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Photo: Björn Olin

Effect of Topographic Conditions on Teak Heartwood Quality in Mountainous Area

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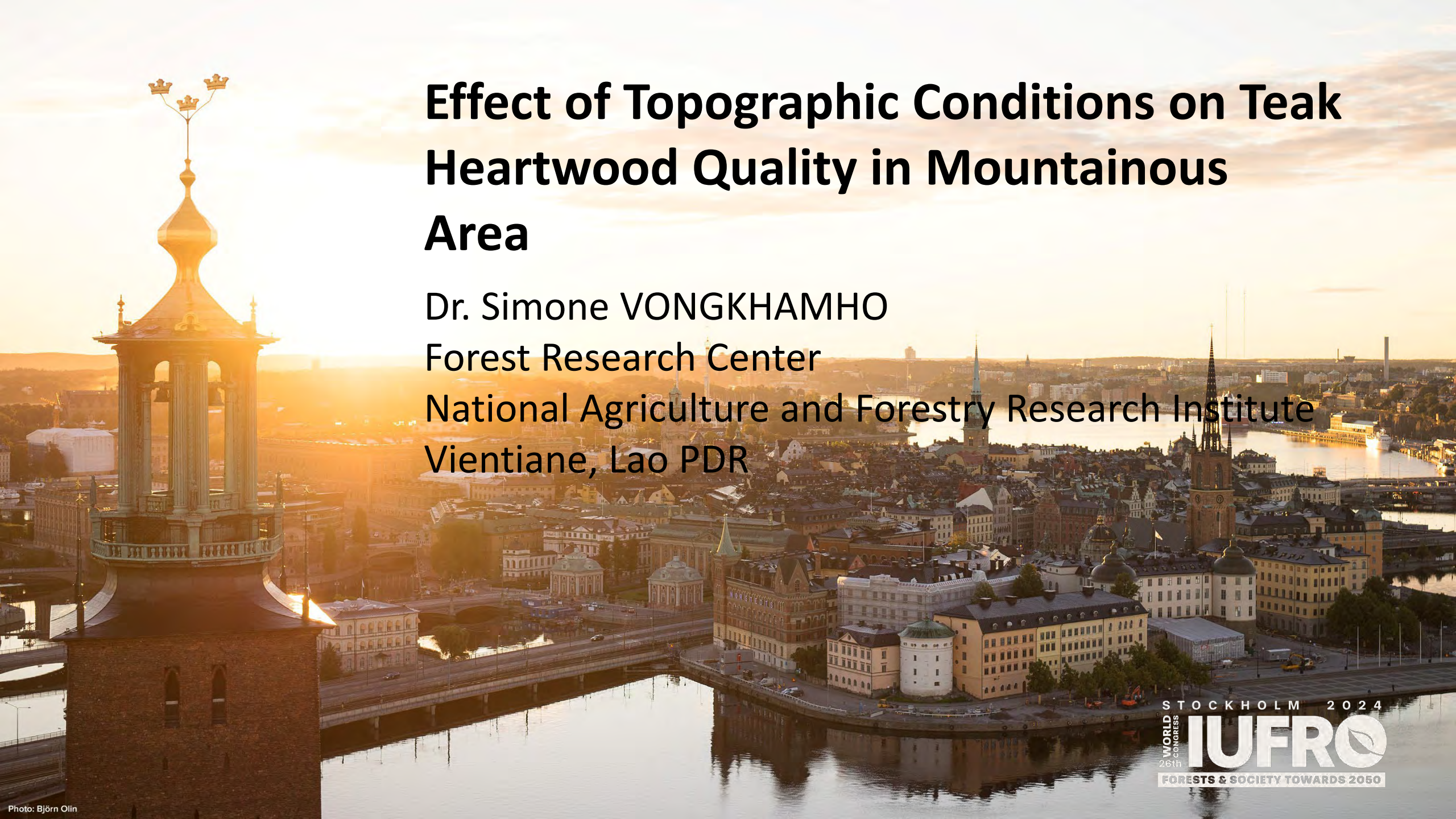

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1. Introduction

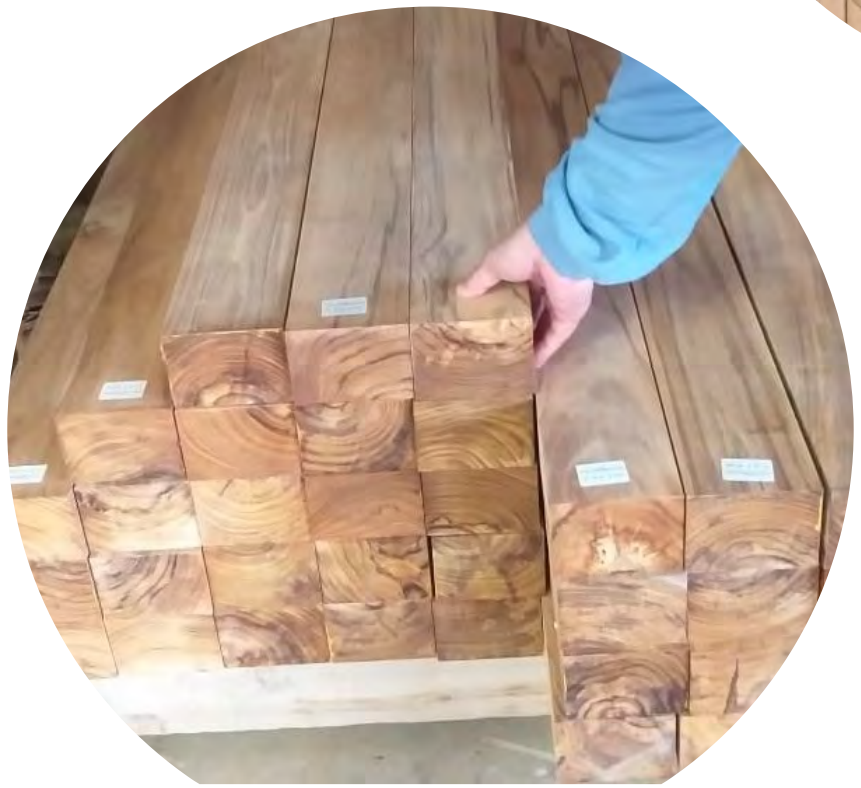
1.1. Teak

- Teak (*Tectona grandis L.f*) is a large tree up to 40 m tall and up 2 m in diameter and has a fast growth. Leaves are shed in the dry season. Teak is a light-demanding tree and grows in mixed deciduous forests with *Xylia xylocarpa*, *Lagerstroemia spp.*, *Afzelia xylocarpa*, *Pterocarpus macrocarpus* and bamboo. Flowering in May-August and fruiting is in December – April (Palanisamy et al., 2003).
- Teak is a native tree species in Asia, and it has a natural distribution area range from India, Myanmar, Thailand to northwestern Lao PDR (Kaosa-ard, 1989; Tanaka et al., 1998).

Natural teak forest in Northwestern Lao PDR
(Photo: FRC, March 2021)

1.2. Application of teak

- Teak is a globally commercial hardwood tree species. Teak wood exhibits a high timber quality owing to properties such as lightness with strength, stability, durability, resistance to termites and fungi, and high adaptability to environmental variations (Kaosa-ard, 1989; Hansen et al., 1997; Jerez et al., 2017).
- Hence, it is widely used in the building of both outdoor and indoor furniture, ships, decorative veneers, etc. (Thulasidas et al., 2006; Midgley et al., 2012, 2015). Due to these widespread applications, the production of high-quality timber with a high yield is essential for successful teak plantations



Teakwood processing factory in northern Lao PDR. The products export to Thailand

1.3. Distribution of teak

- Teak has been planted in a large diversity of site conditions inside and outside of its native area across 70 tropical countries for many centuries. In 2017, the teak plantation area grew up to 6.89 million hectares (Kollert et al., 2017).
- In the Lao People's Democratic Republic (PDR), teak has been planted since 1942 (Keonakone, 2005; Midgley, 2006). However, over the past decades planted teak had not been expanded until 1990s, government has strongly been promoted this species for rehabilitation purpose. In 2019, the total teak plantation area increased to 40,000 hectares (Pachas et al., 2019).

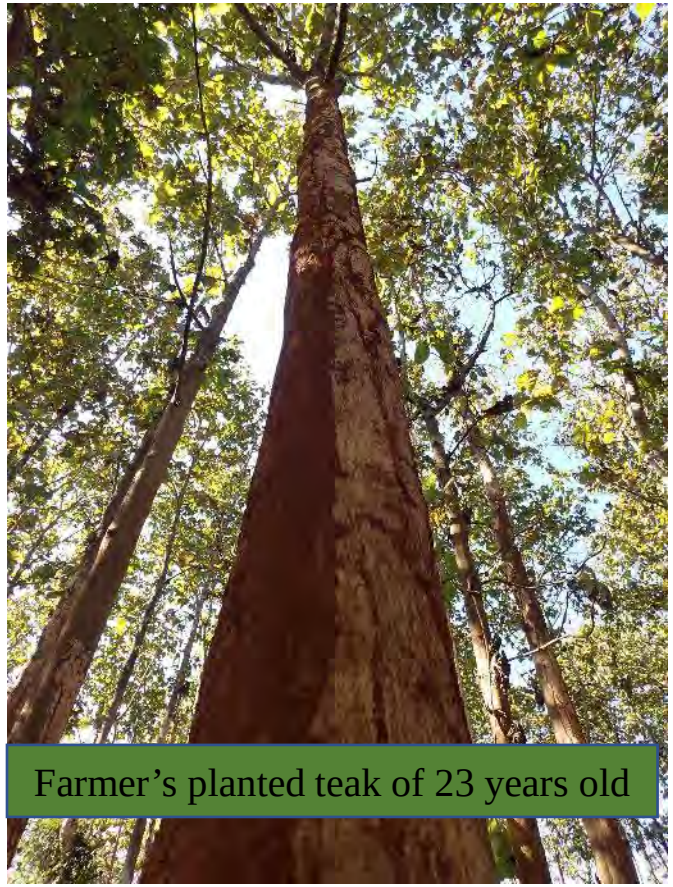
Mature Planted Teak Forest of 79 years old in southern Lao PDR (Photo: FRC, Jan. 2021)

1.4. Controlling factors of teak growth

- Teak growth and development is controlled by various factors, including genotypes (Kaosa-ard, 1989; Sreekanth et al., 2014), good silviculture practices (Perez et al., 2005; Pachas et al., 2019), and environmental factors (e.g., rainfall, temperature, and wind), geology, topography, soil, sunlight, and moisture (Tanaka et al., 1998; Kokutse et al., 2010).
- In general, soil-site conditions are significant factors influence the teak growth and development; for example, it has a good growth in fertilized soil with rich calcium contents, well-drainage soil interaction with gentle slope and bottom of valley (Tanaka et al., 1998; Watanabe et al., 2010).
- In Lao PDR, planted teaks have been established in various site conditions across the country; mountainous land in northern part, flat land in central and southern part and southern plateau land of Bolaven. However, northern part is covered a larger scale of planted teak shared 64% of total area (Phongoudome et al., 2012; Boer et al., 2016; Maraseni et al., 2018).

Mature teak plantation of 53 years in Luang Prabang province (Photo: Imaya, 2019

1.5. Problem



Farmer's planted teak of 23 years old

Heartwood (Hw) content, color, density and shrinkage

Teak timber quality

Tree quality

Tree Growth

Heartwood quality

What kind of effect?

Site and stand Characteristics

Tree Age & Silviculture

Environ-mental factors

Luang Prabang's Teak forest
(98% belong to farmers & private sector)

- High Stand density (1100 – 2500 tree ha^{-1})
- Insufficient management

- Soil Properties (large range of suitable soil for teak)
- Site characteristics

1.6. Previous study of teak in Lao PDR

- Although the government's strategy promoted the increase in teak plantation, the international price of Lao's teak timber has been low (ITTO, 2019), owing to the limited information available on the suitability of environmental conditions for teak plantation compared with Thailand (Tanaka et al., 1998; Sukchan et al., 2012) and Myanmar (Htoo et al., 2020).
- Over the past decades, many researcher had been studied on various matters of teak in Lao PDR; genetics (Keiding et al., 1986; Kjaer et al., 1995), silviculture manage techniques related to growth and yield of teak (Keonakone, 2005; Dieters et al., 2014; Pachas et al., 2019), and wood quality (Wanneng, 2019). These studies were not included to site condition variables. Therefore, the research on environmental factors influence teak timber quality in Lao PDR is very rarely

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1.7. Purpose of the study

This study aimed to determine the effect of site conditions on the growth and quality of teak in northern Laos through investigating the suitable site conditions for teak plantations in the north of Lao PDR. The specific objectives are: To investigate the effect of topographic conditions on teak heartwood quality in mountainous areas

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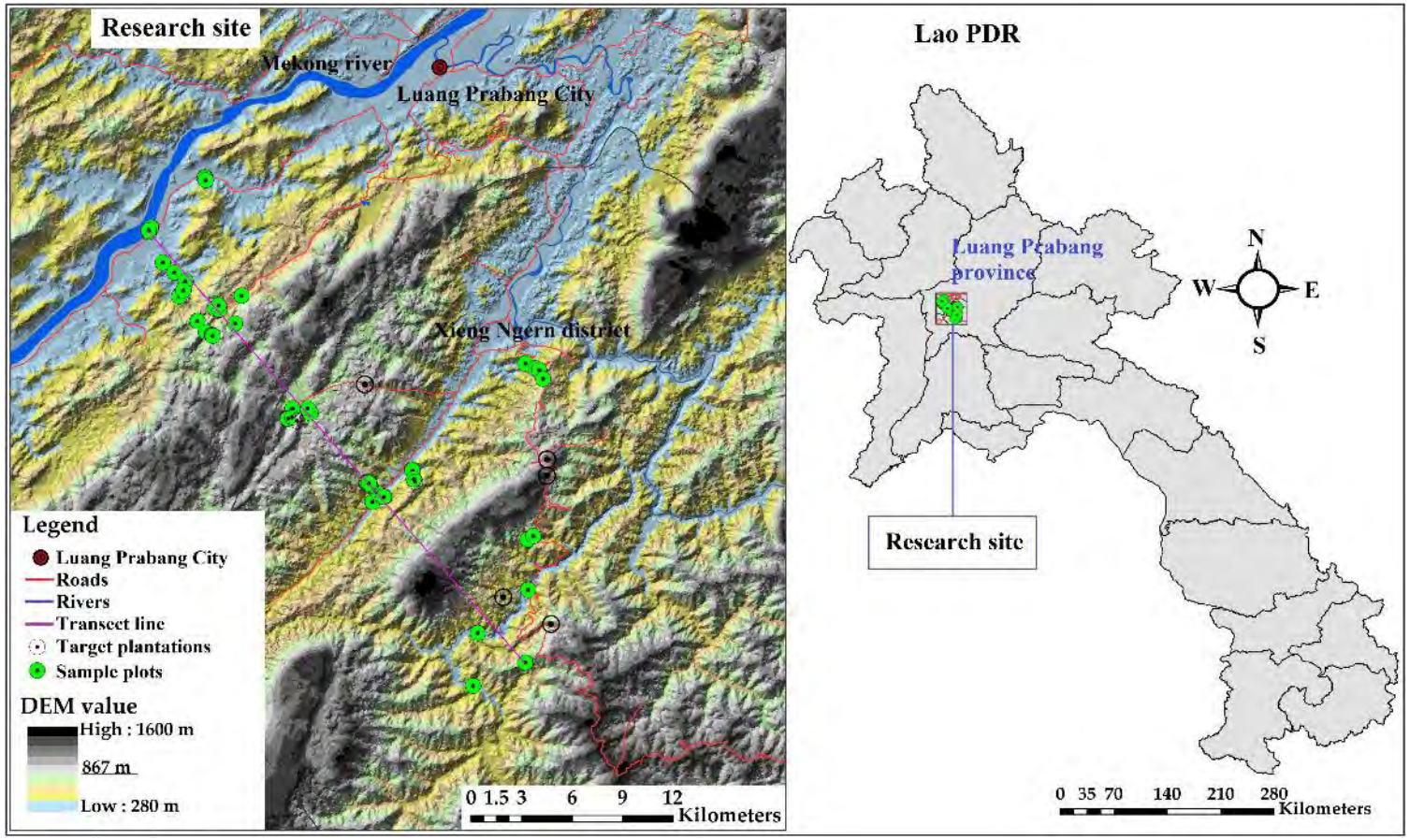
2. Research Area and Methodologies

2.1. Research site

- A 31-km transect line (pink color) was drawn, whereas 16 km west of Luang Prabang city. The line began from the flat land of Mekong riverside in the Thinxom village, Luang Prabang to the highland area of Kiewtaloun village in Xieng Ngern district.
- 61 individual plantations were targeted along a transect line, site elevation range from 287 to 1057 m.a.s.l.

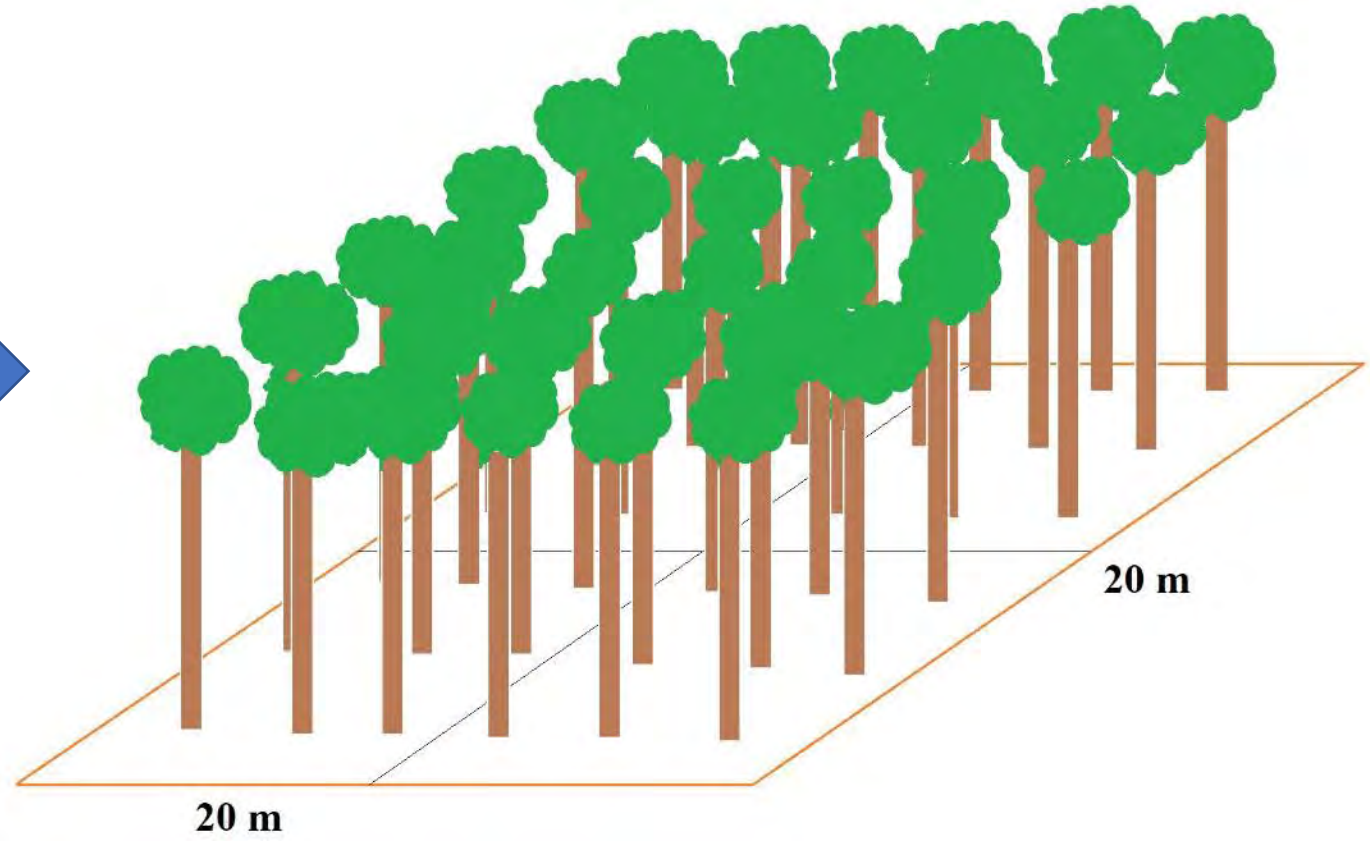
The research site is in a region with a tropical monsoon climate comprising two distinct seasons; The mean annual rainfall was **1628 mm; t**he mean annual temperature was **26.4 ⍰C** ; the average relative humidity was **79%.**



Map of research site

2.2. Temporary sample plots

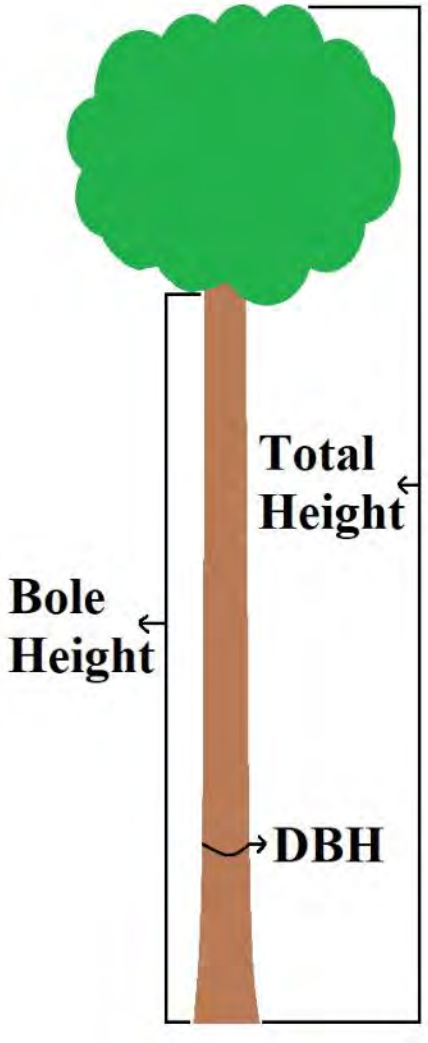
- For assessing the tree timber quality and tree age
- A plot is established in each target plantation.
- Plot area : 400 $\mathbf{m^2}$

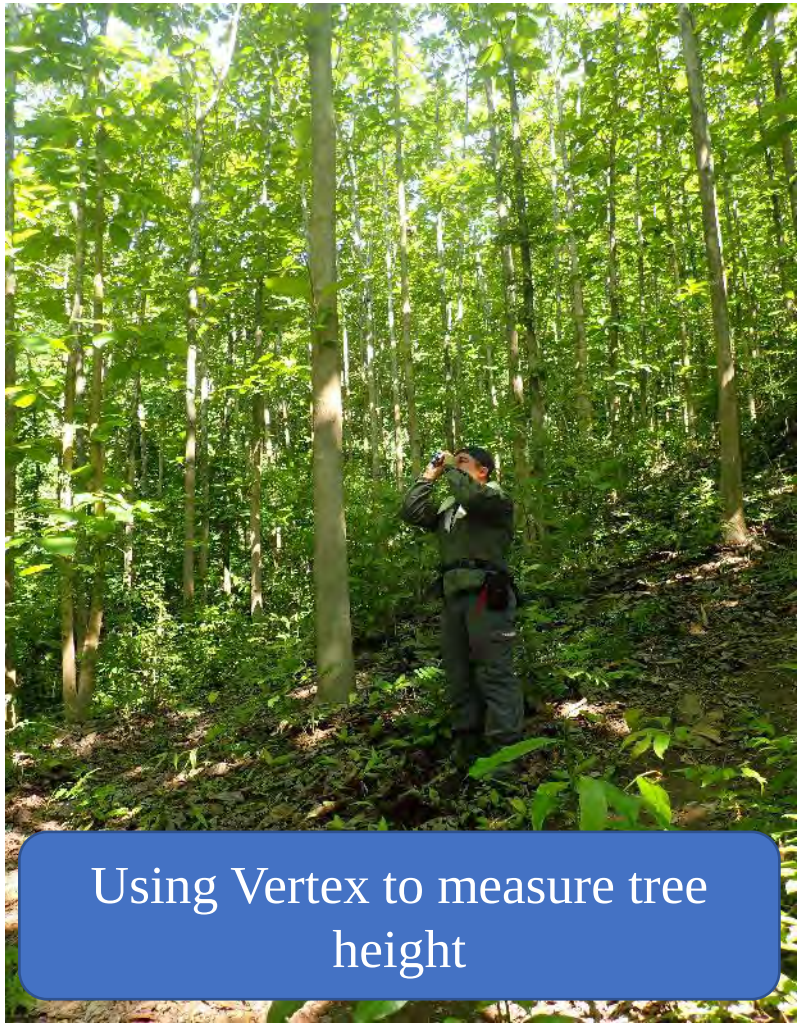


Plot size of 20 m x 20 m

2.3. Tree measurement

- The diameter at the breast height (DBH) was measured using a measuring tape.
- Total Height and Bole Height were measured using a height measurer (Vertex IV, Haglöf, Sweden)





Using Vertex to measure tree height

2.4. Plot sampling

- **49 sample plots** in total with **stand age > 10 years** old, **site elevation <900 m.a.s.l** and **without damages** in heartwood were selected from target plantations.

- **147 short log samples** obtained from the felled tree (three tree per plot) using for heartwood quality assessment.

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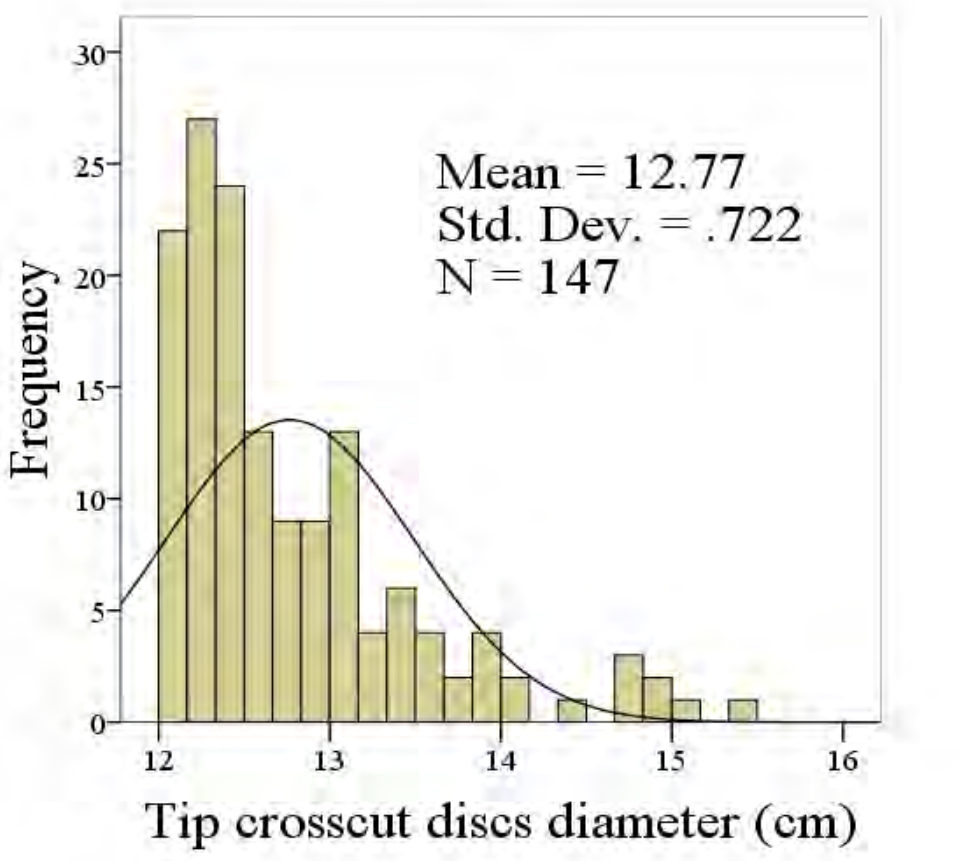
2.5. Assessing heartwood content

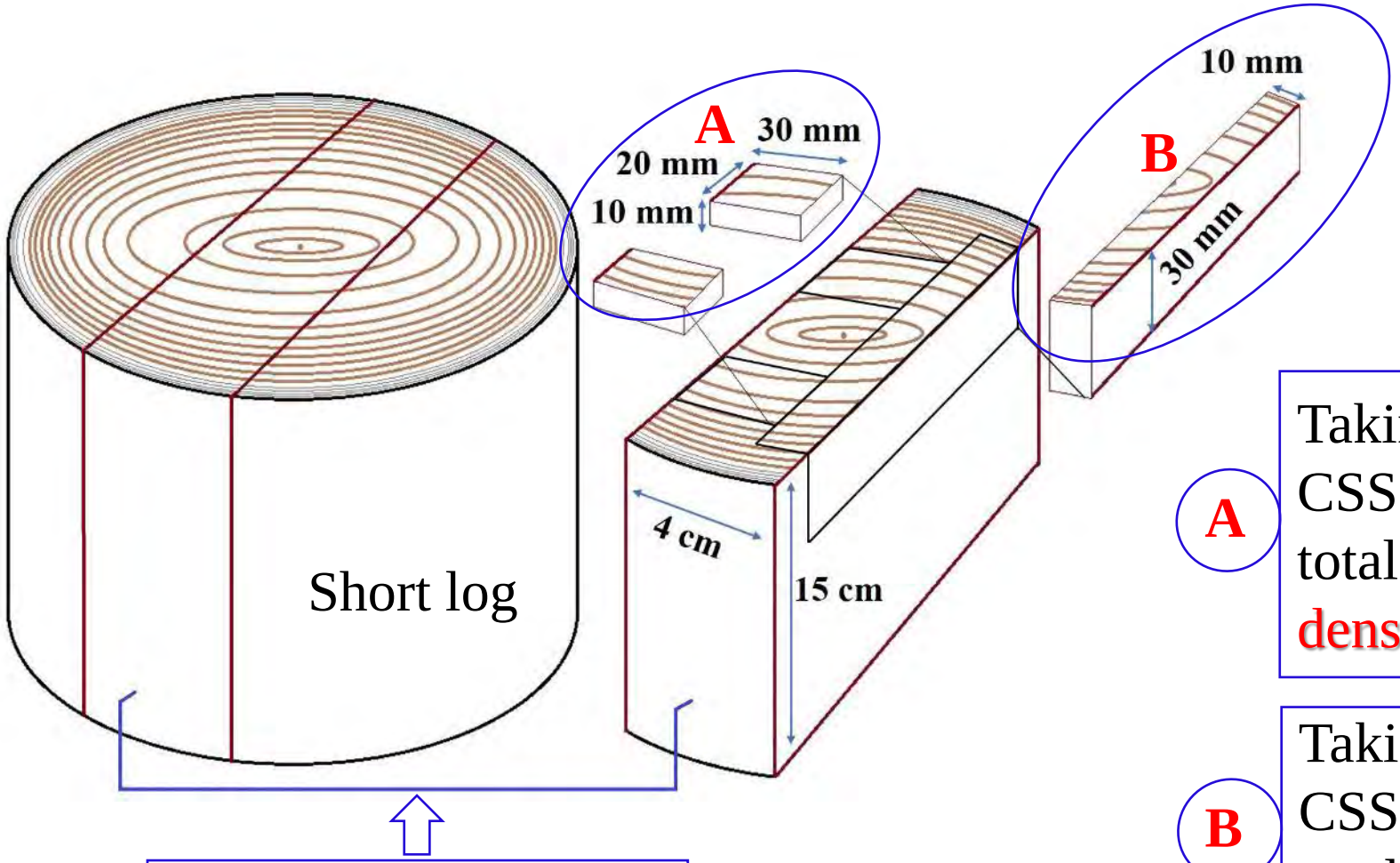


Frequency of tip crosscut discs size of ≥ 12 cm in diameter

- In Lao PDR, the marketable size of the teak is approximately ≥ 12 cm in diameter (Hopewell et al., 2014). In this study, we focus on examining the heartwood content of the commercial volume. A total of 1177 sample discs of ≥ 12 cm in diameter from 147 sample trees obtained from scanning photo file of the crosscut discs
- The selected disc photos were analysed using Imgviewer software to measure the radius of heartwood and stem from outer bark to pith in four directions: north, east, south, and west.
- Mean stem (under and over bark) and heartwood radius was obtained from four direction.
- Heartwood content was calculated using geometric formula (Tewari et al., 2013).

2.6 Assessing heartwood properties and color

a. Wood specimen preparation



147 cross-sectional samples (CSS)

A Taking 2 specimens from each CSS, having 294 specimens in total for measuring basic density and shrinkages

B Taking a specimen from each CSS, having 147 specimens in total for assessing heartwood color

b. Basic density and shrinkage measurement

Cleaning and Marking crosscut line on wood surface. Preparing the digital caliper and scales → Measuring the dimension and weight of green wood specimen → Air-drying the wood specimens at room temperature for a week → Measuring the dimension and weight of oven-dried wood specimens ← Oven-drying the wood specimen at 100°C within 24 hours

Basic density and shrinkages was calculated using following equation (Miranda et al., 2011):

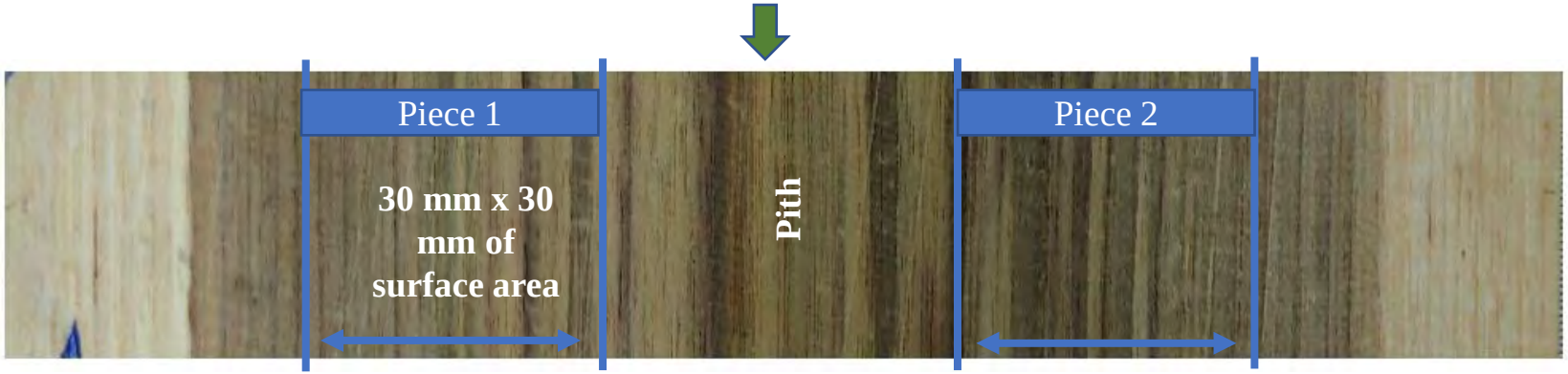
$$\text{Basic Density} = \frac{Oven\text{-}dry\ Weight\ (kg)}{Green\ volume\ (m^3)}$$

$$\text{Shrinkage} = \left(\frac{(Ls - Lo)}{Ls}\right) \text{x}100\%$$

Where *Ls* is green dimension;
Lo is oven-dry dimension

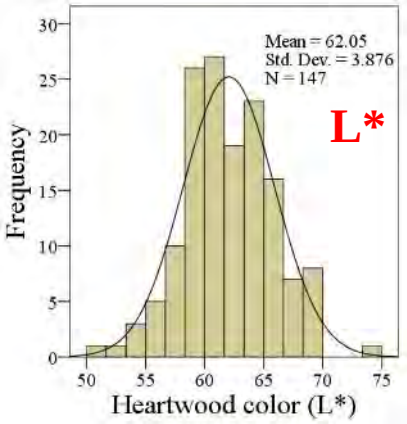
c. Heartwood color measurement

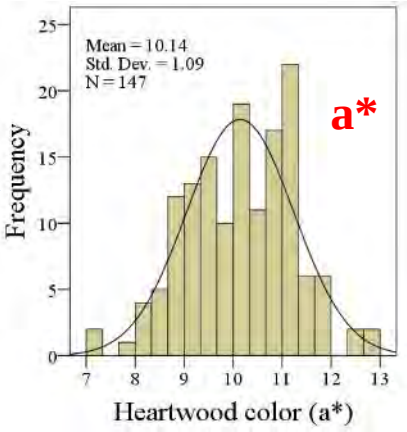
Air-drying 147 wood specimens for several weeks. Taking two pieces from each specimens using sharp shears one by one during measuring work

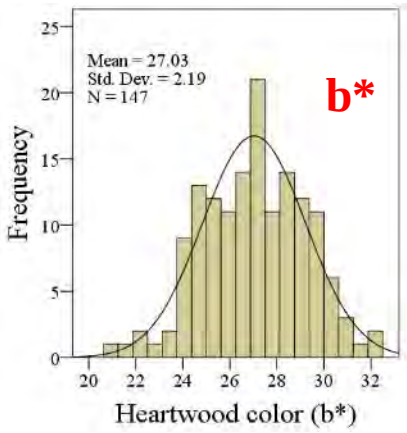


Measurement were performed by a portable spectrophotometer (NF-555, Nippon Denshoku; UV-3100pc, Shimadzu) with an opening diameter of 8 mm (NF-555) or 10 mm (UV-3100pc)with an opening diameter of 10 cm using CIELab color system; L* (Lightness), a* (redness), b* (yellowness) (Lukmandaru et al., 2009; Moya et al., 2012).

Histograms of heartwood color parameters; L*, a*, b*







2.7. Statistical analysis

Partial correlation analysis

- The statistical method for investigating the correlation between two variables after removing the effects of other variables.
- Helps us to reject spurious correlations (i.e., correlations explained by the effect of other variables) as well as to find hidden correlations.
- The spearman's partial rank correlation analysis using R version 4.0.3 (R core Team, 2020) with ppcor package (Kim, 2015) used to investigate the effect of site characteristics after removing the effect of stand characteristics.

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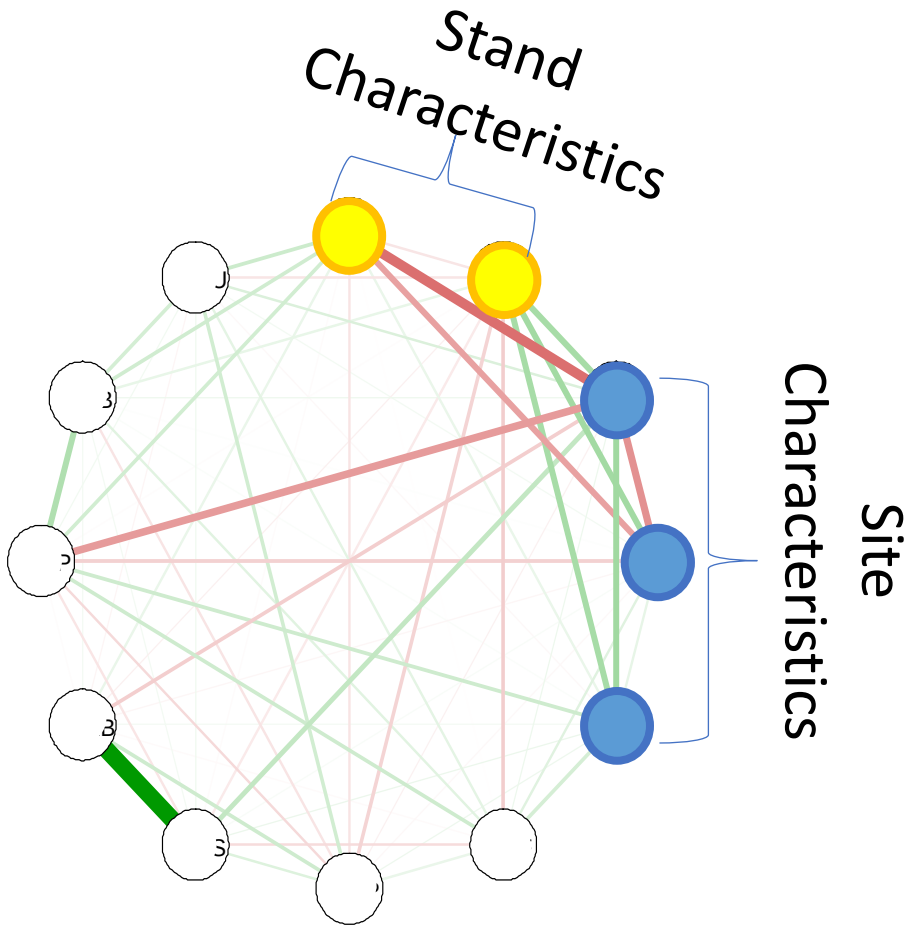
2.8. Statistical analysis (cont.)

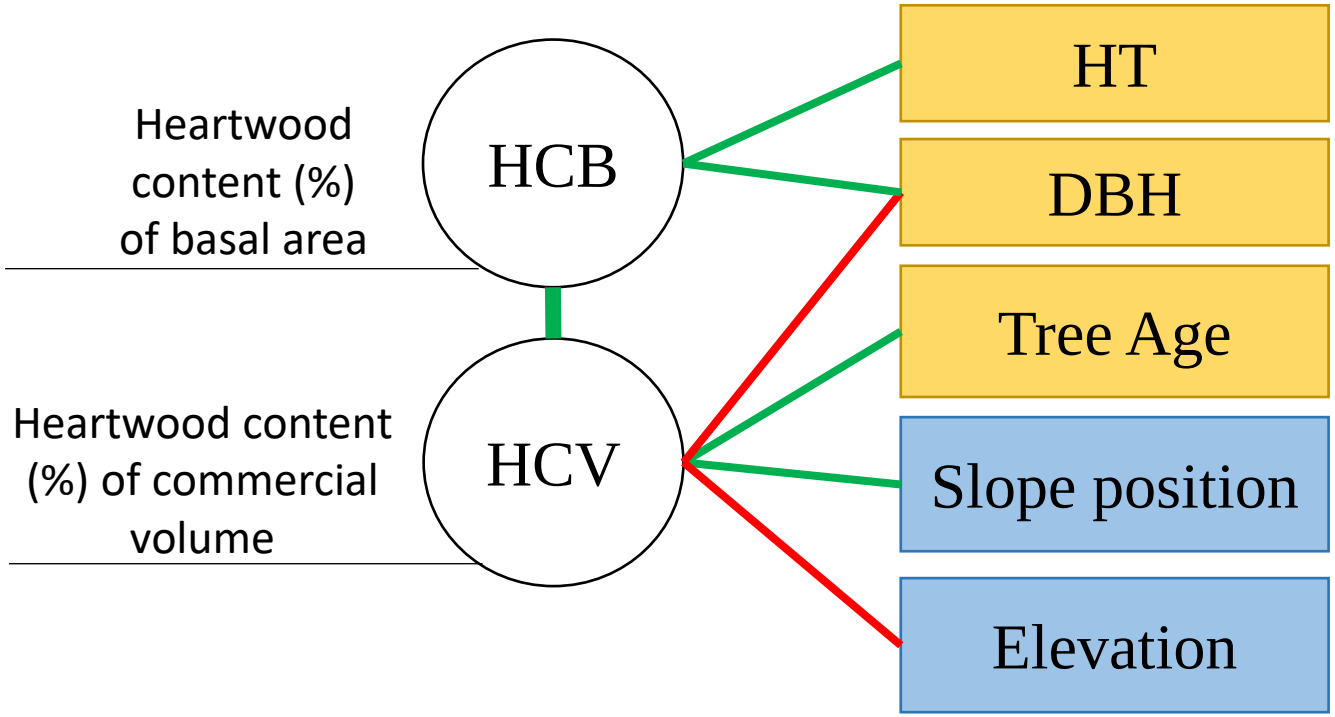
Partial rank correlation network diagram



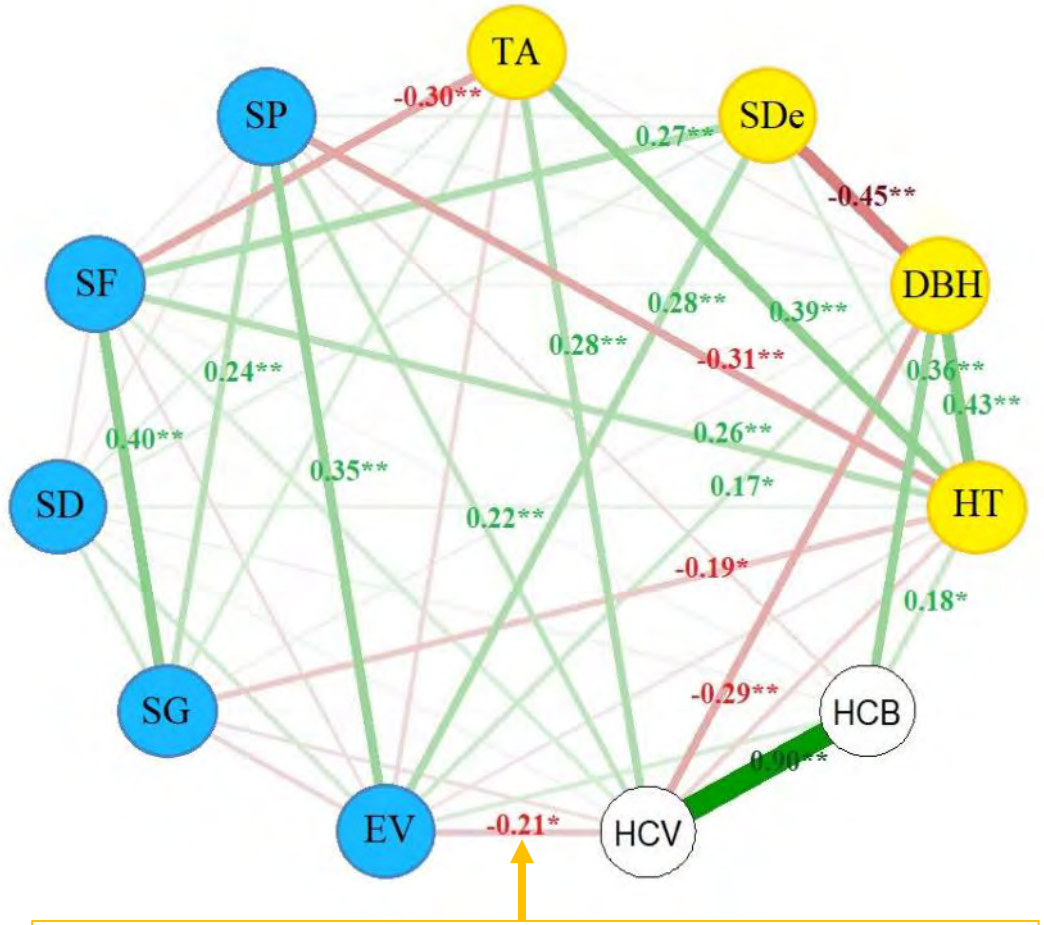
- The partial rank correlation network diagram using the qgraph package (Friedman et al., 2011) were used to investigate the effect of site characteristics after removing the effect of stand characteristics.
- Circle means a variable.
- Color of circle means type of variable.
- Color and width of line between two variables means positive (green) or negative (red) correlation and its strength.

3. Results

3.1. Heartwood content

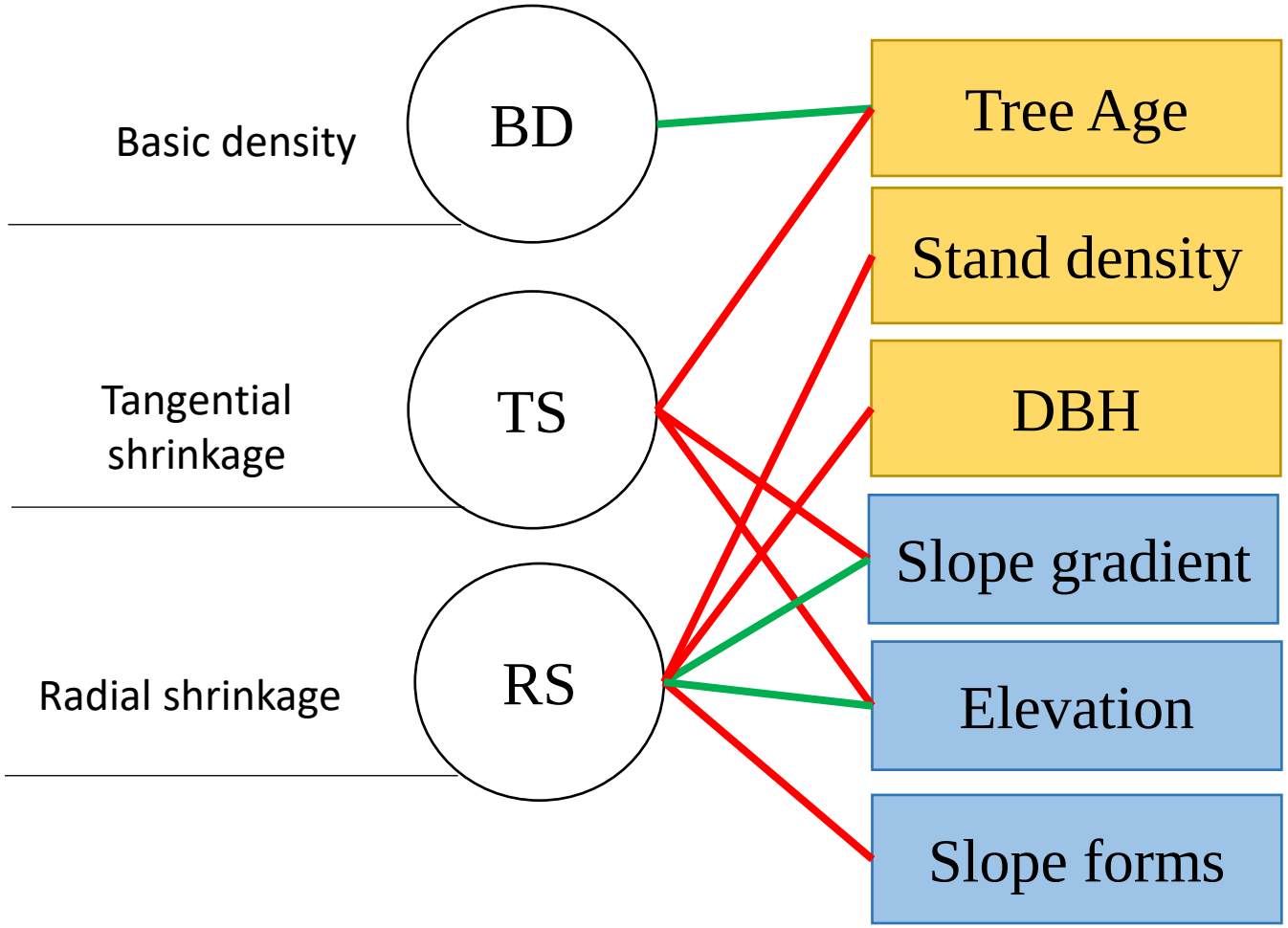


– Negative **✚ Positive**

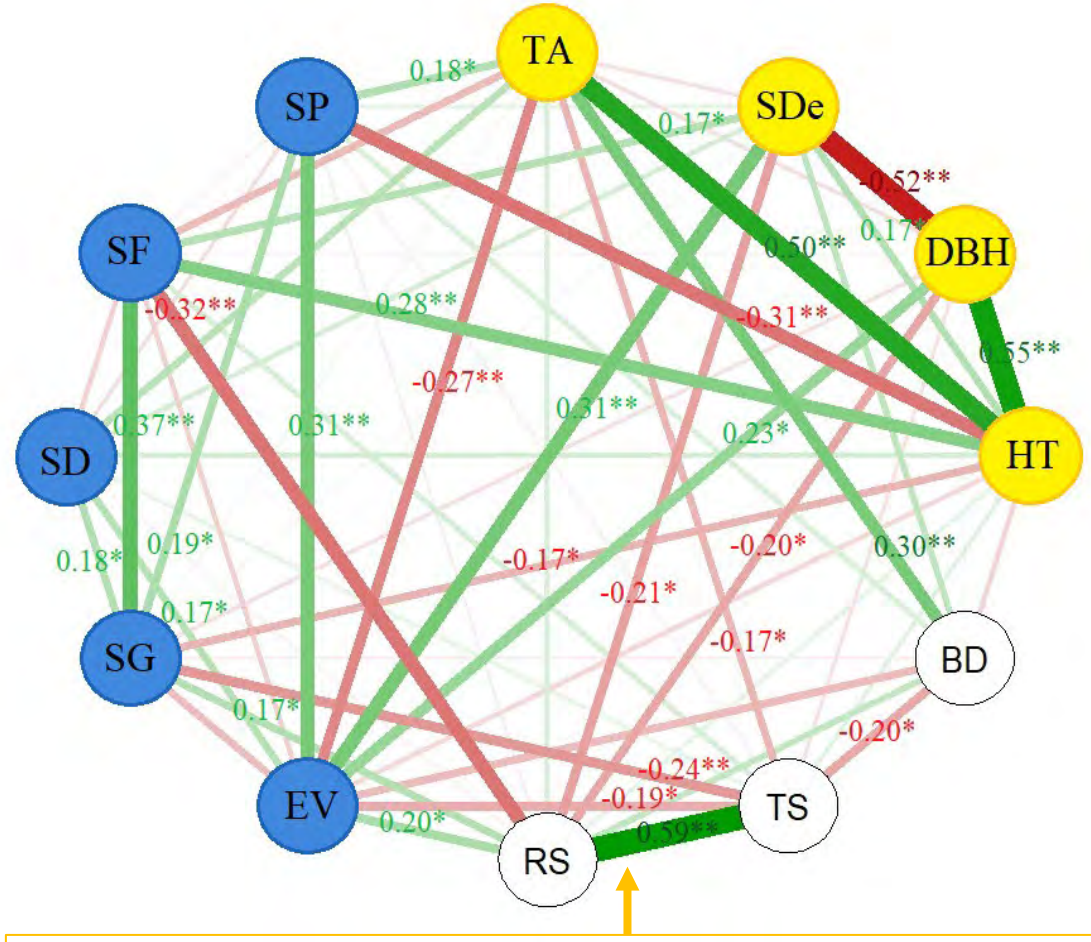


Partial correlation network between heartwood contents and topographic conditions. The letter shown in the white circles indicate heartwood content of basal area (HCB), heartwood content of commercial volume (HCV), variables of stand characteristics as tree age (TA); stand density (SDe); diameter at breast height (DBH); total height (HT), variables of topographic conditions as elevation (EV); slope gradient (SG); slope direction (SD); slope form (SF); slope positions (SP).

3.2 Heartwood properties

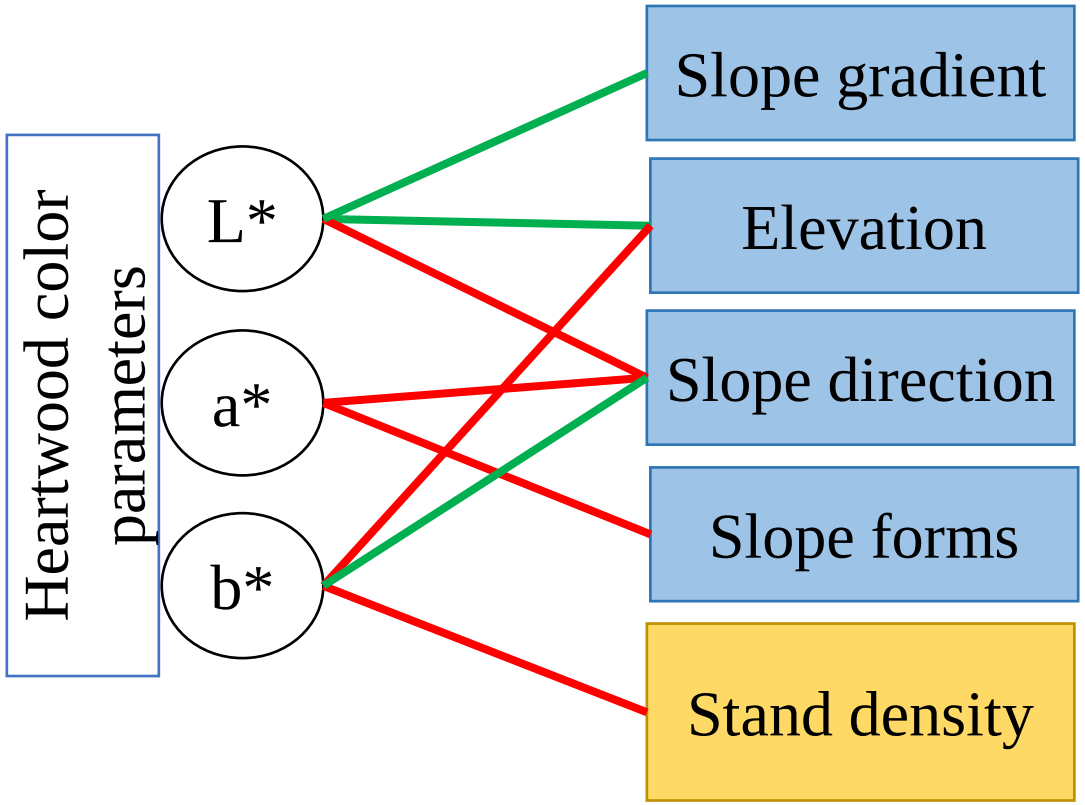


– Negative **+ Positive**

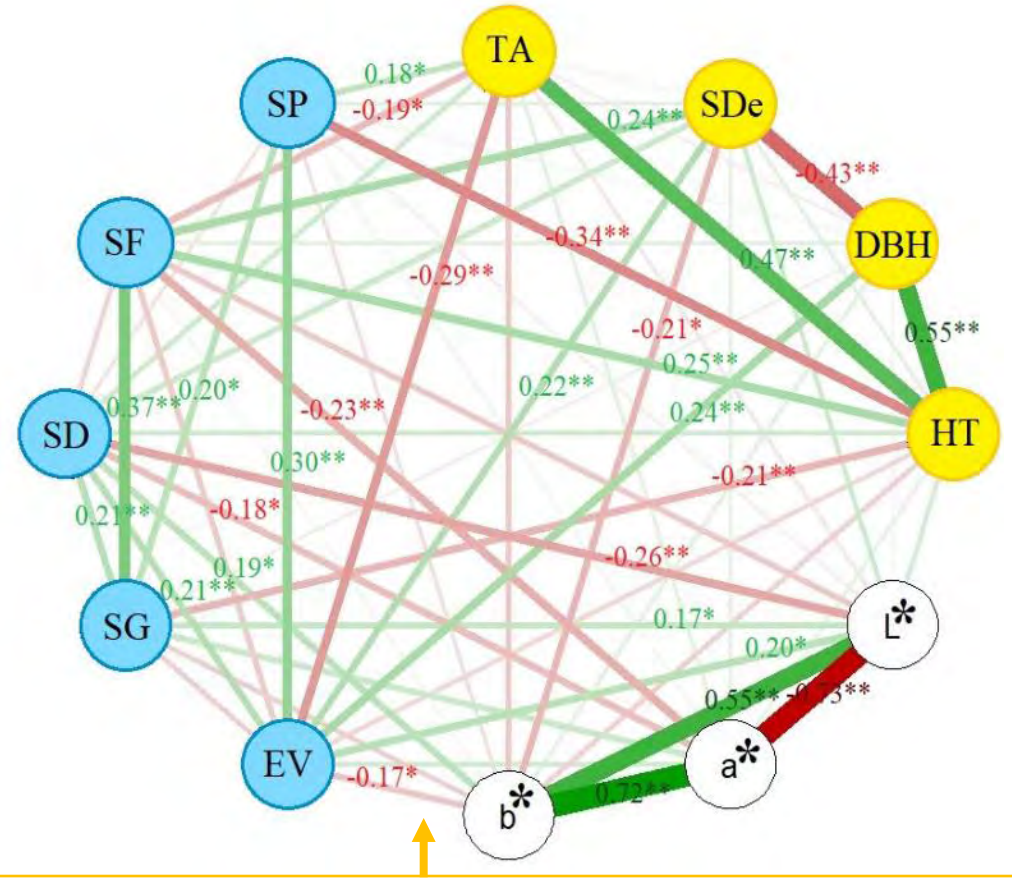


Partial correlation network between heartwood properties and topographic conditions. The letter shown in the circles indicate variables of heartwood properties as basic density (BD); tangential shrinkage (TS); radial shrinkage (RS), variables of stand characteristics as tree age (TA); stand density (SDe); diameter at breast height (DBH); total height (HT), variables of topographic conditions as elevation (EV); slope gradient (SG); slope direction (SD); slope form (SF); slope positions (SP)

3.3 Heartwood color



– Negative **+ Positive**

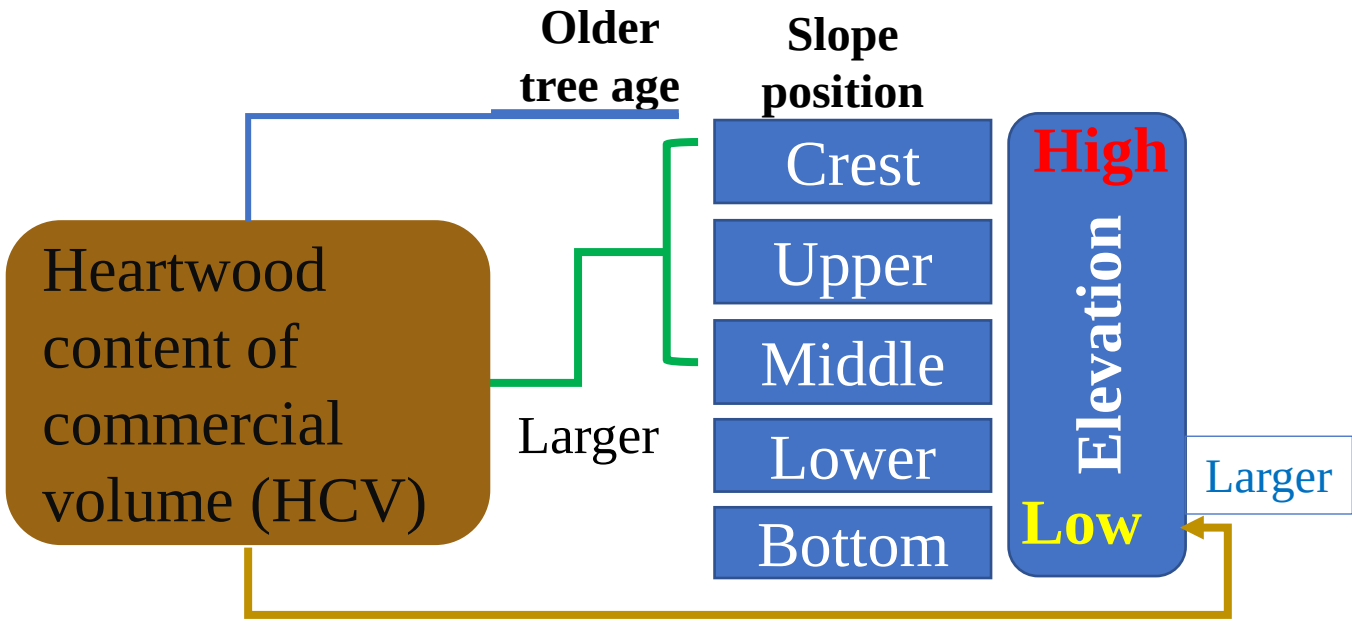


Partial correlation network between heartwood color and topographic conditions. The letter shown in the circles indicate variables of heartwood color as lightness (L*); redness (a*); yellowness (b*), variables of stand characteristics as tree age (TA); stand density (SDe); diameter at breast height (DBH); total height (HT), variables of topographic conditions as elevation (EV); slope gradient (SG); slope direction (SD); slope form (SF); slope positions (SP)

3.4. Discussion

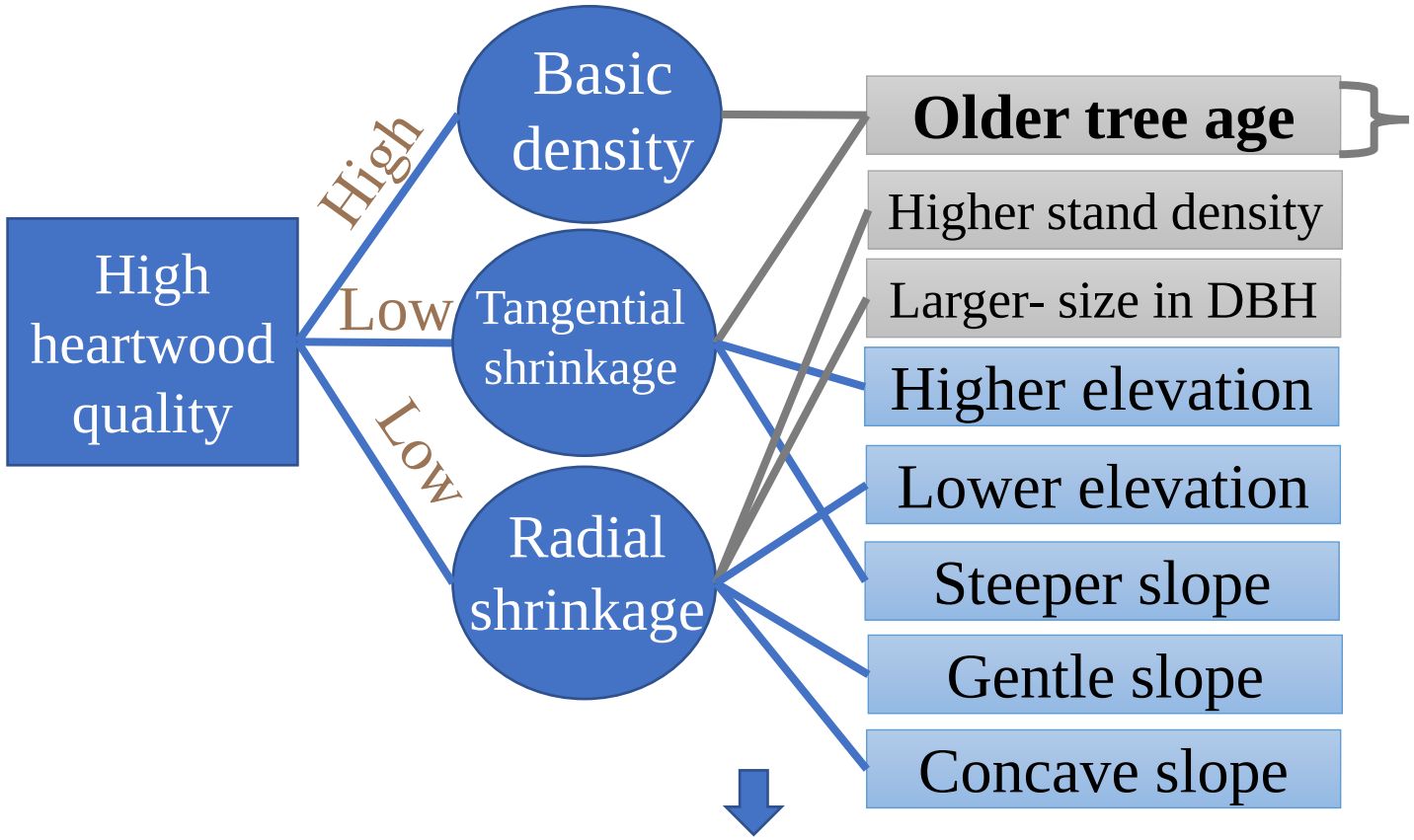
3.4.1. Heartwood content

Luang Prabang's teak plantation were commenced to establishing in the lower site elevation, then expand to higher elevation; teak tree ages showed significant negative correlation with elevation, while slope position was positive.



Teak has a faster growth with larger size at bottom site and lower gentle slope (Kolmert, 2001; Vaides et al., 2019); due to higher soil moisture content (Watanabe, 2010). Heartwood content increase with tree age and stem diameter (Kokutse et al., 2004), larger-size tree produced higher heartwood content (Perez et al., 2005). However, Heartwood content had a larger proportion in dry sites than wet sites (Cordero et al., 2003). Those author's previous findings were consistent with this present results as shows in right-hand side figure).

3.4.2 Heartwood properties

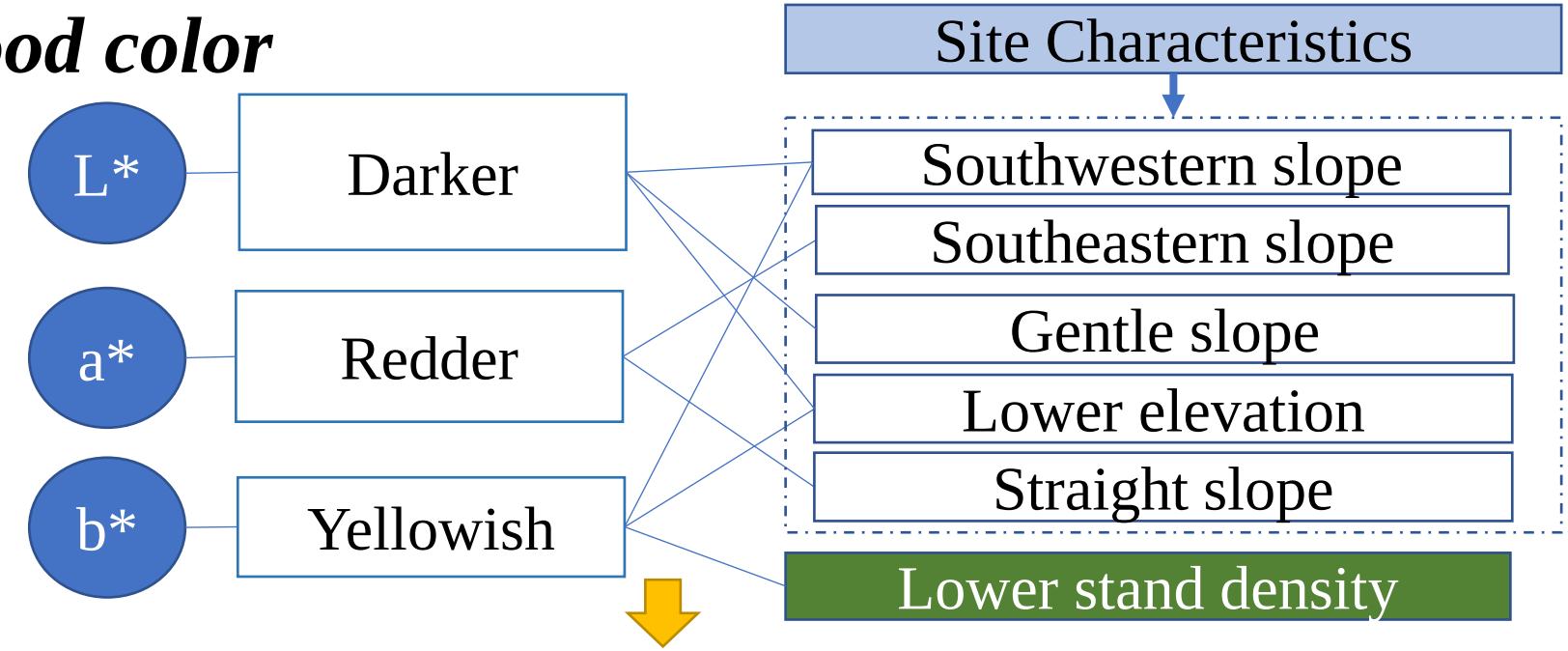


Tangential and radial shrinkage had most correlated with soil characteristic variables such as phosphorus, silt content, iron content (Moya et al., 2008).

- Similar results had been reported that wood basic density had higher at high stocking plantation, and its increasing with tree age and stem diameter (Moya et al., 2003; Perez et al., 2003; Rizanti et al., 2018).
- However, this study showed stand density and DBH had no relationship with tree age because the teak had established with narrow spacing with thinning and pruning was uncommon

Our result disagreed with Wanneng et al., 2014 who reported that wood density, and shrinkages of different ages (10 to 25 years old) had no significance, this may cause by limited wood samples of 9 trees in their study.

3.4.3 Heartwood color



Derkyi et al., 2009 reported that environmental factors had a stronger effect on the teak heartwood color than the stand age, especially soil pH decreased moderately with increasing darkness in Ghana. Moreover, teak heartwood being darker in wetter areas that drier ones. In addition, yellowish brown color of heartwood was produced more at drier and fertile sites in Costa Rica (Moya et al., 2012)

In Luang Prabang province, soil pH distributed in flat, gentle and slope area has no significant differences (Kolmert, 2001). Therefore, present study showed that teak heartwood had a darker at lower elevations might be affect by wet-soil conditions and soil properties.

4. summary

Heartwood content of basal area (HCB) mainly increase with tree size. However, it had slightly affected by topographic conditions. Heartwood content of commercial volume (HCV) increase with tree age, having a greater proportion in middle to upper slope.

Lower shrinkage with higher BD means better wood properties. Therefore, the analysis results suggest that that teak's heartwood properties; basic density and tangential shrinkage has an increasing quality with tree age, steeper slope, while radial shrinkage had a greater quality at gentle concave slope, whereas lower elevation might be affected by soil condition factors.

Teak heartwood color; Darker color (low L*) associated with the south-west facing gentle slope in lower elevation. Redder color (high a*) showed a relationship with south-east facing straight slope. Yellowish (high b*) has higher value at south-west facing slope in lower elevation and lower stand density.

Could you please giving me learn your valuable comments and suggestions!

Thank you very much for your attention

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