Population dynamics and regeneration of *Shorea roxburghii*, a threatened timber species in Southern region, Viet Nam

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**Abstract.** Bao TQ, Viet LH, Hai NH, Tuan NT, Cuong LV. 2021. Population dynamics and regeneration of *Shorea roxburghii*, a threatened timber species in Southern region, Viet Nam. *Biodiversitas* 22: 5649-5656. Despite its wide distribution in South and Southeast Asia, *Shorea roxburghii* G. Don is classified as Vulnerable in the IUCN Red List of Threatened Species due to over-exploitation for its valuable timber. This study aims to investigate the population dynamics and regeneration of *S. roxburghii* in southeastern Vietnam, serving for conservation and sustainable development plan. Six plots of 2,500 m² each (50 m x 50 m) were established at two forest conditions: i) forest with standing volume > 200 m³/ha (SV>200), and ii) < 200 m³/ha (SV<200); to investigate stems with diameter at breast height (DBH) ≥ 5 cm and that < 5 cm. Moisture (%), pH of the topsoil and the occurrence of regenerating *S. roxburghii* were collected from 125 points in the study site. The results indicated that mean stem height, DBH, basal area, and aboveground biomass were significantly higher at the forest stand with SV>200 than that at the forest stand with SV<200 for the pool of all species. Similar higher figures were found in SV>200 for the pool of *S. roxburghii* compared to that in SV<200, except mean DBH, which was larger in SV<200. There were missing stems with DBH < 5 cm in SV<200, while it was numerous in SV>200 (1,313 stems/ha). DBH/stem distributions in both forest types had an inverted-J shape with a peak at 10-15 cm DBH for the pool of all species, while there was no clear pattern for the pool of *S. roxburghii* in both forest types. Regression analysis indicated that higher total crown area of stems ≥ 23 tall leads to higher *S. roxburghii* stems, while the higher total crown area of stems < 23 tall leads to fewer *S. roxburghii* stems with DBH < 5 cm. It is concluded that the total crown area of forest stand plays an important role in the sustainable regeneration of *S. roxburghii*. Silvicultural treatment should be applied to reduce stand density and crown area of stems < 23 m tall to enhance sunlight reaching the forest floor for germination, growth, and survival of *S. roxburghii*. The moisture of the topsoil ranging from 60 - 80% and the pH ranging from 3.8 - 4.6 are suitable conditions for natural regeneration of *S. roxburghii*.

**Keywords:** Forest structure, population dynamics, regeneration, *Shorea roxburghii*

**INTRODUCTION**

*Shorea roxburghii* G. Don, is a commercially valuable timber species from Dipterocarpaceae family. This species has natural distribution in South and Southeast Asia, including India, Myanmar, Thailand, Malaysia, Cambodia, Laos, Vietnam (Ang et al. 2016; Basuuni et al. 2019; Maimunah et al. 2019; Tamilselvan et al. 2021). This species is predominantly found in evergreen, deciduous forests, and even bamboo forests (Le et al. 2020). *S. roxburghii* is a semi-deciduous tree that can grow up to 40 m tall at maturity. The species has an economic significance as it is used as valuable commercial timber and as ‘white meranti’ in many countries of the Southeastern Asia region (Anonymous 1985). For example, it is used for building materials (Pande 2008), local medicines (Morikawa et al. 2012; Subramanian et al. 2013), methanol extract (Morikawa et al. 2012). Besides, thirteen stilbenoids and bioactive constituents were isolated from *S. roxburghii* (Moriyama et al. 2016; Ninomiya et al. 2017).

Because of highly commercial timber and medicinal values, natural populations of *S. roxburghii* had reduced remarkably, leading to Vulnerable status by IUCN (Pooma et al. 2014). This situation is worsened since Dipterocarps, *S. roxburghii* is not flowering annually (i.e. mast flowering and fruiting phenomenon), while it has annual leaf shedding. Once they are fruiting, healthy seeds germinate as soon as they reach the forest floor (Raju et al. 2011), suggesting that their seeds are recalcitrant. Therefore, soil moisture and canopy openness significantly affect the seedlings’ growth, survival, and density (Islam et al. 2016). In this regard, understanding the autecology and population dynamics of *S. roxburghii* is essential for conservation purposes and sustainable management plans.

Sustainable forest management is a major factor in maintaining forest biodiversity (Khuc et al. 2018; Paillet et al. 2010) and population dynamics (Hai et al. 2020; Tran et al. 2011). Population dynamics of any timber species (Tran et al. 2019b; Tran et al. 2010) are represented by three stem layers of seedlings (height ≤ 2 m), saplings (diameter at breast height/DBH < 5 cm, and height > 2 m), and trees (DBH ≥ 5 cm). The balance of individuals among three groups in reducing the order of seedlings > saplings > trees
ensures the sustainable development of the species (Tran et al. 2019b; Tripathi et al. 2007). Meanwhile, stand structure plays a central role in the survival and growth of seedlings and saplings (Tran et al. 2016). Enhancing regeneration of the dominant tree species is a primal condition for sustainable natural forest management (Tran et al. 2016). The establishment, survival, and growth in the natural forest differ among species, depending on its ecological characteristics (Swaine and Whitmore 1988) as plants are categorized as pioneer/light-demanding group, shade-tolerant group, and shade-intolerant group. Thus, understanding the population dynamics and regeneration of S. roxburghii is necessary to conserve this species in South Vietnam evergreen forests. Two main questions will be addressed: i) How are the population structure, regeneration characteristics and aboveground biomass of stems of S. roxburghii at two conditions with different standing volumes (i.e. $> 200$ m$^3$/ha (stable forest) versus $< 200$ m$^3$/ha) (unstable forest)? ii) How do the main ecological factors affect the occurrence probability of S. roxburghii regeneration?

MATERIALS AND METHODS

Study area
Field experiments were conducted in Tan Phu Protection Forest, Dong Nai Province, Southeastern region, Vietnam (N11°08'55"-11°51'30", E106°90'73"-107°23'74") (Fig. 1). The study area has a tropical monsoon climate when the rainy season usually occurs on May to November and the dry season occurs from December to April. The mean annual temperature is 25°C (21.9°C in December and 35.1°C in April, respectively), and the average annual precipitation is 2100 mm (most rainfall occurs from June to October). Annual mean humidity is 80%, and annual average total sunshine time is 2500-2700 hours. The soil type is grey, developed on granite rocks, and has a soil depth of over 100 cm. The is sandy loam in texture with pH (H$_2$O) of 3.8-4.6 (Tran et al. 2019a). The vegetation in the study site is predominated by evergreen broadleaved forests on a lower slope (below 120 m elevation). Most forests in the research region have experienced anthropogenic disturbances by selective logging, leading to the current status of secondary forests.

Data collection
Forests in the study site were classified into two conditions based on standing volume, namely: 1) standing volume $> 200$ m$^3$/ha named as SV>200; and 2) standing volume $< 200$ m$^3$/ha named as SV<200. In each forest condition, main representative plots (four in SV>200 and two in SV<200) of 2,500 m$^2$ (50 m × 50 m) were established. In each main plot, five sub-plots of 16 m$^2$ (4 m × 4 m) were further set in four corners and the central. In the main plots, all stems with DBH ≥ 5 cm were identified to species and measured for DBH (cm), stem height (m), and crown diameter (CR:m). These stems were known as the tree group. In the sub-plots, all stems with DBH < 5 cm were identified to species and measured for stem height, known as an adjacent group.

Moisture (%) and pH$_{H_2O}$ of the topsoil (0-30 cm) were determined by a Soil Integrated Sensor (Soil pH & Moisture Tester, Model DM-15) at 125 random sites 1 m$^2$ (1 m × 1 m) in the study area. At each site, we identified the occurrence of S. roxburghii regeneration (presence as 1; absence as 0). All Shorea roxburghii trees with DBH ≤ 5 cm were divided into two height classes ($H_1 ≤ 100$ cm; $H_2 > 100$ cm).
Figure 1. Map of experimental plots in Tan Phu protection forest, Dong Nai, South Vietnam

Data analysis

Stem basal area (G), crown area (CA), and aboveground biomass (AGB), and standing volume (SV) were estimated for each stem separately. The G, CA, AGB, and SV were defined as in the following equation (Hinh 2012; Huy et al. 2016):

\[ CA = \frac{2.14 \times CR^2}{4} \]  
\[ AGB = 0.12843 \times DBH^{1.409074} \]  
\[ SV = G \times H \times 0.42 \]

where: CR, crown diameter (m); G, stem basal area (m²); DBH, diameter at breast height (cm); CA, crown area (m²); AGB, aboveground biomass (Mg); SV, standing volume (m³); H, stem height (m).

The parameters about density, basal area and Importance Value Index (IVI%) were calculated as below:

Density (d) = number of trees (n_i) per unit area (trees. ha\(^{-1}\))

Basal area (G) = \( \pi \times r^2 = \pi \times \frac{dbh^2}{4} \) (m²)

IVI (%) = (Relative density + Relative Basal area+ Relative volume)/3

where: \( dbh \) = diameter at breast height and \( r \) = radius.

Relative basal area and volume were the total basal area (G) and volume (SV) of species i as a percent of all species.

Spearman's rank correlation coefficient was used to separately test correlations between CA and stem density for each forest type. Besides, we used the nonparametric Mann-Whitney U-test to compare the stand parameters between two forest types.

Gaussian logit regression was used to model the occurrence probability of \( S. \ roxburghii \) regeneration in each forest condition corresponding to topsoil moisture (X₁) and pH\(_{2O} \) (X₂). A quadratic term in logistic regression is being used because species occurrence probabilities often do not show monotonic patterns and have a modal peak (Krishnadas et al. 2021).

\[ \text{Logit}(P/1-P) = b_0 + b_1 \times X_1 - b_2 \times X_1^2 \]  

Where \( P \) = occurrence probability of the \( S. \ roxburghii \) regeneration for two hight classes (H₁ ≤ 100 cm; H₂ > 100 cm), \( X_i \) = X₁ and X₂.

Then analyze function (7) to determine ecological parameters such as ecological optimum (U_i), ecological tolerance (T_i), ecological range (U_i ± 4T_i) and P\(_{\text{Max}}\) (with i = 1-2, two hight classes). Four parameters U_i, T_i, U_i ± 4T_i and P\(_{\text{Max}}\) are determined by function (8)-(11). The combined effect of two variables X₁ and X₂ on the natural regeneration of \( S. \ roxburghii \) was analyzed by multivariable Gaussian logit regression (function 12).

\[ \text{Ecological optimum } U_i = \frac{b_1}{2b_2} \]  
\[ \text{Ecological tolerance } T_i = \frac{1}{\sqrt{2b_2}} \]  
\[ \text{Ecological range } U_i \pm 4T_i \]  
\[ P_{\text{Max}} = \frac{\exp (b_0 + b_1 U_i - b_2 U_i^2)}{1 + \exp (b_0 + b_1 U_i - b_2 U_i^2)} \]  
\[ \text{Logit}(P/1 - P) = b_0 + b_1X_1 - b_2X_1^2 + b_3X_2 - b_4X_2^2 + b_5X_1X_2 \]

All statistical analyses, based on a significant level of \( p<0.05 \), were conducted using SAS 9.2 (SAS Institute Inc.,
RESULTS AND DISCUSSION

Population dynamics of Shorea roxburghii

A total of 92 tree species was recorded in the habitat of S. roxburghii in Tan Phu protection forest. The species richness in stable and unstable forests was 64 species and 61 species, respectively (Tables 1 and 2).

Table 1. The top ten species having the highest Importance Value Index (IVI) of the forest with standing volume > 200 m³ ha⁻¹

| Species                  | Density (trees) | Basal area (m²) | Volume (m³) | Percent (%) | Relative density | Relative basal area | Relative volume | IVI |
|--------------------------|-----------------|-----------------|-------------|-------------|------------------|--------------------|-----------------|-----|
| Shorea roxburghii G. Don | 177             | 8.4             | 76.16       | 26.9        | 30.1             | 30.7               | 29.2            | 1   |
| Parinari anamensis Hance | 31              | 3.38            | 32.86       | 4.7         | 12.1             | 13.2               | 10              | 1   |
| Syzygium zeylanicum (L.) DC. | 50             | 2.57            | 23.21       | 7.6         | 9.2              | 9.3                | 8.7             | 2   |
| Vatica odorata (Griff.) Symington | 38         | 1.5             | 14.63       | 5.8         | 5.4              | 5.9                | 5.7             | 3   |
| Irvingia malayana Oliv. ex A.W.Benn. | 11       | 1.23            | 13.06       | 1.8         | 4.4              | 5.3                | 4               | 4   |
| Anisoptera costata Korth. | 14             | 1.19            | 11.49       | 2.1         | 4.3              | 4.6                | 3.7             | 5   |
| Knema globularia (Lam.) Warb. | 31             | 0.95            | 7.24        | 4.7         | 3.4              | 2.9                | 3.7             | 6   |
| Dalbergia cochinchinensis Pierre | 25       | 0.85            | 6.74        | 3.8         | 3                | 2.7                | 3.2             | 7   |
| Grewia tomentosa Juss. | 20              | 0.48            | 3.75        | 3           | 1.7              | 1.5                | 2.1             | 8   |
| Xylopia vielana Pierre | 21              | 0.45            | 3.42        | 3.2         | 1.6              | 1.4                | 2.1             | 9   |
| Total of 10 species | 418              | 21              | 192.56      | 63.6        | 75.2             | 77.5               | 72.4            | 10  |
| Others (54 species) | 241              | 6.9             | 55.7        | 36.4        | 24.8             | 22.5               | 27.6            | 11  |
| All | 659              | 27.9            | 248.3       | 100         | 100              | 100                | 100             | 12  |

Table 2. The top ten species having the highest Importance Value Index (IVI) of the forest with standing volume < 200 m³ ha⁻¹

| Species                  | Density (trees) | Basal area (m²) | Volume (m³) | Percent (%) | Relative density | Relative basal area | Relative volume | IVI |
|--------------------------|-----------------|-----------------|-------------|-------------|------------------|--------------------|-----------------|-----|
| Shorea roxburghii G. Don | 143             | 6.31            | 56.55       | 17.9        | 30.2             | 32.3               | 26.8            | 1   |
| Syzygium zeylanicum (L.) DC. | 130            | 2.65            | 21.69       | 16.3        | 12.7             | 12.4               | 13.8            | 2   |
| Anisoptera costata Korth. | 45              | 1.94            | 17.25       | 5.6         | 9.3              | 9.8                | 8.3             | 3   |
| Parinari anamensis Hance | 27              | 1               | 8.83        | 3.4         | 4.8              | 5                  | 4.4             | 4   |
| Vatica odorata (Griff.) Symington | 47         | 0.62            | 4           | 6           | 3.1              | 2.8                | 4               | 5   |
| Diospyros lancefolia Roxb. | 48              | 0.42            | 2.34        | 6           | 2                | 1.3                | 3.1             | 6   |
| Goniothalamus gabriacianus (Baill.) | 25          | 0.58            | 4.12        | 3.1         | 2.8              | 2.4                | 2.8             | 7   |
| Lophophelatum wightianum Arn. | 25             | 0.5             | 3.77        | 3.1         | 2.4              | 2.2                | 2.6             | 8   |
| Xylopia vielana Pierre | 19              | 0.55            | 4.61        | 2.4         | 2.6              | 2.6                | 2.5             | 9   |
| Calophyllum calaba L. | 11              | 0.51            | 4.67        | 1.4         | 2.4              | 2.7                | 2.2             | 10  |
| Total of 10 species | 520              | 15.08           | 127.83      | 65.2        | 72.3             | 73.5               | 70.5            | 11  |
| Others (51 species) | 279              | 5.88            | 47.32       | 34.8        | 27.7             | 26.5               | 29.5            | 12  |
| All | 799              | 20.96           | 175.15      | 100         | 100              | 100                | 100             | 13  |

Based on the IVI obtained, Shorea roxburghii had the highest IVI (29.2%) followed by the Parinari anamensis (10%), Syzygium zeylanicum (8.7%). Vatica odorata (5%) in stable forest (Table 1). At unstable forest, Shorea roxburghii had the highest IVI (26.8%) followed by Syzygium zeylanicum (13.8%) and Anisoptera costata (8.3%) (Table 2). Tree density in the stable forest was lower (659 trees ha⁻¹) than that in the unstable forest (789 trees ha⁻¹).

For the pool of all species, the number of species, stems, and total CA at a 2500 m² plot were not different between the two forest sites (Table 3). However, the differences of other parameters including mean H, DBH, G, SV, and AGB were significantly different, indicating the higher figures in the stand with > 200 m³ ha⁻¹ standing volume (SV>200) compared to stand with < 200 m³ ha⁻¹ standing volume (SV<200).

For the pool of S. roxburghii, the mean H was not different between two forest sites (Table 3). While the differences between two forest sites in stem density, mean DBH, G, SV, AGB and total CA were statistically significant. Mean DBH was larger in SV<200 (38 cm) compared to that in SV>200 (27.1 cm). While other parameters were higher in SV>200 compared to that in SV<200. S. roxburghii stems with DBH < 5 cm were not found in SV<200, while that were 1313 stems/ha in SV>200.

For the pool of all species, 66.4% stems belonged to height classes of 9-19 m in SV>200 (Fig. 2a), and 76.7% stems belonged to height classes of 9-17 m in SV<200 (Fig. 2b). While 62.9% CA belonged to height classes of 17-27 m in SV>200, and 67.7% CA belonged to height classes of 9-21 m in SV<200.
For the pool of *S. roxburghii*, stems < 5 m height were not found and 77.1% stems belonged to height classes of 9-21 m in SV<200 (Fig. 2g), while 90.1% stems belonged to height classes of < 5 m in SV>200 (Fig. 2e). In both forest conditions, more than 80% of the CA belonged to height classes of > 13 m (Fig. 2f, h).

Both forest conditions had DBH/stem distributions of inverted-J shape by the reduction of stems in larger DBH with a peak at 10-15 cm DBH (Fig. 3a, b) for the pool of all species. At the same time, there were no clear patterns of DBH/stem distribution for the pool of *S. roxburghii* (Fig. 3c, d). The stems appeared in all DBH classes in SV>200 (Fig. 3c), while in SV<200 (Fig. 2d), there were missing stems in DBH classes of 25-30 cm and 50-65 cm.

Regressions between the stand total crown area and stems of *S. roxburghii* (DBH<5 cm) existed (Fig. 4). Negative linear was best fitted for the relationship between stand total CA of < 23 m tall stems and stems of *S. roxburghii* (Fig. 4a), while positive linear was best fit for the relationship between stand total CA of > 23 m tall stems and stems of *S. roxburghii* (Fig. 4b).

### Table 3. Comparison of stand parameters (±SE) between two forest conditions with different standing volume

| Stand parameters | Stand with standing volume > 200 m³/ha | Stand with standing volume < 200 m³/ha |
|------------------|----------------------------------------|----------------------------------------|
| A                |                                        |                                        |
| Species number/2,500 m² | 38 ±4                                  | 36 ±4                                  |
| Stems/2,500 m²   | 161 ±8                                 | 188 ±36                                |
| Mean height (m)  | 15.6 ±0.5b                             | 11.9 ±0.5b                             |
| Mean DBH (cm)    | 20.9 ±0.9b                             | 16.1 ±0.2b                             |
| Basal area (m²/2,500 m³) | 8.1 ±0.6b                   | 5.6 ±0.6b                             |
| Standing volume (m³/2,500 m³)   | 72.8 ±7.2b                              | 39.2 ±4.6b                             |
| Aboveground biomass (Mg/2,500 m³) | 59.9 ±5.0b                       | 38.4 ±1.7b                             |
| Crown area (m²/2,500 m³)        | 11,569 ±602                             | 9,284 ±1,374                           |

| B                |                                        |                                        |
| Species number/2,500 m² | 34 ±5a                                  | 17 ±13b                                |
| Stems/2,500 m²   | 17.9 ±1.6                              | 17.7 ±3.1                              |
| Mean height (m)  | 27.1 ±3.6a                             | 38.0 ±16.4b                           |
| Mean DBH (cm)    | 2.7 ±0.9a                               | 1.3 ±0.3b                              |
| Basal area (m²/2,500 m³) | 26.6 ±9.4a                        | 11.4 ±2.5b                            |
| Standing volume (m³/2,500 m³)   | 20.7 ±7.0b                               | 10.4 ±1.8b                           |
| Aboveground biomass (Mg/2,500 m³) | 3,230 ±778a                        | 1,273 ±603b                           |
| Crown area (m²/2,500 m³)        | 3,230 ±778a                             | 1,273 ±603b                           |

Note: Different letters a, b in a line indicates a significant means difference between two forest sites at p: 0.05; H: stem height; DBH: diameter at breast height; G: basal stem area; SV: standing volume; AGB: aboveground biomass; CA: crown area

### Figure 2. (A, B, E, F) Height/stem and height/crown area distributions in the forest with standing volume > 200 m³ ha⁻¹ and (C, D, G, H) stand with standing volume < 200 m³ ha⁻¹ (A, B, C, D) for the pool of all species and (E, F, G, H) the pool of *Shorea roxburghii*. Error bars show the standard deviation (SD)
Figure 3. (A, C) DBH/stem distribution at the forest stand with standing volume >200 m$^3$ ha$^{-1}$ and (B, D) forest stand with standing volume <200 m$^3$ ha$^{-1}$ (a, b) for the pool of all species and (c, d) the pool of Shorea roxburghii. Error bars show the standard deviation (SD).

Figure 4. Linear regression between Shorea roxburghii stems (DBH < 5 cm) and stand CA of all < 23 m tall stems (A), and between S. roxburghii stems (DBH < 5 cm) and stand crown area of all ≥ 23 m tall stems (B).

The occurrence probability of Shorea roxburghii regeneration
Statistical analyzes showed that the occurrence probability of S. roxburghii regeneration (P$X$) at 2 height classes (H < 100 cm; H > 100 cm) and 2 topsoil factors ($X_1$ = moisture %, $X_2$ = pH$_{H2O}$) had significant effects with $r^2$ = 17.2-28.1% and P < 0.001 (Tables 4 and 5).

The ecological parameters for topsoil moisture and pH$_{H2O}$ (ecological optimum, range and tolerance) for natural regeneration of the S. roxburghii population were calculated using equations (13-18) (Tables 5). The regeneration of S. roxburghii at the H < 100 cm and H > 100 cm have similar moisture and pH$_{H2O}$ requirements in the topsoil. In both height classes, the optimum topsoil
moisture requirement is 70.0% with an ecological range of 61-80% and tolerance range of 32-100%. The optimum pH\textsubscript{H2O} requirement is 4.0 with an ecological range of 3.8-4.6 and tolerance range 2.6-5.9.

The combined effect of topsoil moisture and pH\textsubscript{H2O} on the natural regeneration of S. roxburghii was analyzed by multivariable Gaussian logit regression.

Statistical analysis shows that the combination of two factors (X\textsubscript{1} = moisture and X\textsubscript{2} = pH\textsubscript{H2O}) affects the occurrence probability of S. roxburghii regeneration. Three multivariable Gaussian logit regression models (Table 6) are statistically significant at P < 0.001. The coefficient b\textsubscript{5} of the three models are statistically significant at P < 0.05, and less than 0, meaning that there is an inverse relationship between topsoil moisture and pH\textsubscript{H2O} and S. roxburghii regeneration. In another word, when topsoil moisture and pH\textsubscript{H2O} increase, the abundance of S. roxburghii regeneration decrease, and vice versa.

### Table 4. The occurrence probability of S. roxburghii regeneration as the effect of topsoil moisture and pH

| Function | Hight class (cm) | Regression coefficients | \( r^2 \)(%) | \( P_x \) |
|----------|------------------|-------------------------|----------------|---------|
| * Effect of topsoil moisture | (13) < 100 | -26,15040 | 0,82563 | -0,00593 | 27,8 | <0,001 |
| (14) > 100 | -22,88920 | 0,72173 | -0,00514 | 21,8 | <0,001 |
| (15) All light | -23,90340 | 0,75075 | -0,00532 | 22,6 | <0,001 |
| * Effect of topsoil pH\textsubscript{H2O} | (16) < 100 | -44,1541 | 23,3147 | -2,9098 | 28,1 | <0,001 |
| (17) > 100 | -34,8796 | 18,4250 | -2,2833 | 19,6 | <0,001 |
| (18) All light | -49,9936 | 24,5884 | -2,9037 | 17,2 | <0,001 |

Note: *Model: \( P = \exp(b_0 + b_1X_1 - b_2X_2^2)/(1 + \exp(b_0 + b_1X_1 - b_2X_2^2)) \)

### Table 5. Ecological optimum, tolerance and range of S. roxburghii regeneration at two height classes

| Functions | Height class (cm) | \( U \pm T \) | Parameters(\%) : \( U \pm 4T \) | \( P_{max} \) |
|-----------|------------------|----------------|-----------------------------|----------|
| * Topsoil moisture (%) | 19 < 100 | 69.7 | 9.2 | 61-79 | 33-100 | 0,9312 |
| 20 > 100 | 70.2 | 9.9 | 60-80 | 31-100 | 0,9210 |
| 21 All | 70.5 | 9.7 | 61-80 | 32-100 | 0,9290 |
| * Topsoil pH\textsubscript{H2O} | 22 < 100 | 4.0 | 0.4 | 3.6-4.4 | 2.3-5.7 | 0,9197 |
| 23 > 100 | 4.0 | 0.5 | 3.6-4.5 | 2.2-5.9 | 0,9027 |
| 24 All | 4.2 | 0.4 | 3.8-4.6 | 2.6-5.9 | 0,8865 |

Note: *U = ecological optimum; \( U \pm T = \) ecological range; \( U \pm 4T = \) ecological tolerance

### Table 6. The occurrence probability of S. roxburghii regeneration corresponding to by topsoil moisture and pH\textsubscript{H2O}

| Regression coefficients | Hight class (m) | All |
|-------------------------|----------------|-----|
| \( b_0 \) | -10,29370 | 2,12125 | -6,68005 |
| \( b_1 \) | 5,05212 | 6,66595 | 6,33450 |
| \( b_2 \) | 0,11412 | 0,14333 | 0,13543 |
| \( b_3 \) | -83,33940 | -118,196 | -108,549 |
| \( b_4 \) | 57,57400 | 75,2791 | 71,0934 |
| \( R^2 \) | -5,31272 | -6,78114 | -6,42935 |
| \( P_x \) (Model) | < 0,001 | < 0,001 | < 0,001 |
| \( P_{b5} \) (bs coefficient) | 0,0427 | 0,0072 | 0,0112 |

Note: (*) Model: Logit\( P(1 - P) = b_0 + b_1X_1 - b_2X_1^2 + b_3X_2 - b_4X_2^2 + b_5X_1X_2 \)

### Discussion

The timber of S. roxburghii is highly commercial valuable; therefore it is targeted by illegal loggers (Tran et al. 2018). Illegal logging of S. roxburghii may considerably reduce the carbon stock of the forest in the studied site as this species accounts for 34.5% AGB in SV>200 and 27% in SV<200. Even the AGB of S. roxburghii is probably underestimated as wood density was not considered in estimation (Chave et al. 2005). The existence of S. roxburghii in the forest plays an important role in biodiversity and carbon storage against global warming and climate change.

A larger mean DBH of S. roxburghii in SV<200 (38 cm) compared to that in SV>200 (27.1 cm; Table 1) was found in the present study. This could be explained by the more numerous stems of different DBH classes, especially in small classes (Fig. 3c) in SV>200. The fewer stems in small DBH classes in SV<200 (Fig. 3d) resulted from missing stems in < 5 cm DBH (Fig. 2g). Such missing may lead to difficulty for the regeneration and long-term management of S. roxburghii in SV<200 stands (Paillet et al. 2010). In addition, the missing stems in DBH classes of 50-65 cm (Fig. 3d) in SV>200 may result from illegal logging, as loggers prefer good quality stems of desirable sizes for their ability to transport timber out of the forest (Tran et al. 2018). Therefore, even stems with > 65 cm DBH were available, they are in bad stem form, rotted timber, and low commercial value.

S. roxburghii was one of the trees with the largest DBH and tallest species on the study site. It forms an emergent and main canopy layer in both forest types. The similarity was also found in other forests (Raju et al. 2011; Tran et al.
Large and adult stems of *S. roxburghii* were found in both forest types (Table 1). At the same time, *S. roxburghii* has winged fruits, which can be dispersed by wind (Raju et al. 2011; Tran et al. 2019a). Therefore, seed rain is available in both forest types. However, small-sized stems of *S. roxburghii* were not found in SV<200. This could be explained by the inability of seed germination from the stem and crown structure (Fig. 2 a, b, c, d). In SV<200, 92.4% crown area (34,000 m²/ha) focused on 5-23 m tall stems, compared to only 63.4% (29,000 m²/ha) in SV>200. Crown area in < 23 m tall stems blocked most sunlight reaching the forest floor, reducing seed germination and causing the immediate death of just-germinated seed in SV<200. The missing small-sized stems of *S. roxburghii* in SV<200 may also result from other unknown reasons. Therefore, further searching for such a phenomenon is necessary (Maury-Lechon et al. 1998).

Crown structure in the present study forest was classified into two groups vertically: one with stems of < 23 m tall and the other with stems of ≥ 23 m tall. Total crown area and arrangement in each group control sunlight to penetrate to the lower layer and then forest floor (Ådjers et al. 1995), affecting natural germination, survival, and growth of seedlings and saplings of all species including *S. roxburghii* (Tran et al. 2019b). The effects of these two groups on *S. roxburghii* stems of < 5 cm DBH were both negative and positive (Fig. 4). The higher crown area of 5-23 m tall stems with many layers (Fig. 1b, d) and numerous stems (Fig. 2a, c) blocked sunlight reaching the forest floor (Tran et al. 2018). Therefore, it reduces the density of *S. roxburghii* stems of < 5 cm DBH, which are generally < 5 m tall. While the higher crown area of ≥ 23 m tall stems with fewer layers (Fig. 2b, d) and stems (Fig. 2a, c) will not fully block sunlight other than control it to more suitable intensity for small-sized stems in the lower canopy, leading to higher stem density of *S. roxburghii* (Fig. 4b).

To conclude, the present study results indicated the population dynamics and stand structure of *S. roxburghii* in two forest conditions in the Southeastern region, Vietnam. The stem density of *S. roxburghii* was more numerous in the stand with standing volume > 200 m³/ha than that in the stand with standing volume < 200 m³/ha. Whereas in the latter one, there were missing small-sized stems (DBH<5 cm stems) and stems in DBH classes of 25-30 cm and 55-65 cm. Increasing total CA of ≥ 23 cm tall stems leads to increasing small-sized stems of *S. roxburghii*, but stems will reduce if the total CA of < 23 m tall stems increases. Topsoil moisture and pH₂CO₃ effect on occurrence probability and abundance of *Shorea roxburghii* regeneration. Based on the finding of this study, it is suggested that to sustainably conserve and manage *S. roxburghii* in the Southeastern region of Vietnam and silvicultural practices should be applied by reducing the stand crown area of < 23 m tall stems. The practices aim to increase sunlight penetrating the canopy and reaching the forest floor for germination, survival, and growth of *S. roxburghii*.
drought regulates species distributions and assembly of tree communities across a tropical forest region. Global Ecol Biogeogr 30 (9): 1847-1862. doi:10.1111/geb.13350.

Le HV, Nguyen HH, Tran QB, Nguyen VT, Le NH. 2020. The spatial structural characteristics of dominant species in tropical moist evergreen closed forest at Tan Phu zone, Dong Nai Province. J For Technol 01, 72-82.

Maimunah S, Capilla B, Harrison M. 2019. Tree diversity and forest composition of a Bornean heath forest, Indonesia. IOP Conf Ser: Earth Environ Sci 270 (1). DOI: 10.1088/1755-1315/270/1/012028.

Maury-Lechon G, Curtet L. 1998. Biogeography and evolutionary systematics of Dipterocarpaceae. In: Appanah S, Turnbull JM (eds) A Review of Dipterocarps: Taxonomy, Ecology and Silviculture. Center for International Forestry Research, Indonesia.

Morikawa T, Chaipech L, Matsuda H, Harao M, Umeda Y, Sato H, Tamura H, Ninomiya K, Yoshikawa M, Pongpiriyadacha Y, Hayakawa T, Muraoka O. 2012. Anti-hyperlipidemic constituents from the bark of Shorea roxburghii. J Nat Med 66 (3): 516-524. DOI: 10.1007/s11418-011-0619-6.

Moriyama H, Moriyama M, Ninomiya K, Morikawa T, Hayakawa T. 2016. Inhibitory effects of oligostilbenoids from the bark of Shorea roxburghii on malignant melanoma cell growth: Implications for novel topical anticancer candidates. Biol Pharm Bull 39(10), 1675-1682. DOI: 10.1248/bpb.b16-00420.

Ninomiya K, Chaipech S, Kunikata Y, Yagi R, Pongpiriyadacha Y, Muraoka O, Morikawa T. 2017. Quantitative determination of stilbenoids and dihydroisocoumarins in Shorea roxburghii and evaluation of their hepatoprotective activity. Int J Mol Sci 18 (2): 451. DOI: 10.3390/ijms18020451.

Paillet Y, Bergès L, Hjälmén J, Ödor P, Avon C, Bernhardt-Römermann M, Bijlsma RJ, Führ M, Grandin U, Kanka R, Lundin L, Luque S, Magura T, Matesanz S, Meszaros I, Sebastia MT, Schmidt W, Ståndovar T, Thotmheresz B, Uotila A, Valladares F, Virnæn R. 2010. Biodiversity differences between managed and unmanaged forests: Meta-analysis of species richness in Europe. Conserv Biol 24 (1): 101-112. DOI: 10.1111/j.1523-1739.2009.01399.x.

Pande PK. 2008. Wood density variations in Meranti timbers of Shorea species of Malay Peninsula. J Timber Develop Assoc India 54 (1/4): 10-19.

Pooma R, Newman M, Burrow M. 2014. Shorea roxburghii. The IUCN red list of threatened species 2017. [17-7-2020]

Raju A, Ramana KV, Chandra PH. 2011. Reproductive ecology of Shorea roxburghii G. Don (Dipterocarpaceae), an Endangered semievergreen species tree of peninsular India. J Threat Taxa 2061-2070. DOI: 10.11609/jtt.2763.2061-70.

Subramanian R, Subramanian P, Raj JVS. 2013. Antioxidant activity of the stem bark of Shorea roxburghii and its silver reducing power. SpringerPlus 2 (1): 1-11. DOI: 10.1186/2193-1801-2-28.

Swaine MD, Whitmore T. 1988. On the definition of ecological species groups in tropical rain forests. Vegetatio 75 (1): 81-86. DOI: 10.1007/BF00044629.

Tamilselvan B, Sekar T, Anbarasan M. 2021. Tree diversity, stand structure and community composition of tropical forest in Eastern Ghats of Tamil Nadu, India. J Asia-Pac Biodivers 147 (5): 481-489. DOI: 10.1016/j.japb.2016.03.019.

Tran QB, Le HV. 2019a. Ecological role of Shorea roxburghii population in tree species composition of tropical moist evergreen closed forest in Tan Phu Zone of Dong Nai Province. J For Sci Technol 5, 90-98.

Tran QB, Le HV. 2019b. The effect of ecological factors to natural regeneration of Shorea roxburghii g. don in tropical moist evergreen closed forest at Tan Phu zone of Dong Nai Province. J For Sci 3, 77-88.

Tran TD, Cam N, Sato T, Binh N, Kozan O, Thang N, Milthörner R. 2016. Post-logging regeneration and growth of commercially valuable tree species in evergreen broadleaf forest, Vietnam. J Trop For Sci 426-435.

Tran TD, Kozan O, Yamamoto M, Dai Hai V, Trung PD, Thang NT, Thinh NH. 2018. A natural forest of commercial timber species: logging or not logging. Small-scale For 17 (4): 555-568. DOI: 10.11842/018-9403-8.

Tran TD, Osawa A, Thang NT. 2010. Recovery process of a mountain forest after shifting cultivation in Northwestern Vietnam. For Ecol Manag 259 (8): 1650-1659. DOI: 10.1016/j.foreco.2010.01.043.

Tran TD, Osawa A, Thang NT, Van NB, Hang BT, Khanh CQ, Tuan DX. 2011. Population changes of early successional forest species after shifting cultivation in Northwestern Vietnam. New For 41 (2): 247-262. DOI: 10.1007/s11056-010-9225-9.

Tripathi R, Khan M. 2007. Regeneration dynamics of natural forests - A review. Proc Indian Nat Sci Acad 73, 167-195.