

Biological characteristics and conservation status of *Sindora tonkinensis* in Hon Ba Nature Reserve, Khanh Hoa province

Dang Viet Hung*, Nguyen Trong Phu

Vietnam National University of Forestry - Dong Nai Campus

Đặc điểm sinh học và bảo tồn loài Gụ lau (*Sindora tonkinensis*) tại Khu Bảo tồn thiên nhiên Hòn Bà, tỉnh Khánh Hòa

Đặng Việt Hùng*, Nguyễn Trọng Phú

Trường Đại học Lâm nghiệp - Phân hiệu Đồng Nai

*Corresponding author: viethung@vnuf2.edu.vn

<https://doi.org/10.55250/jo.vnuf.11.1.2026.073-081>

ABSTRACT

The study was conducted at Hon Ba Nature Reserve, Khanh Hoa province, to investigate the biological characteristics of *Sindora tonkinensis*, a valuable indigenous tree species. Using traditional silvicultural survey and data analysis methods, the research identifies the species' natural distribution and structural features. *S. tonkinensis* is only distributed on the hillsides of mountains with altitudes of 200 – 250 m - in forest evergreen forest type, the stems are usually small in diameter of 17 – 30 cm and height of 12 - 13 m. In the research area, sub - area 239 at an altitude of 215 m has the most distributed the species with a density of 30 trees/ha. The average diameter of the species in the area ranges at 30.8 cm, height ranges at 13.5 m. The good quality regeneration rate of the species in the evaluated forest status is extremely high (over 80%). *S. tonkinensis* species in the area exhibited both seed regeneration and shoot regeneration. The findings of this study offered a scientific and practical foundation for the future conservation and sustainable development the species, as well as ensuring the preservation and cultivation of *S. tonkinensis* population.

Article info:

Received: 18/10/2025

Revised: 28/11/2025

Accepted: 29/12/2025

Keywords:

Conservation, distribution, ecological characteristics, morphological, *sindora tonkinensis*.

TÓM TẮT

Nghiên cứu được thực hiện tại Khu Bảo tồn Thiên nhiên (KBT) Hòn Bà, tỉnh Khánh Hòa nhằm xác định các đặc điểm sinh học của loài Gụ lau (*Sindora tonkinensis*). Các phương pháp điều tra truyền thống đã được sử dụng và số liệu thu thập được phân tích. Kết quả cho thấy, Gụ lau thường phân bố chủ yếu trong kiểu rừng kín lá rộng thường xanh mưa mùa nhiệt đới núi thấp ở độ cao 200 – 250 m, thân cây thường có đường kính từ 17-30 cm, chiều cao từ 12-13 m. Tại tiểu khu 239 ở độ cao 215 m, loài này có mật độ cao nhất đạt 30 cây/ha. Cây gỗ trong khu vực có đường kính bình quân khoảng 30,8 cm, chiều cao 13,5 m. Tỷ lệ tái sinh có chất lượng tốt của loài trong trạng thái rừng được đánh giá là rất cao (trên 80%). Loài Gụ lau tại khu vực nghiên cứu ghi nhận cả hai hình thức tái sinh bằng hạt và tái sinh bằng chồi. Kết quả của nghiên cứu này cung cấp cơ sở khoa học và thực tiễn quan trọng cho việc bảo tồn và phát triển bền vững loài Gụ lau trong tương lai.

Từ khóa:

Bảo tồn, đặc điểm hình thái, đặc điểm sinh thái, Gụ lau, phân bố.

1. INTRODUCTION

Hon Ba Nature Reserve (HBNR) was established in accordance with Decision of No 98/2005/QĐ-UBND issued by the Chairman of Khanh Hoa Provincial People's Committee on December 15, 2005. HBNR is located in Dien Khanh region, west of Khanh Hoa province, Vietnam [1]. The study area, covering 19.285,83 ha, is located between 12°01'45" - 12°12'00" North latitude and 108° 53'45" - 109°02'34" East longitude (Fig. 1).

This Reserve has unique natural conditions and convergence of 752 plant species, 468 genera, 120 families, of which 43 species listed in the Vietnam Red Data Book (2007) [2]. HBNR is located in the south-west of the world-famous Nha Trang Bay and is the homeland of various flora and fauna. But recently, the area's vegetation came under multiple stresses due to anthropogenic factors. Rapid deforestation made it possible that many of the critical plants may have

become extinct before even being documented. Hence, an urgent requirement for documentation of biodiversity was felt. A review of literature and herbarium consultations revealed that apart from some

preliminary species surveys, very little was known about the plant diversity of HBNR, and there is no in-depth study of *Sindora tonkinensis* in HBNR had been made so far [3].

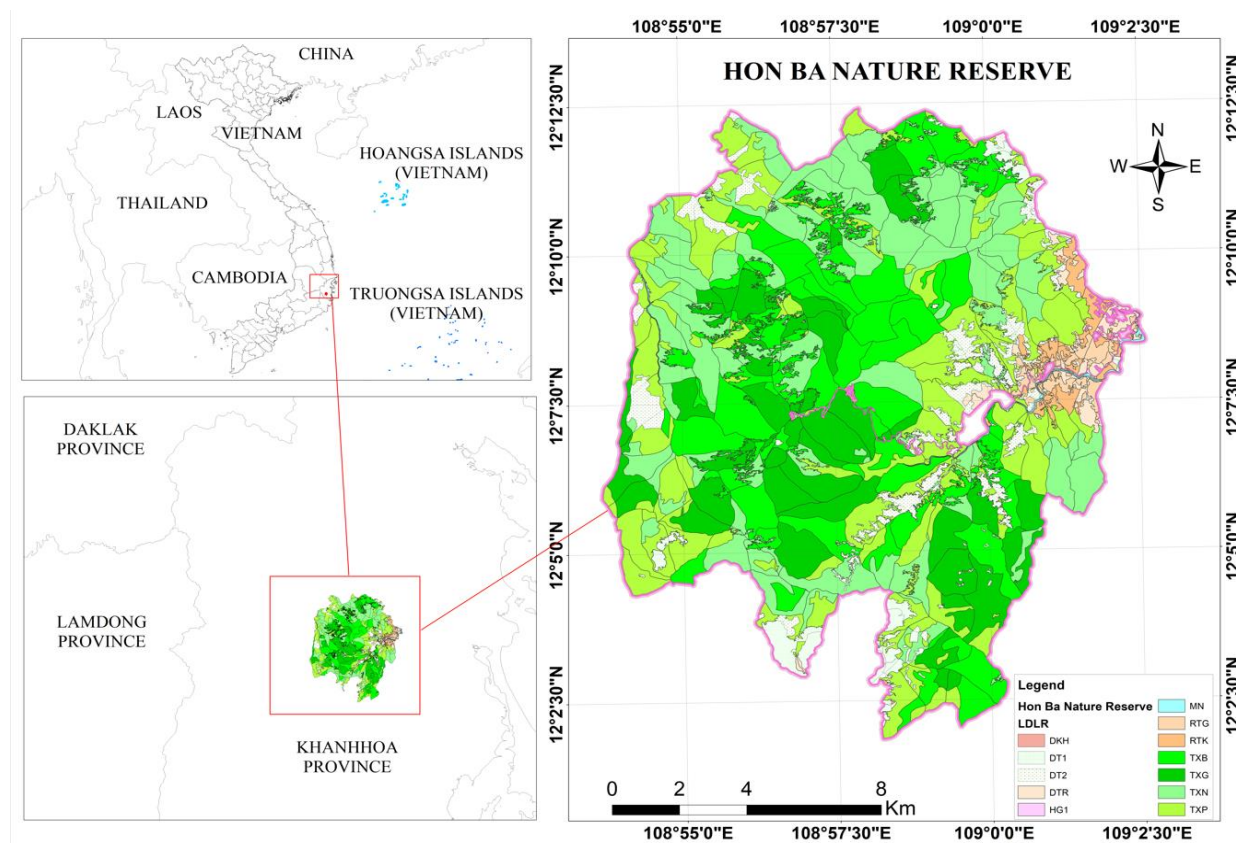


Figure 1. Scheme of location and boundaries of the research object

Sindora tonkinensis A. Chev. ex K. Larsen & S. S. Larsen. is a tree species of high economic and scientific values. Its timber is highly valued for durability, resistance to termites, and is widely used for manufacturing household luxury furniture as well as in the restoration and construction of large-scale structures such as temples and pagodas. The bark contains tannins that can be used for dyeing fishing nets, while the flowers provide nectar for honeybees. However, *S. tonkinensis* has been subject to intensive exploitation and overharvesting, leading to a rapid decline in mature individuals and making the species increasingly rare and threatened with extinction. According to [4], the species is classified as “Endangered” (EN A2 acd). It is also listed in Group II of Decree No. 84/2021/NĐ-CP of the Government of Vietnam, which restricts its exploitation and utilization for commercial purposes. Strict

protection is therefore essential, as the species remains a major target of illegal harvesting. Notably, *S. tonkinensis* is one of the few species prioritized for conservation at HBNR [5].

In forest communities, the survival and development of individual trees depend not only on their adaptation to site conditions but also on their interactions with surrounding plant species. Therefore, alongside research on the distribution characteristics of *S. tonkinensis*, investigations into its ecological traits and associated plant species are essential. Such studies provide a scientific basis for rational species mixtures in reforestation and conservation programs. From these scientific foundations, the identification of silvicultural characteristics will yield critical and practical information to support management planning for the conservation and cultivation of this

endangered species in natural habitats.

2. RESEARCH METHODS

To propose effective measures for the conservation, development, and propagation of *S. tonkinensis*, a thorough understanding of its biological and ecological characteristics is required. Therefore, this study adopts a comprehensive and participatory research approach. Given the limited research timeframe, this study emphasizes the principle of building upon existing research results and conducting only supplementary investigations to fill knowledge gaps. A multi-dimensional approach from different perspectives was employed to ensure reliable and robust outcomes.

2.1. Taxonomic

Accurate taxonomic identification is crucial in field research to avoid misidentification of the target species. This method also provides a clear understanding of the species' taxonomic position within classification systems.

To achieve this, the author reviewed relevant literature on the taxonomy of the genus *Sindora* and the family Fabaceae, both globally and in Vietnam. In addition, herbarium specimens housed at HBNR were examined. All photographs and information related to the target species were documented, analyzed, and compared with type specimens. Morphological traits of the species were also carefully recorded to support subsequent morphological studies.

2.2. Method for studying morphological characteristics

A direct observational and descriptive approach was applied to selected representative individuals, combined with comparison against existing references. This is a commonly used method in botanical research [6], which includes:

(1) Observing, describing, and measuring the morphological traits of *S. tonkinensis*, including trunk, bark, branches, leaves, flowers, fruits, and seeds. Standard trees were selected based on good growth, straight stems without deformities or pests. On each tree, three representative branches were marked at the upper, middle, and lower canopy positions. Additional botanical methods

developed by [7], [8] were applied for morphological observation and description.

(2) Collecting voucher specimens not only of the study species but also of associated species within the plant community to support taxonomic identification. These specimens were compared with previous collections and morphologically similar species to ensure taxonomic accuracy.

2.3. Methods for studying ecological characteristics

2.3.1. Transect surveys

This method followed standard practices in silvicultural surveys [9] and botanical studies of Nguyen Nghia Thin (2007) [6]. At each study site, general information was gathered from Hon Ba Nature Reserve documents and through interviews with local staff and residents. Existing data were combined with supplementary transect-line field surveys to identify the distribution range of *S. tonkinensis*.

Based on forest status maps and known occurrence areas, five transects (each 2–3 km in length) were established, crossing forest types where *S. tonkinensis* was present. Along these transects, site characteristics such as elevation and slope (measured using topographic maps and handheld GPS), forest condition, and soil type were recorded wherever *S. tonkinensis* was encountered. These data provided the basis for selecting representative plots for detailed sampling.

2.3.2. Temporary standard sample plots

Four temporary standard sample plots were established [10, 11], each measuring 1,000 m² (40 × 25 m), representing four typical forest conditions in the study area. Within sample plots, the following parameters were recorded: elevation, slope, canopy cover, forest condition, and number of trees present. For the tree layer, all individuals with diameter at breast height (D1.3) > 6 cm were measured using a 2 m tape with 0.1 cm accuracy. Total tree height (H_{vn}) was measured using a Blume-Leiss hypsometer with 0.1 m accuracy.

2.3.3. Regeneration surveys

Within each sample plots, five subplots of 25 m² (5 × 5 m) were established to assess regeneration. Key forest attributes including

elevation, slope, canopy cover, and stand condition were recorded. Absolute elevation and slope were determined using GPS and a handheld compass. Canopy cover of the upper layer was estimated using the Gap Light Analysis Mobile App, with mean values taken as representative for sample plots. In each subplots, the number of regenerating *S. tonkinensis* individuals per hectare was counted and classified by quality (good, medium, poor). The layout of sample plots and measurement of parameters followed standard silvicultural survey protocols. The method involves using subplots to observe shrubs and herbs, where quantitative data like species name, cover, number, and height are recorded in each subplots.

2.3.4. Survey of associated plant species

The “7-tree plot method” developed by Tran Ngoc Hai et al. (2016) [9] was used to assess associated species. A total of 20 *S. tonkinensis* individuals were selected as focal trees, and for each focal tree, the six nearest neighboring trees were identified and recorded, including their species names. For each of these trees, species name, size, distance from the focal tree, and growth condition were documented.

2.4. Data Processing

Data were processed using statistical

methods commonly applied in forestry, with Microsoft Excel 2019 and SPSS version 25.0 software. The composition of the tree layer was calculated based on the Importance Value Index (IVI%) using the formula:

$$IVI\%=(N\%+G\%+V\%)/3$$

where,

N%, *G%*, and *V%* represent the relative percentage of density, basal area, and tree volume of each species compared to all trees within a sample plot, respectively. The height-class distribution of regenerating *Sindora tonkinensis* individuals was divided into four categories: < 50 cm (Hts < 50 cm), 0.5 to < 1.0 m (0.5 ≤ Hts < 1 m), 1.0 – 2.0 m (1 ≤ Hts < 2 m), and ≥ 2.0 m (Hts ≥ 2 m).

3. RESULTS AND DISCUSSION

3.1. Morphological characteristics

Each species possesses distinctive ecological distribution ranges and exhibits certain morphological variations; therefore, detailed morphological studies across ecological regions are essential and provide important contributions to taxonomy. Based on the synthesis of previous studies on the morphology of *S. tonkinensis* combined with supplementary field investigations at Hon Ba Nature Reserve, the morphological characteristics of the species were identified as follows (Fig. 2).

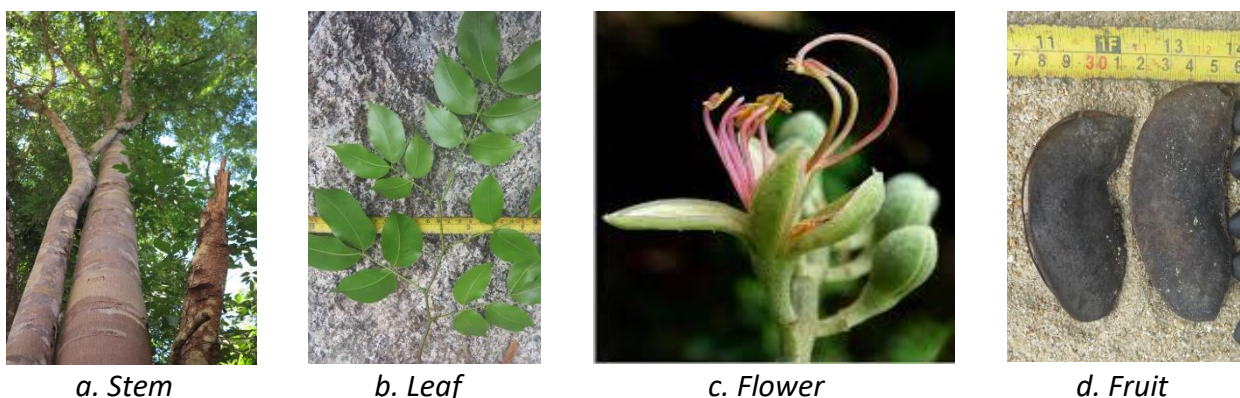


Figure 2. Morphological characteristics of *S. tonkinensis*

+ Stem characteristics: A large tree with a typically straight, cylindrical trunk; deciduous; height 20–25 m; diameter 0.6–0.8 m. The crown is wide-spreading and variable in form. Bark is dark brown to black, non-exfoliating, marked with small tooth-like scars; inner bark is pale pink, containing a small amount of colorless sap.

+ Leaf characteristics: Leaves paripinnate, 8–16 cm long, with 3–5 pairs of leaflets. Leaflets ovate to elliptic, asymmetric, 6–12 cm long and 3.5–6 cm wide, apex acuminate, base rounded or obtuse; glabrous on both surfaces; upper surface dark green, lower surface smooth light green; midrib unevenly off-centered; lateral veins not prominent; margin

entire; petiolules curved, 4–5 mm long.

+ Flower characteristics: Inflorescences are terminal panicles, 10–15 cm long, covered with golden-brown pubescence. Bracts triangular, 5–10 mm long. Calyx externally pubescent. Corolla consists of 1 (occasionally up to 3) fleshy petals, 7–8 mm long, externally hairy. Stamens 10. Ovary shortly stipitate, densely pubescent; style curved, 10–15 mm long; stigma capitate.

+ Fruit and seed characteristics: Pods nearly round or ovoid, often slightly curved, 6–9 cm long and 3–4 cm wide, with a pointed curved beak; pericarp hard and spineless. Each pod contains 2–4 seeds; seeds large, about the size of a fingertip, black, with a whitish-yellow strophiole adhering at the base.

+ Phenology: At HBNR, *S. tonkinensis* flowers from May to June, and fruits ripen between October and November of the following year. The phenological characteristics observed in this study are consistent with the descriptions reported by Tran Hop (2002) [12].

3.2. Ecological Characteristics

3.2.1. Forest habitat characteristics

+ Climate: At HBNR, *S. tonkinensis* is distributed at elevations below 900 m, under a

tropical monsoon climate. The mean annual temperature ranges from 23–26 °C, with an average annual rainfall of 1,900–2,000 mm and mean relative humidity around 80%.

+ Soil characteristics: According to soil surveys at HBNR, *S. tonkinensis* is commonly distributed on ferrallitic red-yellow soils developed from acidic magmatic rocks, which account for approximately 70% of the Reserve's area. These soils occur at elevations of 500–1,000 m and originate from various parent rocks such as granite, rhyolite, and dacite. They are characterized by relatively thick humus layers and moderate fertility.

+ Forest type: The species occurs in lowland tropical evergreen closed broad-leaved monsoon forest.

3.2.2. Structural characteristics of forest plant communities

+ Composition of the upper tree layer: To assess the contribution of species within a forest plant community, species composition can be expressed either by relative density or by the Importance Value Index (IVI%). A higher IVI% indicates a more important ecological role of a species within the community. Results of species composition analysis are presented in Table 1.

Table 1. Species composition structure of the upper canopy

TTR	N	LC _{CTT}	Formula of species composition in the upper canopy layer
TXN	41	23	11.21Bln + 10.45Dc + 7.62Mc + 6.87Cm + 6.51Cy + 5.6Ck + 5.53C + 46.2Lk
TXB	39	32	15.93Tv + 14.75Bl + 7.79Dd + 6.4Tv + 49.85Lk
TXG	45	27	24.86Blo + 9.3Ck + 6.96Bln + 5.91Cx + 5.56 Rh + 47.4Lk
HG	54	26	12.83Dc + 9.78Tn + 6.24Cm + 5.85Tt + 5.68Ck + 5.34Cx + 5.31Gl + 5.04G + 43.9Lk

Notes: TTR: Forest status; N: Number of trees in each sample plots (individuals); LC_{CTT}: Number of species contributing to the composition formula (species). TXN: Poor evergreen broad-leaved forest, TXB: Medium evergreen broad-leaved forest, TXG: Rich evergreen broad-leaved forest, HG: Mixed broad-leaved and coniferous forest.

Table 1 indicates that the tree species contributing to forest composition in the study area are primarily characteristic of secondary forests, with light-demanding and fast-growing traits. However, the species composition of the upper canopy is relatively diverse, ranging from 23 to 32 species. *S. tonkinensis* (Gl) appears in the canopy composition of mixed broad-leaved and coniferous forests, highlighting its potential for conservation and development in HBNR.

+ Density structure: The survey results revealed the density structure of natural forests where *S. tonkinensis* occurs across elevation gradients, as presented in Table 2.

Findings indicate that the distribution of *S. tonkinensis* varies considerably with elevation. At elevations below 250 m, the species exhibited the best growth performance, with a density of 30 trees/ha, alongside larger mean diameter and height values. From 250 to 400 m, the density decreased to only 20 trees/ha,

and mean diameter also declined, whereas mean height showed no significant change.

Overall, *S. tonkinensis* is best adapted to elevations between 200–250 m. Therefore,

enrichment planting or afforestation of *S. tonkinensis* should be prioritized at this elevation range in HBNR.

Table 2. Density structure of *S. tonkinensis* across elevation gradients

No.	Elevation (m a.s.l.)	Forest density (trees/ha)	<i>S. tonkinensis</i>		
			Density (trees/ha)	D _{1,3} tb (cm)	Hvn (m)
1	200 - 250	770	30	30.8	13.5
2	250 - 300	770	20	18.5	12.5
3	300 - 350	740	20	17.0	13.0
4	350 - 400	700	20	17.5	13.3

+ Vertical structure: The vertical stratification of the forest reflects the spatial partitioning of resources among plant species along the vertical axis, thereby maximizing the use of living space and reducing competition for light. Moreover, vertical stratification also represents the successive formation of

vegetation layers over the course of forest development.

Based on both collected data and field observations, the vertical stratification of natural forests containing *S. tonkinensis* in the study area is summarized in Table 3.

Table 3. Vertical structure of the upper canopy in natural forests

Forest stratum	Description
1. Emergent layer	This layer comprises tree species with very high light requirements. During growth, these trees extend above others, occupying the highest canopy position. In the study area, the emergent layer reached heights above 19 m, with species <i>Irvingia malayana</i> , accounting for approximately 0.45% of the total stand.
2. Main canopy layer	This layer also consists of light-demanding tree species. In the study area, canopy height ranged from 12–19 m, including species such as <i>Sindora tonkinensis</i> , <i>Cinnamomum parthenoxylon</i> , <i>Artocarpus melinoxyla</i> , <i>Irvingia malayana</i> , <i>Syzygium zeylanicum</i> , <i>Knema pierrei</i> , <i>Calophyllum inophyllum</i> , <i>Lindera annamensis</i> , <i>Xylopiia pierrei</i> , <i>Lithocarpus garretianus</i> , <i>Garcinia ferrea</i> among others. The main canopy formed a relatively continuous layer, accounting for about 74.44% of the total stand.
3. Sub-canopy layer	This layer comprises shade-tolerant tree species with lower light requirements compared to the main canopy species. In the study area, heights ranged from 5–12 m. This layer could be subdivided into smaller height classes. Immediately below the main canopy were medium-sized trees requiring less light, while beneath them were smaller shade-tolerant trees. Typical species included: <i>Vitex ajugaeflora</i> , <i>Barringtonia macrocarpa</i> , <i>Ancistrocladus cochinchinensis</i> , <i>Gonocaryum lobbianum</i> and others. The sub-canopy accounted for approximately 25.11% of the upper-tree stand.
4. Shrub and herb layer	This layer consists of shrubs and climbing species less than 5 m tall, typically shade-tolerant or regenerating seedlings in their early shaded growth stage. Representative species included <i>Gnetum montanum</i> , <i>Dracaena angustifolia</i> , <i>Eurycoma longifolia</i> , <i>Micromelum hirsutum</i> among others.

In the study area, forest canopy closure was relatively high, ranging from 0.6 to 0.7. Combined with a dense understory of herbs and litter, this condition posed significant constraints on the natural regeneration capacity of *S. tonkinensis*.

+ Associated species with *S. tonkinensis*: To examine the ecological relationships between *S. tonkinensis* and other tree species, 30 individuals of *S. tonkinensis* with DBH ≥ 10 cm, distributed across different sites in the study area, were selected for investigation. The

survey aimed to identify associated species, or “companion species,” using the 7-tree quadrat method.

The results showed that the mean distance between *S. tonkinensis* individuals and their companion trees was 5.5 m (with extremes ranging from 0.5 m to 15 m). A total of 30

quadrats comprising 210 trees were examined, from which 29 associated species were identified with varying frequencies of occurrence. Companion species were ranked according to their frequency, and the results are summarized in Table 4.

Table 4. Species composition associated with *S. tonkinensis*

No.	Scientific name	Number		No.	Scientific name	Number	
		N	%			N	%
Center	<i>S. tonkinensis</i>	20	14.29	24	<i>Dillenia pentagyna</i>	2	1.43
1	<i>Garcinia ferrea</i>	11	7.86	25	<i>Cratoxylum formosum</i>	2	1.43
2	<i>Artocarpus melinoxyla</i>	7	5.00	26	<i>Diospyros buxifolia</i>	2	1.43
3	<i>Castanopsis nhatrangensis</i>	6	4.29	27	<i>Syzygium zeylanicum</i>	2	1.43
4	<i>Lithocarpus garretianus</i>	5	3.57	28	<i>Xerospermum noronhianum</i>	1	0.71
5	<i>Calophyllum thorellii</i>	5	3.57	29	<i>Diospyros crumenata</i>	1	0.71
6	<i>Hopea recopei</i>	5	3.57	30	<i>Elaeocarpus tectorius</i>	1	0.71
7	<i>Syzygium syzygioides</i>	4	2.86	31	<i>Dialium cochinchinensis</i>	1	0.71
8	<i>Xylopia nitida</i>	4	2.86	32	<i>Schima crenata</i>	1	0.71
9	<i>Archidendron chevalieri</i>	4	2.86	33	<i>Gironniera subaequalis</i>	1	0.71
10	<i>Atalantia ceylanica</i>	4	2.86	34	<i>Adina cordifolia</i>	1	0.71
11	<i>Syzygium zeylanicum</i>	4	2.86	35	<i>Brownlowia tabularis</i>	1	0.71
12	<i>Garcinia pedunculata</i>	3	2.14	36	<i>Peltophorum dasyrhachis</i>	1	0.71
13	<i>Elaeocarpus petiolatus</i>	3	2.14	37	<i>Endiandra macrophylla</i>	1	0.71
14	<i>Calophyllum thorellii</i>	3	2.14	38	<i>Alstonia angustifolia</i>	1	0.71
15	<i>Lithocarpus honbaensis</i>	3	2.14	39	<i>Adenanthera microsperma</i>	1	0.71
16	<i>Sindora tonkinensis</i>	3	2.14	40	<i>Lepisanthes amphifolia</i>	1	0.71
17	<i>Diospyros nhatrangensis</i>	3	2.14	41	<i>Cinnamomum iners</i>	1	0.71
18	<i>Altingia poilanei</i>	3	2.14	42	<i>Carallia brachiata</i>	1	0.71
19	<i>Sterculia gracilipes</i>	3	2.14	43	<i>Dillenia indica</i>	1	0.71
20	<i>Irvingia malayana</i>	2	1.43	44	<i>Vatica odorata</i>	1	0.71
21	<i>Quercus chevalieri</i>	2	1.43	45	<i>Cratoxylum cochinchinensis</i>	1	0.71
22	<i>Horsfieldia amygdalina</i>	2	1.43	46	<i>Diospyros pilosanthera</i>	1	0.71
23	<i>Cinnamomum parthenoxylon</i>	2	1.43	47	<i>Podocarpus neriifolius</i>	1	0.71
				48	<i>Syzygium bonii</i>	1	0.71
	Total					140	100

A total of 140 trees were recorded across 20 seven-tree quadrats, representing 48 species. On average, this equates to 2.92

individuals per species. The species most frequently co-occurring with *S. tonkinensis* were those with ≥ 7 individuals, comprising

103 trees from 20 species, including *Garcinia ferrea*, *Artocarpus melinoxyla*, *Castanopsis nhatrangensis*, *Lithocarpus garretianus*, *Calophyllum thorellii*, *Hopea recopei*, *Syzygium wightianum*, *Gonocaryum lobbianum* and others.

These findings suggest that the associated species group could be effectively utilized in

mixed plantation designs with *S. tonkinensis* in HBNR or in ecologically similar environments.

3.3. Characteristics of natural regeneration

+ Density structure of regeneration layer: The density structure of regeneration under the natural forest canopy where *S. tonkinensis* occurs in HBNR is presented in Table 5.

Table 5. Density structure of the regeneration layer in natural forests

Plot	Elevation (m a.s.l.)	Number of regeneration trees (trees/ha)	Number of <i>S. tonkinensis</i> (trees/ha)
1	200 - 250	7.760	960
2	250 - 300	4.160	0
3	300 - 350	4.800	0
4	350 - 400	1.840	0

Table 5 shows that the density of regeneration under the natural forest canopy in HBNR, where *S. tonkinensis* occurs, is relatively high, ranging from 1840 to 7760 individuals/ha. The density of regenerated *S. tonkinensis* varies between 0 and 960 individuals/ha. At foothill sites below 250 m, regeneration density of *S. tonkinensis* is particularly high; in contrast, on hillsides between 250 and 400 m, the species appears to regenerate poorly or not at all. These results indicate that elevation, light, and moisture are critical ecological factors directly

influencing the regeneration density of *S. tonkinensis*.

Therefore, proper site selection for planting and nursery propagation of *S. tonkinensis*, along with the protection of areas where regeneration density is naturally high, will be essential for the conservation and sustainable development of forest resources.

+ Quality and origin of the regeneration layer: The survey results on the origin and quality of regeneration in the study area are summarized in Table 6.

Table 6. Quality and origin of regeneration

Total number of regenerated trees in the stand (N/ha)	Quality of regenerated trees (N/ha)			Origin of regenerated trees (%)	
	Good	Moderate	Poor	Seed	Sprout
4518	2.635	1.435	447	86.46	13.54

Table 6 shows that 447 seedlings were classified as poor quality, accounting for 9.9%, while 31.8% were of medium quality, and 58.3% were of good quality. Overall, the majority of regenerated individuals in the study area were of medium to good quality.

represented only 13.54%. For *S. tonkinensis*, both seed regeneration and sprout regeneration were observed. This finding highlights the potential for further research into clonal propagation techniques for *S. tonkinensis*.

In terms of origin, seedlings derived from seeds predominated, accounting for 86.46%, whereas those originating from sprout/shoot

+ Regeneration stratification by height: The distribution of regeneration by height class in the study area is summarized in Table 7.

Table 7. Distribution of regenerated trees by height class

Plot	Height Class Distribution of Regenerated Trees (trees/ha)								Total (trees/ha)
	<0,5 m		0,5 – 1 m		1 – 2 m		>2 m		
	N (trees/ha)	%	N (trees/ha)	%	N (trees/ha)	%	N (trees/ha)	%	
1	1.680	21.6	2.880	37.1	2.320	29.9	880	11.3	7.760
2	1.567	24.9	1.800	28.6	2.266	36.0	667	10.6	6.300
3	1.120	32.6	960	27.9	960	27.9	400	11.6	3.440
4	1.680	40.4	1.680	40.4	480	11.5	320	7.7	4.160

Table 7 shows that in the study area, the proportion of regenerated trees with a height of less than 0.5 m ranged from 21.6% to 40.4%. This height class corresponds to the shrub and herbaceous layer beneath the forest canopy, suggesting that seedlings in this category may grow under unfavorable conditions and be suppressed by understory competition. Silvicultural interventions are therefore necessary to enhance the growth of these seedlings.

Promising regeneration refers to target seedlings with good growth and vigor, exhibiting heights significantly greater than that of the understory vegetation. Based on field observations, seedlings considered promising were those with heights ≥ 1 m. The proportion of promising seedlings in the study area was relatively high, ranging from 11.5% to 36% of the total regeneration. Notably, most regenerated individuals of *S. tonkinensis* reached heights ≥ 1 m, accounting for 80% of all regenerated *S. tonkinensis* recorded. This demonstrates that the species has strong regeneration potential. In the future, effective forest protection and management, combined with silvicultural techniques, will be crucial to facilitate the growth of shorter individuals and ensure the successful natural regeneration of *S. tonkinensis*.

4. CONCLUSION

+ *S. tonkinensis* recorded in HBNR is a medium to large-sized tree species, capable of reaching heights up to 25 m. It is restricted to tropical monsoon climates with an average annual temperature of 23–26°C, annual rainfall of 1,900–2,000 mm, and average relative humidity of 80%. The species typically grows on ferrallitic yellow-red soils developed on acidic magmatic rocks, characterized by a relatively thick humus layer and moderate fertility. The forest type where *S. tonkinensis* occurs in the study area is classified as lowland tropical evergreen closed forests.

+ The species is primarily distributed at foothills and lower slopes at elevations between 200–250 m, with an average density of 30 trees/ha. The density of regeneration under the natural forest canopy in HBNR ranged from 3,600 to 4,800 individuals/ha, while *S. tonkinensis* regeneration reached approximately 960 individuals/ha. This indicates a moderate natural regeneration

capacity, suggesting that natural regeneration promotion measures could be effectively applied for forest restoration of this species.

+ Among regenerated trees, 58.3% were classified as good quality, 31.8% as medium, and 9.8% as poor. Seed-origin regeneration predominated (86.46%), whereas coppice-origin regeneration accounted for only 13.54%. For *S. tonkinensis*, both seed and coppice regeneration were observed. These findings provide important scientific and practical foundations for the conservation and sustainable development of *S. tonkinensis* in the future.

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