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Book:

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Chapter in book:

Webb CO, Cannon CH, Davies SJ. 2008. Ecological organization, biogeography, and the phylogenetic structure of rainforest tree communities. In: Carson W, Schnitzer S (eds) Tropical Forest Community Ecology. Wiley-Blackwell, New York.

Abstract:

Assaeed AM. 2007. Seed production and dispersal of *Rhazya stricta***.** 50th Annual Symposium of the International Association for Vegetation Science, Swansea, UK, 23-27 July 2007.

Proceeding:

Alikodra HS. 2000. Biodiversity for development of local autonomous government. In: Setyawan AD, Sutarno (eds.) Toward Mount Lawu National Park; Proceeding of National Seminary and Workshop on Biodiversity Conservation to Protect and Save Germplasm in Java Island. Universitas Sebelas Maret, Surakarta, 17-20 July 2000. [Indonesian]

Thesis, Dissertation:

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Information from internet:

Balagadde FK, Song H, Ozaki J, Collins CH, Barnet M, Arnold FH, Quake SR, You L. 2008. A synthetic *Escherichia coli* predator-prey ecosystem. Mol Syst Biol 4: 187. www.molecularsystemsbiology.com. DOI:10.1038/msb.2008.24

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Dimensional stability and tensile strength of biopolymer composite reinforced with hardwood fiber at varying proportions

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Abstract. *Bola TS, Oluyege AO, Aina KS. 2020. Dimensional stability and tensile strength of biopolymer composite reinforced with hardwood fiber at varying proportions. Asian J For 4: 1-5.* Wood-plastic composites (WPCs) are emerging materials that have high potentials to be used in many building applications. This study was designed to produce bio-composites made from three different wood species and at three different mixing ratios of plastic to wood on weight to weight basis. The main variables employed in this study were wood species of *Triplochiton scleroxylon*, *Terminalia superba* and *Gmelina arborea*; at three plastic: wood ratios of 40:60, 50:50, and 60:40. The composite samples were made through compounding and extrusion processes. The properties evaluated were carried out in accordance with the American Standard Testing Methods of 570 and 790 to determine the dimensional stability and strength properties of the composites. The values obtained for the wood species ranged from 0.59 g/cm^3 to 0.72 g/cm^3, 0.59% to 0.71%, 0.63% to 0.7%and 1.84 MPa to 2.07 MPa for density, water absorption, thickness swelling and tensile strength, respectively. Meanwhile, the values obtained from the mixing ratio ranged from 0.54 g/cm^3 to 0.79 g/cm^3, 0.53% to 0.79%, 0.42% to 1.00%, and 1.58 MPa to 2.37 MPa for density, water absorption, thickness swelling and tensile strength, respectively. It was observed that mixing ratio and wood species used in this study influenced the dimensional stability and strength properties of the WPCs. This study revealed that as the wood-flour content increased to plastic, the dimensional properties and tensile strength values increases.

Keywords: Absorption composite, ratio, tensile, wood

INTRODUCTION

Wood-plastic composites (WPCs) are any composites that contain wood and non-wood fibers with thermosets or thermoplastics. WPCs are relatively new generation of composite materials made from the combination of two materials, i.e., wood and plastic which are naturally difficult to combine. WPCs are made by combining wood and polymer together to form panel sheets or molded into shapes, with the display of properties of both components (Yang et al. 2007). WPCs are produced as direct replacements or substitute for solid wood due to the need to replace treated solid timbers that are being scarce and limited in supply. In the last decade, WPCs have emerged as an important member of engineering materials that are useful in many building applications, such as decking, docks, landscaping timbers, fencing, etc (Pilarski and Matuana 2005). WPCs have been received some recognition in building sector due to their favorable properties, which include low density, high dimensional stability, improved strength, high resistance to biodeterioration agents, low cost of raw materials, and recyclable (Zhang et al. 2012).

Previous research works on WPCs showed that factors such as the quantity, geometric sizes, and surface characteristics of the wood component and the interfacial properties between the wood and plastic do influence the properties of the products. Many indigenous and exotic wood species have been investigated with results showing that effect of proportional ratio, components of wood species and type of polymer used significantly influenced the properties of WPCs (Ajigbon and Fuwape 2005; Fuwape and Aina 2008; Fuwape et al. 2010). Similarly, other non-wood flour has also been investigated as well as the possibility and potentials of using agro-residues (Ajayi and Aina 2008). These authors found that agro-residues and non-wood flours, like bamboo and corn cob, also performed well in production of WPCs samples. Other agro-residues, such as yam stem, bagasse (sugar cane) coffee waste, and banana stem, also performed well.

Nigeria has over 6000 wood species with the potentials to be developed for WPCs manufacture. Nonetheless, research is required to investigate various indigenous species for possible raw materials of WPCs. Therefore, this study aimed to investigate the suitability of some wood species for the production of WPCs, and to assess the effect of wood to plastic ratio on the strength and dimensional properties of wood-plastic composites.

MATERIALS AND METHODS

Preparation of materials

Three indigenous wood species, namely *Gmelina arborea*, *Triplochiton scleroxylon* (Obeche), and *Terminalia superba* (Afara) were used in this study. The wood particles of each wood species were collected after sawing with CD-6 band saw machine in the Department of Forest Products Development and Utilization, the Forestry Research Institute of Nigeria (FRIN), Ibadan, Oyo State of Nigeria. The wood particles were thoroughly sieved with a wire mesh of size 60 µm to separate the unwanted and to obtain homogenous flour size of particle designed for production. The wood flour was later oven-dried at 103ºC for 24 hrs to attain the 4% moisture content; this was done to avoid unnecessary air bubbles that could be found in the internal structure of the composite. The polymer powder employed in this study was derived from used plastic sachets used for packaging drinking water; these were collected in large quantities from the dumping yards of DFRIN water packaged factory located at FRIN. The plastic has a density of 0.64 g/cm^3 with melt flow index of (0.2 -0.3) 10/min. The used plastic sachets were thoroughly washed, dried, and agglomerated into powder at a temperature of 75 ºC.

Composite preparation and production

An appropriate quantity of wood flour was prepared for each wood species at three mixing ratios of wood/plastic 40/60, 50/50, and 60/40 in a weight-to-weight basis. The mixtures were fed into co-rotating single screw extruders within the temperature range of 80-120°C to produce molten compounded WPCs strands. The molten compounded WPCs extruded strands were allowed to pass through water bath to solidify, and then the solidified WPCs strands were pelletized into grains for molding. The pelletized WPCs were fed into 120-ton polymer injection molding machine at the temperature of 140ºC to 160ºC to mold WPCs samples. The test samples were designed and done in accordance with the American Standard for Testing Materials (ASTM) D 570 and D638 for determination of physical and mechanical properties with five replicates for each testing procedure.

Properties determination and procedures

Dimensional properties test

The tests for water absorption and thickness swelling were conducted in accordance with ASTM D570-98. The test specimens with dimension of 76.2 x 25.4 x 6.4 mm were oven-dried for 24 hrs at 50ºC (122ºF). After conditioning, the width, length, and thickness of each specimen were measured before immersion in water soak test. The specimen was totally submerged in distilled water at room temperature of 26 ± 2 ºC for a period of 24 hrs (1 day) respectively. After water immersion treatment, the specimens were suspended for 10 min to drain off the water and the remaining water was wiped off with dried towel. The specimens were finally weighed and the thickness measured. The water absorption and thickness swelling of the boards were calculated using equation 1 and 2 below;

$$WA\% = \left[(Wt - Wo)/(Wo)x\right]\left[\left[100\right]^{\wedge}\right] \text{ ………......…. [1]}$$

Where, WA = Water absorption (%), Wo = oven-dry mass (g) and Wt = mass (g) after time t in water immersion

$$TS(\%) = \left[(Tt - To)/(To)\right]\left[\left[100\right]^{\wedge}\right] \text{ …..……………. [2]}$$

Where, TS = Thickness swelling (%), To = panel thickness (mm) before, and Tt = panel thickness after time t in Water immersion

Mechanical tests

Type-I tensile bar of specimens with dimension of 165 x 19 x 6.4 mm were cut from the samples and subjected to Universal Testing Machine of model WDW 5000 (UTM-810 load frame with 50 kN load cell) at a crosshead speed of 2.8 mm/min and lower support of 100 mm. Elongation (strain) of the specimen was measured over 25 mm gauge length using an extensometer. These were done under ambient conditions of 23 ± 2 ºC and 50% relative humidity in accordance with ASTM D638-99. The tensile strength was calculated by dividing the maximum load in Newton by the original minimum cross-sectional area of the specimen in square meters. The young’s modulus of elasticity (MOE) was calculated from the load-elongation curves by using the initial linear part. The MOE is equal to the stress increase over this linear period divided by the corresponding increase in the strain.

$$Tensile\ strength = \frac{Maximum\ load(N)}{cross\ sectional\ area(m^2)} \text{ ………. [3]}$$

Experimental design

All measurements of each treatment were done in five replicates; the data collected was analyzed and the statistical method adopted for analysis of variance was 3 x 3 factorial experiments in Completely Randomized Design (CRD) at 5% level of probability using Statistical Package for Social Sciences (SPSS) version 13.0 software. This was carried out to determine significance of the main and interacting effects on the study variables (wood species and mixing ratio). Descriptive analysis of the data was done to determine the mean values with standard deviation while a follow-up test was carried out to determine the differences between the means values and to choose the best level from the factors considered. Duncan Multiple Range Test (DMRT) was adopted for follow-up test. The two main factors considered in this study were the wood species with three treatments (*T. superba*, *T. scleroxylon*, and *G. arborea*) and mixing proportions with three ratios of wood/plastic (40/60, 50/50, and 60/40) on weight-to-weight basis.

RESULTS AND DISCUSSION

Dimensional stability of the WPC boards

The outcome of the results in descriptive statistics and analysis of variance on dimensional properties are presented in Tables 1 and 2, and the graphical presentations are shown in Fig. 1, 2, 3, and 4 respectively. The effect of wood species and plastic/wood ratio on dimensional properties of the resulted in WPCs was also discussed in this study.

The outcome of average values of density, water absorption, and thickness swelling for WPCs as influenced by the wood species and plastic/wood ratio are presented in Table 1. The values ranged from 0.47g/cm^3 to 0.92 g/cm^3, 0.46% to 0.91%, and 3.58% to 6.99% for density, water absorption and thickness swelling, respectively. The densities obtained from the WPCs made from wood species of *T. superba, T. scleroxylon,* and *G. arborea* were 0.59, 0.72 and 0.62 g/cm^3, respectively. The densities obtained from the WPCs at different plastic/wood ratio of 40/60, 50/50 and 60/40 were 0.53, 0.79, and 0.59 g/cm^3 respectively. However, the values obtained in wood species for water absorption and thickness swellings after water immersion period of 24 hours were 5.02% and 0.77%, 5.03% and 0.64%, and; 4.83% and 0.76% for *T. superba*, *T. scleroxylon*, and *G. arborea* respectively. Similarly, the values obtained in WPCs at plastic/wood ratio for water absorption and thickness swelling were 0.53% and 3.98%, 0.79% and 4.23% and; 0.59% and 6.66% for 40/60, 50/50, and 60/40 respectively.

As illustrated in Figures 1, 2, and 3, it was observed that as the content of wood to plastic increases, the percentage of water absorbed increases, and the thickness also swells. The results as presented in Figures 2 and 3 agree with previous findings by Fuwape and Aina (2008) and Zhang et al. (2012). These authors explained the behavior WPCs in water exposure and natural weather. This observation was attributed to the hygroscopic nature of wood; and when the wood is increasing to the proportion of plastic, some wood fiber was not able to be covered or encapsulated with plastic that acted as matrix to protect the wood fiber. Wood fiber has been known to have high affinity to water; it absorbs water and allows poor fiber-plastic interaction to bond, thereby permitting pores or voids for diffusion of moisture across the internal structure of the composite.

It was also observed that variation occurs among the different wood species investigated in this study for dimensional stability (Figures 2 and 3). It was found in this study that WPCs made from *T. scleroxylon* had the highest values in water absorption and thickness swelling more than the others. This implies that *T. scleroxylon* behaves poorly in water retention than others, suggesting low dimensional stability. Cell wall found in wood varies, this is largely made up of cellulose and hemicellulose, and the hydroxyl groups on these chemicals make the cell wall hydroscopic. Lignin, the agent cementing cells together is a comparatively hydrophobic molecule. This implies that the cell walls found in wood have a great affinity for water, but the ability of the walls to take up water is limited in part by the presence of lignin and this also varies in wood species (FPL 2010). The density or specific gravity of wood species does play a major role in dimensional stability of WPCs as well. Klyosov (2007) reported that wood species of higher density have significant influence on density of the WPCs and also lower water absorption. This study also shows that there are variations in dimensional stability of WPCs as influenced by plastic/wood ratio. As observed in Figures 2 and 3, WPCs made from 60:40 had lower dimensional stability than others. This observation agrees with the studies by Ajigbon and Fuwape (2005), Fuwape and Aina (2008), and Chaharmahali et al. (2007; 2008).

The outcome of the result of analysis of variance carried out at 5% level of probability for density, water absorption, and thickness swelling are presented in Table 2. The results showed that there were significant differences in all the factors considered in density, water absorption, and thickness swelling, the outcome values for significance in all the dimensional properties were found to be 0.00* which is lesser than proposed standard of 0.05 level of probability or significance. This implies that both factors (wood species and mixing proportion) used for the production of WPCs have major influence on the dimensional stability of the boards.

Table 1. Mean values of physical and mechanical properties of wood-plastic composites experimented in this study

Variables		**Physical properties**			**Mechanical properties**
Wood species	**Wood/plastic ratio**	**Density (g/cm^3)**	**Thickness swelling (%)**	**Water absorption (%)**	**Tensile strength (MPa)**
Terminalia superba	40:60	0.539 ± 0.004	0.638 ± 0.161	4.378 ± 1.239	1.690 ± 0.183
	50:50	0.665 ± 0.015	0.838 ± 0.277	4.614 ± 0.469	2.067 ± 0.797
	60:40	0.588 ± 0.033	0.845 ± 0.114	6.070 ± 0.957	1.891 ± 0.061
Triplochiton scleroxylon	40:60	0.593 ± 0.004	0.324 ± 0.130	4.006 ± 0.577	1.780 ± 0.361
	50:50	0.911 ± 0.059	0.479 ±0.163	4.160 ± 1.049	2.343 ± 0.247
	60:40	0.619 ± 0.063	1.114 ± 0.480	6.917 ± 2.686	1.933 ± 0.205
Gmelina arborea	40:60	0.459 ± 0.058	0.278 ± 0.117	3.565 ± 0.752	0.695 ± 0.015
	50:50	0.788 ± 0.097	0.931 ± 0.283	3.934 ± 0.464	2.616 ± 0.083
	60:40	0.578 ± 0.034	1.061 ± 0.426	6.992 ± 1.809	2.204 ± 0.188

Note: Each value is the mean and standard deviation of 9 samples of WPCs

Table 2. Result of the analysis of variance for dimensional properties WPCs

Properties	Source	Type III sum of squares	df	Mean square	F	Sig.
Density	Mixing ratio	0.325	2	0.163	1416.13	0.000*
	Wood species	0.079	2	0.040	345.13	0.000*
	Mixing ratio *wood species	0.054	4	0.014	117.66	0.000*
	Error	0.002	18	0.000		
	Total	0.461	26			
Water absorption	Mixing ratio	0.338	2	0.169	1471.484	0.000*
	Wood species	0.062	2	0.031	271.871	0.000*
	Mixing ratio *wood species	0.053	4	0.031	116.258	0.000*
	Error	0.002	18	0.000		
	Total	0.456	26			
Thickness swelling	Mixing ratio	39.347	2	19.674	1066.33	0.000*
	Wood species	0.213	2	0.107	196736.33	0.000*
	Mixing ratio *wood species	3.016	4	0.754	7539.33	0.000*
	Error	0.002	18	1.000E-4		
	Total	42.578	26			

Note: represents significance at (P ≤ 0.05) probability level

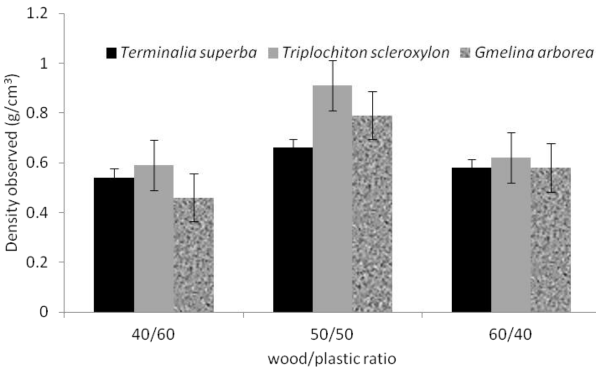

Figure 1. Influence of wood species and mixing ratio on density of the experimented WPCs

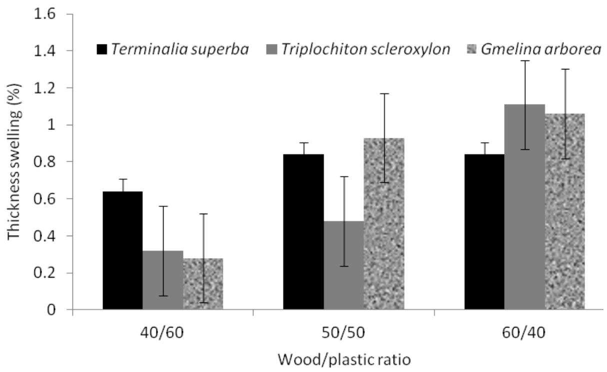

Figure 3. Influence of wood species and mixing ratio on thickness swelling of the experimented WPCs

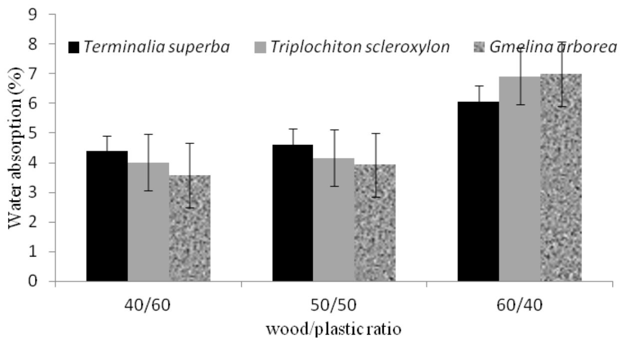

Figure 2. Influence of wood species and mixing ratio on water absorption of the experimented WPCs

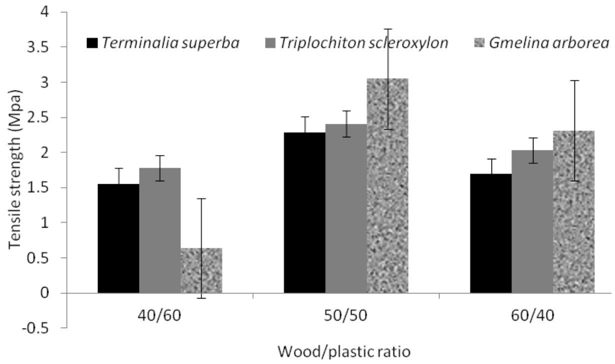

Figure 4. Influence of wood species and mixing ratio on tensile strength of the experimented WPCs

Tensile strength of WPCs

The effects of wood species and mixing proportion on tensile strength of WPCs are also presented in Table 1. The tensile strength values obtained in WPCs made from mixing ratio of 40:60, 50:50, and 60:40 (wood/plastic) ranged from 0.695 to 1.780 MPa, 2.067 to 2.616 MPa, and 1.891 to 2.204 Mpa, respectively. Similarly, in the wood species employed, the tensile strength values obtained from

WPCs made of *T. superba*, *T. scleroxylon*, and *G. arborea* were found to be 5.648 MPa, 6.056 MPa, and 5.515 Mpa, respectively. It was found in this study that the values obtained for tensile strength were low and varied accordingly in wood/plastic mixing ratio and wood species. The tensile values could be attributed to the strength characteristic of individual wood species and it has been noted that wood density has direct influence on the strength properties of WPCs. This agrees with the findings of previous studies (e.g., Stokke and Gardner 2003; Klyosov 2007; Fuwape and Aina 2008; Zhang et al. 2012; Aina et al. 2016). Schoch et al. (2004) further explained that anatomical features of wood species could also contribute to the strength properties of the composite, the intermolecular structure of *G. arborea* and *T. scleroxylon* could have permitted better percolation of molten plastic into the wood cellular network than other *T. superba*. As illustrated in Fig. 4, it was observed that WPCs made from different mixing proportions reacted differently in strength properties. WPC made from equal proportion of wood to plastic (50/50) had the highest tensile values of 7.026 MPa followed by 60/40 and 40/60. This could be attributed to strong fiber interfacial bonds that exist in the structure of the composites with the help of matrix (plastic). The 50% fraction of the fiber gives perfect fiber dispersion and distribution within the 50% of matrix which leads to strong stress transfer in the structure of the composite. But as the fiber fraction is decreasing or increasing (40% and 60%), the fiber interfacial bond got weakened to give gaps that allow weak stress transfer.

The result of the analysis of variance carried out at 0.05 level of probability to test tensile strength of the WPCs made from wood species at different plastic/wood ratio is presented in Table 3. The values obtained for level of significance were higher than 0.05 for wood species while the rest was lesser, this implies that mixing ratio and two-factor interaction were significant except wood species at 0.05 level of probability.

In conclusion, the outcome of this research study revealed that WPCs could be produced from recycled plastic reinforced with wood fiber derived from different wood species. It was also revealed that each wood particle has influence on properties and can play an important role in application. This study demonstrated that some tropical wood species can be suitable for the production of WPCs while some may be less or not suitable. The study also revealed that variations occur in dimensional stability and tensile strength of the WPCs made from different wood species and at mixing proportions. The study found that WPCs made from *G. arborea* at 50/50 gave higher tensile strength than the others. But in dimensional stability, the same WPCs made from *G. arborea* and *T. scleroxylon* performed better at 40/60 and 50/50 (wood/plastic). WPCs investigated in this study, could be of great use if considered for ceiling application as replacement to cement-made ceiling and louvers as replacement for glass.

Table 3. Analysis of variance for tensile strength

Source of variance	Type III sum of squares	df	Mean square	F	Sig.
Mixing ratio	2.841	2	1.421	5.343	0.015*
Wood Species	0.247	2	0.124	0.464	0.636ns
Mixing ratio * Wood species	7.815	4	1.954	7.347	0.001*
Error	4.787	18	0.266		
Total	15.690	26			

Note: represent significant while ns reps not significant at (P ≤ 0.05) probability level.

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Steaming-caused chemical changes of sugi (*Cryptomeria japonica*) wood monitored by NIR spectroscopy

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Abstract. *Mahdiyanti SH, Tsuchikawa S, Mitsui K, Tolvaj L. 2020. Steaming-caused chemical changes of sugi* (Cryptomeria japonica) *wood monitored by NIR spectroscopy. Asian J For 4: 6-9.* Steaming is a common method to change the color of wood to enhance attractiveness. This study aimed to investigate time-dependence of chemical changes of sugi (*Cryptomeria japonica* D. Don) wood steamed with temperature of 90 and 110°C and monitored up to 20 days using NIR spectroscopy. The difference spectrum method was applied to find the absorption increases and decreases. Before the subtraction, the spectra were normalized to one unit at 1739 nm to eliminate the parallel shift of the spectra. The results showed that steam-induced chemical changes in the wavelength range of 1300-2100 nm were related to the absorption of water and the absorption of extractives, especially phenolic contents. These chemical changes were suspected to be strongly related to color changes in steamed wood. Longer duration of steaming caused phenolic compounds to change into similar contents in all wood tissues, which cause their color to change more uniformly. Steaming caused a water bounding capacity loss of the cell wall. This change was much faster at 110°C than at 90°C.

Keywords: Color change, hydroxyl groups, steaming, sugi wood, NIR spectroscopy

Abbreviations: NIR: near infra-red, E: earlywood, L: latewood, H: heartwood, S: sapwood, nm: nanometre

INTRODUCTION

Steaming is a useful method for color modification of wood materials. Some wood species have a white-greyish color without a distinct texture (e.g., poplar, beech, hornbeam, etc.), while some other species have a strikingly inhomogeneous color (e.g., black locust, Turkey oak, beech having red heart, etc.). Disadvantageous wood texture might be turned to a more favorable appearance using steam treatment. The color modification effect of steaming is a widely investigated phenomenon (e.g., Varga and van der Zee 2008; Straze and Gorisek 2008; Tolvaj et al. 2009, 2010, 2012; Milic et al. 2015; Geffert et al. 2017; Dzurenda 2017, 2018a, 2018b; Banadics and Tolvaj 2019).

The color of a material is determined by the presence of conjugated double bond chemical systems. In natural wood material, these systems are located in lignin and in extractives with the color of wood species is primarily determined by the extractive content. Extractives are highly sensitive to heat and this is exploited as the main basis of color modification by steaming where wood material is subjected to the simultaneous effect of heat and moisture. Generally, the maximum steaming temperature is 120°C in industrial practice. This is the upper temperature limit because of the high steam pressure above this temperature. Most of the main chemical substances of wood (cellulose, hemicelluloses, and lignin) are stable below 120°C. It is well known that mainly the thermally less stable polyoses are decomposed due to the influence of heat (Fengel and Wegener 1984). Acetic acid is released by the scission of acetyl groups linked as an ester group to the hemicelluloses (Tjeerdsma and Militz 2005; Windeisen et al. 2007). The degradation products of hemicelluloses modify the initial color of wood. This phenomenon is the second-order producer of color changes during steaming. The main creators of this color change are the extractives, yet the chemical changes of extractives cannot be traced by middle IR spectroscopy because of their low-level quantity (Tolvaj et al. 2013).

The NIR wavenumber range from 12800 to 7000 cm-1 is considered to be influenced by particle size and especially by visible color change, and it has proven to be useful for qualitative purposes (Schwanninger et al. 2011). The NIR wavenumbers related to extractives, 7092 and 6913 cm-1 assigned to first overtone of O-H stretching, is due to the presence of phenolic hydroxyl groups (Schwanninger et al. 2011). Phenolic compounds are suspected to be responsible for wood discoloration related to extractives (Torres et al. 2010). The change in acetyl ester in hemicellulose due to thermal degradation related to color change can be observed in the NIR second-derivative spectra between 8650-8450 cm^{-1} (Schwanninger et al. 2011). The NIR wavenumber, which is adjacent to the visible-light range, is supposed to be sensitive to trace visual color change, and is more suitable for the observation of chemical change related to the color in wood.

The aim of this study was to investigate the chemical changes of sugi (*Cryptomeria japonica* D. Don) wood generated by the steaming temperature of 90 and 110°C. The time-dependence of the chemical changes of sugi wood was monitored up to 20 days of steaming using NIR spectroscopy.

MATERIALS AND METHODS

Preparation of materials

Sugi (*Cryptomeria japonica* D. Don) samples were prepared for steaming. The specimen size was 150x20x10 (mm). The largest surface contained only earlywood or latewood (tangential surface). Half part of the specimens was sapwood and the other half part was heartwood. The average moisture content of the samples was 9.1% before the steaming process.

Steaming treatment

Steaming was carried out at 90 and at 110°C. Wood specimens were placed in a large pot with distilled water beneath for conditioning the air to generate 100% relative humidity. Even at 110°C the pot was able to maintain overpressure. The pot was heated in a drying chamber to the indicated temperatures. The steaming process started with a four-hour pre-heating period. The temperature was regulated automatically around the pre-set values with a tolerance of 0.5°C. Specimens were removed after 5, 9, 14 or 20 days of steaming, respectively. The wood specimens were conditioned for one month both before and after steaming at room temperature before the NIR measurement.

Color changes monitoring

For NIR measurement the sample size was 20x20x10 (mm). The measured surface contained only earlywood or latewood. Three samples were prepared for each NIR measurement (earlywood of sapwood and heartwood, latewood of sapwood and heartwood, before steaming and after each steaming period). Altogether 96 samples were prepared for NIR measurement. The samples of steaming schedule 90°C and 5 days were ignored for NIR measurement, because the color change was small in this case.

The NIR device used to measure the samples was a Fourier transform (FT) NIR spectrometer, Matrix-F (Bruker Optics, Germany), with instrument settings as follows: wavenumber resolution of 8 cm^{-1}, 32 scans of samples and references, and a wavenumber range of 10000-4000 cm^{-1}. After the measurement, wavenumbers were transformed into wavelengths. The measured three NIR spectra were averaged for further evaluation. All NIR spectra were parallel with the horizontal axis in the 1700-1800 nm range. Spectra show that there is no absorption in this region. But the spectra were slightly shifted from each other in the vertical direction. This parallel shift was generated by the different scattering properties of the individual samples. The effect of scattering was eliminated by the normalization of the spectra. All data of the individual spectrum were multiplied with a proper constant to get the unit value at 1739 nm. The normalization eliminated the parallel shift of the spectra. The effect of steaming was presented by the different spectra. The spectrum of the initial (unsteamed) sample was subtracted from the spectrum of steamed sample. In this case, positive and negative bands represent absorption increases and absorption decreases, respectively. Details of spectrum manipulations are explained in previous work (Csanady et al. 2015).

RESULTS AND DISCUSSION

The results showed that chemical changes related to color in the NIR spectra observed in wood samples treated at 110ºC were more obvious than in those treated at 90ºC, especially at the wavelength of 1410 nm (7092 cm^{-1}) and 1447 nm (6913 cm^{-1}). These wavelength ranges are assigned to phenolic hydroxyl compounds (Schwanninger et al. 2011). The values of difference NIR spectra of latewood in both heartwood and sapwood showed a decrease at these wavelengths from day-5 to 14 of treatments, but then increased by the 20th day (Figure 1 and 2). Meanwhile, the values NIR spectra of earlywood in both heartwood and sapwood (Figures 3 and 4) at 110ºC increased from 5 to 14 days of treatment, then decreased by the 20th day. Heartwood and sapwood contain different amounts of phenolic extractives (Fengel and Wegener 1984). This showed in the different changes of phenolic compounds in heartwood and sapwood during steaming, where heartwood had higher extractive contents than sapwood (Figures 1 and 3). There is no clear distinction between latewood and earlywood extractive contents, but in the study of *Pinus radiata*, latewood in the heartwood, especially in the inner heartwood, higher extractive contents were found than in earlywood (Lloyd 1978). This explains the different changes of phenolic extractive contents in the latewood and earlywood of heartwood.

In latewood, the increasing amount of phenolic compounds by the 20th day of treatment indicated the contribution of other wood cell wall components degradation. As explained by Esteves and Pereira (2009), most extractives degrade during heat treatment, but new compounds that can be extracted from wood appear as a result of the degradation of cell wall structural components. Hemicellulose degradation is suspected to contribute to the chemical changes related to color in steamed wood, as it is the least stable cell wall component even at low temperatures (Esteves and Pereira 2009). Latewood appears to have higher hemicellulose contents than earlywood, according to Kurata et al. (2018) in their report on sugi. Steaming causes partial degradation to hemicellulose (Geffert et al. 2017) and sometimes it is accompanied by the relative increase of total extractive contents (Sikora et al. 2018).

A report by Torres et al. (2010) explains that in heartwood, the brown color is primarily related to the oxidation of phenolic compounds. In this experiment, latewood in both heartwood and sapwood tissues had darker color than earlywood in both heartwood and sapwood, indicating higher content of phenolic compounds in latewood. It explained the change of phenolic compounds in latewood, which was greater than in earlywood during steaming. By the 14th to 20th days of treatment, yellowness (b*) showed small change and resulted in an almost uniform yellow color level of all wood tissues (Figure 5). This result is in accordance with the report by Sundqvist (2002) in heat-treated wood, where heat treatment produced similar contents of phenolic compounds in wood tissues, and led to a more uniform color.

The evaluation of color change showed that both yellowness and redness changes were mostly completed before the fifth day of steaming (See the yellowness change presented in Figure 5). At the same time, absorption decrease around 1930 nm occurred during the first five days of steaming at 110°C (Figures 1-4). In contrast, the absorption decrease around 1930 nm continued during the full 20 days of steaming at 90°C (Figure 6).

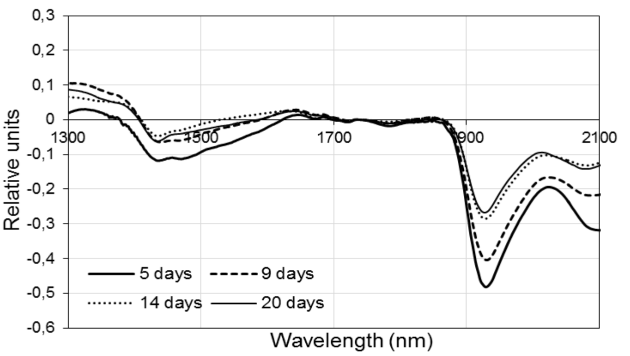

Figure 1. Difference NIR spectra of the latewood in heartwood of sugi steamed at 110°C

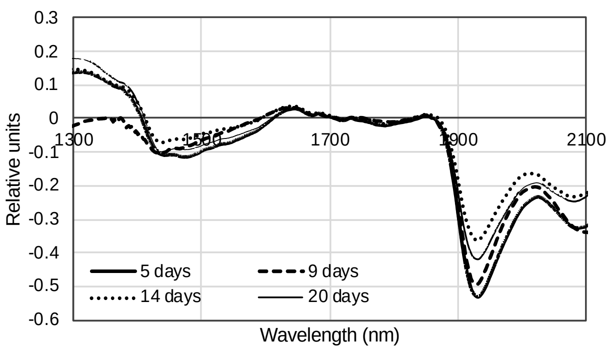

Figure 2. Difference NIR spectra of the latewood in sapwood of sugi steamed at 110°C.

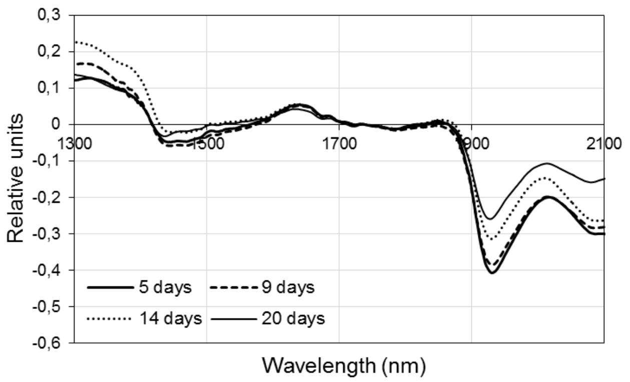

Figure 3. Difference NIR spectra of the earlywood in heartwood of sugi steamed at 110°C.

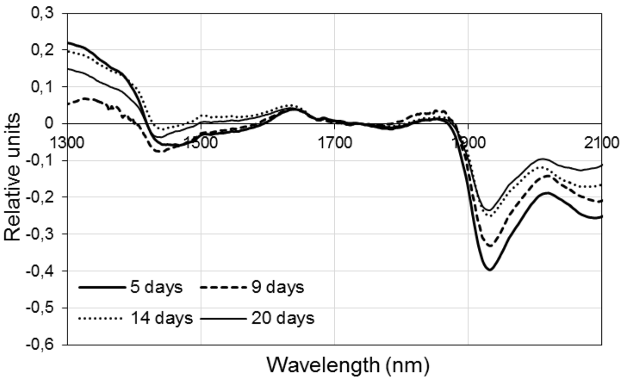

Figure 4. Difference NIR spectra of the earlywood in sapwood of sugi steamed at 110°C.

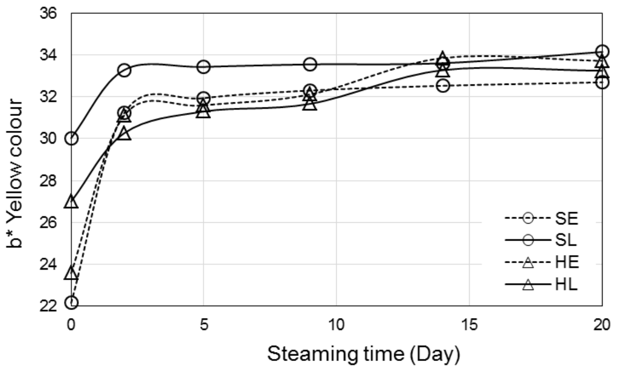

Figure 5. The yellowness changes in different tissues during steaming at 110°C. (S: sapwood, H: heartwood, E: earlywood, L: latewood) (Tolvaj et al. 2019)

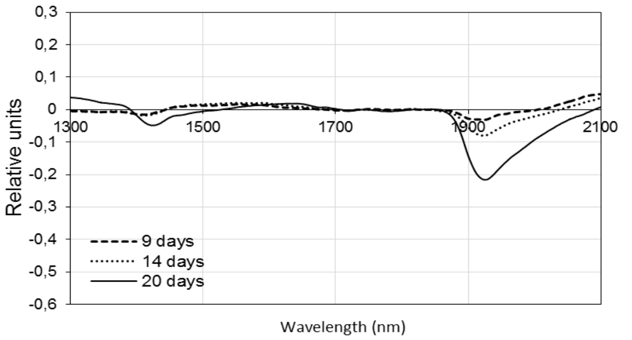

Figure 6. Difference NIR spectra of the latewood in heartwood of sugi steamed at 90°C.

This absorption band around 1930 nm is the typical band of bound water located in the cell wall. (Schwanninger et al. 2011). Figures 1-4 show that steaming reduced the water bounding capacity of sugi wood. As the NIR spectra were measured three months after the steaming, results demonstrate that this water bounding capacity loss was stable. The steaming time dependence of water bounding capacity loss showed a minimum at the fifth day of steaming at 110°C. Our results demonstrated that five days of steaming at 110°C generated the optimum of both color change and water bounding capacity loss. The consequence of decreased water bounding capacity is an increase in dimensional stability. The dimensional stability increase is an important advantage of steaming.

Figure 6 demonstrates that the water bounding capacity loss at 90°C was much slower than at 110°C. The water bounding capacity loss continued during the full 20 days of steaming at this lower temperature.

In conclusion, chemical changes in sugi wood steamed at 90 and 110°C and observed using NIR spectroscopy in the wavelength range of 1300-2100 nm are related to water contents and extractives, especially phenolic contents. These chemical changes are suspected to be strongly related to color changes in steamed wood. Longer duration and higher temperatures of steaming "equalize" the amount of phenolic compounds in all wood tissues, which caused their color to change more uniformly. Phenolic compounds are suspected to show initial changes at steaming temperatures of 90ºC. Hemicellulose is also suspected to contribute to the color changes of steamed wood. Steaming generated a water bounding capacity loss in the cell wall. This change was much faster at 110°C than at 90°C.

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Contribution of non-timber forest products to livelihood of rural communities in Kumbungu District of Northern Ghana

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Abstract. *Ammal A, Mariam M. 2020. Contribution of non-timber forest products to livelihood of rural communities in Kumbungu District of Northern Ghana. Asian J For 4: 10-14.* Non-Timber Forest Products (NTFPs) play an important role to fulfill the livelihood of rural communities. This survey investigated the contribution NTFPs to the livelihood of rural communities in the Kumbungu District of Ghana. Data were collected using structured questionnaires and verbal interviews to obtain information from sampled members of the communities' in the Kumbungu District of Northern Ghana. Personal interviews and direct observation were carried out and a total of 200 structured questionnaires were administered randomly to respondents in 5 selected communities in Kumbungu District namely Cheyohi, Kpalchi, Kokpeng, Zuolanyili and Garizew. Data were analyzed using descriptive statistics (tables, charts, and graphs). The findings indicated that NTFPs were abundant in the study area and were found in all the forest land areas within the communities. NTFPs collection for utilization was usually carried out throughout the year. The respondents in the five communities collected and used the NTFPs for preparation of food for the family and other purposes. The number of respondents involved in the collection of NTFPs was highest in Kokpeng community (21.3%), while only 18.5% of respondents were involved in the Garizew community. The chi-square test revealed that there were highly significant differences (P>0.05) between the number of respondents involved in the collection and non-collection of NTFPs in the district. The lowest income generated from NTFPs ranged between 1-25 (GHC) Ghana cedis per week whilst the highest income was 65+ GHC per week. A proportion of 12.5% of respondents in Zuolanyili had income ranging between 1-25 GHC per week and 10% of respondents had income above 65 GHC per week. A proportion of 47.5% and 30% of respondents' income ranged between 25-45 and 45-65 GHC per week respectively in the Zuolanyili community. Respondents in the Kokpeng community had the highest proportion of respondents (30%) who obtained income above 65 GHC per week whilst Garizew had the lowest proportion of respondents (5%) who obtained income above 65 GHC per week.

Keywords: Food, livelihood, Non-Timber Forest Products, rural community, occupation, poverty

INTRODUCTION

Non-timber forest products (NTFPs) offer livelihood to a larger proportion of the global population, particularly the rural communities in terms of their needs such as food, medicine, employment and cash incomes through trade (Endamana et al. 2016; Pandey et al. 2016; Suleiman et al. 2017). Additionally, NTFPs are vital sources for rural communities especially during times of shortages to mitigate poverty and might lead to socio-economic progress of rural communities (Ojea et al. 2016; Suleiman et al. 2017). NTFPs serve as safety net for rural people payable to their poor financial situations (Alex et al., 2016), and NTFP gathering, use, and trade are similarly significant livelihood and cost-effective activities of rural communities (Raj et al. 2018).

Monetary approximations of USD 90 billion are set for NTFPs per annum globally and almost one-third is consumed in the local economy minus inflows into the market (Raj et al., 2018). The contribution of NTFPs to rural households' income is important in many countries worldwide. For instance, Shackleton et al. (2015) stated that family earnings from NTFPs are occasionally equivalent to or more than the school teachers' least remunerations in Central and West Africa. They additionally stated that traders of NTFPs in the Democratic Republic of Congo received between USD 16 and 160 each week whereas producers made approximately 50-75% of the amount per week. Rural families in Nigeria can get up to 80% of their earnings from the trade of NTFPs (Jimoh et al. 2013). Also, it was observed that over 70% of all families in the country largely depended on fuelwood as one of the key sources of energy with an estimated consumption of 27.5 million kg/day (Verma and Paul 2016).

The association between the rural poor and the high dependence on natural resources has been recognized (Kranjac-Berisavljevic and Gandaa 2002). That is the case with Ghana. The majority of Ghana population live in rural areas with 54% of the total Ghanaians are subsistence farmers. Rural poverty in the country is strongly associated with the available natural resources which are influenced by the ecological zones where the communities are located. In general, the frequency and the profundity of poverty in rural communities are superior in savannah compared to any other ecological zones in Ghana, although poverty also occurs in the forest zone and coastal belts. In the Northern parts of Ghana, gender plays a vital role in the measurement of poverty which indicates differences in the earnings of men and women. The women accept an uneven portion of the liability of being poor and indulge in devoting unlimited time to household initiatives, yet they also support and educate children in executing any additional household tasks (Kranjac-Berisavljevic and Gandaa 2002).

Local people have indigenous knowledge in managing forest resources to obtain food as well as to generate other produce. They occasionally utilize these sources for their livelihood option. In Ghana, there is consequently the need to gather information on the contribution of NTFPs to rural people. Available data regarding the dependence of rural people on the utilization of NTFPs will serve as baseline information for the development of programs to improve rural lives. This study aimed to provide detailed data on the contribution NTFPs that can possibly improve poverty in the rural communities of Kumbungu District of northern Ghana. The purpose of this study is to determine the number of rural folks involved in the utilization of NTFPs in the study area, determine the kinds of NTFPs used and determine the contribution of NTFPs species to the livelihood of Kumbungu District. The results of this study are expected to be beneficial for academics, farmers, industrialists and traders.

MATERIALS AND METHODS

Study period and area

The study was conducted in a period of three months between February and April 2019 in Kumbungu District (Figure 1). It is one of the districts located in northern Ghana and it shares borders to the north with Mamprugu District, Tolon, and North Gonja districts to the west, Sanarigu district to the south and Savelugu/Nanton Municipal to the east. The people are predominantly Dagombas who are mainly peasant farmers. The population is approximately 39,341 (Musah et al. 2013).

Data collection methods

Data were collected using structured questionnaires and verbal interviews to obtain information from sampled members of the communities' in the Kumbungu District of northern Ghana. Personal interviews and direct observation were carried out. A total of 200 structured questionnaires were administered randomly to respondents in 5 selected communities in Kumbungu District namely Cheyohi, Kpalchi, Kokpeng, Zuolanyili, and Garizew, resulting in 40 questionnaires were administered in each community and this was used to prompt information on the uses of NTFPs in the study area.

Data analysis

Descriptive statistics were used to analyze the data obtained. Tables, percentages and charts were used to define variables of respondents to summarize the contribution of NTFPs to households' livelihood.

Figure 1. Map showing the location of the study area in Kumbungu District, northern Ghana

RESULTS AND DISCUSSIONS

The results showed that NTFPs were abundantly available within the communities in the study area. The gathering of NTFPs was regularly carried-out all year round. The collection of NTFPs involved Male (44.5%) and females (56.5%). The respondents ages were grouped into young (10-20 years), middle-aged (21-30 years), working-age (31-40 years) and elderly (41 years and above). The middle-age (21-30 years) showed a higher percentage with 44.6%. The overall mean age of respondents was 21 - 30 years.

Education

The education of respondents was categorized into two groups namely educated and not-educated. Majority of the respondents were educated up to tertiary school level. Only a few respondents were found to be not-educated, who did not have the opportunity of going to school and group includes the elderly people. Cheyohi had the highest percentage of educated respondents (22.2%), while Kokpeng (17.4%) had the least. Likewise, Kokpeng had the highest percentage of not educated respondents of 26.9%, while Cheyohi (14.3%) had the least percentage of not-educated respondents. The chi-square test showed that there were significant differences between educated and not educated respondents among the communities in the Kumbungu District (Table 2).

Occupation

Respondent's occupation was categorized into three groups namely, farming, trading, and students. Farming was the major occupation of the communities. From the response, majority of the occupation in the communities were trading (40%) and farming (40%) while students (20%) were the lowest.

NTFPs collection

Table 3 shows the proportion of respondents who collecting of NTFPs in the district. The result shows that the number of households involved in the collection of NTFPs was highest in Kokpeng community with 21.3% of the respondents being involved, whereas for Garizew community only 18.5% were involved, making it the lowest. The total number of respondents involved in NTFPs collection in the five communities was (99.9%). The chi-square test revealed that there were significant differences between the number of respondents involved in the assembled and not-assembled NTFPs in the Kumbungu District.

Income per week from NTFPs

Table 4 demonstrates the income generated from the sale of NTFPs in the five communities of the Kumbungu District. From the survey, the communities in the district received some money from the collection of NTFPs, for example, honey, construction materials, fodder, bush meat, living animals, medicinal plants, wild food, and fuelwood. The lowest income generated from NTFPs ranged between 1-25 (GHC) Ghana cedis per week whilst the highest income was 65+ GHC per week. A proportion of 12.5% of respondents in Zuolanyili had income ranging between 1-25 GHC per week and 10% of respondents had income above 65 GHC per week. A proportion of 47.5% and 30% of respondents' income ranged between 25-45 and 45-65 GHC per week respectively in the Zuolanyili community. Respondents in the Kokpeng community had the highest proportion of respondents (30%) who obtained income above 65 GHC per week whilst Garizew had the lowest proportion of respondents (5%) who obtained income above 65 GHC per week. This finding is in line with Olsen and Larsen (2003) report that in some rural hilly areas of Nepal, NTFPs contribute up to 50% of total annual family incomes. However, the number of NTFPs collected is high in the communities of the district but only few NTFPs collected are being sold.

The rural folks in communities are extremely reliant on a range of NTFPs for their subsistence needs which also contributes to their annual income (Fajobi and Fingesi, 2018; Olsen and Larsen 2003). Consequently, NTFPs generate little income for the members of the community, however, overutilization of these resources will reduce the forest and land resources in the area. As result of food deficiency by rural folks has resulted in pressure on NTFPs collection to make financial gains for their livelihood. In addition, traders reassure primary collectors to collect larger amounts, predominantly NTFPs that have higher market demand and this depletes the availability of NTFPs species day-by-day.

Table 1. Age of respondent in the Kumbungu District, northern Ghana

Age of respondent	Respondents percentages
10-21	32.4
21-30	44.6
31-40	15.5
41+	7.5
Total	100

Source: Field Survey, 2019

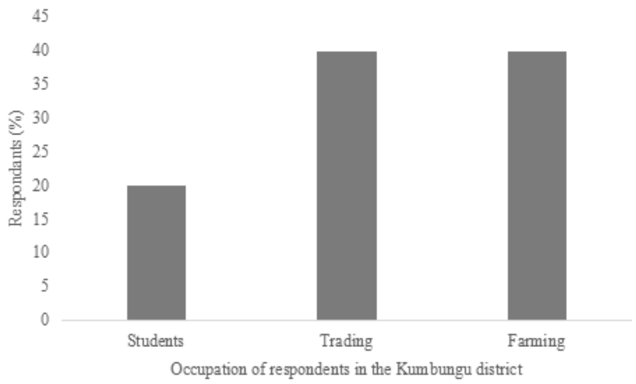

Figure 2. Occupation of respondents (%) in the Kumbungu District, northern Ghana

Table 2. Education of respondents Kumbungu District, northern Ghana

Communities	Educated	Not-educated	$\chi 2$	df	P
Cheyohi	32 (22.2%)	8 (14.3%)	7.4532	4	(p> 0.05)
Kpalchi	28 (19.4%)	12 (21.4%)			
Kokpeng	25 (17.4%)	15 (26.9%)			
Zuolanyili	30 (20.8%)	10 (17.9%)			
Garizew	29 (20.1%)	11 (19.6%)			
Total	144(100%)	56 (100.%)			

Source: Field Survey, 2019 ($\chi 2$ = Chi Square; df = degrees of freedom); (N = 200)

Table 3. The proportion of respondents who collecting or not collecting NTFPs in the Kumbungu District, northern Ghana

Communities	Collecting NTFPs	Not collecting NTFPs	Total	$\chi 2$	df	P
Cheyohi	36 (20.2%)	4 (18.2%)	40	7.4532	4	(p > 0.05)
Kpalchi	34 (19.1%)	6 (27.3%)	40			
Kokpeng	38 (21.3%)	2 (9.1%)	40			
Zuolanyili	37 (20.8%)	3 (13.6%)	40			
Garizew	33 (18.5%)	7 (31.8%)	40			
Total	178 (99.9%)	22 (100%)	200			

Table 4. Income obtained per week from NTFPs in the rural communities of Kumbungu District, northern Ghana

Community	Number of respondents	NTFPs	Income range per week (GHC)			
			1-25 GHC	25-45 GHC	45-65 GHC	65+ GHC
Cheyohi	40	Fodder, bush meat, honey, medicinal plants, construction materials, fuelwood	12 (30%)	9 (22.5%)	15 (37.5%)	4 (10%)
Kpalchi	40	Living animals, wild food, honey, fodder, fuelwood	8 (20%)	16 (40%)	7 (17.5%)	9 (22.5%)
Kokpeng	40	Construction materials, honey, medicinal plants, fodder	11 (27.5%)	15 (37.5%)	2 (5%)	12 (30%)
Zuolanyili	40	Honey, bush meat, wild food, fuelwood, fodder	5 (12.5%)	19 (47.5%)	12 (30%)	4 (10%)
Garizew	40	Construction materials, honey, fodder, bush meat, wild food	6 (15%)	25 (62.5%)	7 (17.5%)	2 (5%)
Total	200					

Economically, the vital parts of NTFPs collected by rural communities were sold either as raw or as processed form. Some of the NTFPs sold were in the form of twigs, shoot, fruit, seed, and leaves which were sold to vendors in the form of bundles, bunches, single pieces, or weighed. The center of the economic significance of NTFPs is that they are found in forest areas inhabited by indigenous communities (Verma and Paul 2016). NTFPs collection is an imperative source of income and employment for forest dwellers/indigenous communities and rural poor (Verma and Paul 2016). There is a need to educate rural communities on the sustainable collection of economically valuable NTFPs species because there is an opportunity for income and employment generation through cultivation of economically valuable NTFPs species.

In conclusion, to supplement the low agricultural production in the rural areas of Ghana, the rural people of the Kumbungu District utilized NTFPs as an effective means to enhance the economic benefits and to help in improving livelihood, household food security, and nutrition. The study revealed that the utilization of NTFPs by the communities helped to bring development to the communities. It was also recorded that the utilization helped to promote the image of the communities as it was noticed that companies, as well as individuals from nearby towns and cities, come to purchase these NTFPs from these communities, especially shea butter oil. The study also showed that the utilization of these NTFPs also boosted the use of herbal medication among humans both in the local communities and urban areas. Therefore, awareness campaigns on the conservation of habitats of NTFPs species, both edible, medicinal plants, and tradable NTFPs species, should be conducted at the village level. At the same time, a local regulatory system should be launched which will regulate the harvesting of NTFPs species from government forests and other lands. This could also lessen the dependence of households on consumption of NTFPs; thereby helping to preserve it for future purposes.

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Assessment of tree species diversity, composition and structure of Medha Kachhapia National Park, Cox's Bazar, Bangladesh

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Abstract. *Uddin M, Chowdhury FI, Hossain MK. 2020. Assessment of tree species diversity, composition and structure of Medha Kachhapia National Park, Cox's Bazar, Bangladesh. Asian J For 4: 15-21.* Tree species diversity assessment is considered an essential task to design robust conservation action plans of Protected Areas (PAs). Numerous researches have assessed tree diversity of different PAs of Bangladesh but tree diversity of Medha Kachhapia National Park (MKNP) is still unknown due to lack of research initiatives. It hinders forest managers of this PA to plan and implement conservation actions successfully. To this end, the study carried out a systematic sampling to ascertain composition, distribution, and diversity of tree species in MKNP. Findings revealed that representation of tree diversity of MKNP was very poor. Only 10 tree species representing 6 families were identified. Besides, MKNP was dominated by different *Dipterocarpus* spp. especially by *Dipterocarpus costatus*. Dominance in height and diameter classes and high Important Value Index (133.94) of *D. costatus* indicated that the tree might find a suitable habitat in MKNP to maintain optimum dispersal, development, and growth. However, recent plantation activities with exotic *Acacia auriculiformis* and intensified human-induced disturbances might hamper its habitat. Thus, to conserve the habitat of *D. costatus* and remaining forest resources of MKNP, reforestation efforts should be shifted from exotic to native tree species, and community anthropogenic disturbances should be minimized.

Keywords: *Dipterocarpus costatus*, exotic vs. natural, importance value index, tree diversity, protected area

INTRODUCTION

Bangladesh has 17.47% forest areas compared to the total land surfaces of the country (BFD 2019). However, the actual forest cover does not exceed 6% of the country's total land, and forest land per capita is only about 0.022 ha (FMP 1993). This small tract of forest land is not sufficient to maintain the ecological balance to provide continuous flows of ecosystem goods and services for the ever-increasing people in the surrounding forests of Bangladesh. Moreover, such a small tract of forest land is also under threats of illegal felling, forest encroachment, and intensification of land-use changes. The increasing trend of forest deforestation and intensification of anthropogenic activities inside the forest areas causes a serious erosion of genetic resources from the terrestrial ecosystems of Bangladesh (Hossain 2001; Rahman and Hossain 2002; Motaleb and Hossain 2011). Such erosion of biodiversity from the forest lands creates negative impacts on the ecosystem functioning (Liang et al. 2016).

Forests of Bangladesh were once rich with more than 5,000 species of angiosperms and 1,609 species of fauna (IUCN 2000; Hossain 2001; Ahmed et al. 2008; Sobuj and Rahman, 2011). However, for some species, half of the population has declined during the last decades, and about 13% of vascular plant species become threatened in natural habitats (IUCN 2000), indicating that the biodiversity loss has been significant in the natural forests of Bangladesh. Biodiversity loss in Bangladesh is mainly attributed to increasing population pressure, anthropogenic disturbances inside and around the forest, over-extraction of forest resources, absence of ecosystem-based forest management practices, and lack of proper conservation initiatives (Dutta et al. 2015). Therefore, the declaration of forest land into Protected Area (PA) is considered as a fundamental strategy to combat deforestation and forest degradation to conserve biodiversity in terrestrial ecosystems. Over the years, forest areas of the country have been declared as PA to meet the conservation priorities of Bangladesh which are divided into different categories including national parks, biodiversity conservation areas, eco-parks, and wildlife sanctuaries (Khan et al. 1997; Hassan 2000; Mukul et al. 2008).

Medha Kachhapia National Park (MKNP) is one of the PA of Bangladesh belonging to the category of IV according to the IUCN PA management categories (IUCN 1994). The forests in this area are among the few remaining but degraded natural forest patches of Bangladesh. These forest patches have been famous for harboring century-old mother Garjan trees (*Dipterocarpus* spp.) (Biswas and Misbahuzzaman 2008) and serving as an active corridor of Asian elephants (*Elephas maximus*). The presence of elephants in this national park indicates that the forest might have the ability to support rich biological diversity and possesses the elements of an ideal forest environment. However, the forest area of MKNP is subjected to degradation because of encroachment inside the forest area for settlement and agricultural expansions.

Acquiring and updating the forest's plant biodiversity is an enormous, but necessary, task to get a deeper insight into forest dynamics, plant-animal interactions, and nutrient cycling (Hossain et al. 2013). Thus, assessing the floristic composition is still considered an important tool to make good decisions on forest management actions so that the sustainability and resiliency of a forest ecosystem can be ensured (Nath et al. 2000). Over the years, numerous researches have been conducted to assess the plant species diversity in different PAs of Bangladesh (e.g., Nath et al. 2000; Uddin and Misbahuzzaman 2007; Motaleb and Hossain 2011; Hossain et al. 2013; Hossain and Hossain, 2014). However, there is no research carried out to assess the tree diversity and structural composition of the MKNP forest. Here, the study aimed (i) to assess the quantitative structure of the tree species; and (ii) to quantify tree species diversity and composition of the MKNP of Bangladesh. By fulfilling these objectives, the study attempted to provide a comprehensive list of tree species along with their present status, diversity, and composition at the MKNP. The findings of this study could aid forest managers of MKNP to plan, designing, and implement proper forest conservation initiatives. Besides, a complete list of tree species diversity and quantitative structure of MKNP could assist policymakers to prioritize tree species or zones that need immediate conservation attention which in a broader context assist to fulfill the targets of biodiversity conservation of the country.

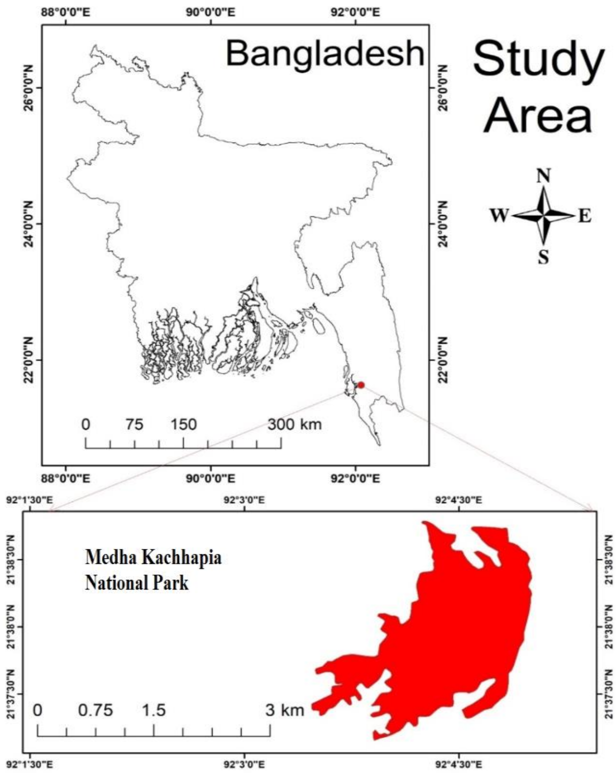

Figure 1. Map of Medha Kachhapia National Park, Bangladesh

MATERIALS AND METHODS

Study area

The study was conducted in the Medha Kachhapia National Park (MKNP), a tropical semi-evergreen forest, located in the south-eastern part of Bangladesh (Figure 1). MKNP is situated under the Medha Kachhapia Forest Beat of Fulchari Range under Cox's Bazar North Forest Division of Bangladesh. It comprises an area of 395.92 ha, and lies between 21°37′47″ N latitude and 92°04′36″ E longitude. The forest area has been declared as MKNP under the provision of Wildlife Preservation Order 1973 in the year 2004 (BFD 2015).

The geology of MKNP is largely made up of gently sloping hills. The soil in the area ranges from clay to clayey loam on the flat ground whereas sandy loam to coarse sand on hilly land. The climate is characterized by a humid, tropical climate with little temperature variability. Temperatures remain high with some seasonal variability, and mean monthly temperature ranges from 11.11°C in January to 35°C in May. Rainfall is high during the monsoon season, with pre-monsoon rains beginning in April-May, and post-monsoon rains lasting until October. November to March-April is usually a relatively dry period. There is heavy dew during winter when rainfall is low.

During the field data collection, it was observed that the forested area of MKNP was subjected to forest degradation as a result of different types of anthropogenic pressures such as agricultural expansion, road construction, encroachment, illegal felling activities, etc. (Figure 2).

Sampling framework

The study followed the systematic sampling approach to determine the sample plots and to assess the tree species diversity of MKNP. There were 28 plots, each of 50 m x 50 m square-quadrant size, taken at 400 m intervals. Plants having $\geq$ 10 cm Diameter at Breast Height (DBH) were considered as trees. Hence, only trees having $\geq$ 10 cm DBH were considered for measurement. From each plot, the number of each tree was counted and recorded in the field data sheet while total height and DBH of the trees were measured using Suunto Clinometer and diameter tape respectively. The standard scientific method of DBH measurement was followed in other critical situations, i.e., buttressed stem, leaned tree, slope, etc. (Walker et al. 2010). Tree species were identified directly in the field with assistance from the staff of the Bangladesh Forest Department and local guides.

Data analysis

For each of the tree species, density, relative density, frequency, relative frequency, abundance, relative abundance, and Importance Value Index (IVI) were calculated by using the methods described in Dallmeier et al. (1992), and Shukla and Chandel (2000). Species richness was measured by using Margalf's diversity index (Margalef 1958) and species evenness was calculated by Pielou's measure of evenness (Pielou 1966). The species diversity was assessed with Simpson's concentration index and Shannon's information index (Simpson 1949; Shannon and Wiener 1963). The equations used for these purposes are listed below:

Figure 2. Anthropogenic disturbances inside Medha Kachhapia National Park, Bangladesh. A. Agricultural expansion in MKNP, B. Human trespass inside MKNP, C. Encroachment inside MKNP, D. Illegal felling at MKNP

(i) Density of a species = $\frac{Total\ number\ of\ individuls\ of\ a\ species\ in\ all\ the\ quadrats}{Total\ number\ of\ quadrats\ studied}$;

(ii) Relative density of a species= $\frac{Total\ number\ of\ individuls\ of\ a\ species\ in\ all\ the\ quadrats}{Total\ number\ of\ individual\ of\ all\ species} \times 100$;

(iii) Frequency of a species = $\frac{Total\ number\ of\ quadrats\ in\ which\ the\ species\ occur}{Total\ number\ of\ quadrats\ studied} \times 100$;

(iv) Relative Frequency of a species = $\frac{Frequency\ of\ one\ species}{Sum\ of\ all\ frequencies} \times 100$;

(v) Abundance of a species = $\frac{Total\ number\ of\ individuls\ of\ a\ species\ in\ all\ the\ quadrats}{Total\ number\ of\ quadrats\ in\ which\ the\ species\ occurs}$;

(vi) Relative abundance of a species = $\frac{abundance\ of\ one\ species}{Total\ abundance\ of\ all\ the\ species} \times 100$;

(vii) Relative dominance of a species = $\frac{Total\ basal\ area\ of\ a\ species\ in\ all\ the\ quadrats}{Total\ basal\ area\ of\ all\ species\ in\ all\ quadrats} \times 100$

(viii) Importance Value Index (IVI) = Relative density (RD) + Relative frequency (RF) + Relative Abundance (RA) (Shukla and Chandel 2000; Dallmeier et al. 1992)

(ix) Shannon-Wiener index: $H = -\sum_{i=1}^{n} P_i \ln P_i$

where, quantity Pi is the proportion of individuals found in the i^{th}species and is estimated using the maximum likelihood estimator and Pi = $\frac{ni}{N}$ where, ni is the number of individuals in the i^{th}species, and N is the total number of individuals of all species. Information is maximum when the probabilities (number of individual) for all species are equal and information is zero if there is only one possibility.

(x) Simpson's Index: $D = \sum Pi^2$

where, Pi = ni/N, ni is the number of individuals of each species; N is the total number of trees of all species.

(xi) Margalef's Index of Species Richness R = (S-1)/ln N

where, R = Species richness index, S = Total no. of species, and N = Total no. of individuals of all species.

(xii) Pielou's Measure of Evenness: E = H/ln S

where, E = Species evenness, H = the Shannon-Weiner Index of Diversity, and S = Total No. of species.

(xiii) Basal area= $\pi D^2/4$; where, D = Diameter at breast height, and π=3.1416.

RESULTS AND DISCUSSION

Tree species composition in MKNP

This study measured a total of 250 tree stems (34.48 stems/ha) belonging to 10 tree species at 28 sampled plots of MKNP (Table 1). These 10 tree species belong to 6 families and 7 genera (Tables 1, 2). Among the recorded families, Dipterocarpecae had the highest number of species (3) followed by Mimosaceae (2), Anacardiaceae (1), Clusiaceae (1), Moraceae (1) and Myrtaceae (1).

On the other hand, the study showed the Shannon-Wienner Diversity index and Simpson's index of 1.16 and 0.45504 respectively. The study also found that Margalef's index of species richness and Pielou's measure of species evenness were 1.63 and 0.2106 respectively (Table 2). The average stem density of MKNP was found at 34.48 stems/ha (Table 2) while the total basal area was 11.97 m^2/ha (Figure 4).

Structural composition of different tree species in MKNP

Tree species in different height class

The study had determined six height classes to assess the vertical distribution of tree species in MKNP, i.e. ≤ 5 m, 5.1-≤15 m, 15.1-≤25 m, 25.1-≤35 m, 35.1-≤45 m and 45.1-≤55 m. Most of the height classes (i.e. ≤5 m, 15.1-≤25 m, 25.1-≤35 m, 35.1-≤45 m and 45.1-≤55 m) were dominated by *Dipterocarpus costatus* whereas *Acacia auriculiformis* dominated only in 5.1-≤15 m height class (16.00%) (Table 3). The highest percentage (44.40%) of tree stems was recorded in 25.1-≤ 35 m height class (111 tree individuals and 3 species) followed by 25.6% tree stems in 5.1-≤ 15 m height class (64 tree individuals and 3 species), 18.80% tree stems in 35.1-≤ 45 m height class (47 tree individuals and 2 species) and 8% tree stems in 15.1-≤ 25 m height class (20 tree individuals and 7 species). The lowest percentage (1.60%) of tree stems were found in ≤ 5 m (4 tree individuals and 2 species) and 45.1-≤ 55 m height class (4 tree individuals and 1 species) (Table 3; Figure 3.B).

In the MKNP, the upper canopy (45.1 ≤ 55m) was dominated only by *D. costatus*. The second stratum (35.1 ≤ 45m) was dominated by *D. costatus* and *D. turbinatus* while the third stratum (25.1-≤ 35m) was dominated by *D. costatus*, and *D. turbinatus*. The fourth stratum (15.1-≤ 25 m) was dominated by *D. costatus*, *M. indica*, *D. turbinatus*, *Acacia mangium*, *Artocarpus heterophyllus*, and *Syzygium cumini*, whereas the fifth stratum (5.1-≤15 m) was dominated by *A. auriculiformis*, *D. costatus*, *D. turbinatus*, *M. indica*, *A. heterophyllus*, *A. mangium*, and *Hopea odorata*. The lowest tree stratum (≤5 m) was dominated by the young poles of *Acacia auriculiformis* and *D. costatus* (Table 3).

Table 1. Tree species (≥10 cm dbh) recorded in Medha Kachhapia National Park, Bangladesh

Local name	Scientific name	Family
Akashmoni	*Acacia auriculiformis*	Mimosaceae
Mangium	*Acacia mangium*	Mimosaceae
Kanthal	*Artocarpus heterophyllus*	Moraceae
Dhulia garjan	*Dipterocarpus altatus*	Dipterocarpaceae
Baitta Garjan	*Dipterocarpus costatus*	Dipterocarpaceae
Telly Garjan	*Dipterocarpus turbinatus*	Dipterocarpaceae
Telsur	*Hopea odorata*	Dipterocarpaceae
Kao	*Garcinia cowa*	Clusiaceae
Aam	*Mangifera indica*	Anacardiaceae
Jam	*Syzygium cumini*	Myrtaceae

Table 2. Diversity indices and associated details of tree species recorded in Medha Kachhapia National Park, Bangladesh

Parameters	Values
No. of tree species	10
No. of families	6
Stem density (stem/ha)	34.48
Shannon-Wienner diversity index	1.16
Simpson's index	0.45504
Margalef's index of species richness	1.630003
Pielou's measure of species evenness	0.21066

Table 3. Percentage distribution (%) of tree species at different height classes (m) in Medha Kachhapia National Park, Bangladesh

Scientific name	Height classes (m)						Total
	≤5	5.1-≤15	15.1-≤25	25.1-≤35	35.1-≤45	45.1-≤55	
Acacia auriculiformis	0.4	16	0	0	0	0	16.4
Acacia mangium	0	1.2	0.4	0	0	0	1.60
Artocarpus heterophyllus	0	1.6	0.4	0	0	0	2.0
Dipterocarpus altatus	0	0	0	0.8	0	0	0.80
Dipterocarpus costatus	1.2	2.4	4.4	37.6	16.8	1.6	64.00
Dipterocarpus turbinatus	0	2	0.8	6	2	0	10.80
Hopea odorata	0	0.4	0	0	0	0	0.40
Garcinia cowa	0	0	0.4	0	0	0	0.40
Mangifera indica	0	2	1.2	0	0	0	3.20
Syzygium cumini	0	0	0.4	0	0	0	0.40
Total	1.6	25.6	8	44.4	18.8	1.6	100

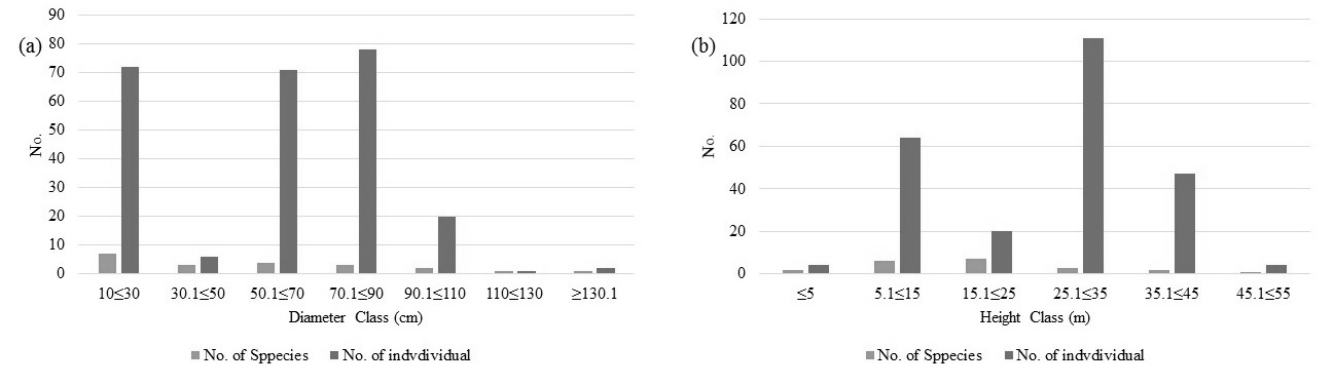

Figure 3. Distribution of the number of species and number of individuals in Medha Kachhapia National Park, Bangladesh based on: **A.** Diameter class (cm) and B. height classes (m)

Table 4. Percentage distribution (%) of tree species at different diameter classes (cm) in Medha Kachhapia National Park, Bangladesh

Scientific name	10-≤30	30-≤50	50-≤70	70-≤90	90-≤110	110-≤130	≥130.1	Total
Acacia auriculiformis	16.4	0.00	0.00	0.00	0.00	0.00	0.00	16.4
Acacia mangium	1.20	0.40	0.00	0.00	0.00	0.00	0.00	1.60
Artocarpus heterophyllus	2.00	0.00	0.00	0.00	0.00	0.00	0.00	2.00
Dipterocarpus altatus	0.00	0.00	0.00	0.80	0.00	0.00	0.00	0.80
Dipterocarpus costatus	2.80	1.60	24.8	26.4	7.20	0.40	0.80	64.0
Dipterocarpus turbinatus	2.80	0.40	2.80	4.00	0.80	0.00	0.00	10.8
Hopea odorata	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.40
Garcinia cowa	0.00	0.00	0.40	0.00	0.00	0.00	0.00	0.40
Mangifera indica	3.20	0.00	0.00	0.00	0.00	0.00	0.00	3.20
Syzygium cumini	0.00	0.00	0.40	0.00	0.00	0.00	0.00	0.40
Total	28.8	2.40	28.4	31.2	8.00	0.40	0.80	100

Tree species in different diameter classes

The study had divided the diameter classes (in cm) into seven groups, e.g. 10-≤30 cm, 30-≤50, 50-≤70, 70-≤90, 90-≤110, 110-≤130 and ≥130.1 cm. Here, most of the diameter classes (i.e. 30-≤50, 50-≤70, 70-≤90, 90-≤110, 110-≤130 and ≥130.1 cm) was dominated by *D. costatus* whereas *A. auriculiformis* dominated only in 10-≤30 cm height class (16.40%) (Table 4). Besides, the highest percentage (31.20%) of tree stems were recorded from 70-≤90 (78 individuals of 3 species) diameter class followed by 21.80% tree stems from 10-≤30 cm diameter class (72 individuals and 7 species), 28.40% tree stems from 50-≤70 diameter class (71 individuals and 4 species), 8% tree stems in 90-≤110 cm diameter class (20 individuals and 2 species), 2.30% tree stems were recorded from 30-≤50 cm diameter class (6 individuals and 3 species) and 0.8% tree stems from ≥130.1 cm diameter class (2 individuals and 1 species). The lowest percentage (0.4%) of tree stems were recorded from 110-≤130 cm diameter class (1 individual and 1 species) (Figure 3.A, Table 4).

Quantitative structure of the tree species in MKNP

Basal area (BA)

In terms of basal area, *D. costatus* dominated with 10.02 m^2/ha. Notable BA for *D. turbinatus* (1.29 m^2/ha) and *M. indica* (0.27 m^2/ha) was found but very low BA was recorded for *A. auriculiformis* (0.10 m^2/ha), *A. heterophyllus* (0.08 m^2/ha), *D. alatus* (0.08 m^2/ha), *Garcinia cowa* (0.05 m^2/ha), *S. cumini* (0.04 m^2/ha) and *A. mangium* (0.03 m^2/ha). The lowest BA was recorded for *H. odorata* (0.01 m^2/ha) (Figure 4).

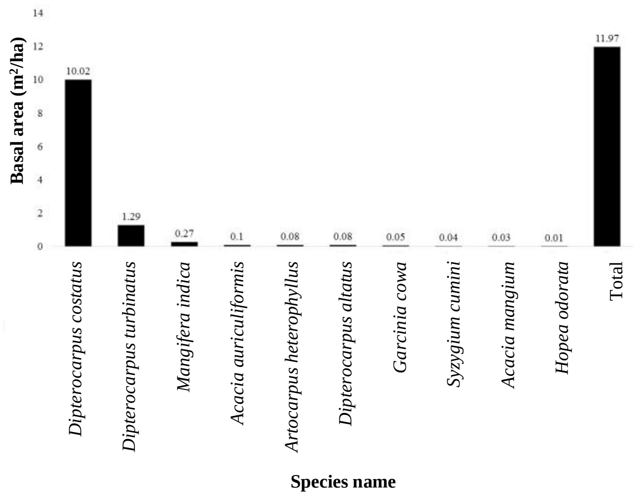

Figure 4. Basal area (m^2/ha) of different species in the study area

Table 5. Relative density, relative frequency, relative abundance and importance value index of different tree species at Medha Kachhapia National Park, Bangladesh

Species name	RD (%)	RF (%)	RA (%)	IVI
Acacia auriculiformis	16.4	6.12	33.3	55.82
Acacia mangium	1.6	4.1	4.87	10.57
Artocarpus heterophyllus	2	2.04	12.18	16.22
Dipterocarpus altatus	0.4	2.04	2.44	4.88
Dipterocarpus costatus	64.4	55.1	14.44	133.94
Dipterocarpus turbinatus	10.8	22.45	5.98	39.23
Hopea odorata	0.4	2.03	2.42	4.85
Garcinia cowa	0.4	2.04	2.44	4.88
Mangifera indica	3.2	2.04	19.49	24.73
Syzygium cumini	0.4	2.04	2.44	4.88
Total	100	100	100	300

Note: Relative density (RD), relative frequency (RF), relative abundance (RA) and importance value index (IVI)

Relative Density (RD), Relative Frequency (RF), Relative Abundance (RA) and Importance Value Index (IVI)

In the case of RD, it was found that most of the MKNP area was occupied by *D. costatus*. The highest RD was recorded for *D. costatus* (64.4%) while the lowest RD was found for *D. altatus*, *G. cowa*, *S. cumini* and *H. odorata* (0.4% each). Besides, the tree species with the highest RF was found for *D. costatus* (55.10%), whereas the lowest RF was 2.04% which found for *D. altatus*, *A. heterophyllus*, *G. cowa*, *H. odorata*, *M. indica*, and *S. cumini*. Furthermore, the highest RA was recorded for *A. auriculiformis* (33.30%) and the lowest RF was found for *D. altatus* (2.44%), *G. cowa*, *H. odorata* (2.44%), and *S. cumini* (2.44%). Finally, the highest IVI was found for *D. costatus* (133.94%), while the lowest IVI was recorded for *H. odorata* (2.45%). Another notable IVI was found in *A. auriculiformis* (55.82%) and *D. turbinatus* (39.23) (Table 5).

Discussion

In the present study, MKNP showed a poor tree composition with only 10 species recorded (Table 1 and 2) and also showed the absence of natural distribution of mature tree species except for *D. costatus* (Table 3 and 4; Figure 3.A, 3.B) which might be attributed by the continuous degradation of the forest ecosystem of MKNP. Deforestation and forest degradation were mostly caused by forest encroachment, agricultural expansions, and other anthropogenic disturbances inside the forest areas (Figure 2).

The floristic composition of MKNP was very poor in comparison to other PAs of Bangladesh. For example, 31 tree species were recorded at Dulhazara Safari Park (Uddin and Misbahuzzaman 2007) and 48 tree species at Dudhpukuria-Dhopachori Wildlife Sanctuary of Chittagong (South) Forest Division (Hossain et al. 2013). The stem density of MKNP (34.48 stems/ha) was also lower than the other PAs of Bangladesh. For example, Motaleb and Hossain (2011) found 62 naturally growing tree species having the DBH ≥ 10 cm in 1.2 hectares sampled area in Tankawati Natural Forest.

Most of the diversity indices also showed a poor representation of floral diversity in the MKNP (Table 2) compared to other PAs of Bangladesh. For example, the Shannon-Wiener diversity index (1.16) was lower in Chunati Wildlife Sanctuary (3.762) (Hossain and Hossain 2014), Sitapahar Reserve Forest (2.98) (Nath et al. 2000), Tankawati Natural Forest of Chittagong (3.25) (Motaleb and Hossain 2011) and Dudhpukuria-Dhupachori Wildlife Sanctuary (4.45) (Hossain et al. 2013). Margalef's index also showed poor diversity of tree species at MKNP with a value of just 1.63. Researchers found higher Margalef's index in different PAs than MKNP; for example, 23.46 in Dudhpukuria-Dhupachori Wildlife Sanctuary (Hossain et al. 2013), 19.21 in Chunati Wildlife Sanctuary (Hossain and Hossain 2014) and 14.83 in Tankawati natural forest of Chittagong (Motaleb and Hossain 2011). Species evenness (0.2106) was also found lower in MKNP than Chunati Wildlife Sanctuary (0.7834) (Hossain and Hossain 2014) and Dudhpukuria-Dhupachori Wildlife Sanctuary (0.853) (Hossain et al. 2013).

However, the Simpson's index (0.45504) was found higher in the study area than Chunati Wildlife Sanctuary (0.056) (Hossain and Hossain 2014) and Dudhpukuria-Dhupachori Wildlife Sanctuary (0.0192) (Hossain et al. 2013). The higher Spimpson's index in the study area might be attributed due to higher RD, RF, RA, and IVI of *D. costatus* in the MKNP (Table 5).

The study found that the forest patches of MKNP were dominated by different *Dipterocarpus* spp. especially by *D. costatus*. The *D. costatus* was found in all height and diameter classes and also had a very high value of IVI (Table 3, 4, and 5) and BA (Figure 4). It had indicated that (i) *D. costatus* individuals were distributed across the forest of MKNP because of the efficient dispersal of seeds of this tree species throughout the MKNP, (ii) the tree can sustain regeneration and can be recruited successfully in the study area, and (iii) the tree possesses a suitable natural habitat to maintain the optimum growth and development (Tables 3, 4, and 5; Figures 3 and 4). Unfortunately, the study had also found that *A. auriculiformis* had the second-highest percentage at height (16.4%) and DBH (16.4%) class as well as had the second-highest value of IVI (55.82) although its distribution was limited only in ≤5 m and 5.1-≤15 m height class, and 10-≤30 cm DHB class, and had a lower value of BA (0.1 m^2/ha) (Table 3, 4 and 5; Figure 4). This finding came with the notion that recent plantation activities were carried out at MKNP with *A. auriculiformis*, and that *A. auriculiformis* became a preferable plantation tree species in the study area in recent years. But, the choice of exotic species for plantation over the native species should be minimized or stopped, if possible; otherwise, the habitat of mother trees of *D. costatus* might be disturbed because of the continuation of *A. auriculiformis* plantation. Thus, plantation activities should be concentrated with the different *Dipterocarpus* spp. with a special emphasis given on *D. costatus* as this forest patch was dominated by these species. Besides, the habitat of *D. costatus* was under the threat of different anthropogenic pressures inside the forest of MKNP (Figure 2). Further continuation of different anthropogenic activities such as deforestation, agricultural practices and forest encroachments (Figure 2) could decline the natural habitat of this globally vulnerable tree species (Ly et al. 2017). Thus, these anthropogenic activities should be stopped immediately to protect the habitat of mother *D. costatus* trees.

Conclusion and recommendations

In Bangladesh, saving the remaining natural forests from further degradation and deforestation is a key challenge for policymakers. PA could play a key role to reduce such deforestation, and wildlife habitat degradation while strengthening biodiversity conservation strategies. Unfortunately, the study found that the MKNP was low in tree species diversity and composition in comparison to other PAs of Bangladesh. The study also found that the forest of MKNP possesses a suitable habitat for *Dipterocarpus* spp. especially for *D. costatus*. However, *A. auriculiformis* becomes the major plantation species in recent times in this area which could degrade the habitat of *D. costatus* tree. Hence, plantations with native tree species especially with *D. costatus* should be prioritized to replace the *A. auriculiformis*. The study also prescribes to control anthropogenic disturbances inside the forest of MKNP to preserve and sustainably manage the natural habitat of *D. costatus* along with other native flora and fauna. Awareness campaigns from Governments and local NGOs could be an effective method to halt the habitat degradation of mother *D. costatus* trees. Future conservation actions of this vulnerable tree species could be made through *ex-situ* collections (Ly et al. 2017) because globally *D. costatus* has not been recorded in any *ex-situ* collection (BGCI 2017).

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Thinning scenarios to reconcile biodiversity conservation and socio-economic co-benefits in protected forest of Vietnam: Effects on habitat value and timber yield

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Abstract. *Segalina F, Dang CN, Grado RSD. 2020. Thinning scenarios to reconcile biodiversity conservation and socio-economic co-benefits in protected forest of Vietnam: effects on habitat value and timber yield. Asian J For 4: 22-35.* Forest protection policy since the 1990s in Vietnam has led to an overall increase in forest cover, but has also adversely impacted the livelihoods of local populations and has displaced deforestation to neighboring countries. As such, it is necessary to explore strategies to achieve sustainable utilization of tropical forests in a way that is compatible with the preservation of biodiversity. One of which is by selective thinning. This study aimed to analyze the habitat and economic value of the trees in a forest block, then compare the effects of four thinning scenarios on profit and habitat value. We simulated four thinning scenarios and assessed their effects on biodiversity and economic value. The scenarios were defined according to two criteria: tree dominance and tree habitat value. The study took place in a one-hectare plot of marteloscope located in a naturally regenerated mixed forest enriched with native tree species. The habitat value, evaluated by tree-related microhabitats, was used as a proxy for biodiversity. In our study, as many 58 different tree species were found within the marteloscope. Co-dominant trees with a higher diameter at breast height yielded the highest average habitat value, which coincides weakly with findings in temperate forests. In our study, the biodiversity conservation criterion had only a marginal effect on economic benefit. Both results together show that a meeting point between profitability and biodiversity conservation is possible.

Keywords: Biodiversity, forest policy, marteloscope, thinning, tree-related microhabitats, tropical forest

Abbreviations: TreMs: Tree-related microhabitats, DBH: diameter at breast height, S1, S2, S3, S4: Scenario 1,2,3,4

INTRODUCTION

Tropical forests comprise the greatest biodiversity on the earth (Gardner et al. 2009; Gibson et al. 2011), yet their conservation is the worst compared to other ecosystems (Bradshaw et al. 2009). Because of many natural ecosystems in the tropics have been lost or degraded, biodiversity conservation in these regions largely depends on the management of human-modified ecosystems, imposing challenges for researchers and forest managers (Gardner 2009). Nonetheless, the complexity of ecological processes in tropical forests makes it difficult to carry out forest management activities with considerations on biodiversity conservation (Magurran et al. 2003).

In recent decades, interest in biodiversity conservation through preserving and expanding forest cover has increased (Rocchini and Ricotta 2007), although the progress is unequal among countries, especially in the tropics (Wilson et al. 2016). Deforestation is still a big threat to some tropical countries, while others are experiencing overall forest growth (Pekka et al. 2006). In Vietnam, forest protection is the objective of the Vietnam National Forest Policy enacted since the 1990s. This policy has led to a remarkable increase in the national forest area, but also to a huge increase in wood imports from other countries such as Cambodia and Thailand (International Trade Centre 2019), causing a displacement of deforestation (Meyfroidt 2009).

The Vietnamese Forest Protection and Development Law in 1991 classifies the forest of the country into three types: special-use, protection, and production forests. Special-use forest includes protected areas and they have a principal role in meeting the obligations of the Convention on Biodiversity (United Nations 1992). In special-use and protection forests, timber extraction and forest resources utilization are largely limited to a few specified non-timber forest products (Prime Minister of Vietnam 2007), giving rise to a range of problems and conflicts (Kimdung et al. 2013; Thi Hoan 2014) including the more dependence of local people on state funds (Tan 2006). At the same time, budget allocation to support such policy is limited (Hoan 2014) and revealed to be not effective enough to eliminate illegal logging (Chatham House 2020), so a different type of forest management involving sustainable use may provide win-win solutions, i.e. forest management that can achieve both biodiversity conservation and socio-economic benefits (Quang and Ph 2005). Between the extremes of total forest protection (i.e. being banned from any kind of use) and plantations forestry (i.e. intensive management with reduced biodiversity), there may be an alternative of sustainable use and management of forests that can provide some income without compromising conservation of biodiversity.

We hypothesized that some forest management operations could be undertaken without heavily affecting forest biodiversity and functioning. One of the proposed strategies is through stand thinning based on criteria that favor biodiversity conservation. This would provide local people with additional income while taking a step towards sustainable management of protected forest areas, as indicated in United Nations Sustainable Development Goal 15 (United Nations 2015). To aid decision-making for thinning in a forest, it is necessary to evaluate trade-offs between the economic value of each tree and its value for biodiversity. This study aimed to analyze the habitat and economic value of the trees, then compare the effects of four thinning scenarios on profit and habitat value. To achieve this, we used TreMs framework, which is defined as indirect indicators for the specialized species that use them as substrates or habitat at least for a part of their life-cycle (Larrieu et al. 2018; Santopuoli et al. 2019). These include cavities, wounds, deadwood and other features as meaningful bioindicators for the habitat value of the tree. We expect the results of this study is to contribute to the management and conservation of secondary tropical forests in Vietnam.

MATERIALS AND METHODS

Study area

The study area was located at the Me Linh Station for Biodiversity (coordinates: 21º23’19” to 21º24’02” N, and 105º42’45” to 105º42’50” E), about 50 km from Hanoi and nearby Dai Lai tourist site in Ngoc Thanh Commune, Phuc Yen District, Vinh Phuc Province (Northern Vietnam). It borders Tam Dao National Park in the West and is considered as a green buffer zone of the National Park. The elevation of the station stretches from 60 to 500 m above sea level and the extent comprises 170 ha, consisting of 69 ha of secondary forest, 30 ha of plantation forest, 68.3 ha of grassland, rocky streams, and ponds, and 3 ha of administration area. The natural vegetation is tropical rain evergreen closed forest. The weather is tropical and varies throughout the year with a seasonally wet climate. The mean annual rainfall is 1600 mm and the rainy season is from April to October with over 90% of rain occurring during this period (Vu 2008). (Figure 1). The Melinh Station was established in 1999 and belongs to the Institute of Ecology and Biological Resources (Hanoi), which supports education and scientific research. It boasts rich plant diversity with 1,227 vascular plant species, 670 genera, 172 families, and 6 divisions.

In 1992, on the flat edges of this site, the natural vegetation was clear-cut to plant *Acacia* spp and *Pinus massoniana*. These forest plantations failed and naturally grow vegetation has since been generated occupied by light-demanding plants such as *Liquidambar formosana*, *Cratoxylum cochincinensis*, *Aporosa dioica*, and *Wendlandia paniculata*. In 2002, the shrub and grass layers on the area were clear-cut and native species were planted for enrichment. Among them were *Erythrophleum fordii*, *Lithocarpus corneus*, *Pelthophorum dasyrrhachis*, *Machilus bonii*, *Aphanamixis grandiflora*, *Dipterocarpus retusus* and others. Today, there are various kinds of ecosystems in the Melinh station, including the flat area that hosts plantations of tea trees, medicinal plants, and regenerated forest, while natural forest occurs on the slopes.

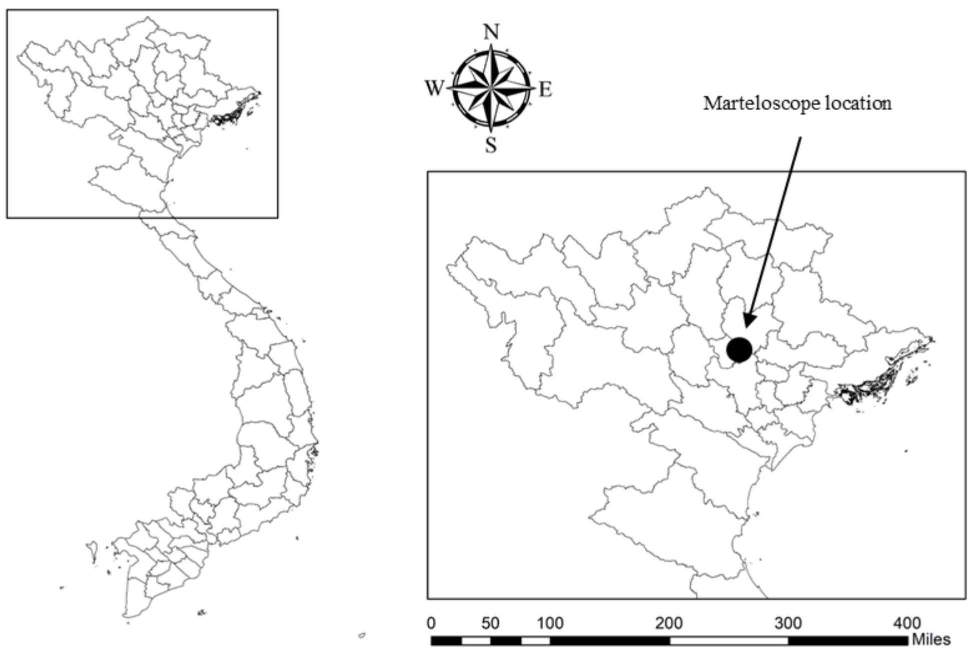

Figure 1. Location of the Melinh Station for Biodiversity in Phúc Yên municipality, Vinh Phuc Province (Northern Vietnam)

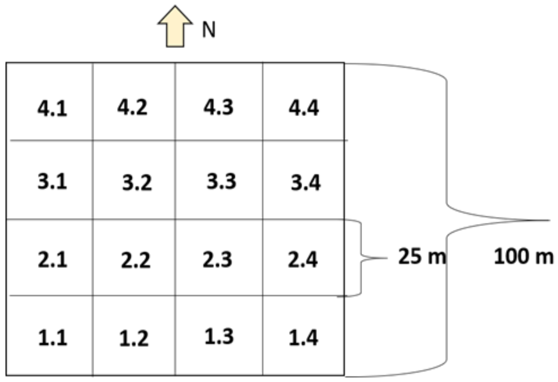

Figure 2. Diagram of the marteloscope plot at the Melinh Station for Biodiversity, Northern Vietnam

Procedures

Marteloscope set-up

A marteloscope is a permanent plot of 1 ha (Schuck et al. 2015) combined with a "computer compiler" intended to simulate the immediate effect of a harvesting choice (Soucy 2014). It must meet three criteria: be representative of the forest heterogeneity including gaps, different kinds of vegetation and forest stages; the selected forest must show a certain “need” to be managed in the sense that it has to be suitable for virtual management exercises; to renounce to the real management for at least 10 years justifying the set-up cost and ensuring the medium-term site usage (Schuck et al. 2015).

In 2018, a marteloscope was established under the framework of the BioEcoN Project (Erasmus +, Capacity Building in the field of Higher Education), by the Thai Nguyen University of Agriculture and Forestry, a partner in this Project (http://bioecon.eu/). The entire plot (1 ha) belongs to the Melinh Station for Biodiversity and has good accessibility. Its altitude ranges from 69 to 83 m.a.s.l.

The plot was divided into 16 square subplots measuring 25x25 meters each (Figure 2). The position of the first corner of the plot (1.1) was established by 2 reference points outside the plot, using GPS 64sx. Starting from the first corner, the coordinates of each corner of each subplot were then recorded. The marteloscope area is almost entirely flat, except for subplots 1.1, 2.1, and 3.1 which are at the base of a slope.

Data collection

All trees were recorded by two teams of four people. All the living trees with a diameter at breast height (DBH) equal to or greater than 7 cm were considered. Because the average DBH was very small, the decision was made to consider trees from 7 cm DBH instead of 9 cm prescribed by Soucy (2014). The DBH was measured indirectly using tape. Tree height at crown base and height at largest crown width diameter were measured using Terinox LRF 1800 and 1200 along with the slope angle.

The recorded variables included tree id (number), tree species, DBH (cm), slope angle (degrees), tree total height (m), tree height to crown base (m), timber quality, stem straightness, potential use, tree health status, tree microhabitats. All trees were geolocated. Timber quality and health status were assigned on a scale from one (good) to three (bad), according to marteloscope installation protocol criteria (Soucy 2014). Stem straightness was ranked from one (straight) to six (very curved). The species name of the tree was determined by experts, and the potential use of each tree species was assigned according to information contained in the reference book “Tên cây rừng Việt Nam” (The Names of Forest Plants in Vietnam) (Ministry of Agriculture and Rural Development 2000). We identified a total of 58 tree species in the plot; the 15 most abundant ones are reported in Figure 3.

Subsequently, timber volume was calculated using the formula developed by Hinh (2012) which has been applied to natural forests in Northern Vietnam:

$$V\,(m^3) = 0.00006341 * \mathrm{DBH}^{1.8786} * H^{0.9697}$$

Where:
V= Tree timber volume
DBH= Diameter at breast height
H= Total height of the tree

We used TreMs, which are “indirect indicators for the specialized species that use them as substrates or habitat at least for a part of their life-cycle” (Larrieu et al. 2018). These include cavities, wounds, deadwood and other features as meaningful bioindicators for the habitat value of the tree. The TreMs classification used for data collection is shown in Table 1. We followed the criteria of Larrieu et al. (2018), except that the height limit for TreMs observation was 3 m instead of 5 m. The decision was based on the high forest density (805 trees/ha), with thick under-canopy vegetation and abundant liana. These reduce the visibility of the upper part of the trunks, making TreMs evaluation potentially misleading.

All the data were collected in February 2019, except for TreMs, which were recorded in May 2019.

Economic valuation

Finding information to assign an economic value to the trees within the marteloscope required a literature review process. We found that the Ministry of Agriculture and Rural Development & Ministry of Trade, General Department of Customs, Vietnamese Government 1995, published a joint circular concerning simplification and regulation of timber trade. They identified the 354 least endangered most valuable tree species on the market and divided them into eight timber classes. After publication of that document, Vietnamese enterprises could set buying prices according to the timber class, thereby overcoming the need to evaluate each tree species every time.

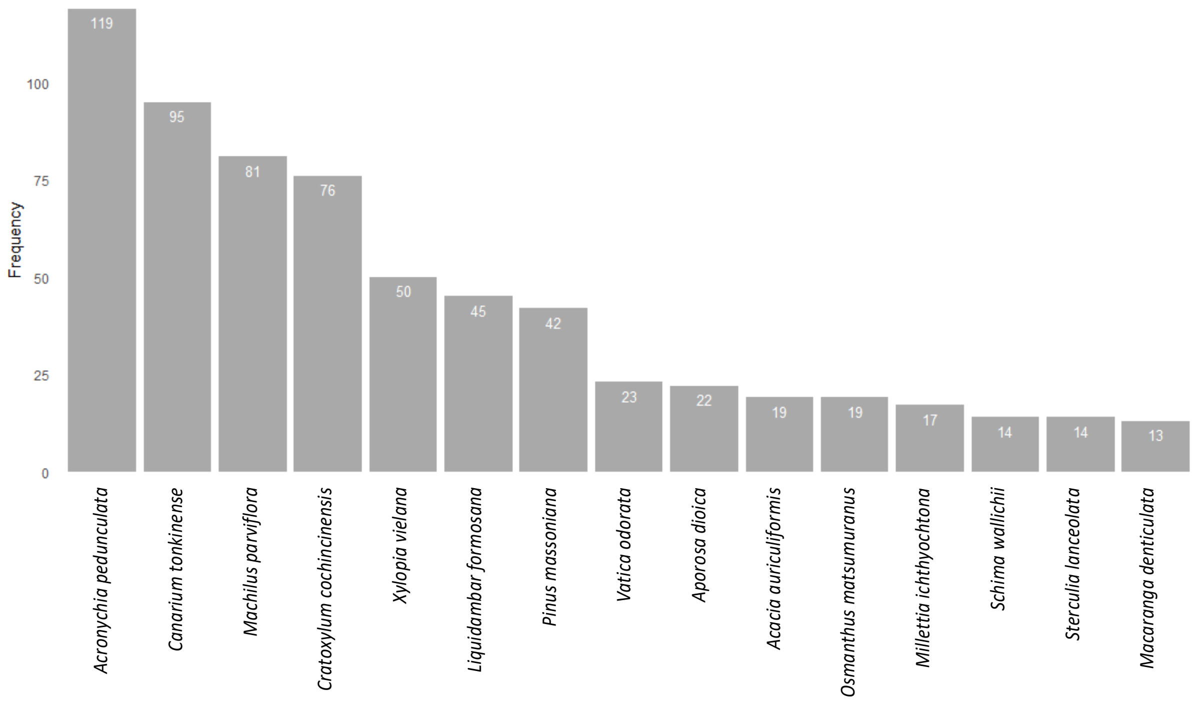

Figure 3. Frequency distribution of 15 most abundant tree species within the one-hectare marteloscope. As many 58 tree species were found in the plot, comprising a total of 805 individuals.

After that, we looked for the prices that Vietnamese timber companies pay for each timber class. We selected the price list provided by the Chúc mừng năm mới company website because it referred to Nguyễn (2018), which was the most up-to-date, and most comprehensive price list. The list was consulted on 16 June 2019 and shows prices for standing trees in different timber classes (Table 2). It did not provide any information about possible reductions of the buying price depending on the wood quality (straightness and presence of defects) or tree diameter, for example. The search to find more precise pricing proved unsuccessful, forcing us to rely on the data of Nguyễn (2018). We calculated the total economic value of the trees by multiplying the total amount of wood (in m^3) in each timber class by the relative buying price.

Data analysis

Habitat value

The data analysis was done using R software v.3.5.3. The first part involved assigning each tree a habitat value, calculated for each tree based on the number of recorded TreMs, using the formula proposed by Kraus et al. (2018). The calculation considers the relative rarity of habitat in the forests and the time span needed for it to develop.

$$H_i = \sum_{j=1}^{n} N_j \times s_j \times (R_j + D_j)$$

Where: H_i is the habitat value of tree i, N_j the number of microhabitat type j, R is the value of the rarity of a TreMs, D is the value of the time that a microhabitat takes to develop or to be available, and S is the size score (physical size of a TreMs) within a TreMs type (see Tables 1 and 3). The result H_i is then expressed in "habitat points".

The R-value was assigned by counting the frequency of each type of TreMs and then rescaling the result from one to five, where one is the minimum rarity and maximum frequency, and five is the maximum rarity and the lowest frequency.

Thinning scenarios

We simulated four thinning operations to compare their effects on basal area and tree distribution, along with economic value and habitat value. Two criteria were used to define the harvesting (Table 4): the relative position of trees in crown classes (codominant or suppressed) and the habitat value of the tree (any or low habitat value). Those criteria were applied at the subplot level, which means that each thinning simulation was implemented individually for each of the 16 subplots. The quantity of basal area removed was always 30% ± 1% of the total.

Using five as a reasonable number for tree diversity conservation, we excluded species within the marteloscope with five individuals or less from the thinning simulations. Accordingly, each simulation spared at least five individuals of each tree species at the plot level. We also excluded all threatened and endangered species, based on the IUCN red list of threatened species (IUCN 2019). After that, we fitted linear models for each scenario, in which the habitat value of the removed trees is a function of tree DBH.

Table 1. Illustrations of TreMs types in European temperate and Mediterranean forests from Larrieu et al. (2018) were used for data collection and to derive the habitat value of the trees.

Form	Group	Types					
Cavities l.s.	Woodpecker breeding cavities	**Small woodpecker breeding cavity** Entrance ø<4cm	**Medium-sized woodpecker breeding cavity** Entrance ø = 4-7cm	**Large woodpecker breeeding cavity** Entrance ø >10cm	**Woodpecker flute** Entrance ø > 3cm		
	Rot-holes	**Trunk base rot-hole (closed top, ground contact)** Opening ø >10cm	**Trunk rot-hole (closed top, no ground contact)** Opening ø >10cm	**Semi-open trunk rot-hole** Opening ø >30cm	**Chimney trunk base rot-hole** Opening ø >30cm	**Chimney trunk rot-hole** Opening ø >30cm	**Hollow branch** Opening ø >10cm
	Insect galleries	**Insect galleries and bore holes** Hole ø >2cm or area >$300cm^2$					
	Concavities	**Dendrotelm** ø >15cm	**Woodpecker foraging excavation** Depth >10cm, ø >10cm	**Trunk bark-lined concavity** Depth >10cm, ø >10cm	**Root-buttress concavity** Entrance ø >10cm		
Tree injuries and exposed wood	Exposed sapwood only	**Bark loss** Area > $300cm^2$	**Fire scar** Area > $600cm^2$	**Bark shelter** Gap >1cm, depth >10cm, height>10cm	**Bark pocket** Gap >1cm, width >10cm, height>10cm		
	Exposed sapwood and heartwood	**Stem breakage** ø >10cm at break point	**Limb breakage** Exposed heartwood >$300cm^2$	**Crack** Length > 30 cm, width > 1 cm, depth > 10 cm	**Lightning scar** Length > 30 cm, width > 1 cm, depth > 10 cm	**Fork split at insertion** Length > 30 cm	
Crown deadwood	Crown deadwood	**Dead branches** Branch ø >10cm, or Branches ø >3cm and >10% of the crown is dead	**Dead top** ø >10cm at the base of the piece of deadwood	**Remaining broken limb** broken end ø >20cm, length of the remaining piece >0.5m			

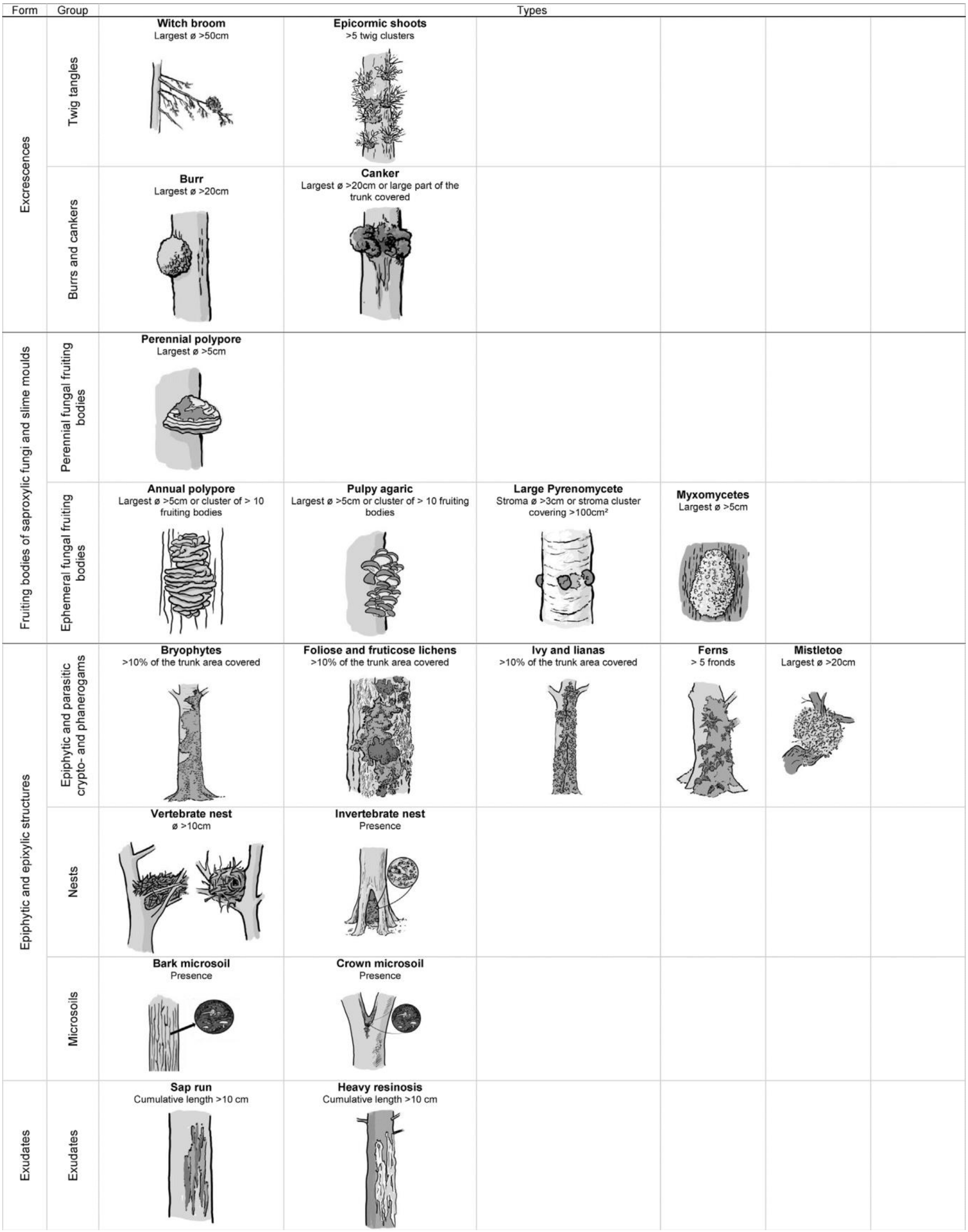
Form
Group
Types
Excrescences
Twig tangles
Witch broom
Largest ø >50cm
Epicormic shoots
>5 twig clusters
Burrs and cankers
Burr
Largest ø >20cm
Canker
Largest ø >20cm or large part of the trunk covered
Fruiting bodies of saproxylic fungi and slime moulds
Perennial fungal fruiting bodies
Perennial polypore
Largest ø >5cm
Ephemeral fungal fruiting bodies
Annual polypore
Largest ø >5cm or cluster of > 10 fruiting bodies
Pulpy agaric
Largest ø >5cm or cluster of > 10 fruiting bodies
Large Pyrenomycete
Stroma ø >3cm or stroma cluster covering >100cm²
Myxomycetes
Largest ø >5cm
Epiphytic and epixylic structures
Epiphytic and parasitic crypto- and phanerogams
Bryophytes
>10% of the trunk area covered
Foliose and fruticose lichens
>10% of the trunk area covered
Ivy and lianas
>10% of the trunk area covered
Ferns
> 5 fronds
Mistletoe
Largest ø >20cm
Nests
Vertebrate nest
ø >10cm
Invertebrate nest
Presence
Microsoils
Bark microsoil
Presence
Crown microsoil
Presence
Exudates
Exudates
Sap run
Cumulative length >10 cm
Heavy resinosis
Cumulative length >10 cm

Table 3. The criteria of R, D and s for evaluation of TreMs

Rarity gradient (R-value)	Development time (D-value)	Size (s)	Points
Very common	Fast or linked to a very common event	ø ≤ 4 cm	1
Common	Fairly fast or linked to a fairly common event	4 cm < ø ≤ 10 cm	2
Fairly rare	From fairly slow to slow or linked to an uncommon event	10 cm < ø ≤ 15 cm	3
Rare	Slow or linked to a rare event	15 cm < ø ≤ 20 cm	4
Very rare	Very slow or linked to a very rare event	ø > 20 cm	5

Table 2. Timber groups and relative average prices per cubic meter of Roundwood in 2018 in Vietnamese and USA currencies.

Wood type	Price (m^3 roundwood) in VND	Price (m^3 roundwood) in USD
Group 1	3,600,000.00	154.8
Group 2	2,500,000.00	107.5
Group 3	2,700,000.00	116.1
Group 4	1,900,000.00	81.7
Group 5	1,700,000.00	73.1
Group 6	1,300,000.00	55.9
Groups 7 & 8	1,100,000.00	47.3

Table 4. Criteria used to simulate the harvesting operations (tree removal)

Scenario	Criterion1	Criterion 2
S1	Suppressed trees	Any habitat value
S2	Suppressed trees	Low habitat value
S3	Codominant trees	Any habitat value
S4	Codominant trees	Low habitat value

RESULTS AND DISCUSSION

Results

Forest inventory

The inventory revealed 805 trees with a DBH of 7 cm or higher (Figure 4). The tree species with the largest DBH was *Liquidambar formosana* (50.4 cm), followed by *Pinus massoniana* (47 cm). The total volume of wood in the plot was estimated to be 89.2 m^3, which when divided by the number of trees, gave an average wood volume of 0.11 m^3 per tree. The amount of valuable timber was 48.2 m^3. The only endangered or vulnerable tree species found in the marteloscope was *Erythrophleum fordii* (IUCN 2019), which had 5 individuals. All the other species are classified in 'least concern' or 'data deficient' categories.

The spatial distribution of tree species should be noted since it was visually apparent that *Pinus massoniana* was grouped mainly on one side of the plot (Figure 5). The trees found in the marteloscope has grown up almost entirely since the year 2002, when shrubs were removed and native trees were planted to enrich the forest composition. Using the volume of 89.2 m^3, the mean annual increment since 2002 has been 5.25 m^3/year.

TreMs and tree habitat value

A total of 4755 TreMs of diverse types were found in the marteloscope. The most abundant TreMs types were the epiphytic and parasitic cryptogams and phanerogams, with 2079 recorded. These bryophytes, foliose and fruticose lichens, along with ivy and lianas, accounted for 43% of the total recorded TreMs. However, some of the TreMs described in Larrieu et al. (2018) were not present at all in our plot. There were no woodpecker cavities of any kind, fire scars, perennial polypores, witches' broom, mistletoe, or ferns. Similarly, we found no vertebrate nests, but this was probably due to low visibility in the forest.

We observed insect holes on three trees: one *Itea chinensis* and two *Archidendron clypearia*. Each tree had about 50 holes with diameters equal to or greater than 2 cm (below the 3 m height threshold). Those 3 trees had very low DBH (less than 10 cm) and the highest number of recorded TreMs (67, 54, and 53 respectively). Notably, the *Itea chinensis* was the tree with the highest habitat value (2296 habitat points) and the *Archidendron clypearia* trees were among the top 15 trees with highest habitat values (1164 and 1195 habitat points). We found only 3 trees with no TreMs, belonging to 3 different species: *Cratoxylon cochinsinensis*, *Acacia auriculiformis*, and *Machilus parviflora*, with DBH of 9.8, 17.5 and 15.8 cm and total height of 7.5, 11, and 9.2 m, respectively.

Generally, the larger TreMs, such as the semi-open trunk rot-hole, dead top, or chimney trunk base rot-hole, were also less frequent than the small TreMs (bark shelter and dead branches) or biotic TreMs. Bryophytes, foliose and fruticose lichens, insect galleries and boreholes, invertebrate nests, ivy, lianas, and resin flow were the most abundant biotic TreMs. For example, we found only 1 chimney trunk base rot-hole, 1 trunk bark-lined concavity and 1 annual polypore, hosted in an *Acronychia pedunculata* (10.3 cm DBH and 6.43 m total height), *Xylopia vielana* (7.8 cm DBH and 8 m total height) and a *Liquidambar formosana* (20.3 cm DBH and 9 m total height). The total height of those trees was slightly below the average (Table 5), while their DBH was above average (Figure 4) except for *Xylopia vielana*, with a DBH among the lowest measured.

Economic value

We identified 360 trees with associated economic value (Table 6), representing 45% of the total number of trees (805) in the marteloscope. However, occurrence was low for many of those species, making them non-harvestable from a sustainability or conservation perspective. If there are only one or two trees of a species, we assume that harvesting may significantly reduce their chances of reproduction.

The most abundant tree species found in the plot was *Acronychia pedunculata* (Table 6), with 119 individuals.

This species is mainly used for traditional medicine (Ministry of Agriculture and Rural Development 2000) and does not appear in the joint circular of the Vietnamese government, suggesting that its timber quality is relatively poor. Even if *Acronychia pedunculata* timber has some use-value, and though it was used for construction in the past (Ministry of Agriculture and Rural Development 2000), our analysis indicated that it is not marketable and therefore its economic value equals to zero. Within the entire plot, we found only one tree belonging to Timber Class 1 and none belonging to Timber Class 2 which are the most valuable timber classes (Table 6).

Thinning scenarios

At the time of data collection, the estimated tree economic value for the marteloscope was 3,219 USD, the total basal area was 14.75 m^2 and the total habitat value was 189,360 habitat points. We observed a big difference in the removed habitat value between Scenario 1 (S1) and S2, reflecting variation in both the quantity and quality of removed TreMs (Figure 6). The removed economic value in S2 was higher than in S1, though timber volume was the same (23 m^3). Also significant was the difference between the number of trees removed in S1 and S2, which amounted to 324 and 288 trees, respectively.

The difference between the two criteria was also visible in S3 and S4, where the number of thinned trees was higher in S4 than in S3. In S4, the removed habitat value was much lower than in S3, and the economic value in S4 was close to that of S2. The highest removed economic value occurred in S3 but no big differences were observed among the 4 scenarios, where revenues ranged from 500 to 600 USD.

Figure 7 shows the linear regressions of DBH as function of the habitat value of the marked trees in S1, S2, S3, and S4. When looking at the average habitat value of all the marked trees within each scenario, we find that the expected DBH value (intercept) is smaller in S1 than in S3. Its slope, though significant in both cases, is very small and positive (i.e. 0.0026 for S1 and 0.0062 for S3). This means that the relationship between DBH and habitat value is very small, but habitat value grows when DBH grows. To assist in the interpretation of the results, we also calculated the average habitat value of the removed trees for each scenario and found that S3 and S4 gave the highest values (Table 7).

In Figure 5, it is possible to appreciate the spatial distribution of removed trees in the different scenarios, compared to the current situation. We can also see that the trees with the greatest basal area often have the highest economic value as well. For example, *Pinus massoniana* are very large, tall trees (Figures 4 and 5) with high amounts of timber, which leads to high economic value. At the same time, their habitat value is low because they have few TreMs.

Table 5. Summary of the total height of the trees in the marteloscope

Summary of total height (m)					
Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
2.14	7.700	9.440	9.713	11.459	32.190

Table 6. Number of species, names of tree species and number of individuals of each species in the marteloscope plot ordered by frequency and timber class according to the Vietnamese Government Joint Circular of 22 December 1995

Tree species	Number of individuals	Timber class
Acronychia pedunculata	119	
Canarium tonkiense	95	6
Machilus parviflora	81	6
Cratoxylum cochinsinensis	76	
Xylopia vielana	50	
Liquidambar formosana	45	5
Pinus massoniana	42	5
Vatica odorata	23	
Aporosa dioica	22	
Acacia auriculiformis	19	
Osmanthus matsumuranus	19	
Millettia ichthyochtona	17	7
Schima wallichii	14	6
Sterculia lanceolata	14	8
Macaranga denticulata	13	8
Canthium horridum	11	
Styrax tonkinensis	11	8
Archidendron clypearia	10	
Cansjera rheedii	10	
Elaeocarpus griffithii	10	
Eucalyptus citriodora	9	6
Chaetocarpus castanocarpus	7	
Phoebe tavoyana	7	
Canarium album	6	7
Engelhardtia roxburghiana	6	
Ficus hispida	6	
Acacia mangium	5	
Clausena excavata	5	
Erythrophleum fordii	5	
Itea chinensis	5	
Mallotus mollissimus	5	
Actinodaphne pilosa	4	6
Choerospondias axillaris	3	
Lithocarpus fissus	3	7
Clausena dunniana	2	
Hydnocarpus hainamensis	2	
Michelia balansae	2	
Toxicodendron succedanea	2	
Bischofia javanica	1	
Carallia diplopetala	1	7
Castanopsis indica	1	3
Diospyros apiculata	1	1
Endospermum chinense	1	
Eurya ciliata	1	
Garcinia hainanensis	1	
Garcinia multiflora	1	
Hymenodictyon orixense	1	
Litsea cubeba	1	
Litsea umbellata	1	
Memecylon edule	1	
Mischocarpus pentapetalus	1	5
Peltophorum dasyrrhachis	1	5
Stereospermum colais	1	
Symplocos laurina	1	8
Wendlandia paniculata	1	
Wrightia pubescens	1	
Xanthophytum polyanthum	1	
Zanthoxylym avicennae	1	

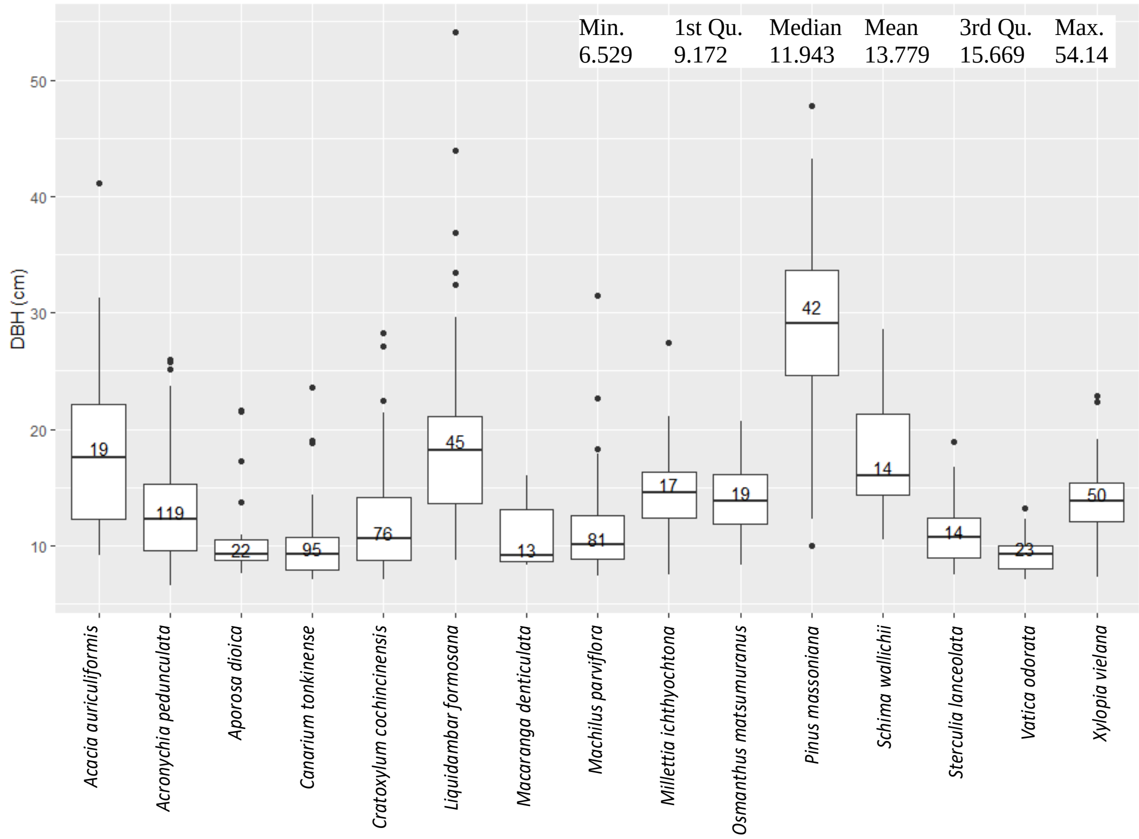

Figure 4. Boxplot of the DBH of the 15 most abundant tree species in the marteloscope, indicating the number of individuals and the mean DBH (line inside the box) of each of those species. Summarized above are the minimum, first quartile, median, mean, third quartile and max for DBH

Table 7. Average habitat value (habitat points) of the marked trees for each thinning scenario.

Scenario	Mean tree habitat value
1	199.50
2	161.37
3	230.80
4	177.86

Discussion

Forest inventory and TreMs

The number of TreMs recorded in the marteloscope in this study (4755) is more than 6 times higher than the number recorded in the study of Santopuoli et al. (2019) for the Mediterranean region (754). To the best of our knowledge, this is the first study of its kind in a Southeast Asian tropical forest. Another difference between the two studies is the most abundant TreMs category: in our case, 43% of TreMs corresponded to epiphytic and parasitic cryptogams and phanerogams, while in the Mediterranean study, 42% of TreMs were cavities. The similar quantitative approach implemented in both studies uncovers important differences between Mediterranean and tropical forests in terms of quantity and type of microhabitats. More precisely, the epiphytic and parasitic cryptogams and phanerogams category included 895 bryophytes, 888 foliose and fruticose lichens, and 701 ivy and lianas. While bryophytes and lichens simply live on the bark of the trees, ivy and lianas rely on the tree stem for structural support while twisting around the tree stem in search of light. Furthermore, the same liana can twist around and bond to more than one tree, making thinning operations harder. They can also develop stems that are sometimes thicker than the supporting tree stem (Jacobs 1976). In our study, lianas were considered as TreMs, so their timber volume, basal area, and the TreMs they host were not considered.

The most recurrent TreMs type on the same tree was the insect borehole, which occurred in 3 cases. It was unexpected to find that the pests had attacked each of the three trees - a single *Itea chinensis* and two *Archidendron clypearia* - more than 50 times without attacking the surrounding trees or other trees of the same species (altogether, we found five *Itea chinensis* and ten *Archidendron clypearia* trees). As mentioned above, the DBH of those trees was less than 10 cm and their habitat value was the highest among all the recorded trees. This shows that despite the low rarity of insect galleries and holes, they can contribute significantly to the habitat value of the trees. The reason for the high occurrence of these TreMs types remains unexplored and further research is needed to clarify their causal dynamics.

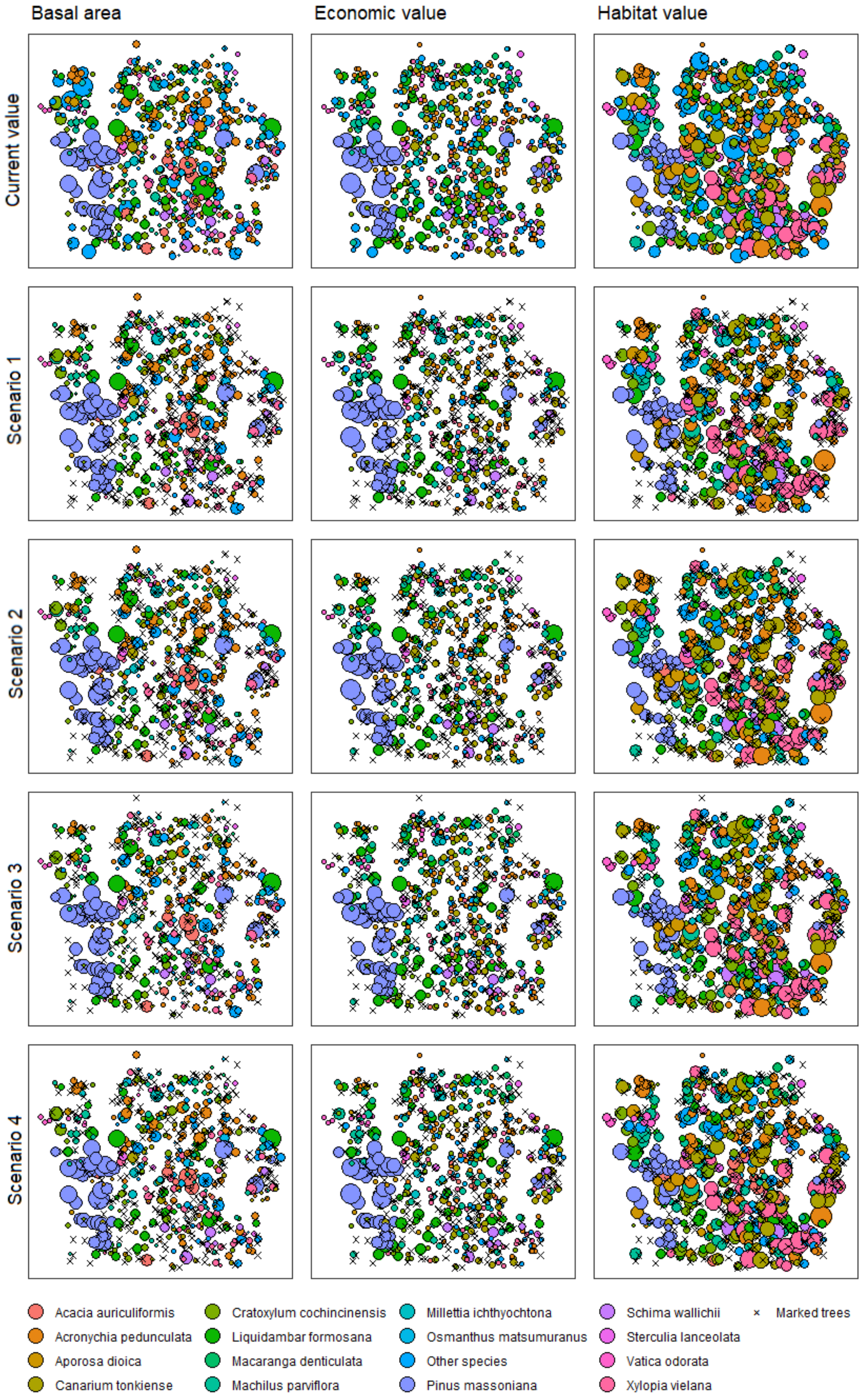

Figure 5. Forest intervention scenarios show the tree spatial distribution inside the marteloscope by considering basal area, economic value, and habitat value. The colors indicate the 15 most abundant tree species while the rest are grouped under the name "other species" to simplify viewing. Removed trees are marked with an "x". The dimension of the circle reflects basal area (m^2) in the first column, economic value (USD) in the second column and habitat value (habitat points) in the third column

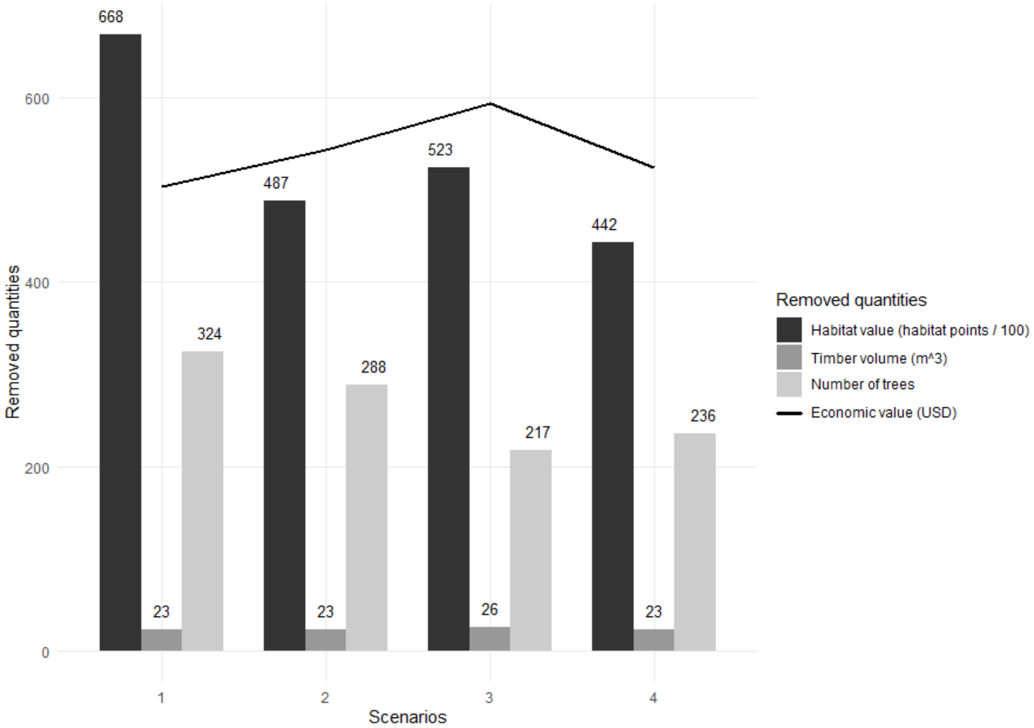

Figure 6. Comparison of the four simulated scenarios, indicating removed quantities in terms of habitat value, divided by 100 (habitat points) for better visualization; timber volume (m^3); number of trees and economic value (USD) obtainable from the harvested trees

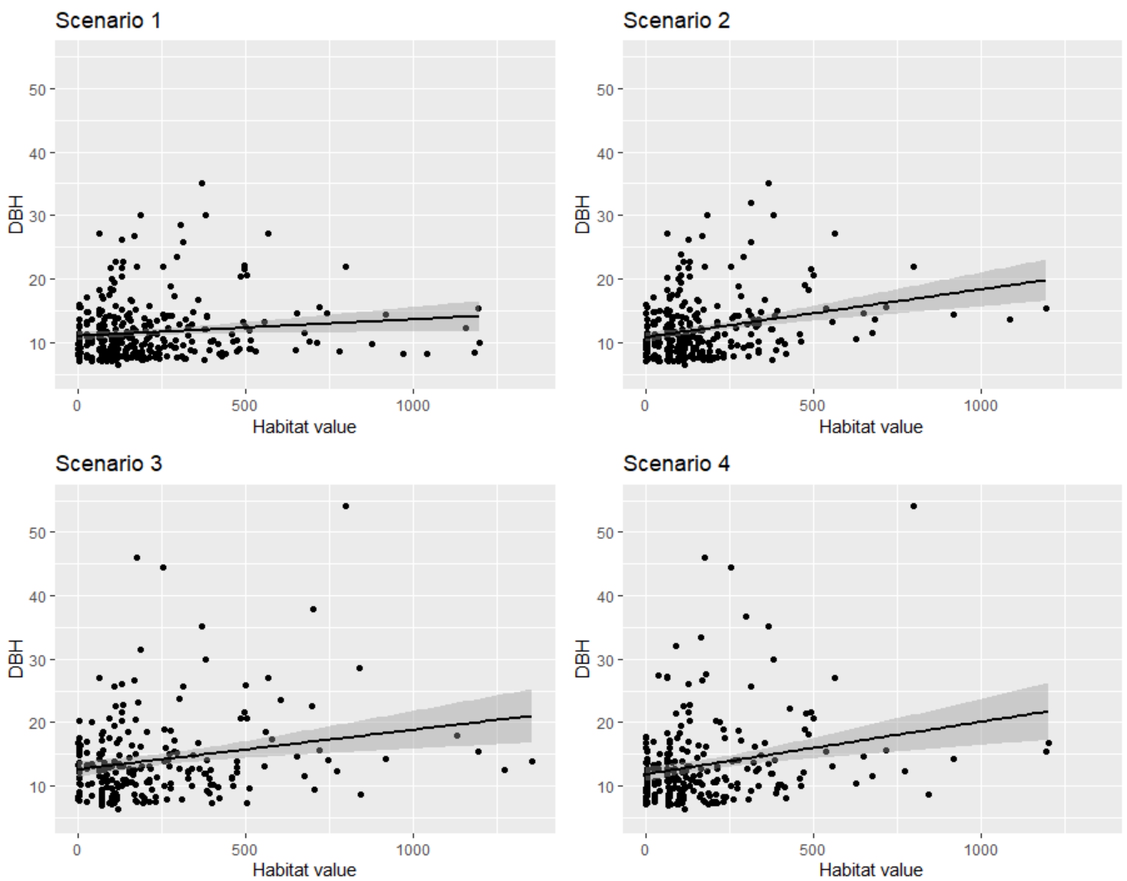

Figure 7. Relationship between DBH and habitat value of the marked trees in the four intervention scenarios

Some of the TreMs described by Larrieu et al. (2018) (i.e. woodpecker cavities, fire and lighting scars, and perennial polypore) were not present in our plot. However, we did not find any TreMs types that were not classified in Table 1. Furthermore, in Larrieu et al. (2018), TreMs type groups are combined in a table that links each TreMs with one or more specific order of invertebrates and vertebrates. In our study area, we do not know if all those links coincide in the same way. This type of information would help us to understand exactly which orders are linked to each TreMs type.

Regarding nests, insect galleries, and boreholes, from the ground, it was not possible to verify the presence of vertebrate nests in the crown because of the high canopy density and the massive presence of lianas. However, termites were abundant on most of the trees and sometimes made their nests as galleries along with the bark and inside the stem (Yanagihara et al. 2018). This made it difficult to distinguish between insect-only galleries and insect galleries plus invertebrate nests. Furthermore, nesting inside the trees causes the two TreMs definitions to overlap: insect galleries and invertebrate nests become a single feature. During data collection, we tried to distinguish the two, but the difficulty of the task invites a degree of human error. Anyway, the effect of this error on the average tree habitat value should be low due to the low habitat value of both TreMs types.

We think that the uneven site characteristics across the study area explain the distribution of *Pinus massoniana* (Figure 5) since topographic variations in slope and orientation create different microclimates in the marteloscope. This also implies differences in solar radiation and soil characteristics (Holland and Steyn 1975; Noguchi et al. 1999), thereby favoring different tree species in different plot areas (Podwojewski et al. 2011). At the same time, those pines might have been spared in the last clear-cut that occurred in the 1990s. To verify these premises, we would need data about soil characteristics, solar radiation, and the age of the trees, which were not considered in the marteloscope set up. To understand the spatial distribution of *Pinus massoniana*, we should also consider past experience: the main reason why the forest plantation on this site failed in the 1990s, as explained in Paragraph 3.1, was because the species planted there (*Acacia* spp. and *Pinus massoniana*) were suppressed by more light-demanding species. Consequently, it could be that *Pinus massoniana* trees have remained in areas of relatively lower solar radiation in the plot.

Economic and habitat values

Economic and habitat values were the key elements in this research. The Vietnamese government identified 354 marketable tree species out of more than 4000 known species in Vietnam (The Names of Forest Plants in Vietnam 2000). Of the 58 tree species found in the marteloscope, only 19 are recognized as economically valuable according to the government list. Aside from that, economic value was calculated based on the value of the timber itself, without considering any additional harvesting costs that might reduce revenue. The data we used to define economic value is related to the buying price per cubic meter of each timber class. That data does not contemplate price variations that may occur as a function of tree characteristics such as diameter and straightness, or the presence of sap flows, trunk rot-holes, and other microhabitats. Many microhabitats are considered timber "defects" in that they logically reduce the amount of useful timber for industrial processing, which directly decreases the tree value.

Further attempts in literature review to discover more information about tree pricing of natural forests in Northern Vietnam were unsuccessful. This suggests a lack of data and constituted a limitation to our study. Given such considerations, we might assume that some trees that host-specific microhabitats can be partially or totally used as firewood. We must also recognize that firewood in Vietnam and other developing countries is considered a free commodity, which may be collected without any other cost than that associated with the personal effort of gathering it (Kim et al. 2016). This reveals once more the differences between Mediterranean and tropical forests, as natural environments but also as socio-economical spaces. By comparing our study area with Southern Italy in the research of Santopuoli et al. (2019), we see how that study evaluated the price of firewood without even considering roundwood, which is not possible in our study area.

Furthermore, habitat value was assessed by the rarity, size, and development time of each TreMs type. Our results also showed that DBH can predict habitat value, as was found in previous studies involving Mediterranean and temperate forests (Michel and Winter 2009; Vuidot et al. 2011; Regnery et al. 2013; Asbeck et al. 2019; Santopuoli et al. 2019), but the correlation is weak (Figure 7). This suggests that more complex forest dynamics and factors interact to determine the TreMs type and the habitat value of the trees, which provides a challenge for future studies.

Finally, the average annual increment of the timber in the marteloscope is 5.25 m^3/year and 54% of it has economic value. Plantations for timber production of *Acacia* spp. in Vietnam are known to produce from 10 to 25 m^3 per hectare each year over a ten-year period, which is also affected by the use of inputs such as fertilizers (Nambiar et al. 2015). The valuable timber production in the marteloscope was not comparable with that of an *Acacia* plantation.

Thinning scenarios

The different thinning scenarios showed very different results. When comparing S2 and S4, we see that the habitat value, number of trees, and economic value parameters were higher in S2. The timber volume was the same for both, as expected, because we were comparing the removal of suppressed vs. codominant trees and removed 52 trees less in S4 than in S2. It is very clear how removed TreMs after thinning was significantly reduced by including Criterion 2 in the tree selection. This can be appreciated both for the S1-S2 and the S3-S4 comparisons. The average habitat value of the marked trees within each scenario (Table 7) shows that S1 had the highest removed habitat value because we removed more trees to reach 30% of the basal area and the habitat value generally increases slightly with the DBH. The determining factor was the combination of the removed basal area and Criterion 1 about suppressed/codominant trees.

Finally, we would recommend the S4 approach of thinning from above rather than S2 thinning from below, as it implies removing 52 fewer trees but the same volume of timber. The removed economic value was also very similar (544 vs 524 USD), which makes S4 more efficient than S2 in terms of revenue per removed tree. The difference in the removed habitat value was negligible, amounting to 4500 habitat points (2%) out of a total of 189,360.

Future perspectives

Considering the results discussed above, this study has demonstrated the utility of estimating the habitat value of each tree within the marteloscope. We cannot say the same about estimating the economic value, which proved to be a debatable task. We also demonstrated how the TreMs criterion can be used as a proxy for biodiversity conservation in thinning plans. The comparison between economic benefit and TreMs conservation among the scenarios shows a win-win situation as the two objectives coincided.

This study also opens the door to other questions about how forest value will evolve in the future. For example, does high economic revenue today lead to less valuable timber in the future and take us back to the original issue of harvesting only high-value trees? The marteloscope is a good instrument for seeing the immediate effects of forest management; might it also be useful for medium-and long-term forecasting of tropical forest dynamics?

Our research compared habitat value and economic value for different thinning simulations, but it cannot predict forest response. By knowing which tree species have better chances for growth after the prescribed interventions, we might improve our understanding of this vast ecosystem and identify more precise guidelines for forest intervention.

In conclusion, higher habitat values corresponded to suppressed trees with low DBH. However, the general trend shows that TreMs and habitat values increased with increasing tree DBH. Forest protection policies in Vietnam made assessing the economic value of each tree highly debatable views: only 45% of the total number of trees was marketable for roundwood. Among the four thinning operations, the clear contribution of biodiversity conservation criteria in forest management led us to prefer S2 and S4 over S1 and S3. Of the two preferred scenarios, S4 proved to be the best option for biodiversity conservation. Though S3 was the best-performing scenario in terms of revenue and revenue per number of trees since it selected the most valuable trees, S4 still presented the best compromise between profit and habitat conservation.

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