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NATURAL REGENERATION OF DIPTEROCARPACEAE DOMINATIONS UNDER THE CANOPY OF THE TROPICAL SEMI-MOIST EVERGREEN CLOSED FOREST IN THE BINH CHAU - PHUOC BUU COASTAL AREA OF BA RIA - VUNG TAU PROVINCE

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SUMMARY

This paper presents the results of a study on the natural regeneration of Dipterocarpaceae dominations in the tropical semi-moist evergreen closed forest in the Binh Chau - Phuoc Buu coastal area of Vung Tau Province. The data was collected from five 2,000 m^2 plots, each containing twenty 25 m^2 sub-plots. Fifty-two regenerating tree species were found under the forest canopy of which six (*Shorea roxburghii*, *Dipterocarpus insularis*, *Anisoptera costata*, *Shorea siamensis*, *Vatica odorata*, *Hopea odorata*) were Dipterocarpaceae. *Shorea roxburghii* was the ecologically dominant, and *D. insularis* the co-dominant species. The similarity coefficient between the regenerating tree species under the forest canopy and the woody species in the overstorey was 96.5%. Natural regeneration of the Dipterocarpaceae dominations has been occurring continuously under the forest canopy. The density of the regenerating trees was 9,844 trees/ha of which the number of trees of good from with a height >2 m was about 363 trees/ha. Protecting the current status of the tropical semi-moist evergreen closed forest in the coastal area of Binh Chau - Phuoc Buu should ensure that the Dipterocarpaceae successfully contribute to a climax forest.

Keywords: Natural regeneration, Dipterocarpaceae dominations, regenerating tree-species composition, similarity coefficient, Binh Chau - Phuoc Buu

ĐẶC ĐIỂM TÁI SINH TỰ NHIÊN CỦA ƯU HỢP HỌ SAO DẦU DƯỚI TÁN RỪNG KÍN THƯỜNG XANH HƠI ẨM NHIỆT ĐỚI Ở KHU VỰC VEN BIỂN BÌNH CHÂU - PHƯỚC BỬU THUỘC TỈNH BÀ RỊA - VŨNG TÀU

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TÓM TẮT

Bài báo này giới thiệu kết quả nghiên cứu về tình trạng tái sinh tự nhiên của các ưu hợp họ Sao dầu trong kiểu rừng kín thường xanh hơi ẩm nhiệt đới ở khu vực ven biển Bình Châu - Phước Bửu thuộc tỉnh Bà Rịa - Vũng Tàu. Số liệu thu thập bao gồm 5 ô tiêu chuẩn (OTC) điển hình với kích thước 2.000 m^2 và 100 ô dạng bản với kích thước 25 m^2. Kết quả nghiên cứu đã cho thấy rằng số loài cây tái sinh bắt gặp dưới tán rừng là 52 loài; trong đó số loài cây tái sinh của họ Sao dầu là 6 loài (Sến cát, Dầu cát, Vên vên, Cẩm liên, Làu táu, Sao đen). Trong kết cấu loài cây tái sinh của ưu hợp họ Sao dầu; Sến cát là loài ưu thế sinh thái, còn Dầu cát là loài đồng ưu thế sinh thái. Hệ số tương đồng giữa các loài cây tái sinh dưới tán rừng với các loài cây gỗ ở tầng trên là 96,5%. Tái sinh tự nhiên của ưu hợp họ Sao dầu diễn ra liên tục dưới tán rừng. Mật độ cây tái sinh là 9.844 cây/ha; trong đó số lượng cây tốt với chiều cao lớn hơn 200 cm là 360 cây/ha. Bảo vệ nguyên trạng rừng kín thường xanh hơi ẩm nhiệt đới ở khu vực ven biển Bình Châu - Phước Bửu sẽ giúp cho các ưu hợp họ Sao dầu diễn thế theo hướng tiến về cao đỉnh.

Từ khóa: Tái sinh tự nhiên, ưu hợp, họ Sao dầu, kết cấu loài cây tái sinh, hệ số tương đồng, Bình Châu - Phước Bửu

I. INTRODUCTION

Natural forest regeneration is the process of forming new generations of young trees under the forest canopy to replace old generations of trees (Them & Toai, 2024). Analyzing the factors impacting the natural regeneration of forests is an important category of forestry. Such information can provide a scientific basis for applying silvicultural principles to manage regeneration.

Binh Chau - Phuoc Buu Nature Reserve was established in 1996 in the Dipterocarp forest ecological region of Southern Vietnam, recognized as a key biodiversity conservation area by WWF. According to the forest classification system of Trung (1999), Binh Chau - Phuoc Buu Nature Reserve comprises several forest types, primarily tropical semi-moist evergreen closed forest (Rkn). The forest type is found along the coast and at altitudes below 300 meters above sea level. The tropical semi-moist evergreen closed forest in the Binh Chau - Phuoc Buu Nature Reserve area of Ba Ria - Vung Tau province is a protected area that boasts a rich supply of timber and non-timber forest products. This forest play an important role in preventing soil erosion, maintaining the food chain, and offering valuable resources and habitats for numerous plant and animal species.

Dipterocarpaceae dominations are a basic unit and the dominant species of the tropical semi-moist evergreen closed forest subtype (Rkn) (Trung, 1999). While the flora, structure, and tree - species diversity of the Rkn forest type have been previously studied (Cuong, 2025; Hop *et al*., 2023; Viet *et al*., 2020; Xuan, 2019) its regeneration characteristics remain to be determined. The objective of this study was to explore the natural regeneration traits of Dipterocarpaceae dominations in the Rkn forest type in the coastal area of Binh Chau - Phuoc Buu. The investigation focused on the composition, origin, distribution, and quality of regenerating trees according to height (H) class. The findings will be used to develop silvicultural methods to manage and conserve natural forests of the Rkn type.

II. RESEARCH METHODS

2.1. Study area

The study was conducted from 2022 - 2023 in the coastal area of Binh Chau - Phuoc Buu, Ba Ria - Vung Tau province (10°28′65″-10°38′05″N, 107°24′77″-107°33′52″ E). In this tropical monsoon climate zone the rainy season occurs from May to November, and the dry season from December to April. The mean annual air temperature, rainfall and relative humidity are 25.3°C, 1396 mm and 85.2%, respectively. The two soil types are reddish brown ferralitic soil derived from basalt rocks and gray-white to pale-yellow ferralitic soil from granite rocks.

2.2. Data collection

The natural regeneration characteristics of Dipterocarpaceae denominations in the Rkn forest in the study area were determined in five 2000 m^2 standard (50 × 40 m) plots (OTC) (Cuong, 2025). In each, twenty 25 m^2 (5 × 5 m) sub-plots were arranged on two lines parallel to the 50-m edges of the standard plots (Figure 1). In each sub-plot, the species of the regenerating tree, its height, H, origin (seed trees and bud trees), and vitality or quality were measured. Only trees ≥ 10 cm height (H) and with < 6 cm stem diameter at breast height (D) were included. This was because trees < 10 cm H of many species had diverse morphology and were difficult to identify. The species names were identified according to Ho (1999 - 2000) and Hop & Quynh (2003). The H was measured by a pole to 0.10 m and their vitality as good, average, and bad. Good trees had straight stems,

no truncated tops, and no double stems, were free from pests and diseases, and exhibited balanced, rounded foliage. Bad trees had truncated tops or double stems, were affected by pests and diseases, and displayed flag-shaped foliage. Trees exhibiting intermediate characteristics were classified as average.

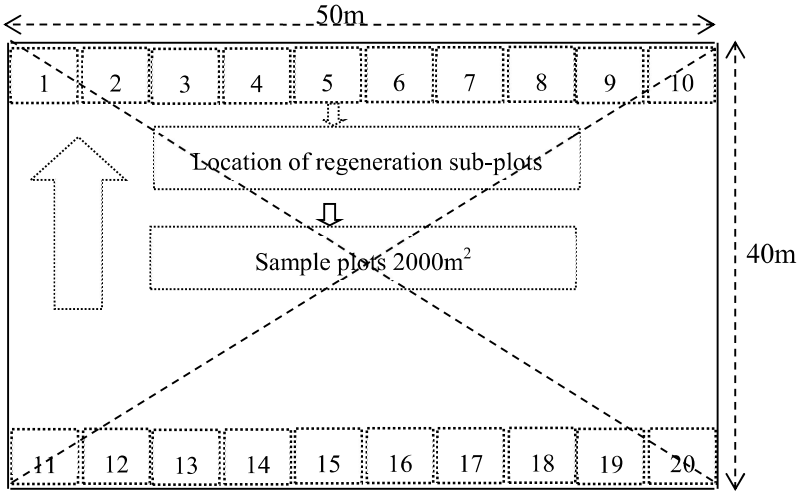

Figure 1. Schematic diagram of sample plots and sub-plots in the study of regeneration characteristics of Dipterocarpaceae dominants

2.3. Data processing

(1) Density. The mean density of regenerating trees (N, trees/ha) was calculated for the 100 subplots, and then converted to 1 ha (Formula 1). In Formula 1, Y = 10,000 m^2, s = 25 m^2, and ni is the number of regenerating trees in the sub-plots.

$$N\ (trees/ha) = \frac{Y \times n_i}{s} \quad (1)$$

(2) Species composition. The species composition of regenerating trees was determined by Formula 2, in which Ni (trees/ha) is the number of regenerating trees of species i, and N (trees/ha) is the total number of regenerating trees of all species. The similarity between the regenerating species and mature tree species (D ≥ 6 cm) was determined by Sorensen"s similarity coefficient (C_S) (Formula 3), in which a and b are the number of regenerating species and the number of mature species, respectively, c is the number of regenerating tree species and the number of similar mature tree species. The data for mature tree species were referenced from Cuong (2025).

$$N\% = \frac{N_i}{N} \times 100 \quad (2)$$

$$C_S\ (\%) = \frac{2 \times c}{a + b} \times 100 \quad (3)$$

(3) Distribution with height (H). To determine whether the yearly natural regeneration occurred continuously or periodically, the regenerating trees were divided into six 50-cm height classes (H, cm): $H_1 \leq 50$ cm, $H_2 = 50$ - 100 cm, $H_3 = 100$ - 150 cm, $H_4 = 150$ - 200 cm, $H_5 = 200$ - 250 cm and $H_6 \geq 250$ cm. The number of regenerating trees (N_i) in each height class H_i (i = 1, 2,..., 6) was described by an exponential function (Equation 4); m is the number of regenerating trees in class H_1, b and k are parameters. When transforming Equation 4 into the form $Ln(N_i - k) = Ln(m) - b \times H_i$, the parameter b is the ratio or speed of decrease in the number of trees after each class H_i. The ratio

at which the number of regenerating trees at a lower class H moves to an upper-class H is 100-(b×100).

$$N_i = m \times \exp(-b \times H_i) + k \quad (4)$$

(4) Origin and quality. The origin of the regenerating trees was divided into seed origin (referred to as seed trees) and bud origin (referred to as bud trees). The quality of the regenerating trees was divided into three groups: good, average, and poor (see Section 2.2).

(5) Status of the natural regeneration. The status of the natural regeneration was evaluated using the composition, density, distribution of regenerating trees, the proportion of regenerating trees originating from seeds and buds, and the quality of the regenerating trees across H classes. To determine the stability of the tree species composition, the similarity coefficient (C_S) between the regenerating and mature trees was calculated. If the regenerating trees were dominant and C_S > 50%, the tree species composition was expected to be stable. Conversely, if C_S < 50%, the tree species composition was expected to be unstable. If the N/H distribution was continuous, the natural regeneration was continuous. In contrast, if the N/H distribution was discontinuous or interrupted, the natural regeneration was periodic. Regeneration was also assessed by the ratio of good trees within specific H classes and the promising regenerating trees. Healthy regenerating trees and their H, those that have surpassed the influence of shrubs and grasses under the forest canopy have the potential to reach the upper canopy. The shrub and grass layers typically had H < 200 cm. Regenerating trees of good quality that had H > 200 cm were therefore deemed promising. In this study, according to density criteria, the number of regenerating trees in > 100 cm H classes and the number of regenerating trees with good vitality in > 200 cm H classes; the natural regeneration status of Dipterocarpceae dominations in the coastal area of Binh Chau - Phuoc Buu was divided into three classes: good, average, and poor (Table 1).

Table 1. Natural regeneration assessment criteria of Dipterocarpceae dominations

Regeneration classes	H > 100 cm (trees/ha)	H > 200 cm	
		Total (trees/ha)	Good trees (trees/ha)
Good	≥ 2000	≥ 1000	≥ 250
Average	1000-2000	500-1000	125-250
Poor	≤ 1000	≤ 500	≤ 125

III. RESULTS

3.1. Family and species composition of regenerating trees

3.1.1. Family composition of regenerating trees

The number of regenerating tree families was 24 (Table 2). The density of regenerating trees was 9,844 trees/ha (100%); Dipterocarpaceae accounted for 42.7%. Regenerating trees from the Myrtaceae were co-dominant (8.3%). Trees from 10 families accounted for 93.9% of the regeneration; the remaining 6.1% was contributed by 14 other families. The Clusiaceae had the highest number of regenerating tree species (7), followed by the Dipterocarpaceae (6), and the Annonaceae and Anacardiaceae (5 each).

Table 2. Composition of the regenerating tree families

Tree families	Density of regenerating trees		Number of species	
	N (trees/ha)	%	Species	%
Dipterocarpaceae	4,204	42.7	6	11.5
Myrtaceae	820	8.3	3	5.8
Ebenaceae	764	7.8	4	7.7
Clusiaceae	716	7.3	7	13.5
Annonaceae	708	7.2	5	9.6
Anacardiaceae	696	7.1	5	9.6
Sapindaceae	444	4.5	2	3.8
Elaeocarpaceae	364	3.7	1	1.9
Euphorbiaceae	292	3.0	1	1.9
Lythraceae	232	2.4	1	1.9
Total 10 families	9,240	93.9	35	67.3
Others (14 families)	604	6.1	17	32.7
Total (24 families)	**9,844**	**100**	**52**	**100**

3.1.2. Composition of regenerating tree species

A total of 52 regenerating tree species belonging to 38 genera across 24 families were observed (Table 3). The overall density was 9,844 trees/ha (100%). Among these, *Shorea roxburghii* was the dominant species, with a density of 1,284 trees/ha (13.0%); *Dipterocarpus insularis* was co-dominant, with a density of 1,052 trees/ha (10.7%).

Table 3. Composition of regenerating tree species

Regenerating tree species	N (trees/ha)	%
Shorea roxburghii G.Don	1,284	13.0
Dipterocarpus insularis Hance	1,052	10.7
Diospyros variegata Kurz	672	6.8
Anisoptera costata Korth.	660	6.7
Xylopia pierrei Hance	576	5.9
Vatica odorata Sym.	576	5.9
Syzygium cumini (L.) Druce	504	5.1
Shorea siamensis Miq	468	4.8
Garcinia vilersiana Pierre	428	4.4
Elaeocarpus dongnaiensis Pierre	364	3.7
Total 10 species	6,584	66.9
Others (42 species)	3,260	33.1
Total (52 species)	**9,844**	**100**

The density of regenerating trees from the 10 most dominant species was 6,584 trees/ha, or 66.9% of the total (Table 3). The remaining 33.1% (equivalent to 3,260 trees/ha) accounted for 42 other species. A comparison between the regenerating tree component (52 species) and the overstorey mother tree component (56 species) revealed a similarity coefficient of 96.5%.

Table 4. Composition of regenerating tree species in layer H < 100 cm

Regenerating tree species	N (trees/ha)	%
Shorea roxburghii G.Don	744	12.5
Dipterocarpus insularis Hance	600	10.1
Vatica odorata Sym.	468	7.9
Diospyros variegata Kurz	420	7.1
Anisoptera costata Korth.	404	6.8
Xylopia pierrei Hance	352	5.9
Shorea siamensis Miq	348	5.8
Elaeocarpus dongnaiensis Pierre	276	4.6
Syzygium cumini (L.) Druce	256	4.3
Garcinia vilersiana Pierre	244	4.1
Total 10 species	4,112	69.0
Others species (41 species)	1,844	31.0
Total (51 species)	**5,956**	**100**

The composition of regenerating tree species varied across different H classes. In the < 100 cm H classes (Table 4), a total of 51 species of regenerating trees was identified; N was 5,956 trees/ha (100%); *S. roxburghii* was dominant (12.5%) and *D. insularis* co-dominant (10.1%) (Table 4). Amongst the 10 most dominant species N was 4,112 trees/ha (69%). In the H class > 100 cm (Table 5), 47 species of regenerating trees were encountered. The density of these 47 species was measured at 3,888 trees/ha (100%), with *S. roxburghii* being the dominant species at 540 trees/ha (13.9%) and *D. insularis* as the co-dominant species at 452 trees/ha (11.6%). Here, the density of the 10 most prevalent species was 2,780 trees/ha (71.5%), while the other 37 species made up the remaining 28.5% (1,108 trees/ha). The similarity coefficient between the regenerating tree species in the H class < 100 cm and those > 100 cm was found to be 96.5%. Additionally, the similarity coefficient between the regenerating species in the H class > 100 cm and the overall composition of regenerating tree species in the Dipterocarpaceae dominations was 99% and 94.9%, respectively (Table 6).

Table 5. Composition of regenerating tree species in the > 100 cm H class

Regenerating tree species	N (trees/ha)	%
Shorea roxburghii G.Don	540	13.9
Dipterocarpus insularis Hance	452	11.6
Aporosa dioica (Roxb.) Muell.A.	280	7.2
Anisoptera costata Korth.	256	6.6
Diospyros variegata Kurz	252	6.5
Syzygium cumini (L.) Druce	248	6.4
Xylopia pierrei Hance	224	5.8
Nephelium hypoleucum Kurz.	212	5.5
Garcinia vilersiana Pierre	184	4.7
Melanorrhoea usitata Wall.	132	3.4
Total 10 species	2,780	71.5
Others (37 species)	1,108	28.5
Total (47 species)	**3,888**	**100**

Table 6. Similarity coefficient of regenerating tree species in Dipterocarpceae dominations

H Classes (cm)	H < 100	H > 100	Total dominance
<100	100		
>100	93.9	100	
Total dominance	**99.0**	**94.9**	**100**

3.1.3. Distribution of regenerating trees according to height classes

The distribution of regenerating trees under the canopy by H_i (Table 7) was represented by the following exponential equation 4, is summarized in Table 7. An Equation was developed to estimate the number of regenerating trees (N, trees/ha) based on these H classes (Equation 5). In Equation 5, N_i represents the number of regenerating trees in the H_i class (where H_i denotes the order of height classes from 1 to 6). Additionally, r^2 indicates the coefficient of determination, SEE represents the standard error of estimation for the number of trees, and MAPE stands for the mean absolute percentage error of the estimation.

$$N_i = 5{,}374.6 \times \exp(-0.2928 \times H_i) - 538 \quad (5)$$

$r^2 = 99.6\%$; SEE = ±92.7; MAPE = 7.2%

Table 7. Distribution of regenerating trees according to height classes

H Classes (cm)	Actual number of trees		Estimated number of trees	
	N (trees/ha)	%	N (trees/ha)	%
< 50	3,440	34.9	3,472	35.3
50-100	2,516	25.6	2,454	24.9
100-150	1,712	17.4	1,695	17.2
150-200	1,108	11.3	1,128	11.5
200-250	592	6.0	705	7.2
>250	476	4.8	390	4.0
Total	9,844	100	9,844	100

The estimated density of regenerating trees was 9,844 trees/ha: 35.3% (3,472 trees/ha) were in the < 50 cm H_1 class, 24.9% (2,454 trees/ha) in the > 50 - 100 cm H_2 class, 7.2% (705 trees/ha) in the 200 - 250 cm H_5 class and 4.0% (390 trees/ha) in the ≥ 250 cm H_6 class (Table 7). Coefficient b = -0.2928 or -29.3% is the rate of decrease in the number of trees between each Hi class. Consequently about 70.7% (calculated as 100 - 29.3%) of the trees in a lower H class can move up to the next higher H class.

3.1.4. Distribution of regenerating trees by origin

Of the total number of regenerating trees, 9,844 trees/ha (100%), 70.4% were of seed and 29.6% of bud origin. In the < 100 cm H classes, 64.6% were of seed and 35.4% of bud origin; in the > 100 - 200 cm H classes, 74.4% were of seed and 25.6% of bud origin; in the H > 200 cm class, 92.7% were of seed and 7.3% of bud origin. Hence, there was a marked increase in the proportion of trees of seed origin with H.

3.1.5. Distribution of regenerating trees by quality classes

Of the total, 9,844 trees/ha, 29.2% were of good, 50.6% were of average and 20.2% of poor quality. The proportion of good quality trees increased with H: from 25.5% in the < 100 cm H class, to 34.5% in the > 250 cm H class, and those of poor-quality decreased from 26.0% in the < 100 cm H class to 9.7% in the > 250 cm H class. Compared with the total number of good quality regenerating trees under the Dipterocarpaceae dominations canopy (2,871 trees/ha or 100%), the number of good quality regenerating trees in the < 100 cm, 101 - 200 cm, and > 200 cm H classes was 1,585 trees/ha (55.2%), 923 trees/ha (23.1%) and 363 trees/ha (12.6%), respectively. In general, The total number of promising naturally regenerating trees (≥ 200 cm H class and healthy) was 363 trees/ha or 3.7% of the total number of regenerating trees.

Table 8. Distribution of regenerating trees to the origin

H Classes (cm)	H (cm)		Classification by origin			
			Seed trees		Bud trees	
	N (trees/ha)	%	N (trees/ha)	%	N (trees/ha)	%
< 50	3,440	100	2,078	60.4	1,362	39.6
50-100	2,516	100	1,769	70.3	747	29.7
100-150	1,712	100	1,224	71.5	488	28.5
150-200	1,108	100	873	78.8	235	21.2
200-250	592	100	534	90.2	58	9.8
>250	476	100	456	95.7	20	4.3
Total	**9,844**	**100**	**6,933**	**70.4**	**2,911**	**29.6**

Table 9. Distribution of regenerating trees according to quality classes

H Classes (cm)	Total trees		Classification by origin					
			Good		Average		Poor	
	N (trees/ha)	%	N (trees/ha)	%	N (trees/ha)	%	N (trees/ha)	%
< 50	3,440	100	876	25.5	1,670	48.5	895	26.0
50-100	2,516	100	710	28.2	1,255	49.9	552	21.9
100-150	1,712	100	553	32.3	861	50.3	298	17.4
150-200	1,108	100	369	33.3	603	54.5	135	12.2
200-250	592	100	198	33.5	326	55.1	67	11.4
>250	476	100	164	34.5	266	55.9	46	9.7
Total	**9,844**	**100**	**2,871**	**29.2**	**4,981**	**50.6**	**1,993**	**20.2**

3.2. Natural regeneration characteristics of Dipterocarpaceae

3.2.1. Tree species composition

Six regenerating tree species of Dipterocarps were observed beneath the canopy. The most abundant was *S. roxburghii* with a density, N = 1,284 trees/ha (13.0% of the total) (Table 10). The next most common species was *D. insularis*; *H. odorata* had the lowest density. Dipterocarpaceae species accounted for 42.8% of the regeneration.

Table 10. Species composition

Regenerating trees species	N (trees/ha)	%
Shorea roxburghii G.Don	1,284	13.0
Dipterocarpus insularis Hance	1,052	10.7
Anisoptera costata Korth.	660	6.7
Vatica odorata Sym.	576	5.9
Shorea siamensis Miq	468	4.8
Hopea odorata Roxb.	164	1,.7
Total 6 species	4,204	42.8
Others (46 species)	5,640	57.2
Total	**9,844**	**100**

3.2.2. Distribution of regenerating trees of Dipterocarpaceae by height classes

The distribution of regenerating trees from the Dipterocarpaceae across various height (H) classes is shown in Table 11. The overall regeneration density of Dipterocarpaceae was found to be 9,844 trees/ha (100%), with 40.9% of these regenerating trees belonging to the Dipterocarpaceae trees. The proportion of regenerating Dipterocarpaceae trees decreased progressively with increasing H classes. Specifically, it dropped from 44.5% in the < 50 cm H class to 38.6% in the 150 - 200 cm H class, and further to 37.0% in the > 250 cm H class. In summary, when considering the total number of regenerating trees beneath the forest canopy (100%), the proportion of regenerating Dipterocarpaceae trees also declined gradually: from 45.2% in the < 100 cm H class, to 39.0% in the 100-200 cm H class, and finally to 38.6% in the > 200 cm H class.

3.2.2. Distribution by height classes

Of the total regeneration (9,844 trees/ha) (100%), 40.9% belonged to the Dipterocarpaceae (Table 11). Their proportion decreased with increasing H class.

Table 11. Distribution of regenerating trees of Dipterocarpaceae according to height class

H Classes	Total trees		Dipterocarpaceae trees		Other trees	
(cm)	N (trees/ha)	%	N (trees/ha)	%	N (trees/ha)	%
< 50	3,440	100	1,532	44.5	1,908	55.5
50 - 100	2,516	100	1,160	46.1	1,356	53.9
100 - 150	1,712	100	672	39.3	1,040	60.7
150 - 200	1,108	100	428	38.6	680	61.4
200 - 250	592	100	236	39.9	356	60.1
> 250	476	100	176	37.0	300	63.0
Total	9,844		4,204	40.9	5,640	59.1

The number of regenerating trees of the Dipterocarpaceae family (N, trees/ha) was estimated based on H classes using the data in Table 11 (Equation 6); in which, Ni represents the number of regenerating trees in the H_i class, where H_i denotes the order of H classes ranging from 1 to 6. In Equation 6, the coefficient b = -0.32631 or -32.6% is the decrease ratio in the number of trees after each H_i class; r^2 is the determination coefficient; SEE is the error in the number of trees of the estimation function; MAPE is the average absolute percent error of the estimation function.

$$N_i = 2{,}467.13 \times \exp(-0.32631 \times H_i) - 215 \quad (6)$$

r^2 = 99.02%; SEE = ±69.2; MAPE = 9.9%.

From Equation 6, we estimated the proportion of Dipterocarpaceae trees according to H classes, as illustrated in Figure 2. The survey revealed that the density of regenerating Dipterocarpaceae trees was 4,204 trees/ha (100%). Among these, 37.2% (1,566 trees/ha) were classified in the < 50 cm H class, 25.5% (1,070 trees/ha) fell within the

50-100 cm H class, 6.4% (268 trees/ha) were in the 200-250 cm H class, and 3.2% (134 trees/ha) reached a ≥ 250 cm H class. Overall, the Dipterocarpaceae dominations showed a very high density of regenerating trees at 4,204 trees/ha (100%). Of this total, approximately 62.7% (2,636 trees/ha) were in the < 100 cm H class, 27.8% (1,167 trees/ha) were in the > 101-200 cm H class, and 9.6% (402 trees/ha) exceeded 200 cm in H class. It is noteworthy that about 67.4% of the regenerating trees in the lower H classes have the potential to be transferred to the next higher H class.

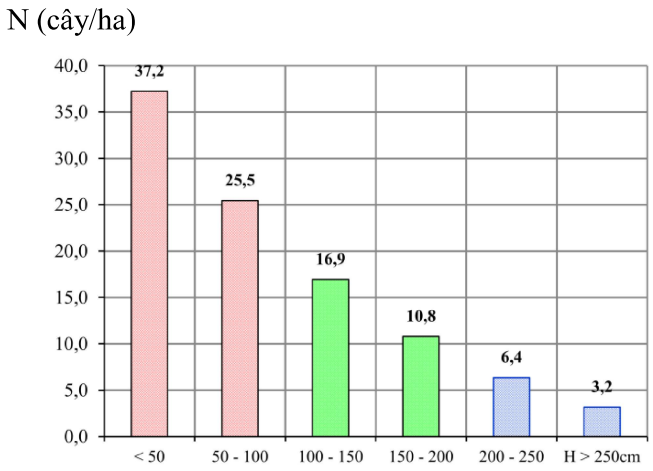

Figure 2. Graph showing the distribution of regeneration ratio of Dipterocarp trees according to H classes estimated by Equation 6

3.2.3. Distribution according to origin

The origin of regenerating trees of Dipterocarpaceae is presented in Table 12. Compared to the total number of regenerating trees of Dipterocarpaceae under the forest canopy (4,204 trees/ha or 100%), the seed origin trees were 73.7% (3,097 trees/ha), the remaining 26.3% (1,107 trees/ha) were the bud origin trees. Generally, the proportion of regenerating trees of Dipterocarpaceae originating from seeds increased gradually from 65.8% at < 100 cm H class to 80.2% at 150 - 200 cm H class and 97.3% at > 200 cm H class. The number of bud trees decreased gradually from 34.2% at < 100 cm H class to 19.8% at 150 - 200 cm H class and 2.7% at > 200 cm H class.

Table 12. Distribution of regenerating trees of Dipterocarpaceae according to the origin

Class H (cm)	Total trees (trees/ha)		Classification by origin			
			Seed trees		Bud trees	
	Number	%	Number	%	Number	%
< 50	1,532	100	1,008	65.8	524	34,2
50-100	1,160	100	838	72.2	322	27,8
100-150	672	100	514	76.5	158	23,5
150-200	428	100	343	80.2	85	19.8
200-250	236	100	223	94.5	13	5.5
>250	176	100	171	97.3	5	2.7
Total	**4,204**	**100**	**3,097**	**73.7**	**1,107**	**26.3**

3.2.4. Distribution of regenerating trees of Dipterocarpaceae according to quality classes

Table 13 provides an overview of the distribution of naturally regenerating Dipterocarpaceae trees categorized by quality class. The total number of naturally regenerating Dipterocarpaceae was 4,204 trees/ha (100%). Among these, the numbers of trees classified as good, average, and poor quality were 1,095 trees/ha (26.0%), 2,169 trees/ha (51.6%), and 940 trees/ha (22.4%), respectively. The proportion of regenerating trees deemed to be of good quality increased gradually with height. Specifically, for trees measuring < 100 cm H class, 23.1% were classified as good quality; this increased to 30.8% for those measuring 150 - 200 cm H class, and reached 36.9% for trees > 250 cm H class. Conversely, the percentage of poor-quality regenerating trees declined from 27.2% at < 100 cm H class to 13.8% at 150 - 200 cm H class, and further to 9.1% at > 250 cm H class. In terms of good quality regenerating trees, out of the total 1,095 trees/ha, the numbers in the H categories were as follows: 621 trees/ha (56.7%) for the < 100 cm H class, 329 trees/ha (30.1%) for the 101-200 cm H class, and 145 trees/ha (13.2%) for the > 200 cm H class. Overall, in relation to the total number of naturally regenerating Dipterocarpaceae trees (4,204 trees/ha or 100%), the number of promising regenerating trees that were healthy and measured ≥ 200 cm H class was just 145 trees/ha, accounting for 3.4% of the total.

Table 13. Distribution of Dipterocarpaceae regenerating trees according to quality classes

Class H (cm)	Total trees (trees/ha)		Classification by quality class					
			Good trees		Average trees		Poor trees	
	Number	%	Number	%	Number	%	Number	%
< 50	1,532	100	354	23.1	762	49.7	416	27.2
50-100	1,160	100	267	23.0	596	51.4	297	25.6
100-150	672	100	197	29.3	352	52.4	123	18.3
150-200	428	100	132	30.8	237	55.4	59	13.8
200-250	236	100	80	33.9	127	53.8	29	12.3
>250	176	100	65	36.9	95	54.0	16	9.1
Total	**4,204**	**100**	**1,095**	**26.0**	**2,169**	**51.6**	**940**	**22.4**

3.3. Discussion

A total of 52 regenerating tree species from 38 genera and 24 families were recorded under the canopy dominated by Dipterocarpaceae. In the coastal area of Binh Chau - Phuoc Buu, the overstory was comprised of 56 species of mother trees within the Dipterocarpaceae dominations (Cuong, 2025). Comparing the components of regenerating trees with those of the mother trees revealed a similarity coefficient of 96.5%. Although the composition of regenerating tree species within the Dipterocarpaceae dominations varied according to H classes, the similarity coefficient between regenerating tree species in the > 100 cm H class and those in the same class was 99% and 94.9%, respectively (Table 6). This proves that the composition of regenerating trees remains stable across different H classes. These two pieces of evidence suggest that most woody species within the Dipterocarpaceae dominations naturally regenerate under the forest canopy. This characteristic ensures that the Dipterocarpaceae dominations maintain stability in tree species composition during the succession process toward a climax forest.

Regenerating tree species of the Dipterocarpaceae dominations were observed in all H classes (Table 7). This trend was also noted among different Dipterocarpaceae species (Table 11). For the Dipterocarpaceae dominations, there was a reduction ratio of 29.3% in the number of regenerating trees from one H class to the next. This means that only about 71.7% of the regenerating trees in a lower H class were able to progress to the next higher H class. The corresponding values for regenerating trees within the Dipterocarpaceae were 32.6% and 67.4%. The presence of regenerating trees across all H classes demonstrates that Dipterocarpaceae trees continuously regenerate under the forest canopy. This phenomenon is attributed not only to the biological traits of the tree species but also to the specific site conditions.

Although the Dipterocarpaceae dominations displayed a very high density of naturally regenerating trees (9,844 trees/ha), only 70.4% of these trees originated from seeds, while the remaining 29.6% developed from buds. The proportion of trees arising from seeds increased gradually with the H class, reaching 95.7% for trees taller than 250 cm (Table 8). Among the Dipterocarpceae regenerating trees, this proportion was even higher at 97.3% (Table 12). Despite the high density of naturally regenerating trees within the Dipterocarpaceae dominations, only 29.2% were of good quality, with 20.2% classified as poor quality. The number of promising naturally regenerating trees (≥ 200 cm H class and in healthy condition) that could penetrate the forest canopy was 362 trees/ha, accounting for 3.7% of the total number of regenerating trees under the Dipterocarpaceae canopy (Table 9). Research by Cuong (2025) indicated that the Dipterocarpaceae dominations in the coastal area of Binh Chau - Phuoc Buu had a very high density of 1,576 trees/ha. Thus, if the number of naturally regenerating trees capable of reaching the forest canopy increases, they could help replace old and dead mother trees.

The number of Dipterocarpceae regenerating tree species found in the Dipterocarpceae dominations was 6 species (Table 10). Among these, *S. roxburghii* plays a dominant role, while *D. insularis* is co-dominant. Research conducted by Cuong (2025) demonstrated that in the coastal area of Binh Chau - Phuoc Buu, only 6 six species of Dipterocarpceae trees were identified, with *S. roxburghii* as the dominant species and *D. insularis* as co-dominant. The total dominance of Dipterocarpceae regenerating trees was found to be 42.8%, whereas 57.2% comprised 46 other tree species. The presence of a significant number of regenerating trees under the forest canopy indicates that Dipterocarpaceae regenerates effectively in this environment. This natural regeneration is crucial for ensuring the long-term sustainability of Dipterocarpus dominations. The similarity between the composition of regenerating trees and that of the mother trees creates favorable conditions for Dipterocarpceae species to maintain stability during the ecological succession process towards a climax forest.

In general, Dipterocarpaceae dominations exhibited a very high density of naturally regenerating trees, with a total of 9,844 trees/ha (100%). Among these, 3,888 trees/ha (39.5%) fell into the H > 100 cm class, while 1,068 trees/ha (10.8%) measured at > 200 cm H class, and 362 trees/ha (3.7%) also exceeded at > 200 cm H class (Table 9). According to the standard for assessing the status of natural regeneration under the forest canopy (Them & Toai, 2024), the natural regeneration within Dipterocarpaceae forests was classified as good (Table 1). Therefore, conservation efforts should focus on protecting the original status of Dipterocarpaceae dominations in the coastal area of Binh Chau-Phuoc Buu.

This study has not yet addressed several important issues: (1) the biological characteristics of tree species and how the site influences the natural regeneration of

Dipterocarpus-dominated areas; (2) the factors that affect the emergence of regenerating trees in the form of buds; and (3) the time required for regenerating trees in the lower H class to move to higher H class. The author recommends that research agencies and the Binh Chau - Phuoc Buu Nature Reserve continue conducting more in-depth studies on the ecological regeneration characteristics of Dipterocarpus-dominated areas.

4. CONCLUSION

The number of tree species recorded regenerating under the canopy of Rkn in the coastal area of Binh Chau - Phuoc Buu in Ba Ria - Vung Tau Province was 52 species. The similarity coefficient between the regenerating tree species under the forest canopy and the woody species in the overstory was over 96.5%. The number of regenerating tree species of the Dipterocarpaceae was 6 species (*S. roxburghii, D. insularis*, *A. costata, V. odorata, S. siamensis*, *H. odorata*); in which *S. roxburghii* was the ecological dominant species, and *D. insularis* was the ecological co-dominant species. The six species of the Dipterocarpaceae family contributed 42.8% to the density of regenerating trees under the forest canopy, while the remaining 57.2% consisted of 46 other tree species. The natural regeneration process under the forest canopy occurs continuously every year. The density of regenerating trees was very high (9,844 trees/ha); in which the number of good trees with a H greater than 200 cm was about 362 trees/ha. In general, Dipterocarpceae dominations naturally regenerating very well under the forest canopy. Hence, protecting the original status of Rkn in the coastal area of Binh Chau-Phuoc Buu will help Dipterocarpceae dominations to succeed towards the climax forest.

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