The structure of stands and renewal of the *Shorea* formation in evergreen forest of Binh Chau–Phuoc Buu Nature Reserve, Vietnam

D A Danilov*, Nguyen Thi Duong and N V Belyaeva

Institute of forests and natural resources, Saint-Petersburg State Forest Technical University named after S.M. Kirov, 5 Institutsky lane, Saint-Petersburg 194021, Russian Federation

*Corresponding email: stown200@mail.ru

Abstract. This work analyzes the quality of the restored forests with the prevalence of the Dipterocarpaceae family tree species in Binh Chau – Phuoc Buu Nature Reserve, Vietnam. To predict the number of plants in each diameter class, we verified the correspondence of theoretical distributions with an empirical distribution \( N - D \). A theoretical model is best described by an exponential distribution. To establish natural regeneration, we determined the structure of renewed tree species and their relative thickness. The similarity between the composition of renewed plants and the composition of parent plants was determined by the Sorensen coefficient. A natural regeneration of 14 plant species is observed under the canopy of the *Shorea* formation. The similarity coefficient between the composition of the maternal stratum and renewed plants is 20.3%. This indicates that generations of renewed plants can alter the composition of maternal plants in the upper stratum. The analysis of the distribution structure of diameters and the similarity coefficient between the composition of the maternal tree and the renewed trees showed that the *Shorea* formation in the Reserve is in the process of succession to achieve a higher hierarchy of environmental stability, i.e., the climax stage.

1. Introduction

The plains of southern Vietnam are often dominated by the evergreen moist tropical forests with a predominance of wood species of the *Dipterocarpaceae* family. Studies of the nature of formation and functions of tropical forests allow solving some applied problems, such as restoration, deforestation, use and protection of forest resources. However, these issues are not thoroughly developed yet in Vietnam. Until the 1950s of the 20th century, the Dipterocarpaceae forests occupied a large area in Vietnam at altitudes below 700 m \([1, 2]\). A series of studies have been carried out to determine the species composition, structure, and natural renewal of a number of wood species that comprise tropical moist evergreen forests in the south of Vietnam, the evergreen closed forest type in the south of Vietnam comprises several subtypes: among them, the subtype characteristic of the Malaysia-Indonesia flora with the dominance of the *Dipterocarpaceae* group \([3-5]\).

Tree species of the *Dipterocarpaceae* family have the largest role in the formation of the structure of evergreen tropical and half-evergreen closed and half-evergreen forest plant communities in southeastern Vietnam. They are involved in the formation of high stock in the forest plant community (300 - 400 m\(^3\)/ha) and their timber is important for construction and export \([6-7]\). Numerous researchers in Vietnam made studies in this direction \([8-9]\). *Shorea roxburghii* wood has a beautiful...
color and texture. Strong and durable wood is used to make furniture, residential buildings, flooring, sleepers, doors, frames ... and many other products with high economic value [6].

Plant communities in the Nature Reserve with the dominance of Shorea roxburghii are unique forest phytocenoses with decreasing area. The restoration of this type of forest should create conditions for the revival of the main tree species in the forest, while an understanding of the structure of such tree communities can help determining appropriate silvicultural treatment. The aim of the study is the analysis of the structure of stands and restoration of plant communities with a predominance of the Shorea roxburghii tree species. The results will allow developing effective measures for the successful restoration and conservation of forests, as well as their further usage for the economic and social development of Vietnam. The main objectives of the study are to assess the quality of the restored forests and develop measures to regulate succession in tropical forests to preserve their biodiversity.

2. Methods and Materials

2.1. Objects of study

The objects of the study were plant communities with a predominance of the Dipterocarpaceae family wood species in the Binh Chau – Phuoc Buu Nature Reserve. Binh Chau – Phuoc Buu Nature Reserve is situated in the southeast of the Republic of Vietnam within the Xuyen Moc District of Ba Ria - Vung Tau Province. Founded in 1984, the Binh Chau – Phuoc Buu Nature Reserve has the following geographical coordinates: 10°28’-10°38’ north latitude, 107°25’- 107°36’ east longitude. The total area of the Binh Chau – Phuoc Buu Nature Reserve is 10 326.0 ha, including 4 959.8 ha of a specially protected territory. The area of ecological restoration of vegetation cover is 62.5 ha; the area of virgin forests - 5 303.7 ha.

To identify the characteristics of forest management in the Nature Reserve in the stands dominated by the Shorea group, 3 experimental areas of 2000 m² were created for the study. All tree species with a height of at least 10 m and a diameter of 8.0 cm were registered. On each experimental area were created 25 experimental plots with an area of 4 m² (2x2 m). Experimental plots were placed arbitrarily [10, 11]. The components of the plants species (IVI) are determined by Thai Van Trung (1999) method [5].

\[ \text{IVI} = \frac{(N\% + G\% + 1\%)}{3} \]  

(1)

Where N% is a relative thickness of the species, G% is a relative trunk cross-section, V% is a relative stem volume, given as

\[ V = g \times h \times F \quad F = 0.45 \]  

(2)

Description and analysis of the structure of the dominant plants of the Dipterocarpaceae family included the criteria of distribution of trunk diameters (N - D) and trunk heights (N - H). Statistical characteristics D and H of dominant plants of the Dipterocarpaceae family included mean (Dav), mode (Mav), median (me), maximum value (max), minimum value (min), variance (S²), standard error (S), standard error of the mean (Se), coefficient of variation (V%), deviation (Si), and kurtosis coefficient (Ku).

To predict the number of plants in each diameter class, we verified the correspondence of theoretical distributions with an empirical distribution N - D. For that, D was first divided into classes. Depending on the range of their change, the trunk diameter is divided between 4 - 8 cm, and the number of levels is from 6 to 12 classes. Theoretical models suitable for the experimental distribution of N - D were then tested. The selected theoretical model is an exponential distribution model, given as:

\[ N = a \times \exp(-b \times D) + k \]  

(3)

In equation (3) a, b, and k are the coefficients of the model; exp is the Napier’s constant.
To establish natural regeneration, we determined the structure of renewed tree species and the relative thickness of the species (N %). The N/H distribution of renewed trees is divided into classes on a scale with 50 cm increments. The similarity between the composition of renewed plants and the composition of parent plants is determined by the Sorensen coefficient, and the index of similarity is given as:

\[
Cs = \frac{(2 \times C)}{(A+B)}
\]

where, \(A\) is the number of species in the stratum of the stand; \(B\) is the number of undergrowth species; \(C\) is the number of species found in the stratum of the stand and the undergrowth.

Stability was assessed from the structure (N/D distribution and N/H distribution) and Sorensen coefficient (Cs). If the N/D distribution has a reduced shape and a Sorensen coefficient (Cs) > 50%, a stable environment (Climax) the will be reached. If the N/D has a peak distribution (left or right) and the coefficient (Cs < 50%), the optimization is under development to achieve a higher hierarchy for environmental stability, i.e. a climax state.

### 2.2. Experimental part

The result of the study shows that the dominant plant *Shorea roxburghii* is in a formation of 86 species, and the Dipterocarpaceae family has 5 species - *Shorea roxburghii* G. Don, *Vatica odorata* (Subsp.) Sym., *Dipterocarpus alatus* Roxb, *Dipterocarpus costatus* Gaertn, and *Anisoptera costata* Korth (table 1). The stand thickness of the *Shorea* formation is 387 pcs per ha, the thickness of the dominant species - 145 pcs per ha, which constitutes 38.4%, 5 species from the *Dipterocarpaceae* family - 125 pcs per ha, constituting 33.0%, of those, *Shorea roxburghii* G. Don - 96 pcs per ha (comprising 25.4%). Five dominant species constitute the Important value of 52.9 %. The dominant species: *Shorea roxburghii* G. Don, *Irvingia malayana* Oliv. ex Benn, *Xerospermum noronhianum* (Blume), *Vatica odorata* (Subsp.) Sym., *Lagerstroemia calyculata* Kurz. The density of the *Shorea* formation is 0.8.

| Species                               | \(N\) (pcs per ha) | \(G\) (m²) | \(V\) (m³) | \(N\) | \(G\) | \(V\) | IV |
|---------------------------------------|--------------------|------------|------------|------|------|------|----|
| *Shorea roxburghii*                    | 96                 | 4.18       | 32.02      | 25.4 | 39.8 | 44.6 | 36.6 |
| *Irvingia malayana*                   | 9                  | 0.75       | 6.2        | 2.4  | 7.1  | 8.6  | 6.1 |
| *Xerospermum noronhianum*             | 19                 | 0.34       | 1.94       | 5.0  | 3.2  | 2.7  | 3.7 |
| *Vatica odorata*                      | 16                 | 0.34       | 1.93       | 4.2  | 3.2  | 2.7  | 3.4 |
| *Lagerstroemia calyculata*            | 5                  | 0.4        | 3.29       | 1.3  | 3.8  | 4.6  | 3.2 |
| 5 species in total                     | 145                | 6.01       | 45.38      | 38.4 | 57.3 | 63.2 | 52.9 |
| *Dipterocarpus alatus*                | 7                  | 0.3        | 2.27       | 1.9  | 2.9  | 3.2  | 2.6 |
| *Dipterocarpus costatus*              | 4                  | 0.17       | 1.18       | 1    | 1.6  | 1.6  | 1.4 |
| *Anisoptera costata*                  | 2                  | 0.11       | 0.84       | 0.5  | 1    | 1.2  | 0.9 |
| ...                                   |                    |            |            |      |      |      |    |
| 78 other plants species               | 233                | 4.48       | 26.48      | 61.64| 42.71| 36.85| 47.07|
| All species                           | 378                | 10.4       | 71.8       | 100  | 100  | 100  | 100 |
The thickness structure ($N$, pcs per ha), the cross-section ($G$, m$^2$ per ha) and the average stock ($V$, m$^3$ per ha) vary depending on the class of trunk diameters. Table 2 shows the results.

| # | Diameter group $D_{13}$ (cm) | $N$ (pcs per ha) | $G$ (m$^2$) | $V$ (m$^3$) | Proportion (%) |
|---|-----------------------------|------------------|------------|------------|----------------|
| 1 | < 20                        | 273 (50)         | 3.0 (0.59) | 14.7 (2.9) | 72.2 (18.3)    |
|   |                             |                  | 28.85 (19.4)| 20.47 (19.7)| 40.5 (19.1)   |
| 2 | 20 – 40                     | 97 (42)          | 5.6 (2.6)  | 39.6 (18.3)| 25.7 (43.3)   |
|   |                             |                  | 53.85 (45.4)| 55.15 (45.8)| 44.9 (44.8)   |
| 3 | > 40                        | 8 (4)            | 1.8 (1.05) | 17.5 (10.1)| 2.1 (50.0)    |
|   |                             |                  | 17.3 (59.7)| 24.38 (62.8)| 14.6 (57.5)   |
| 4 | in total                    | 378              | 10.4       | 71.8       | 100            |

### 3. Results and Discussion

The results of the analysis show that the number of species found in classes of diameters decreases from the class $D < 20$ cm (69 species accounting for 80.2%) to the class $D = 20-40$ cm (37 species presenting 43.1% of the total number of species in this case), and the class $D > 40$ cm (4 species - *Shorea roxburghii* G. Don, *Lagerstroemia calyculata*, *Irvingia malayana* Oliv. ex Benn, *Dipterocarpus alatus* Roxb).

In this case, the dominance of *Shorea roxburghii* G. Don is the most notable and decreased from the class $D < 20$ cm (19.1%) to the class $D = 20-40$ cm (44.8%), and $D > 40$ cm (57.5%). The thickness of the dominant plants is the biggest in the class $D < 20$ cm (72.2%), however, the cross-section and wood stock are the greatest in the class $D = 20-40$ cm (53.85% and 55.15%) (Figure 1).

Statistical characteristics of the distribution of the number of trees by diameter in the *Shorea* formation: average ($D_{av}$) - 15.1 cm; Mo mode - 8.0; median Me - 12.4; maximum value Max 76.1 cm; minimum value Min 8.0 cm; variance $S^2$ 78.6, standard error of the mean Se 0.3 cm, the coefficient of variation $C_V\%$ is 58.7%, deviation Sk is 2.7, and the kurtosis coefficient Ku is 10.3.

![Figure 1](image1.png)  
**Figure 1.** Thickness of the species, cross-section, and average stock by trunk diameter class.

![Figure 2](image2.png)  
**Figure 2.** Empirical and theoretical distribution of the number of trees by diameter in the *Shorea* formation.

N/D distribution of the dominant species *Shorea roxburghii* G. Don is a decreasing distribution and depends on the number of plants (Figure 2, Table 3). Equation of the N/D distribution of the dominant species *Shorea roxburghii* G. Don. is given as:

$$N = 637.576 \times \exp\left[(-0.12421 \times D) + 2.7759\right]$$  \hspace{1cm} (5)

Used parameters: $R^2 = 98.58\%$; $Se = 8.1$; MAE = 5.3; MAPE = 90.2%.
Equation (4) allows determining the average number of trees distributed over different classes of $D$ for the dominant species *Shorea roxburghii* G. Don.

**Table 3. N/D distribution of the dominant species *Shorea roxburghii* G. Don.**

| $D$ (cm) | $N$ (pcs per ha) | $N$ (%) | $N_{(theory)}$ (pcs per ha) | $N_{(theory)}$ (%) |
|----------|------------------|---------|----------------------------|-------------------|
| 10       | 191              | 50.5    | 191                        | 50.5              |
| 16       | 75               | 19.8    | 266                        | 70.4              |
| 22       | 53               | 14.0    | 319                        | 84.4              |
| 28       | 32               | 8.5     | 351                        | 92.9              |
| 34       | 16               | 4.2     | 367                        | 97.1              |
| 40       | 5                | 1.3     | 372                        | 98.4              |
| 46       | 3                | 0.8     | 375                        | 99.2              |
| 52       | 1                | 0.3     | 376                        | 99.5              |
| 58       | 1                | 0.3     | 377                        | 99.7              |
| 64       | 1                | 0.3     | 378                        | 100.0             |
|          | **in total**     | **378** |                           | **100.0**         |

The research results show that the composition of plant species of the dominant *Shorea roxburghii* G. Don differs depending on the trunk height (table 4). The group $H < 10$ m comprises a total of 65 tree species, including 6 dominant species (*Shorea roxburghii* G. Don, *Barringtonia macrostachya*, *Xerospermum noronhianum* (Blume), *Vatica odorata* (Subsp.) Sym., *Garcinia sp.*, *Diospyros venosa*). For the group $H = 10-20$ m, the number of tree species is 62; including 6 dominant plant species (*Shorea roxburghii* G. Don, *Irvingia malayana* Oliv. ex Benn, *Lagerstroemia calyculata*, *Xerospermum noronhianum* (Blume), *Vatica odorata* (Subsp.) Sym., *Dipterocarpus alatus* Roxb). In the group $H > 20$ m, there are only two species of trees: *Shorea roxburghii* G. Don and *Irvingia malayana* Oliv. ex Benn. The species *Shorea roxburghii* G. is the most dominant (72%) in the structure of the stands of this group. Compared with the total number of tree species found in this case, the similarity coefficient of species composition decreases from the group $H < 10$ m (75.6%) to the group $H = 10-20$ m (72.1%), and $H > 20$ m (2.3%).

**Table 4. Thickness structure, cross-section, and average stock by height group of *Shorea roxburghii* G. Don.**

| Height groups $H_m$(m) | $N$ (pcs per ha) | $G$ (m$^2$) | $V$ (m$^3$) | Proportion (%) |
|------------------------|------------------|-------------|-------------|----------------|
|                        |                  | $N$ | $G$ | $V$ | $IV$ |
| $< 10$                 | 146              | (21) | (0.09) | (0.36) | 38.6 | 7.7 | 4.8 | 17.0 |
|                        | (10.4)           | (8.19) | (23.47) | (60.6) | 82.7 | 80.2 | 74.5 |
| $10 - 20$              | 229              | (73) | (3.36) | (25.47) | 60.6 | 82.7 | 80.2 | 74.5 |
|                        | (10.7)           | (6.19) | (23.47) | (60.6) | 82.7 | 80.2 | 74.5 |
| $> 20$                 | 3                | (2)  | (0.73) | (8.19) | 0.8  | 9.6  | 15.0 | 8.5  |
|                        | (1.0)            | (10.8) | (23.47) | (60.6) | 82.7 | 80.2 | 74.5 |
| in total               | 378              | 10.4  | 71.8 | 100 | 100 | 100 | 100 |

In plant communities with the dominance of the plant *Shorea roxburghii* G. Don, this species is the highest. The representation of trees in height classes increases from class $H < 10$ m (12.7%) to class $H = 10 - 20$ m (37.3%), and class $H > 20$ m (72%) (table 4).
Figure 3. Thickness of the species, cross-section, and average stock by trunk height group.

Figure 4. Empirical and theoretical distribution of the number of trees by height.

$N/H$ distribution of the dominant species *Shorea roxburghii* G. Don corresponds to one-peak distribution. Equation of the $N/D$ distribution of this formation is:

$$P_x = (1 - 0.2513) \times (1 - 0.5646) \times 0.5646^{(x-1)}$$  \hspace{1cm} (6)

$$N = 378 \times (1 - 0.2513 \times (1 - 0.5646) \times 0.5646^{(x-1)}$$  \hspace{1cm} (7)

Equation (6, 7) allows determining the average number of trees distributed over different classes of $H$ $N/H$ distribution of the dominant species *Shorea roxburghii* G. Don is a one-peak distribution (figure 4, table 5). The average thickness is 378 pcs per ha (100%); in which tree species reaching $H<10$ m have 95 pcs per ha (which is 25.1%), tree species reaching $H = 10 - 20$ m are 276 pcs per ha (which is 73.0%), the remaining 5 pcs per ha (1.3%) and 2 pcs per ha (0.5%) are the plants with $H = 20$ m and $H> 20$ m, respectively.

Table 5. $N/H$ distribution of the dominant species *Shorea roxburghii* G. Don.

| $H$ (m) | $N$ (pcs per ha)$^a$ | $N\%$ | $N_{(theory)}$ (pcs per ha) | $N\%(theory)$ |
|---------|------------------|--------|-----------------|----------------|
| 8       | 95               | 25.1   | 95              | 25.1           |
| 10      | 108              | 28.6   | 203             | 53.7           |
| 12      | 65               | 17.2   | 268             | 70.9           |
| 14      | 58               | 15.3   | 326             | 86.2           |
| 16      | 32               | 8.5    | 358             | 94.7           |
| 18      | 13               | 3.4    | 371             | 98.1           |
| 20      | 5                | 1.3    | 376             | 99.5           |
| 22      | 1                | 0.3    | 377             | 99.7           |
| 24      | 1                | 0.3    | 378             | 100            |
| in total| 378              | 100.0  | -               | -              |

$^a$ for the dominant species *Shorea roxburghii* G. Don.

In particular, at the level of $H = 10$ m, the largest number of distributed plants is 108 pcs per ha (28.6%). As a rule, the dominant *Shorea roxburghii* G. Don consists by about 95% of the plants located at a level of $H<20$ m, the remaining 5% of plants have a height of 22 to 24 m.

The analysis of the characteristics of natural regeneration in stands dominated by the plants *Shorea roxburghii* G. Don show that there are 14 species of plants under the canopy. The total amount of renewal is 3000 pcs per ha (100%). Of which, 3 species have a thickness of 2086 pcs per ha or 69.5% of the total amount: *Shorea roxburghii* G. Don, *Syzygium zeylanicum* (L.) DC, *Calophyllum calaba* L.
Two plant species belong to the *Dipterocarpaceae* family: *Shorea roxburghii* G. Don and *Dipterocarpus costatus* Gaertn. Compared with the total thickness of reforestation (3000 pcs per ha), the number of plants of the *Dipterocarpaceae* is 1583 pcs per ha (52.8%). The similarity coefficient between the composition of the maternal stratum and renewed plants is 20.3%. This indicates that generations of renewed plants under the canopy can alter the composition of maternal plants in the upper stratum. An analysis of the origin of renewed plants shows that the number of plants that originate from seeds is 2667 pcs per ha (88.9%), the rest of the plants originate from shoots and make up 333 pcs per ha (11.1%).

The analysis of a quality of naturally renewed plants under the canopy showed that the thickness of well-developed plants is 2.333 pcs per ha (77.8%), the plants of average development level have the thickness of 500 pcs per ha (16.7%), and there are 167 pcs per ha (6%) of poorly developed plants. In the group of renewed plants with a height of 100 cm or more (833 pcs per ha, 100%), the number of good quality renewed plants is 584 pcs per ha (70.1%). In general, under the canopy of the dominant *Shorea roxburghii* G. Don, the natural renewal of the plants is quite good. The is a relatively large number of prospective plants (*H* ≥ 100 cm with good development) that can replace maternal plants.

**Figure 5.** Distribution of the quality undergrowth renewal in the *Shorea* formation.

Thus, the *Shorea* formation has good natural regeneration under the forest canopy, but the similarity coefficient between the stand components and the undergrowth is rather low (20.3%), therefore, it might change the future composition of the tree species of the upper stratum.

### 4. Conclusion

- The number of woody plants found in the *Shorea* formation in the Binh Chau – Phuoc Buu Nature Reserve is 86 species. There are five dominant species: *Shorea roxburghii* G. Don, *Irvingia malayana* Oliv. ex Benn, *Xerospermum noronhianum* (Blume), *Vatica odorata* (Subsp.) Sym., *Lagerstroemia calyculata* Kurz. . The *Dipterocarpaceae* family is represented by 5 species – *Shorea roxburghii* G. Don, *Vatica odorata* (Subsp.) Sym., *Dipterocarpus alatus* Roxb, *Dipterocarpus costatus* Gaertn, and *Anisoptera costata* Korth.

- The N/D distribution of the dominant species *Shorea roxburghii* G. Don is a continuously decreasing distribution. The largest number of trees is mainly concentrated in the group of diameters <20 cm, however, the greater cross-section and stock are mainly in the group *D* = 20-40 cm and *H* > 10 m. N/H distribution of the dominant species *Shorea roxburghii* G. Don is a one-peak distribution.

- Under the canopy of the *Shorea* formation there is observed a natural regeneration of 14 plant species. The similarity coefficient between the composition of the maternal stratum and renewed plants is 20.3%. This indicates that generations of renewed plants can alter the composition of maternal plants in the upper stratum.

- The analysis of the distribution structure of N/D0.3 and the similarity coefficient (CI <50%) between the composition of the maternal tree and the renewed trees showed that the *Shorea* formation in the
Reserve is in the process of succession to achieve a higher hierarchy of environmental stability, i.e., the climax stage.

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