

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 × 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_{H2O} 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_{H2O} 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; Basyuni 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 as 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. $> 200 \text{ m}^3/\text{ha}$ (stable forest) versus $< 200 \text{ m}^3/\text{ha}$) (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 soil is sandy loam in texture with pH (H₂O) 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 $> 200 \text{ m}^3/\text{ha}$ named as SV >200 ; and 2) standing volume $< 200 \text{ m}^3/\text{ha}$ named as SV <200 . In each forest condition, main representative plots (four in SV >200 and two in SV <200) of 2,500 m² (50 m \times 50 m) were established. In each main plot, five sub-plots of 16 m² (4 m \times 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_{H₂O} 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 m² (1 m \times 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 (H₁ ≤ 100 cm; H₂ > 100 cm).

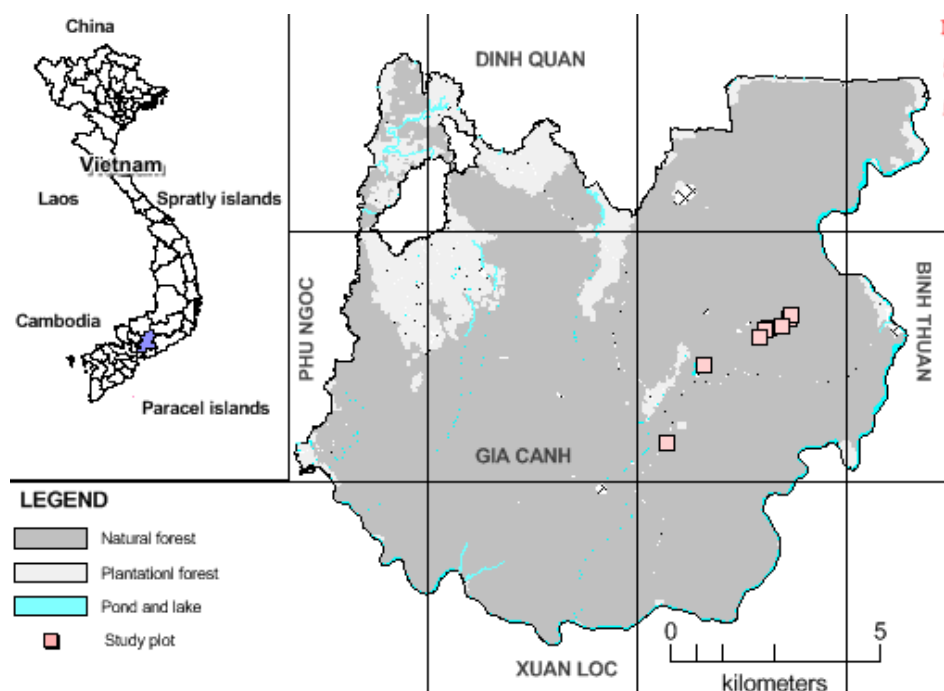


Figure 1. Map of experimental plots in Tan Phu protection forest, Dong Nai, South Vietnam

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):

$$CA = \frac{3.14 \times CR^2}{4} \quad [1]$$

$$AGB = 0.12843 \times DBH^{2.409074} \quad [2]$$

$$SV = G \times H \times 0.42 \quad [3]$$

where: CR , crown diameter (m); G , stem basal area (m^2); DBH , diameter at breast height (cm); CA , crown area (m^2); AGB , aboveground biomass (Mg); SV , standing volume (m^3); 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}) [4]

Where, n_i = total individual trees calculated for species i .

$$\text{Basal area } (G) = \pi \times r^2 = \pi \times \frac{dbh^2}{4} (m^2) \quad [5]$$

Where: dbh = diameter at breast height and r = radius.

$$IVI (\%) = (\text{Relative density} + \text{Relative Basal area} + \text{Relative volume})/3 \quad [6]$$

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 (X_1) and pH_{H_2O} (X_2). 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).

$$\text{Logit}(P/1-P) = b_0 + b_1 \cdot X_1 - b_2 \cdot X_1^2 \quad [7]$$

Where P = occurrence probability of the *S. roxburghii* regeneration for two height classes ($H_1 \leq 100$ cm; $H_2 > 100$ cm), $X_i = X_1$ and X_2

Then analyze function (7) to determine ecological parameters such as ecological optimum (U_i), ecological tolerance (T_i), ecological range ($U_i \pm 4T_i$) and P_{iMax} (with $i = 1-2$, two height classes). Four parameters U_i , T_i , $U_i \pm 4T$ and P_{iMax} are determined by function (8)-(11). The combined effect of two variables X_1 and X_2 on the natural regeneration of *S. roxburghii* was analyzed by multivariable Gaussian logit regression (function 12).

$$\text{Ecological optimum } U_i = b_1/2b_2 \quad [8]$$

$$\text{Ecological tolerance } T_i = 1/\sqrt{2b_2} \quad [9]$$

$$\text{Ecological range } U_i \pm 4T_i \quad [10]$$

$$P_{iMax} = \frac{\exp(b_0 + b_1 U_i - b_2 U_i^2)}{1 + \exp(b_0 + b_1 U_i - b_2 U_i^2)} \quad [11]$$

$$\text{Logit}(P/1 - P) = b_0 + b_1 X_1 - b_2 X_1^2 + b_3 X_2 - b_4 X_2^2 + b_5 X_1 X_2 \quad [12]$$

All statistical analyses, based on a significant level of $p < 0.05$, were conducted using SAS 9.2 (SAS Institute Inc.,

Cary, NC, USA) and SPSS 22.0 (IBM Corp., NY, USA) software packages.

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

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

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 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 standing volume (*SV*>200) compared to stand with < 200 m³/ha 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 (\pm SE) between two forest conditions with different standing volume

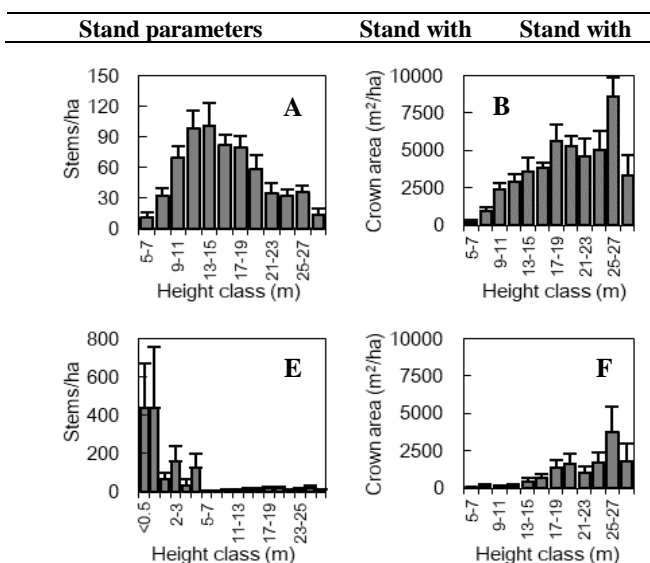


Figure 2. (A, B, E, F) Height/stem and height/crown area distributions in the forest with standing volume $> 200 \text{ m}^3 \text{ ha}^{-1}$ and (C, D, G, H) stand with standing volume $< 200 \text{ m}^3 \text{ ha}^{-1}$ (A, B, C, D) for the pool of all species and (E, F, G, H) the pool of *Shorea roxburghii*.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

	standing volume > 200 m ³ /ha	standing volume < 200 m ³ /ha
A pool of all species		
Species number/2,500 m ²	38 \pm 4	36 \pm 4
Stems/2,500 m ²	161 \pm 8	188 \pm 36
Mean height (m)	15.6 \pm 0.5 ^a	11.9 \pm 0.5 ^b
Mean DBH (cm)	20.9 \pm 0.9 ^a	16.1 \pm 0.2 ^b
Basal area (m ² /2,500 m ²)	8.1 \pm 0.6 ^a	5.6 \pm 0.6 ^b
Standing volume (m ³ /2,500m ²)	72.8 \pm 7.2 ^a	39.2 \pm 4.6 ^b
Aboveground biomass (Mg/2,500 m ²)	59.9 \pm 5.0 ^a	38.4 \pm 1.7 ^b
Crown area (m ² /2,500 m ²)	11,569 \pm 602	9,284 \pm 1,374
Pool of <i>Shorea roxburghii</i>		
Stems with DBH ≥ 5 cm		
Stems/2,500 m ²	34 \pm 5 ^a	17 \pm 13 ^b
Mean height (m)	17.9 \pm 1.6	17.7 \pm 3.1
Mean DBH (cm)	27.1 \pm 3.6 ^a	38.0 \pm 16.4 ^b
Basal area (m ² /2,500 m ²)	2.7 \pm 0.9 ^a	1.3 \pm 0.3 ^b
Standing volume (m ³ /2,500m ²)	26.6 \pm 9.4 ^a	11.4 \pm 2.5 ^b
Biomass (Mg/2,500 m ²)	20.7 \pm 7.0 ^a	10.4 \pm 1.8 ^b
Crown area (m ² /2,500 m ²)	3,230 \pm 778 ^a	1,273 \pm 603 ^b
Stems with DBH < 5 cm		
Stems/ha	1,313 \pm 277 ^a	0 ^b

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

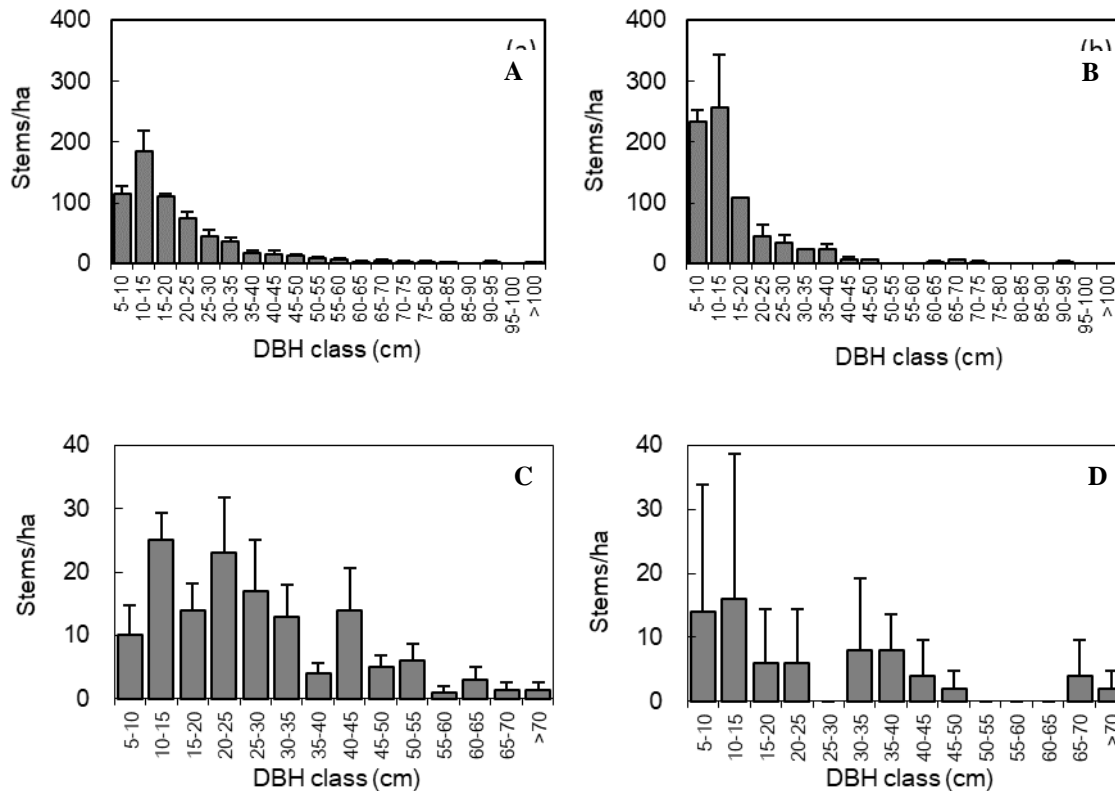


Figure 3. (A, C) DBH/stem distribution at the forest stand with standing volume $>200 \text{ m}^3 \text{ ha}^{-1}$ and (B, D) forest stand with standing volume $<200 \text{ m}^3 \text{ ha}^{-1}$ (a, b) for the pool of all species and (c, d) the pool of *Shorea roxburghii*. Error bars show the standard deviation (SD)

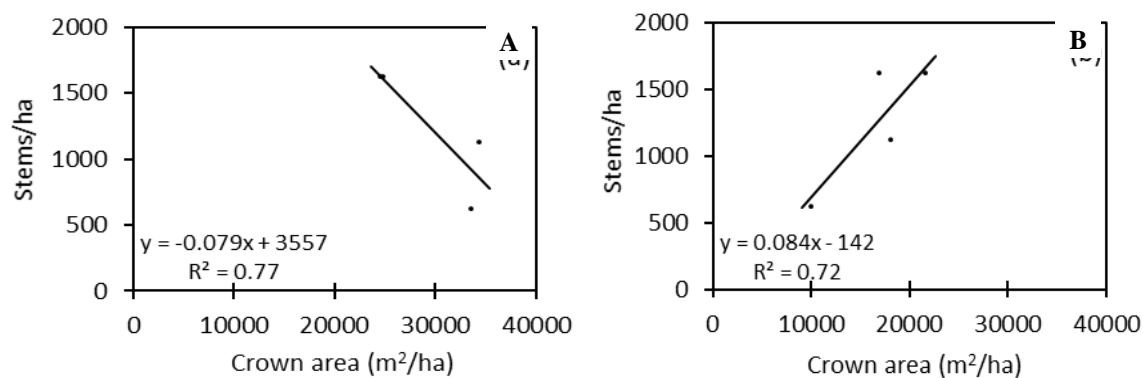


Figure 4. Linear regression between *Shorea roxburghii* stems (DBH < 5 cm) and stand CA of all < 23 m tall stems (A), and between *S. roxburghii* stems (DBH < 5 cm) and stand crown area of all ≥ 23 m tall stems (B)

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 = $\text{pH}_{\text{H}_2\text{O}}$) 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 $\text{pH}_{\text{H}_2\text{O}}$ (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 $\text{pH}_{\text{H}_2\text{O}}$ 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_{H_2O} 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_{H_2O} on the natural regeneration of *S. roxburghii* was analyzed by multivariable Gaussian logit regression.

Statistical analysis shows that the combination of two factors (X_1 = moisture and X_2 = pH_{H_2O}) 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_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_{H_2O} and *S. roxburghii* regeneration. In another word, when topsoil moisture and pH_{H_2O} 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				
		b_0	b_1	b_2	$r^2(\%)$	P_a
* 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 hight	-23,90340	0,75075	-0,00532	22,6	<0,001
* Effect of topsoil pH_{H_2O}						
(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 hight	-49,9936	24,5884	-2,9037	17,2	<0,001

Note: *Model: $P = \exp(b_0 + b_1X_1 - b_2X_1^2)/(1 + \exp(b_0 + b_1X_1 - b_2X_1^2))$

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

Functions	Height class (cm)	Parameters ^(*) :				
		U	$\pm T$	$U \pm T$	$U \pm 4T$	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_{H_2O}						
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_{H_2O}

Regression coefficients	Hight class (m)		
	< 100	> 100	All
b_0	-10,29370	1,21125	-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
b_5	-5,31272	-6,78114	-6,42935
R^2	32,3	29,2	29,9
P_a (Model)	< 0,001	< 0,001	< 0,001
P_{b5} (b_5 coefficient)	0,0427	0,0072	0,0112

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

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, but 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.

2019a). Dey et al. (2021) also mentioned that crown diameter has a profound correlation with tree diameter and height. Stems of different heights from < 5 m to 28 m tall were found in SV>200 (Fig. 2e), while the total stand crown area was >44,000 m²/ha. This indicated that *S. roxburghii* is shade-intolerant timber species. Such species require shading at some levels in seedling and sapling stages, and the sunlight requirement increases with increasing ages in their life (Maury-Lechon et al. 1998; Tran et al. 2019b).

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. 2 a, 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 pH_{H2O} 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*.

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