung Zaw Moe, Research Officer, Forest Research Institute

Dr. Mu Mu Aung, Research Officer, Forest Research Institute

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ABSTRACT

Myanmar is one of the tropical countries and the contribution of forest carbon storage in Myanmar significantly takes part in the overall amount of tropical forests. The scientific study on carbon storage is a today trend and quite necessary for future forest management. More specifically, it is very important to know the diversity and structural drivers that could change carbon storage of forest so that we can conserve and manage the forest more effectively and sustainability. Due to the research gap in that field, this study addressed the research questions: how much carbon can the forests in Bago Yoma Region store?; Do species diversity and stand structure affect the carbon storage of forests?; and If so, how significantly do these factors affect the carbon storage of forests?. Based on the results, the Bago Yoma forests have high potential of carbon storage showing 220.4 ± 10.56 to 266.3 ± 32.42 Mg C ha^{-1} of above-ground carbon. *Tectona grandis* Linn.f, *Xylia dolabriformis* Benth. *Mitragyna rotundifolia* (Roxb.) Kuntze have been found under the list of dominant species and significantly contribute to the total carbon storage. The result showed the effect of diversity and structure of forest on carbon storage, giving positive evidences between carbon storage and the species richness, Shannon diversity, Simpson diversity and ecosystem complexity at 99% confidence interval ($p < 0.01$). It had positive correlations with the basal area, the density, the diameter, and height of forests at 99% confidence interval ($p < 0.01$). The distribution of above-ground carbon storage among three strata was as follows: middle stratum > upper stratum > lower stratum. This information could be very useful for carbon management of forests and sustainable forest management of Myanmar.

Keywords: Above-ground carbon; density; diversity; species richness; stand structure; strata.

ပဲခူးရိုးမသစ်တောများတွင် အပင်မျိုးစုံမျိုးကွဲနှင့် သစ်တောဖွဲ့စည်းမှုပုံစံတို့၏ ကာဗွန်သိုလှောင်နိုင်မှုအပေါ် လွှမ်းမိုးဆက်သွယ်မှုအခြေအနေကို လေ့လာခြင်း

ဒေါက်တာအင်ကြင်းခိုင်၊ လက်ထောက်ညွှန်ကြားရေးမှူး၊ သစ်တောဦးစီးဌာန

ဦးနေအောင်၊ တောအုပ်ကြီး၊ သစ်တောသုတေသနဌာန

ဦးအောင်ဇော်မိုး၊ သုတေသနအရာရှိ၊ သစ်တောသုတေသနဌာန

ဒေါက်တာ မူမူအောင်၊ သုတေသနအရာရှိ၊ သစ်တောသုတေသနဌာန

စာတမ်းအကျဉ်း

မြန်မာနိုင်ငံသည် အပူပိုင်းဒေသနိုင်ငံ တစ်နိုင်ငံဖြစ်ပြီး မြန်မာ့သစ်တောများ၏ ကာဗွန် သိုလှောင် နိုင်မှုသည် ပမာဏများပြားသကဲ့သို့ ကာကွယ် ထိန်းသိမ်းရန်နှင့် ရာသီဥတုပြောင်းလဲမှု တိုက်ဖျက် ရေးတွင် အဓိကအရေးပါသော အစိတ်အပိုင်းတစ်ခု ဖြစ်ပါသည်။ ကာဗွန်သိုလှောင်မှု နှင့် ပတ်သက်၍ သုတေသနပြု လေ့လာချက်များကို အလေးပေးဆောင်ရွက်လျက်ရှိရာ မြန်မာနိုင်ငံတွင်လည်း ခေတ်နှင့်အညီ သုတေသနလေ့လာချက်များကို ပြုလုပ်ဆောင်ရွက်လျက် ရှိရာတွင် အပင်မျိုးစုံ မျိုးကွဲနှင့် သစ်တောဖွဲ့စည်းမှုပုံစံတို့၏ ကာဗွန်သိုလှောင်နိုင်မှုအပေါ် လွှမ်းမိုးဆက်သွယ်မှု အခြေအနေကို လေ့လာရန်အတွက် သုတေသနပြုလုပ်ရန် လိုအပ်လျက် ရှိပါသည်။ သို့ဖြစ်ပါ၍ ဤစာတမ်းတွင် ပဲခူးရိုးမ သစ်တောများတွင် ကာဗွန်သိုလှောင်နိုင်မှု ပမာဏနှင့် အပင်မျိုးစုံမျိုးကွဲနှင့် သစ်တောဖွဲ့စည်းမှုပုံစံတို့၏ ကာဗွန်သိုလှောင်နိုင်မှုအပေါ် လွှမ်းမိုးဆက်သွယ်မှုအခြေအနေကို လေ့လာသုတေသနပြုခဲ့ပါသည်။ သုတေသနရလဒ်များအရ ပဲခူးရိုးမသစ်တောများအတွင်း ကာဗွန်

သိုလှောင်နိုင်မှုသည် တစ်ဟက်တာလျှင် ၂၂၀.၄ ± ၁၀.၅၆ မှ ၂၆၆.၃ ± ၃၂.၄၂ Mg အထိ ကာဗွန်သိုလှောင်နိုင်ကြောင်း တွေ့ရှိရသည်။ ပဲခူးရိုးမသစ်တောအတွင်း ကျွန်း၊ ပျဉ်းကတိုးနှင့် ဘင်္ဂပင်များကို အများဆုံး တွေ့ရှိရပြီး အဆိုပါ အပင်များ၏ ကာဗွန် သိုလှောင်နိုင်သည့် ပမာဏမှာ သစ်တောတစ်ခုလုံး၏ ကာဗွန်ပမာဏတွက်ချက်ရာတွင် များစွာ အရေးပါလှပါသည်။ သုတေသန တွေ့ရှိချက်များအရ အပင်မျိုးစုံမျိုးကွဲနှင့် သစ်တော ဖွဲ့စည်းမှုပုံစံသည် ကာဗွန်သိုလှောင်နိုင်မှုအပေါ် များစွာ လွှမ်းမိုး ဆက်သွယ်မှုရှိကြောင်း တွေ့ရှိရပါသည်။ ပဲခူးရိုးမသစ်တောများတွင် အပင်မျိုးစုံ မျိုးကွဲကြွယ်ဝမှုနှင့် complexity တို့ များပြား လာမှုနှင့်အတူ သစ်တော၏ ကာဗွန်သိုလှောင်နိုင်မှု များပြားလာကြောင်း ထင်ရှားစွာ တွေ့ရှိရပါ သည်။ ထို့အတူ သစ်တော၏ ဖြတ်ပုံဧရိယာbasal) (area၊ လုံးပတ်၊ အမြင့်၊ သိပ်သည်းမှု များလေလေ ကာဗွန်သိုလှောင်မှု ပိုမိုများပြားသည်ကို တွေ့ရှိရပါသည်။ အထူးသဖြင့် ဖြတ်ပုံ ဧရိယာသည် ကာဗွန်သိုလှောင်မှုအပေါ် ပိုမို လွှမ်းမိုးမှုရှိသည့် အချက်တစ်ချက် ဖြစ်ပါသည်။ ရွက်အုပ်အလွှာသုံးလွှာရှိကာဗွန်သိုလှောင်နိုင်မှုကိုလေ့လာရာတွင် အလယ်အလွှာတွင် အများဆုံး တွေ့ရှိရသည့်အတွက် သစ်တော၏ ကာဗွန်သိုလှောင်မှုတွင် ရွက်အုပ် အလယ်အလွှာ၏ ဖွဲ့စည်း ပုံပေါ်မူတည်၍ ပြောင်းလဲမှု ပြုနိုင်သည်ကို ဖော်ထုတ်တွေ့ရှိရပါသည်။ ဖော်ပြပါ သုတေသန တွေ့ရှိချက်များသည် မြန်မာနိုင်ငံ၏ ရေရှည်တည်တံ့စေသော သစ်တောစီမံ အုပ်ချုပ်ခြင်းနှင့် သစ်တောကာဗွန် စီမံခန့်ခွဲသည့် ကဏ္ဍများကို များစွာအထောက်အကူ ဖြစ်စေသော တွေ့ရှိချက် များဖြစ်ကြောင်း တင်ပြအပ်ပါသည်။

Carbon Storage and its Links to Diversity and Structural Drivers of Forest in Bago Yoma Region, Myanmar

1. Introduction

The world forests cover about one third of the global land area, and it could be considered as a sink or source of carbon (Köhl et al. 2015). Globally, forests stored 650 Pg of carbon (Khaine and Woo 2015). Tropical forests alone cover about half of the global forest areas and their contribution significantly takes part in the overall amount (Keenan et al. 2015).

Myanmar is a tropical country that is located between the latitudes of 9° 28' and 28° 29' North and the longitudes of 92° 10' and 101° 10' East. The total land area is 67.66 M ha. East-to-west Myanmar is 936 km long, and north-to-south the country is 2,051 km long. Forests cover about 42.19% of the land, making Myanmar one of the countries with the highest forest coverage in the Asia-Pacific region (FAO 2020; Ministry of Natural Resources and Environmental Conservation 2020).

Six types of forests are mainly found throughout the country: tropical evergreen forests, tropical deciduous forests, mangrove forests, dry forests, deciduous dipterocarp forest, and hill and temperate evergreen forests. Over 2,000 of floristic species are distributing in various forest types. Among the six forest types, tropical deciduous forests have the largest forest coverage of the country. About 38.26% of the total forest areas is covered by tropical deciduous forests. The Bago Yoma region represents the tropical deciduous forests of Myanmar. Nearly all species adapted to tropical deciduous forests in Myanmar are found in this region. The Bago Yoma region is located between the latitudes of 16º 50' and 19º 29' North, the longitude of 94º 41' and 97º 13' East. It has been separated into two regions called Eastern Bago Yoma and Western Bago Yoma. These regions have been known as ideal place for teak, covering 3.87 M ha. Therefore, the carbon storage of forests in the Bago Yoma region should be explored in Myanmar.

The carbon storage of tropical forests in Asia and Oceania regions was about 89 □ 180 Mg C ha^{-1} whereas the carbon storage of tropical forests in Latin America was 84 □ 160 Mg C ha^{-1} and those in Sub-Saharan Africa was 44 □ 165 Mg C ha^{-1} (Saatchi et al. 2011). On average, the tropical teak dominant forests stored 112.19 Mg C ha^{-1} of above-ground carbon

(Juwarkar et al. 2011). In contrast, tropical teak dominant forest in Myanmar stored 185.2 – 227.7 Mg C ha^{-1} of above-ground carbon (Oo 2009). In temperate forests, the amount of carbon storage showed a range of 42.63 – 181.88 Mg C ha^{-1} while the amount of carbon storage in temperate grassland showed 3.74 – 9.83 Mg C ha^{-1} (Mendoza-Ponce and Galicia 2010). Therefore, it can be clearly understood that forests in the planet have a considerable amount of carbon storage potential, although capacity will vary among regions.

Because of wide variations in forest carbon storage have been found throughout different climatic regions worldwide, researchers are now striving to study each country or region for site-specific information (Toledo et al. 2011; Thompson et al. 2014; Castro-Izaguirre et al. 2016; Chheng et al. 2016).

Likewise, it should not be neglected the drivers or overwhelming factors that are related to the variation of the storage of carbon. Understanding the main mechanisms that effects carbon storage of forests is crucially important to assess and manage for the increase of the carbon storage potential of forests (Cai et al. 2016).

Many studies such as those by Tilman et al. (2001), Zhang et al. (2012), Gamfeldt et al. (2013), and Vila et al. (2013), have found that species richness has a positive effect on biomass, even with as few as three to eight species. One the other hand, Paquette and Messier (2011) found that species diversity only weakly influenced the productivity of temperate forests while it strongly influenced that of boreal forests. Only a few studies have focused on tropical forests, and it will be necessary to conduct similar studies in the tropics (Poorter et al. 2015).

Only a few studies have tested the structural influence of forests on carbon storage. Imani et al. (2017) found that forest structure affected the above-ground biomass more significantly than species diversity did. Mensah et al. (2016) tested the influence of basal area on biomass and carbon storage in forests. A similar study was done by Chaturvedi and Raghubanshi (2015). The latter study found that species diversity did not correlate significantly with carbon storage. In contrast, species richness, evenness, and basal area did significantly correlate with carbon storage. Vayreda et al. (2012) highlighted the fact that carbon storage in forests varies with structural variables. For this, further studies should consider the effects of both forest diversity and forest structure on carbon storage, and should clarify the factors with the greatest impact on carbon storage in forests.

Therefore, the following research questions were addressed in this study:

(1) How much carbon can the forests in Bago Yoma Region store?

(2) Do species diversity and stand structure affect the above-ground carbon storage of forests?

(3) If so, how significantly do these factors affect the carbon storage of forests?

2. Objectives

Based on the research questions, the following main objectives have been explored in this study:

(1) To explore the carbon storage forests in Bago Yoma Region

(2) To investigate the linkages of species diversity and stand structure to the above-ground carbon storage of forests

3. Materials and Methods

3.1 Study sites

The study was conducted in Yedashae (Site 1), Gyobingauk (Site 2) and Nattalin (Site 3) Townships of Bago Yoma Region of Myanmar. The research survey was taken in Lone Yan and Sabyin reserve forests in Yedashe, North Zarmani and Bawbin reserve forests in Gyobingauk, Taung Nyo and Bawbin reserve forests in Natalin Townships of Bago Region. The sample plots were situated between the latitudes and longitudes of 19° 15′N - 19° 23′N and 95° 51′E - 95° 58′E; 18° 15′N - 18° 24′N and 95° 49′E - 95°59′E; and 18° 28′N - 18° 46′N and 95° 49′E - 95° 57′E in Yedashae (Site 1), Gyobingauk (Site 2) and Nattalin (Site 3)

Townships, respectively. Tropical savanna climate was found in this region within an average annual precipitation range of 1400 mm to 2000 mm (Department of Meteorology and Hydrology of Myanmar). The average annual temperature is ranging from 25.7°C to 27°C. The forests are tropical deciduous forests and they are protected as reserve forests.

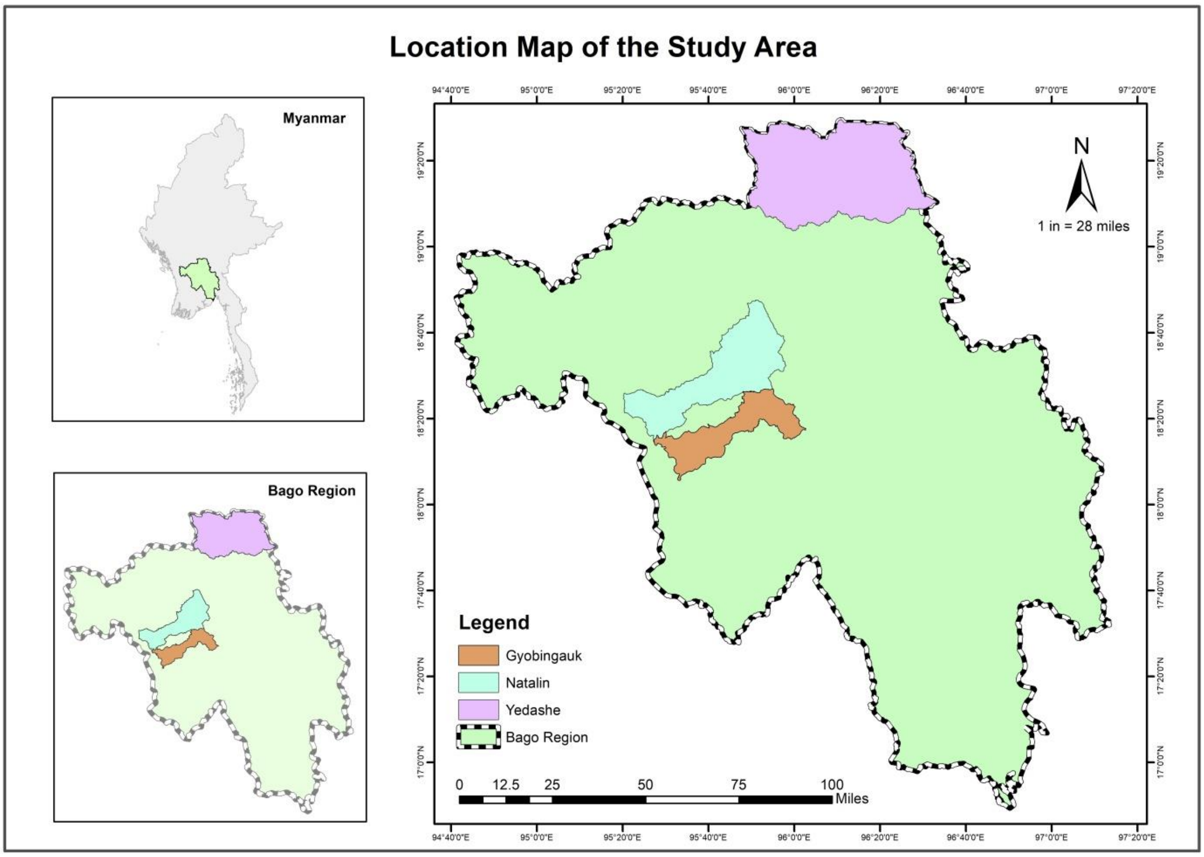

Figure 1. Location of the study area of Bago Yoma Region in Myanmar {Yedashae (Site 1), Gyobingauk (Site 2) and Nattalin (Site 3)}

3.2 Sampling procedure, data collection and analysis

Sampling plots were laid down at each study site using the stratified sampling. A preliminary survey was performed in each site before establishing the sample plots. Then the forests were stratified depending on the apparent density of forests and the occurrence of minor disturbance (Khaine et al. 2017). In each stratum, the sample plots were laid out randomly so that the sample plots covered and represented the individual sites. The size of each sample plot was 2,500 m^2 (50 m × 50 m). The species area curve was performed to be representative of the population by the samples (Cain 1938; Cencini et al. 2012). A total of 30 sample plots were set up in the study area.

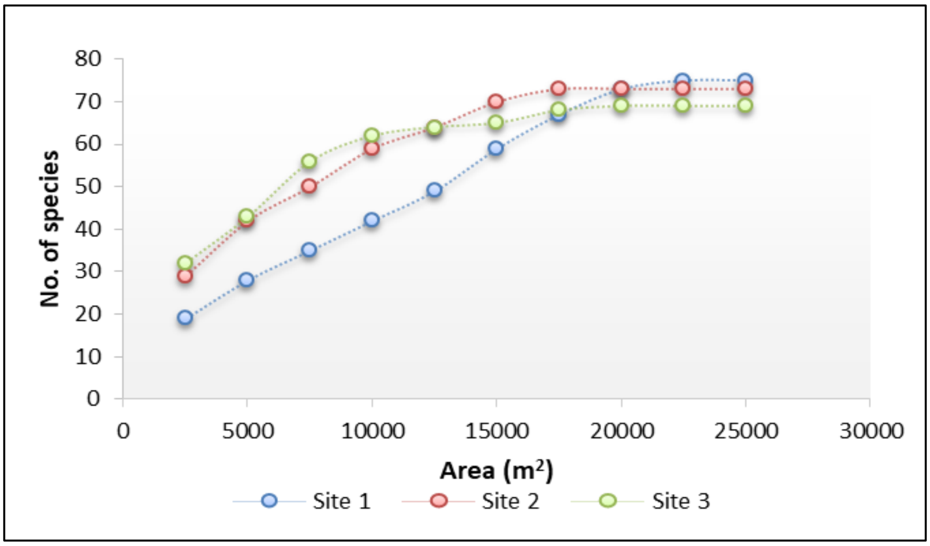

Figure 2. Species-area curves of forests

In each plot, the diameter and height of all trees greater than 5 cm in diameter at breast height (dbh) were measured. The layers of tree height were divided into three clusters: upper layer (greater than two-third of the top height), middle layer (the interval between the height of less than two-third of the top height and the height greater than one-third of the top height), and lower layer (less than one-third of the top height) (Lamprecht 1989; Oo 2009).

The importance value index (IVI) was also calculated to determine the dominant species of a forest (Lamprecht 1989; Oo 2009). Undoubtedly, screening of dominant species in a forest has been accepted as a core of forest ecology and management. The highest IVI value of species in a forest stand points out the most dominant species of that forest. The IVI was calculated by the following formula (Lamprecht 1989; Oo 2009):

$$IVI = RD + RF + RC$$

where, IVI = important value index

RD = relative density

RF = relative frequency

RC = relative coverage

In case of species diversity, two commonly accepted diversity indices, namely, Shannon index (Shannon and Weaver 1949) and Simpson index (Simpson 1949) were calculated. The diversity index could be defined as a mathematical measure of species diversity of a forest. The Shannon diversity index give a favor for rare species, while the Simpson diversity index give a more outweigh to the common species (Heip et al. 1998; Oo 2009; Hakkenberg et al. 2016). Both indices are the products of the richness of species and the abundance of individual species in a forest. Duncan's multiple range tests was used to express the differences among indices.

The formula for Shannon's diversity index is as follows:

$$H' = \sum_{i=1}^{s} (Pi)(\ln Pi),$$

where, H' = Shannon's diversity index

s = the number of species in the sample

Pi = the proportion of the total sample belonging to the i^{th} species

ln = the natural logarithm

The formula for the Shannon evenness index is as follows:

$$E\ (\%) = 100\ (H'/\ln H_{max})$$

where, E = the Shannon evenness index in percentage

H' = Shannon's diversity index

H_{max} = the number of total species

The formula for Simpson's diversity index is as follows:

$$D = \sum_{i=1}^{s} \{n_i\ (n_i - 1)/N\ (N - 1)\}$$

where, $(1 - D)$ = Simpson's index of diversity

n_i = the number of individuals of species i

s = the number of species in the sample

N = the total number of individuals in the sample.

The above-ground carbon storage was calculated using formulas recommended by Brown (1997) and FAO (2015):

$$Y = \exp\{-2.134 + 2.530 \times \ln(D)\}$$

where, Y = above-ground biomass of forest

D = diameter of tree

The carbon conversion factor, 0.47, (IPCC 2006) was used for calculating the carbon storage of forests.

The Holdridge complexity index (HI) is a widely used measure for the determination of ecosystem complexity (Lugo et al. 1978; Kalacska et al. 2004). The HI was developed by the multiplication of the number of species, density of forest, mean height in meter, basal area in square meter, and times (2.5×10^{-3}) in each forest (0.1ha basis). Cluster analysis in R program was used for the classification of forest type based on ecological distance (Bray measure) among forests. Agglomerative cluster analysis using the Agnes-algorithm was applied for forest type classification.

Correlation and coordination analysis was done using diversity and structural variables as independent variables and carbon storage as dependent variable. The statistical analyses were performed using the R program (Version 3.4.2, R Foundation for Statistical Computing, Vienna, Austria, 2017) and SPSS statistical software (Version 24, International Business Machines Corporation (IBM), United States, 2016).

4. Results and Discussions

4.1 Species richness and diversity

Occurrence of species in the study sites of Bago Yoma region was high. A total of 75 species (32 families), 73 species (30 families), and 69 species (26 families) were found at sites 1, 2 and 3, respectively. The values of the Jackknife species index were 75.65, 73.32, 69.71. Shannon diversity index ranged from 3.05± 0.25 to 3.20 ± 0.06 and Simpson diversity index ranged from 0.95 ± 0.02 to 0.96 ± 0.01. The richer species diversity was found in the study area if we compare in degraded forest area in the Bago Yoma region. According to Khaine et al. (2019) findings, the Shannon index showed 2.29±0.32 in degraded forests. The result was also higher in comparison with *Terminalia* forest (1.13), *Acacia* forest (0.43), *Diospyros* forest (1.71) and *Dipterocarpus* forest (1.18) by Khaing (2014). The result in this study was similar with the result of deciduous forests with assistant natural regeneration operation in Bago Yoma region (Khaine et al. 2019) and of deciduous forest in Bago Yoma region (Oo 2009). However, the richness was approximately 2.5 times lower than that in Alaungdaw Kathapha national park in Myanmar (Oo 2009).

Table 1. Species diversity of forests in the study areas

Site	Shannon diversity index	Simpson diversity index	Shannon evenness	Species richness	Jackknife species index
Site 1	3.05 ± 0.25 [a]	0.95 ± 0.02 [a]	93.65 ± 1.84 [a]	75	75.65 [a*]
Site 2	3.16 ± 0.24 [a]	0.96 ± 0.02 [a]	94.74 ± 2.26 [a]	73	73.32 [a*]
Site 3	3.20 ± 0.06 [a]	0.96 ± 0.01 [a]	95.33 ± 1.52 [a]	69	69.71 [a*]

Mean value ± standard deviation. Different lowercase letters indicate the differences among the sites was significant by Duncan's multiple range tests (DMRT) at $p < 0.05$.

Xylia xylocarpa Roxb. Taub, *Tectona grandis* Linn.f, *Protium serrata* (Wall. Ex Colebr.) Engl., *Mitragyna rotundifolia* (Roxb.) Kuntze, and *Lagerstroemia tomentosa* C. Presl are the most dominant species in site 1 and *Xylia xylocarpa* Roxb. Taub., *Cordia grandis* Roxb., *M. rotundifolia* (Roxb.) Kuntze, *Dalbergia cultrata* Graham ex Benth., and *Lannea grandis* Engl. are the most dominant species in site 2. In site 3, the most dominant species are *X. xylocarpa*, *Terminalia tomentosa* (Roxb.) Wight & Arn, *M. rotundifolia* (Roxb.) Kuntze, *Tectona grandis* Linn.f, and *P. serrata* (Wall. Ex Colebr.) Engl.. Generally, we accepted that *Tectona grandis* Linn.f, *Xylia xylocarpa* Roxb. Taub., *Mitragyna rotundifolia* (Roxb.) Kuntze were under the list of dominant species in Bago Yoma region. The accumulation pattern of the diversity of forests can be clearly seen in the following Figure 3.

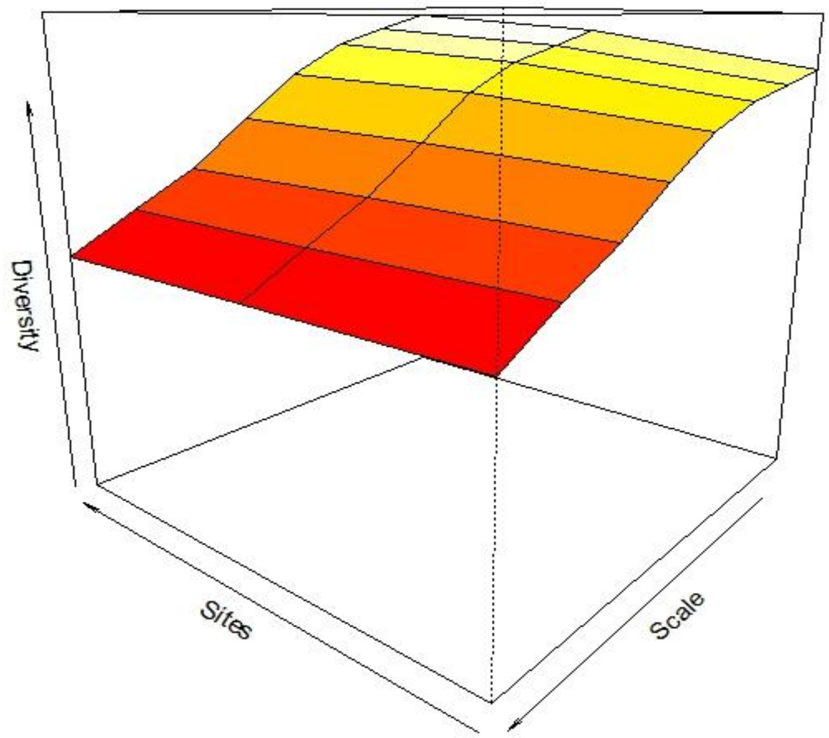

Figure 3. Accumulation pattern of diversity of forests

Cluster analysis showed the bray distance showed not a very much differences among the sites although site 1had high species richness. High ecosystem complexity occurred at the study sites ranging from 23.73 to 25.76. The growth, basal area, species richness, and abundance of plants were major factors for the increase or decrease of ecosystem complexity. Furthermore, species diversity had a tendency to change the ecosystem complexity because it exhibited a positive trend with ecosystem complexity.

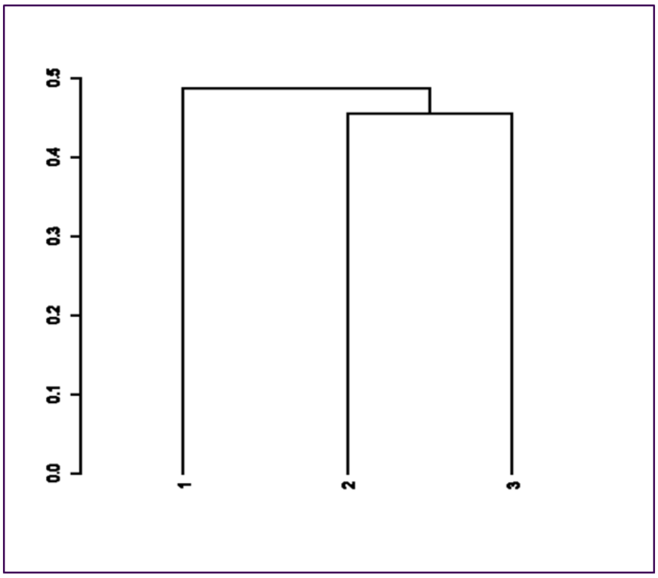

Figure 4. Cluster analysis of forests

4.2 Stand structure

Maintenance of the diversity and stand structure of living ecosystem is crucial for functional ecology (Chiarucci et al. 2011). Therefore, analysis of forest structure plays an important role. Based on the results, a high structure inequality was found in the Bago Yoma region. This result indicated a full usage of an area than other forests where low structure inequality occurred. In addition, positive skewness of size distribution showed indirectly indicated that there had enough young plants that can constitute or reach to the larger classes of trees, which is very important for the sustainability of forests.

The quadratic mean diameter of forests from site 1 to site 3 were 40.58 cm, 37.69 cm, and 39.40 cm, respectively. Diameter distribution showed positive skewness in all of the forest stands (Figure 3). Diameter size classes greater than 100-cm comprised 6.41 m^2 ha^{-1} (14.76%) of the total basal area at site 1, 2.06 m^2 ha^{-1} (5.02%) at site 2, and 0.33 m^2 ha^{-1} (0.82%) at site 3. Basal areas of forests were 43.41 ± 2.2, 41.11 ± 2.18, 39.66 ± 2.20 m^2 ha^{-1} at sites 1 to 3, respectively, while the densities were 336 ± 36.55, 368 ± 30.03, and 325 ± 24.30 trees ha^{-1}, respectively

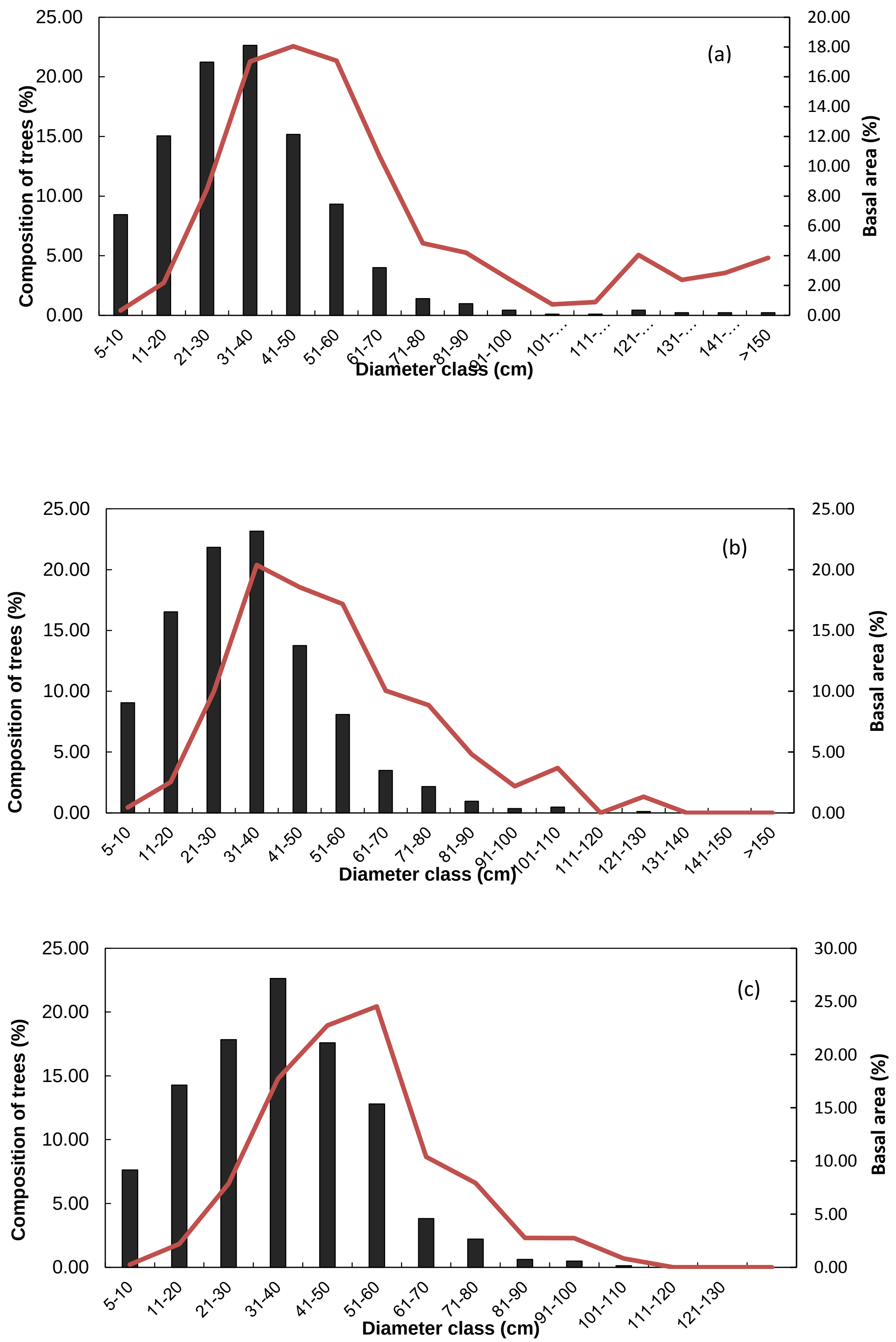
(a)
Composition of trees (%)
Basal area (%)
Diameter class (cm)
5-10
11-20
21-30
31-40
41-50
51-60
61-70
71-80
81-90
91-100
101-…
111-…
121-…
131-…
141-…
>150
(b)
Composition of trees (%)
Basal area (%)
Diameter class (cm)
101-110
111-120
121-130
131-140
141-150
(c)
Composition of trees (%)
Basal area (%)
Diameter class (cm)

Figure 5. Diameter distribution of the study sites, (a) site 1, (b) site 2, (c) site 3.

As of vertical diagnosis, the basal area was the highest in the middle layer of forests. The range of basal area of the middle layer showed 21.92 ± 2.25 to 25.66 ± 2.95 m^2 ha^{-1}, an average of 23.71 ± 1.88 m^2 ha^{-1} in the Bago Yoma region. Therefore, the middle layer of forests plays a significant role in the management of basal area of the forests. Moreover, the Bago Yoma forests have still a potential of forest recruitment because of a large amount of trees were occurred in the lower layer of forests.

Table 2. Density and basal area of forests in the study area

Site	Parameter	Upper layer	Middle layer	Lower layer
Site 1	Density per ha	6.91 ± 5.25 ^{c,C}	105.82 ± 38.09 ^{b,B}	222.91 ± 61.58 ^{a,A}
	BA per ha (m^2)	8.14 ± 8.63 ^{b,B}	23.55 ± 7.05 ^{a,A}	11.73 ± 4.02 ^{b,A}
Site 2	Density per ha	24.44 ± 9.89 ^{c,B}	193.33 ± 20.98 ^{a,A}	150.67 ± 37.09 ^{b,B}
	BA per ha (m^2)	11.66 ± 3.98 ^{b,B}	25.66 ± 2.95 ^{a,A}	3.79 ± 1.12 ^{c,B}
Site 3	Density per ha	50.40 ± 8.88 ^{c,A}	194.40 ± 21.92 ^{a,A}	80.40 ± 21.94 ^{b,C}
	BA per ha (m^2)	16.43 ± 2.33 ^{b,A}	21.92 ± 2.25 ^{a,A}	1.31 ± 0.27 ^{c,C}
Average	Density per ha	27.25 ± 21.88 ^{c}	164.52 ± 50.84 ^{a}	151.33 ± 71.26 ^{b}
	BA per ha (m^2)	12.08 ± 4.16 ^{b}	23.71 ± 1.88 ^{a}	5.61 ± 5.44 ^{c}

Different lowercase letters indicate significant differences among layers, and different uppercase letters indicate significant differences among the sites by Duncan's multiple range test at $p < 0.05$.

4.3 Structural diversity

In case of structural diversity, a regular distribution showed that there will be the maximum growing spaces and environment for every tree and species while cluster distribution showed a reduction in diameter increment of each tree because of competition among individuals (Neumann and Starlinger 2001). In this study, individual species in each forest seemed to have enough growing spaces and conditions for their growth since all study sites showed regular distributions with an index of 0.95 to 0.54. However, variations among sites were occurred due to the difference of climatic factors, latitudinal gradients, elevation effects, and soil conditions among sites.

4.4 Aboveground carbon storage of forests

Based on the results, the forests in the study sites had a big carbon storage showing 220.4 ± 10.56 to 266.3 ± 32.42 Mg C ha^{-1} of above-ground carbon. An average amount of 239.81 ± 23.73 Mg C ha^{-1} of above-ground carbon were stored in the forests. It was an indicator that the Bogo Yoma forests have a high potential of carbon storage. Our finding is similar with the findings of Oo (2009) conducted in Bago Yoma deciduous forests. According to Oo's (2009) study, the forests in Bago Yoma region stored 227.7 Mg C ha^{-1}. Our result (239.81 ± 23.73 Mg C ha^{-1}) is higher than those results in degraded forests in Bago Yoma region showing 58.76±4.33 Mg C ha^{-1}. In comparison of our results with other findings in mixed temperate forests and birch forests by Cai et al. (2016), it was significantly higher than those results in mixed temperate forests (120.3 Mg C ha^{-1}) and birch forests (78.5 Mg C ha^{-1}).

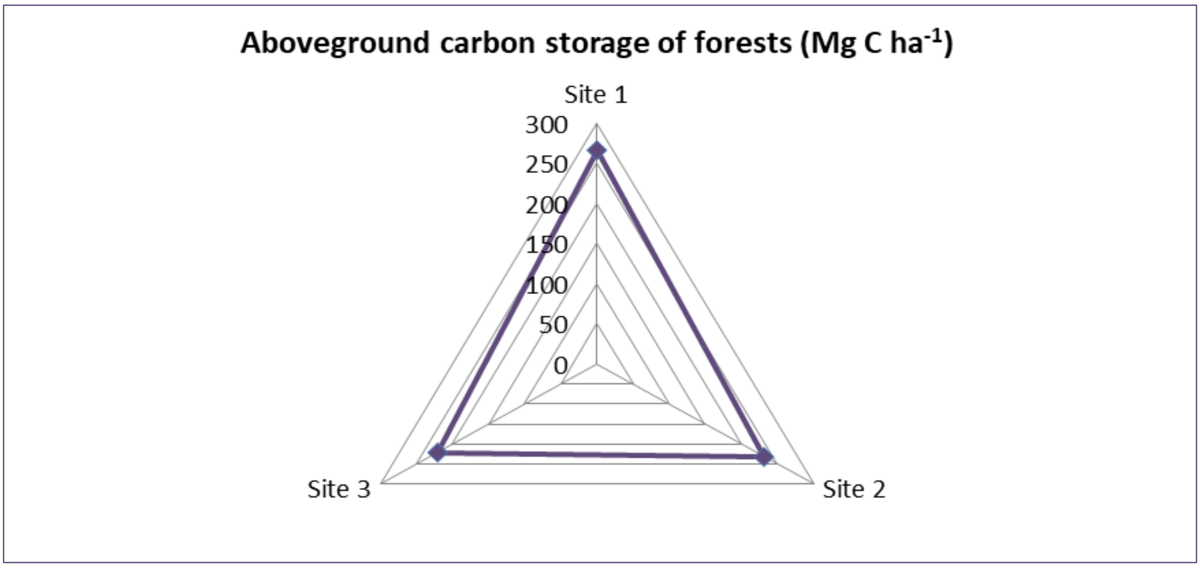

Figure 6. Aboveground carbon storage of forests in the study areas

Among three strata, the above-ground carbon storage of the middle stratum was the highest at all study sites (by DMRT, $p < 0.05$). The average storage of carbon was 94.07± 11.11 Mg C ha^{-1} in the upper stratum, 127.08 ± 14.97 Mg C ha^{-1} in the middle stratum and

18.66 ± 17.77 Mg C ha^{-1} in the lower stratum. The high carbon storage was found in the middle stratum because of its high basal area and followed up density.

Table 3. Aboveground carbon distribution of forests across different strata

Site	Upper stratum (Mg C ha^{-1})	Middle stratum (Mg C ha^{-1})	Lower stratum (Mg C ha^{-1})
Site 1	90.85 ± 87.21 ^{ab,A}	136.95 ± 40.20 ^{a,A}	38.47 ± 17.79 ^{b,A}
Site 2	84.92 ± 27.62 ^{b,A}	134.44 ± 16.60 ^{a,A}	13.38 ± 4.29 ^{c,B}
Site 3	106.43 ± 16.71 ^{a,A}	109.85 ± 11.35 ^{a,B}	4.13 ± 0.87 ^{b,C}
Average	94.07± 11.11 ^{b}	127.08 ± 14.97 ^{a}	18.66 ± 17.77 ^{c}

Mean carbon storage ± standard deviation. Different lowercase letters indicate significant differences among layers, and different uppercase letters indicate significant differences among the sites by Duncan's multiple range test at $p < 0.05$.

The five most dominant species contribute 42.41% of the total aboveground carbon storage of forests. Among five most dominant species at site 1, the first most dominant species, *Xylia xylocarpa* Roxb. Taub., contained 17.66% (47.04 Mg C ha^{-1}) of the total above-ground carbon. Not surprisingly, this was the highest percentage among the five dominant species (Table 4). The second and third most dominant species, *Tectona grandis* Linn.f and *Protium serrata* (Wall. Ex Colebr.) Engl., contained 7.85% (20.90 Mg C ha^{-1}), and 7.45% (19.83 Mg C ha^{-1}) of the total above-ground carbon, respectively. Together, the top three dominant species contained 32.96% of the total above-ground carbon.

Table 4. Carbon distribution of dominant species in the total carbon of forests

Dominant species	PD	Biomass (Mg ha^{-1})	AC (Mg C ha^{-1})	TAC (Mg C ha^{-1})	PCD (%)
Site 1				266.3	
Xylia xylocarpa Roxb. Taub.	1st dominant	100.07	47.04		17.66
Tectona grandis Linn.f	2nd dominant	44.48	20.90		7.85

Protium serrata (Wall. Ex Colebr.) Engl.	3^{rd} dominant	42.19	19.83		7.45
Mitragyna rotundifolia (Roxb.) Kuntze	4^{th} dominant	29.72	13.97		5.25
Lagerstroemia tomentosa C. Presl	5^{th} dominant	23.81	11.19		4.20
	TD	**240.27**	**112.93**		**42.41**
Site 2				232.7	
Xylia xylocarpa Roxb. Taub.	1^{st} dominant	34.51	16.22		6.97
Cordia grandis Roxb.	2^{nd} dominant	22.43	10.54		4.53
Mitragyna rotundifolia (Roxb.) Kuntze	3^{rd} dominant	14.26	6.70		2.88
Dalbergia cultrata Graham ex Benth.	4^{th} dominant	12.94	6.08		2.61
Lannea grandis Engl.	5^{th} dominant	23.19	10.90		4.68
	TD	**107.33**	**50.44**		**21.68**

Table 4 (continued).

Dominant species	PD	Biomass (Mg ha^{-1})	AC (Mg C ha^{-1})	TAC (Mg C ha^{-1})	PCD (%)
Site 3				221.81	
Xylia xylocarpa Roxb. Taub.	1^{st} dominant	63.70	29.94		13.58
Terminalia tomentosa (Roxb.)	2^{nd}	33.95	15.96		7.24

Wight & Arn	dominant			
Mitragyna rotundifolia (Roxb.) Kuntze	3rd dominant	18.36	8.63	3.92
Tectona grandis Linn.f	4th dominant	28.01	13.17	5.98
Protium serrata (Wall. Ex Colebr.) Engl.	5th dominant	25.92	12.18	5.53
	TD	**169.93**	**79.87**	**36.24**

At site 2, the above-ground carbon storage of the five most dominant species was 50.44 Mg C ha^{-1}, which was 21.68% of the total above-ground carbon storage (Table 4). The first most dominant species of site 2, *Xylia xylocarpa* Roxb. Taub., contained 6.97% (16.22 Mg C ha^{-1}) of the total above-ground carbon. The first most dominant species at site 2 was the same as that of site 1, although its proportion of above-ground carbon storage was lower at site 2 than at site 1. The second most dominant species, *Cordia grandis* Roxb., possessed 4.53% of the total above-ground carbon. The third most dominant species, *Mitragyna rotundifolia* (Roxb.), covered 2.88% of the total above-ground carbon. Together, the three dominant species at site 2 contained 14.38% of the total above-ground carbon.

The above-ground carbon storage of the five most dominant species at site 3 displayed 36.24% (79.87 Mg C ha^{-1}) of the total above-ground carbon (Table 4). In this site, the first most dominant species (*Xylia xylocarpa* Roxb. Taub.) stored significantly more carbon (29.94 Mg C ha^{-1}) than the other species, with 13.58% of the total above-ground carbon. The second most dominant species, *Terminalia tomentosa* (Roxb.) Wight & Arn, stored 15.96 Mg C ha^{-1} (7.24% of total above-ground carbon), whereas the third most dominant species, *Mitragyna rotundifolia* (Roxb.) Kuntze, stored 8.63 Mg C ha^{-1} (3.92% of total above-ground carbon). The three species covered 24.74% of the total above-ground carbon.

4.5 Linkages of diversity and structure to carbon storage of forests

The carbon storage was strongly correlated with the diversity as well as the structure of the forest (Table 5). The positive correlation was found between the carbon storage and the diversity of forests such as the ecosystem complexity, the species richness, Shannon diversity, Simpson diversity, and Shannon evenness at 99% confidence interval ($p < 0.01$).

In terms of forest structure, the carbon storage had positive correlations with the basal area, the density, the diameter, and height of forests at 99% confidence interval ($p < 0.01$). In particular, the ecosystem complexity (r = 0.906, $p < 0.01$), the species richness (r = 0.786, $p < 0.01$)and the Shannon diversity (r = 0.742, $p < 0.01$) affected more strongly to the carbon storage of forests when considering the effect of diversity, while the basal area (r = 0.966, $p < 0.01$), the diameter (r = 0.831, $p < 0.01$) and height (r = 0.871, $p < 0.01$) affected more strongly to carbon storage of forests when considering the effect of forest structure.

Table 5. Pearson correlation coefficients among diversity, structural drivers and carbon storage.

Parameter	Carbon storage
Ecosystem complexity	0.906**
Species richness	0.786**
Shannon diversity	0.742**
Simpson diversity	0.592**
Shannon evenness	0.465**
Basal area	0.966**
Density	0.640**
Diameter	0.831**
Height	0.871**

** Correlation is considered significant at 0.01 level.

According to the results, species richness was positively correlated with above-ground productivity. This resembles the findings of Cai et al. (2016) in successional temperate forests, Potvin et al. (2011) in Panama forests, and Nadrowski et al. (2010) and Zhang et al. (2012) of the global reviews. Another similar finding was found in South African forest, where species richness was positively correlated with carbon and biomass in regions where the annual rainfall ranged from 600 mm to 1,800 mm (Mensah et al. 2016).

To better understand the factors that affect carbon storage in the tropical forests of Myanmar, we tested the effects of density, species richness, diversity, and structural variables on carbon storage. Our results suggest that the carbon storage potential of tropical forests is strongly influenced by species diversity (including species richness) and by forest structure. Of the forest structural parameters, basal area was the most influential factor, followed by height and diameter ($p < 0.01$).

Poorter et al. (2015), who conducted a study in Neotropical forests from Mexico to Bolivia, demonstrated that tree density and tree size strongly affected above-ground biomass. However, based on the findings of this study, the effect of tree density was not as strong as the effects of basal area and tree size in tropical forests of Myanmar. This may be due to the tree density is much greater in small-diameter classes of forest. And the second reason is the carbon storage of forests is directly affected by the growth of trees.

Many studies have ignored the effects of ecosystem complexity on carbon storage. Based on the results, ecosystem complexity varies with the growth of forests. Consequently, it may potentially influence the carbon storage of forest. In fact, an effect of ecosystem complexity on the carbon storage of forests was discovered in this study. The results clearly show that ecosystem complexity correlated with carbon storage more highly than richness, diversity, or structural parameters (with the exception of basal area) did ($p < 0.01$). Therefore, ecosystem complexity must be considered when the goal is to enhance carbon storage in tropical forests. The correspondence analysis expressed a clear correlation between species distribution, abundance, basal area, ecosystem complexity and carbon. The first and second axes showed 59% of the total fitted variation.

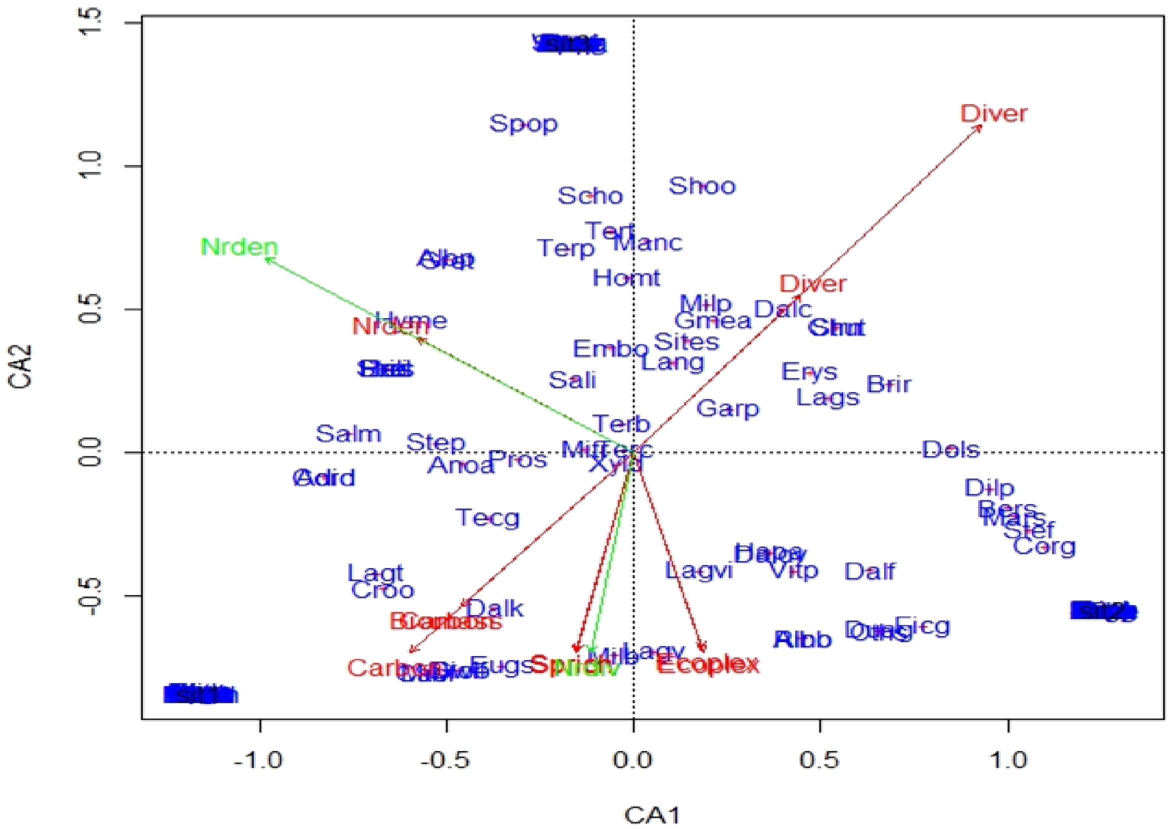

Figure 7. Correspondence analysis of species variables in relation to different drivers.

The letters expressed in the figure are the abbreviations of species names (Annex).

5. Conclusion

Bago Yoma forests are rich in species occurring 69 to 75 species in the study sites. Shannon diversity index of forests ranged from 3.05± 0.25 to 3.20 ± 0.06 and Simpson diversity index ranged from 0.95 ± 0.02 to 0.96 ± 0.01. In addition, high ecosystem complexity occurred at the study sites ranging from 23.73 to 25.76.

Basal areas of forests were from 39.66 ± 2.20 to 43.41 ± 2.2 m^2 ha^{-1}. All the results pointed out the Bago Yoma forests have high potential of carbon storage expressing 220.4 ± 10.56 to 266.3 ± 32.42 Mg C ha^{-1} of above-ground carbon. *Tectona grandis* Linn.f, *Xylia xylocarpa* Roxb. Taub., *Mitragyna rotundifolia* (Roxb.) Kuntze have been found under the list of dominant species and significantly contribute to the total carbon storage. The result showed the effect of diversity and structure of forest on carbon storage, giving positive evidences between carbon storage and the species richness, Shannon diversity, Simpson diversity and ecosystem complexity at 99% confidence interval ($p < 0.01$). It had positive correlations with the basal area, the density, the diameter, and height of forests at 99% confidence interval ($p < 0.01$). The distribution of above-ground carbon storage among three strata was as follows: middle stratum > upper stratum > lower stratum. This information could be very useful for carbon management of forests and sustainable forest management of Myanmar.

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Annex**.** Species name and their abbreviations of the study sites.

Sr. no.	Scientific name	Abbreviation
1	*Tectona grandis* Linn.f	Tecg
2	*Xylia xylocarpa* Roxb. Taub.	Xylx
3	*Acacia catechu* (L.f.) Willd.	Acae
4	*Acacia leucophloea* (Roxb.) Willd	Acal

5	*Adina cordifolia* (Roxb.) Brandis	Adic
6	*Albizzia chinensis* (Osbeck) Merr.	Albc
7	*Albizzia lebbek* (L.) Benth.	Albl
8	*Albizzia lucida* (Roxb.) Benth.	Alblu
9	*Albizzia odoratissima* (L.f.) Benth.	Albo
10	*Albizzia procera* (Roxb.) Benth	Albp
11	*Anogeissus acuminata* (Roxb. Ex Candolle)	Anoa
12	*Anthocephalus cadamba* (Roxb.) Miq.	Antc
13	*Aporosa villosa* (Lindl.) Baill.	Apov
14	*Artocarpus calophyla* Kurz.	Artc
15	*Bauhinia acuminata* L.	Baua
16	*Bauhinia racemosa* Lam.	Baur
17	*Bauhinia variegata* L.	Bauv
18	*Berrya* spp.	Bers
19	*Bridelia retusa* (L.) Spreng.	Brir
20	*Buchanania lanzan* Spreng.	Baul
21	*Cassia fistula* L.	Casf
22	*Cassia renigera* Wall. Ex Benth	Casr
23	*Chukrasia tabularis* M.Roem.	Chut
24	*Cleidion speciflorum* Merr.	Cles
25	*Cordia dichotoma* G.Forst.	Cord
26	*Cordia grandis* Roxb.	Corg
27	*Cratoxylon neriifolium* Kurz	Cran
28	*Croton oblongifolius* Roxb.	Croo
29	*Dalbergia cultrata* Graham ex Benth.	Dalc
30	*Dalbergia fusca* Pierre	Dalf
31	*Dalbergia kurzii* Prain	Dalk
32	*Dalbergia oliveri* Gamble ex Prain	Dalo
33	*Dalbergia ovata* Grah. Ec Benth.	Dalov
34	*Derris robusta* (Roxb. Ex DC.) Benth	Derr
35	*Dichrostachys cinera* Wight et Am.	Dicc
36	*Dillenia pentagyna* Roxb.	Dilp
37	*Diospyros burmanica* Kurz	Diob
38	*Dipterocarpus tuberculatus* Roxb.	Dipt
39	*Dipterocarpus grandifloras* Blanco	Dips
40	*Dolichandrone serrulata* (Wall. Ex DC.) Seem.	Dols
41	*Duabanga grandiflora* (Roxb. Ex DC.) Walpers	Duag
42	*Emblica officinalis* Gaertn.	Embo
43	*Eriolaena candollei* Wall.	Eric

44	*Erythrina suberosa* Roxb.	Erys
45	*Eugenia* spp.	Eugs
46	*Ficus* spp.	Fics
47	*Ficus glomerata* Roxb.	Ficg
48	*Ficus roxburghii* Wall.	Ficr
49	*Firmiana colorata* Roxb.	Firc
50	*Flacourtia cataphracta* Roxb. Ex Willd.	Flac
51	*Gardenia erythroclada* Kurz	Gare
52	*Gardenia turgida* Roxb.	Gart
53	*Garuga pinnata* Roxb.	Garp
54	*Gmelina arborea* Roxb.	Gmea
55	*Grewia tiliaefolia* Vahl.	Gret
56	*Haplophragma adenophyllum* (Wall. Ex G.Don) Dop	Hapa
57	*Holarrhena antidysenterica* (Linn.) Wall.	Hola
58	*Holoptelea integrifolia* (Roxb.) Planch	Holi
59	*Homalium tomentosum* (Vent.) Benth.	Homt
60	*Hymenodictyon excelsum* (Roxb.) Wall.	Hyme
61	*Kydia calcine* Roxb.	Kydc
62	*Lagerstroemia calyculata* Kurz	Lagc
63	*Lagerstroemia parviflora* Roxb.	Lagp
64	*Lagerstroemia speciosa* (L.) Pers.	Lags
65	*Lagerstroemia tomentosa* C. Presl	Lagt
66	*Lagerstroemia venusta* Wall.	Lagv
67	*Lagerstroemia villosa* Wall. Ex Kurz	Lagvi
68	*Lannea grandis* Engl.	Lang
69	*Limonia acidissima* L.	Lima
70	*Linociera terniflora* Wall.	Lint
71	*Litsaea monopetalla* (Roxb.) Pers.	Litm
72	*Macaranga denticulata* Muell. Arg.	Macd
73	*Mangifera caloneura* Kurz	Manc
74	*Mangifera indica* L.	Mani
75	*Manglietia insignis* Wall.	Manin
76	*Markhamia stipulata* (Wall.) Seem.	Mars
77	*Melanorrhoea usitata* Wall.	Melu
78	*Miliusa velutina* (Dunal) Hook. F. & Thomson	Milv
79	*Millettia brandisiana* Kurz	Milb
80	*Millettia pendula* Benth.	Milp
81	*Mitragyna purvifolia* (Roxb.) Korth.	Mitp
82	*Mitragyna rotundifolia* (Roxb.) Kuntze	Mitr

83	*Morinda tinctoria* Roxb.	Mort
84	*Neonauclea excelsa* (Blume) Merr.	Neoe
85	*Oroxylum indicum* (L.) Benth. Ex Kurz	Oroi
86	*Parashorea stellata* Kurz	Pars
87	*Pentace griffithii* King	Peng
88	*Premna latifolia* Roxb.	Prel
89	*Premna pyramidata* Wall. Ex Schauer	Prep
90	*Protium serrata* (Wall. Ex Colebr.) Engl.	Pros
91	*Pterocymbium tinctorium* Merr.	Ptet
92	*Pterospermum acerifolium* (L.) Willd.	Ptea
93	*Pterospermum semisagittum* Kuntze	Ptes
94	*Quercus brandisiana* Kurz	Queb
95	*Randia uliginosa* (Retz.) Poir.	Ranu
96	*Rinorea bengalensis* (Wall.) Kuntze	Rinb
97	*Azadirachta indica* A. Juss.	Oths
98	*Salmalia insignis* (Wall.) Schott & Endl	Sali
99	*Salmalia malabarica* (DC.) Schott & Endl	Salm
100	*Sapindus* spp.	Saps
101	*Sapium insigne* (Royle) Trimen	Sapi
102	*Schima noronhae* Reinw. ex Blume	Schn
103	*Schleichera oleosa* (Lour.) Oken	Scho
104	*Semicarpus anacardium* L.f.	Sema
105	*Shorea oblongifolia* Thw.	Shoo
106	*Sideroxylon tomentosum* Roxb.	Sidt
107	*Spondias pinnata* (L. f.) Kurz	Spop
108	*Sterculia* spp.	Stes
109	*Stereospermum fimbriatum* Wall. ex G. Don	Stef
110	*Stereospermum personatum* (Hassk.) Chatterjee	Step
111	*Strychnos nux-blanda* A.W. Hill	Strn
112	*Swintonia floribunda* Griff.	Swif
113	*Terminalia belerica* (Gaertn.) Roxb.	Terb
114	*Terminalia chebula* Retz.	Terc
115	*Terminalia pyrifolia* Kurz	Terp
116	*Terminalia tomentosa* (Roxb.) Wight & Arn	Tert
117	*Tetrameles nudiflora* R.Br.	Tetn
118	*Vitex pubescens* Vahl	Vitp
119	*Wendlandia glabrata* DC.	Weng
120	*Xerospermum noronhianum* (Blume) Blume	Xern
121	*Archidendron jiringa* (Jack) I.C.Nielsen	Arcj

122	*Pittosporum nepaulensis* DC.	Pitn
123	*Rhus paniculata* Wall.	Rhup
124	*Carissa carandas* Linn.	Carc
125	*Boscia variabilis* Collett & Hemsl.	Bosv
126	*Polyalthia simiarum* Benth. & Hook. f. ex Hook. f.	Pols
127	*Dalbergia paniculata* Roxb.	Dalp
128	*Gardenia obtusifolia* Roxb.	Garo
129	*Zizyphus mauritiana* Lam.	Zizm
130	*Croton joufra* Roxb.	Croj