Systematic Survey Report

of *Dalbergia cochinchinensis and Dalbergia oliveri*

for Piloting Assessment on Sustainable Genetic Conservation

in Choam Ksant district, Preah Vihear Province

Integrating the Development of Guidelines and Incentives for Piloting the Establishment of Small-scale Private *Dalbergia* Plantations with the Determination of a Non-detriment Findings Report

in Preah Vihear Province, Cambodia

Forestry Administration

March, 2021

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Acronyms

asl	Above sea level
CAI	Current Annual Increment
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CF	Community Forestry
CTSP	Cambodian Tree Seed Program
DBH/dbh	Diameter at Breast Height
IUCN	The International Union for the Conservation of Nature
FA	Forestry Administration
MAI	Mean Annual Increment
NDVI	Normalized Difference Vegetation Index
UTM	Universal Transverse Mercator

Executive Summary

This report reflects on the systematic survey to determine the population distribution, stocking levels, and diameter class distributions of *D. cochinchinensis* and *D. oliveri* that was undertaken in the Choam Ksant management district in Preah Vihear province, Cambodia. The biological risks, habitat specificity, and vulnerabilities of those two species were also evaluated for use in the determination of a non-detriment findings report and for piloting the establishment of small-scale private *Dalbergia* plantations throughout the country.

The Normalized Difference Vegetation Index (NDVI) was used to facilitate the use of less costly. time-saving spatial distribution procedures that allowed reducing the number of sampling sites the survey required over an extensive study area. There were 63 sample flora plots that were established in semi-evergreen forest and 23 sample flora plots that were established in mixed deciduous and dry deciduous forests with the rank NDVI indexes corrected for land use changes ranging from 0.4 to 0.7. In the course of the field survey, there were 72 timber species that were recorded, including 8 Luxury Grade species, 19 Grade 1 species, 8 Grade 2 species, 9 Grade 3 species, and 28 Ungraded species. The occurrence of *D. cochichinensis* was reported in 5 of the 86 plots (5.8%), while *D. oliveri* was recorded in 7 of those plots (8.1%).

D. cochinchinensis displayed a negative exponential relationship between population density and diameter distribution that approximated a standardized reverse J-shape curve. The maximum DBH that was recorded for *D. cochinchinensis* in natural habitats was only 20 cm, however, which, together with the very low average wood volume of *D. cochinchinensis* (0.139 m^3 /ha) underscores the requirement for more effective conservation efforts if the species is to continue to survive in its natural forest habitat in Cambodia.

The average population density of *D. cochinchinensis* was 113.1± 64.5 plants/ha and, of those 113.1 plants/ha, 87.2 plants/ha, on average, were seedlings and 23.3 plants/ha, on average, were saplings. There were only 2.6 plants/ha with diameters ≥ 5 cm.

In assessing the natural distribution of *D. cochinchinensis* in forest habitats, correlation tests were conducted using various plausible covariates, including elevation, slope, the NDVI, and forest type. The tests were performed using observations from 133 locations established in systematic plots and where preliminary spot checks were performed. The results of those tests revealed that there was a significant relationship between occurrences of *D. cochinchinensis* and forest type ($P < 0.001$) on the basis of the use of both field records and national data (Forest Cover 2014), although that significance was tempered to some extent by a coefficient of determination, or R^2, of only 0.101 or 0.128.

The distribution of *D. cochinchinensis* is primarily limited to forest habitats, especially mixed deciduous and some dry deciduous forests. Nevertheless, not all occurrences of *D. cochinchinensis* would be expected to be in deciduous forests since dry deciduous forests with their open spaces and waterlogged conditions during the rainy season would not be particularly conductive to supporting the occurrences of *D.* cochinchinensis. Such reasoning suggests that geographical characteristics beyond forest types may also influence its distribution in natural habitats.

The results of projecting the mean annual growth over the next 10 years are indicative of annual increments of growth of *D. cochinchinensis* that are consistent with a pattern of rapid growth of all of the trees, including those < 5 cm, during the first 4 years of growth followed by a slower rate of growth during the following years.

The population estimates and estimates of wood volume of *D. oliveri* were determined from trees observed in deciduous and semi-evergreen forests. The overall average population density of *D. oliveri* was 234.5 ± 191.5 plants/ha. Of those 234.5 plants/ha, moreover, 145.4 plants/ha, on average, were seedlings and 88.4 plants/ha, on average, were saplings. There were only 0.8 plants/ha with diameters ≥ 5 cm.

The average population density of *D. oliveri* in the deciduous forests was 294.5 ± 258.3 plants/ha and, of those 294.5 plants/ha, 198.4 plants/ha, on average, were seedlings and 95.2 plants/ha, on average, were saplings. There were only 0.8 plants/ha with diameters ≥ 5 cm.

The average population density of *D. oliveri* in the semi-evergreen forests was 70.1 ± 0.7 plants/ha and, or those 70.1 plants/ha, 69.6 plants/ha, on average, were saplings. There were no seedlings and only 0.6 plants/ha with diameters ≥ 5 cm.

D. oliveri's negative exponential relationship between population density and diameter distribution also approximated a standardized reverse J-shape curve, but despite the presence of this relationship, the sustainability of the species seems to be very much threatened by the relatively small number of large DBH trees – less than one per hectare - that were observed during field observations in natural forest habitats. Those observations provide compelling evidence that the harvesting of the species should be strictly prohibited while every effort is made to protect remaining mother trees. The requirement to prohibit harvesting to protect remaining mother trees is borne out by the measure of the average wood volume of *D. oliveri* in its natural forest habitats, which was only 0.308 m^3/ha in deciduous forests and 0.197 m^3/ha in semi-evergreen forests.

In assessing the natural distribution of *D. oliveri* in forest habitats, correlation tests were conducted using observations from 118 locations established in systematic plots and where preliminary spot checks were performed. The results of the tests revealed that while there were no significant relationships between occurrences of *D. oliveri* and either the NDVI or the forest type on the basis of the use of field records, there were significant relationships with elevation and with slope ($P < 0.05$), as well as with forest type on the basis of the use of national data ($P < 0.01$). These results suggest that the distribution of *D. oliveri* would be expected to be observed across different natural forest habitat types, but primarily limited to certain ranges of altitude and slope, and specific forest types, including steep slopes, such as those found in the alleys of hills, or in the upper elevations of the Dang Rek Mountain range along the trans-boundary area between Cambodia and Thailand.

Some natural issues and human-induced disturbances were observed exerting servere pressures that have the ability to affect the reproduction, resilience capacities, and natural growth of both of these species, which can result in either mortality or increased vulnerability. Those threats are comprised of annual forest fires during the dry season; irregular flowering and fruiting; the increasingly severe risk due to a relatively long reproductive cycle; unregulated selective longing; and the limited records of artificial propagation of these species by local populations.

Responding to the imperative of their genetic conservation, the planting of both of these *Dalbergia* species should be incentivized and promoted in as many forms as available, including through the establishment of industrial plantations, household plantations, and agroforestry systems, as well as on public lands throughout its natural range.

I. Introduction

Dalbergia cochinchinensis and *Dalbergia oliveri* are representative of several species of *Dalbergia*, which together with a few other genera are commonly referred to in international trade as rosewood. In responding to increasing demand, traffickers have expanded their sources of rosewood and targeted several countries throughout the tropics where rosewood species grow. Rosewood, indeed, has become the world's most trafficked wild product according to the United Nations Office of Drugs and Crime and currently accounts for one-third of all such seizures by value. CITES has placed the 300 species of rosewood, including *D. cochinchinensis*~~,~~ and *D. oliveri*, under trade restrictions, which means that criminals may no longer readily pass off illegally-logged species as legitimate.

The illegal logging and trafficking of *D. cochinchinensis* and *D. oliveri* associated with Cambodia has several transboundary connections that culminate in markets in China. These connections have been especially reflected in the volume of Vietnam's imports of logs and sawnwood from Cambodia that are destined for Chinese markets (Phuc et al., 2016).

There are no official statistics, differentiated by species, that are available to determine the extent of the illegal logging and smuggling of *D. cochinchinensis* and *D. oliveri* occurring in Cambodia. The information that is accessible, moreover, is often fragmented and not very well-documented. The evaluation of such occurrences is relegated to a review of the reports that are provided in public media outlets and newspaper articles, in particular, that record instances of government seizures of illegally harvested or transported logs and sawnwood of *D. cochinchinensis* or *D. oliveri*.

In recognizing of these shortcomings, the project for 'Integrating the development of guidelines and incentives for piloting the establishment of small-scale private *Dalbergia* plantations with the determination of a non-detriments findings report in Preah Vihear province in Cambodia' was proposed. It was developed to coincide with the assorted factors of success that accompanied the favorable phasing associated with the promulgation of the Cambodian government's Declaration on Private Forests. The emphasis of the project on the establishment of small-scale private plantations of *D. cochinchinensis* and *D. oliveri* responds to the illegal logging of the species that has been occurring throughout Southeast Asia, which accentuates the relevance to the project of both the CITES Tree Species Programme and the listing of endangered tree species in CITES Appendix II.

Selected as the pilot study area on the basis of the extent of the distribution of *D. cochinchinensis* and *D. oliveri* that occurs in Cambodia, Choam Ksant district in Preah Vihear province is located in the northern part of the country. This is where the two species of *Dalbergia* that are native to Cambodia are considered to be 'precious wood' and are highly valued in international trade for a range of their inherent qualities.

This report reflects on the project's primary objective, which was to undertake systematic field surveys to determine the population distribution, stocking levels, and diameter class distributions of *D. cochinchinensis* and *D. oliveri* in the Choam Ksant management district in Preah Vihear province. The biological risks, habitat specificity and vulnerabilities of those two species were also evaluated as a part of the study,

II. Methodology

2.1 Reviews

Reviews of the taxonomy, biology, ecology, as well as the status, trend, and population structure and dynamics, of *D. cochinchinensis* and *D. oliveri* in Cambodia were conducted to test whether there was a relationship between observed samples and other covariate factors such as elevation, slope, and forest habitat.

2.2 Preliminary Spot Checks

The Normalized Difference Vegetation Index (NDVI) was employed to investigate the spatial distribution of different tree species in terms of variations of surface spectral reflectance (Jan-Chang Chen & Chaur-Tzuhn Chen, 2008). Its use provided less costly, time-saving procedures that allowed reducing the number of sampling sites required over an extensive study area. The preliminary spot checks of the distribution of *D. cochinchinensis* and *D. oliveri* were conducted prior to undertaking a systematic sampling of flora in Choam Ksant management district. There were more than 50 occurrences of *D. cochinchinensis* and *D. oliveri* that were detected in identified habitats as a result of the spot checks (Figure 1.). Their NDVI values were calculated using satellite images that were able to be used for establishing systematic flora plots, the number of which was subsequently reduced by restricting the plots to those within a selected range of NDVI.

Figure 1. Preliminary spot check of occurences of *D. cochinchinensis* in natural habitats.

2.3 Satellite Images

The Sentinel 2, which contains 12 bands of satellite images with high spatial resolution (10x10 m), was employed to determine the NDVI of each plant species occurrence (Table 1).

Table 1. The satellite images used for assessing the NDVI of each plant species occurrence.

No	*Entity ID*	*Tile Number*	*Spatial (m)*	*Acquisition Date*
1	L1C_T48PVA_A023753_20200109T033739	T48PVA	10	09 January 2020
2	L1C_T48PWA_A023710_20200109T032732	T48PWA	10	06 January 2020

Source: golvis.usgs.gov.

The mosaic of those satellite images was used for further verification of forest habitat changes in sampling plot establishment. The flora plots were selected, with those plots where the NDVI rank was greater or less than the corrected rank excluded.

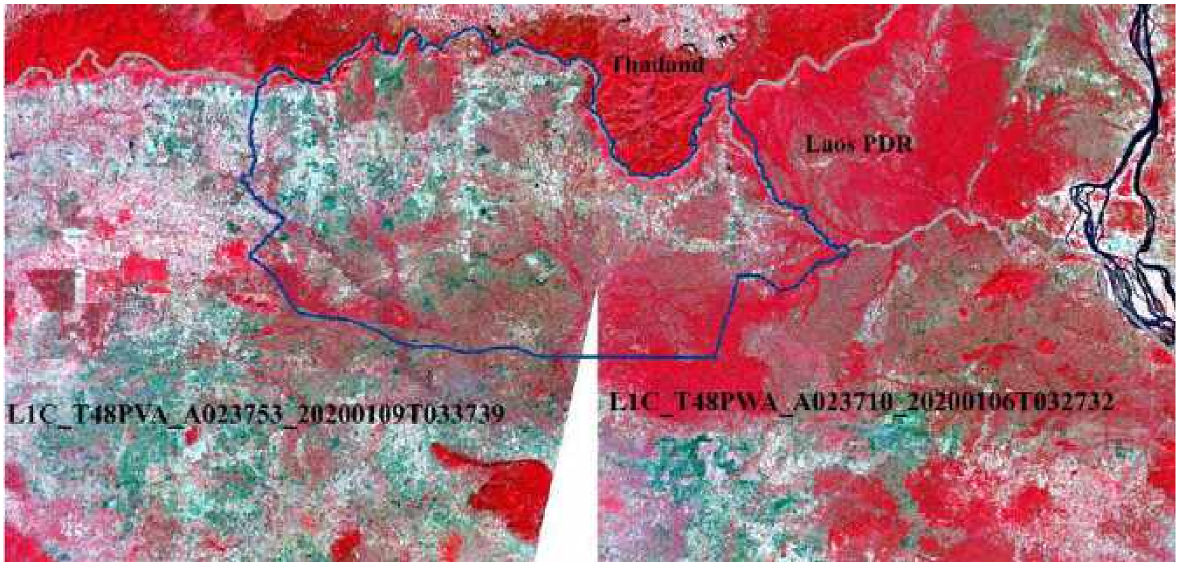

Figure 2. Sentinel 2 false color composite.

2.4 NDVI

In selecting the sampling design for establishing systematic inventory plots, the reflectance of vegetation index was used to model spatial distribution. The NDVI was calculated using Sentinel 2 images containing bands of near infrared and red at points at which *D. cochinchinensis* and/or *D. oliveri* occured within an area of vegetation or forest habitat type.

The NDVI quantifies vegetation by measuring the difference between near infrared light (which vegetation strongly reflects) and red light (which vegetation absorbs). The reflectance from a leaf is determined by its leaf structure, as well as its biochemical constituents, The vegetation spectrum typically has high absorbance in the red and blue wavelengths, high reflectance in the green wavelength, strongly reflects in the near infrared (NIR) wavelength, and displays strong absorbance in wavelengths in which atmospheric water is present.[1] The NDVI ranges from -1 to +1 as expressed in the following equation:

NDVI= $\frac{(NIR-Red)}{(NIR+Red)}$ where, NIR = near infrared

The higher the NDVI value, the denser the vegetation. The preliminary spot checks of 50 locations resulted in a wide range of vegetation structures in which *D. cochinchinensis* and *D.oliveri* occurred in an NDVI range between a minimum of 0.09 and a maximum of 0.7, with an average measure of 0.36 ± 0.14. Those figures are indicative of the progression from non-forestland through open dry deciduous forest, mixed deciduous forest, and semi-evergreen forest. The NDVI map incorporates those points in which the NDVI represents either non-forestland, grassland, rice fields, shrubs, or recently grown crops, as well. Those NDVI values, nevertheless, do not reflect the real natural forest habitat types as a result of land use changes that have occurred since those locations where *D. cochinchinensis* and *D. oliveri* were observed were formerly dry deciduous forests or mixed deciduous forests that have been converted to agricultural plantations or residential land. The natural forest types of those lands within a corrected NDVI range from 0.4 to 0.7 are representative of open dry deciduous forest, mixed deciduous forest, and semi-evergreen forest (Figure 3).

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[1] GISGeography. Normalized Difference Vegetation Index (NDVI). Retreived from: https://gisgeography.com/ndvi-normalized-difference-vegetation-index/

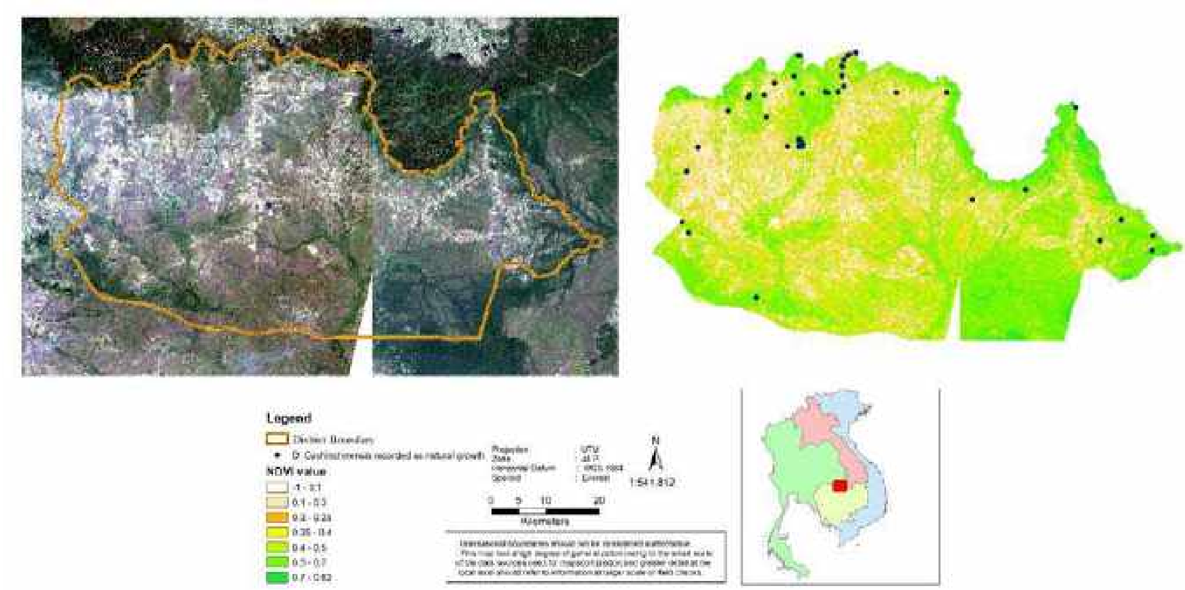


Figure 3. The mosaic of satellite images and a processed NDVI rank of the study area.

2.5 Sampling Design

The systematic field surveys to determine the population distribution, stocking levels, and diameter classes of *D. cochinchinensis* and *D. oliveri* in the Choam Ksant management district were undertaken in 86 plots. A rank NDVI raster was plotted and those values representing an NDVI greater than 0.7 or less than 0.4 were excluded from consideration (Figure 4).

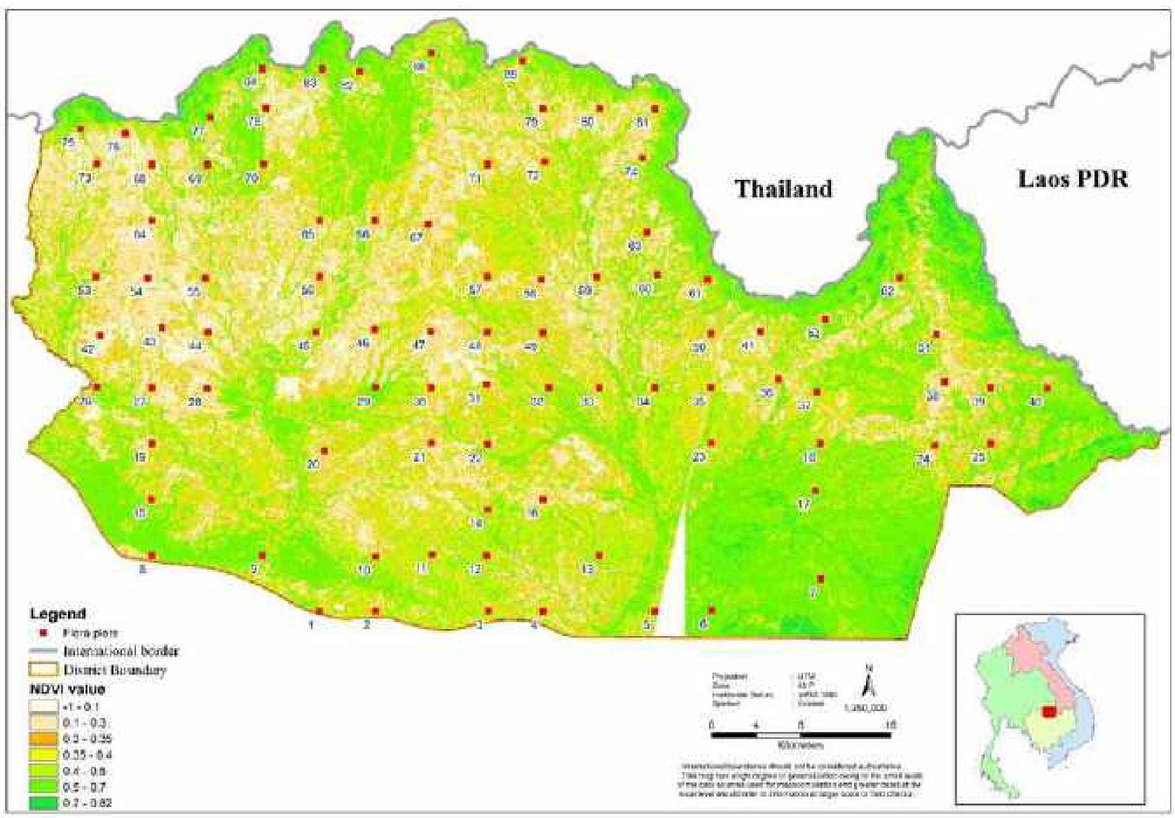


Figure 4. A map of systematic flora sampling plots based on NDVI ranks between 0.4-0.7.

The design of the sampling plots followed National Forest Inventory (NFI) 2014 procedures. Rectangular plots were established since the resulting nesting of plots increases the accuracy of sampling intensity, especially for recording larger trees, and ensures the more efficient use of time (Vesa et al., 2014). Under this structure, there are three levels of sub-plots in each plot, including (1) a sub-plot for measuring large trees (DBH ≥ 30 cm); (2) a sub-plot for measuring medium size trees (10 cm ≤ DBH ≤ 30 cm); and (3) a sub-plot for measuring small trees (5 cm ≤ DBH <10 cm) (Table 2 and Figure 5).

Table 2. Plot design and sub-plot specification.

Plot & Sub-plot	*Dimensions*	*Area (m^2)*	*DBH class*
Plot: Larger Trees	30 m × 50 m	1500	DBH ≥ 30 cm
Subplot 1: Medium Size Trees	30 m × 25 m	750	DBH ≥ 10 cm
Subplot 2: Small Trees	10 m × 10 m	100	DBH ≥ 5 cm
Subplot 3: Trees and saplings*	5 m × 5 m	25	Trees: 1cm ≤ DBH ≤ 5 cm; Height >1 m
Subplot 4: Trees and seedlings*	2 m × 2 m	4	Trees: DBH < 1cm; Height ≤ 1 m

Note: * Only *D. cochinchinensis* and *D.oliveri* were recorded in these 2 sub-plots.

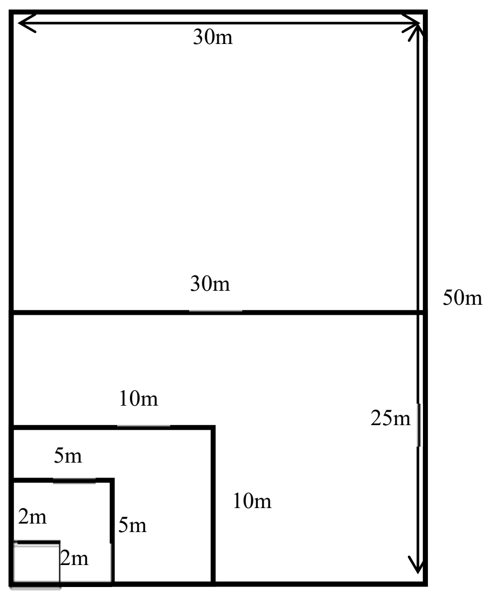
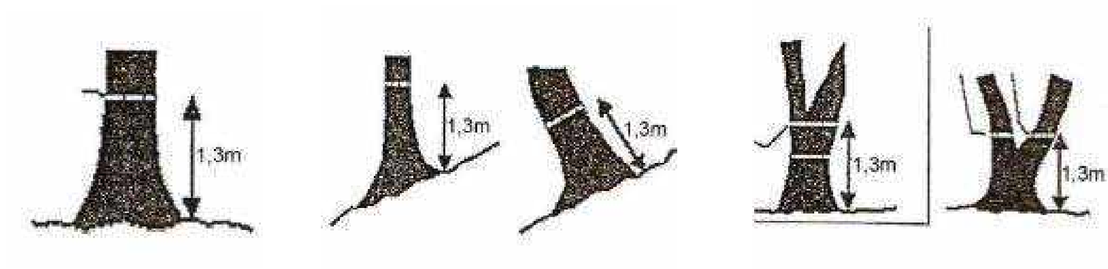


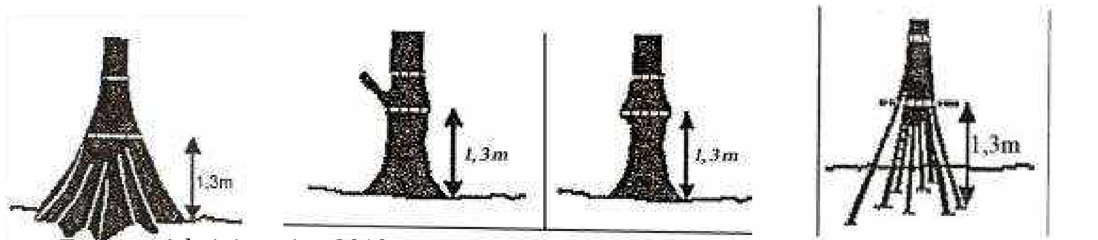
Figure 5. Plot and sub-plots design.

2.6 Measurements

The local and scientific names of every tree species were recorded. The DBH of every tree with a DBH ≥ 5 cm was measured with a measuring tape at a height of 1.3 m above the ground using a 1.3 m long measuring stick. The DBH of every tree was measured twice to ensure accuracy. The following figures illustrate the applications of measurement techniques under various conditions.



If a fork of a tree originated at a height of 1.3 m or more above the ground, every tree was measured below the fork for its DBH. If a fork originated below 1.3 m, each trunk was measured differently at a height of 1.3 m above the ground. If a tree had an irregular shape at a height of 1.3 m above the ground because of bulges, wounds, hollowed out trunks, or branches, its DBH was measured above the deformation (Forestry Administration 2010; Vesa et al., 2014).



Source: Forestry Administration 2010.

Figure 6. Measuring a tree during the field survey.

2.7 Analyses and Data Visualization

To determine the population density and volume of trees, as well as the population distribution of *D. cochinchinensis* and *D. oliveri*, tree volume equations and other statistical analytical tools were applied in accordance with National Forest Inventory protocols.

2.7.1 Tree Volume Equations

The tree volume equations developed by the Forestry Administration were based on differences in tree families (Dipterocarp vs Non-Dipterocarp), forest types (semi-evergreen vs deciduous), and the DBHs of individual trees (Table 3).

Table 3. Wood volume equations for different forest types.

Tree Family	*DBH*	*Forest types*	
		Semi-evergreen forest	Deciduous forest
Dipterocarp	< 15 cm	V= $0.03+4.8*D^2$	V= $0.00849+4.097*D^2$
	> 15 cm	V= $0.0012+6.167*D^2$	V= $0.051+5.864*D^2$
Non-Dipterocarp	>15 cm	V= $0.0083+4.3*D^2$	V= $0.03+3.3*D^2$
	15-30 cm	V= $0.008+5.3*D^2$	V= $0.03+3.55*D^2$
	> 30 cm	V= $0.0083+6.081*D^2$	V= $-0.413+7.819*D^2$

Source: Forestry Administration, 2010.

2.7.2 Statistical Analysis Tools

The IBM SPSS's statistical analysis tools were used to conduct statistical analyses of relationships and associations (e.g., Chi-square, Pearson correlation) between the presence of each species and other covariate factors, including elevation, slope, forest type, and the NDVI. The open source R program was used, as well, to perform statistical tests using regression and negative exponential models to assess whether the relationship between diameter class distribution and population density (numbers of trees) fit classic growth and reverse "J-shape" curves, respectively. The Chapman-Richards growth model of nonlinear regression was also used for assessing the relationship between DBH and the ages of *D. cochinchinensis* and *D. oliveri,* expressed as:[2]

$y = \alpha\left(1 - e^{-\beta x}\right)^{\gamma}$ *where α = upper asymptote;* β = growth rate; γ = slope of growth

2.7.3 Data Visualization

In order to present data and results in a visual manner, selected R software packages were used for developing and displaying graphs, plots, linear models, and other related representations.

2.8 Biological Risks Assessment

The biological risks associated with *D. cochinchinensis* and *D. oliveri* were assessed with respect to habitat specificity and vulnerabilities, including natural and/or human-induced disturbances and resilience of tree species reflected in reproduction patterns. These assessments were conducted when there was a *D. cochinchinensis* or *D. oliveri* tree with a DBH ≥ 5 cm located in a plot that was concurrently used for recording flora inventory information and a local person was available who had lived near the location long enough to be able to provide accurate information about seasonal flowering and fruiting of those species.

2.9 Artificial Propagation

Locations of *D. cochinchinensis* and *D. oliveri* trees that had been previously planted were also recorded, along with the diameters of the trees and the geographical locations (UTM[3]) for plotting the trees on the distribution map. The plantations of those species, or even of a few trees of planted *D. cochinchinensis* and/or *D. oliveri,* were assessed with respect to the favorability of the locations and the potential for piloting, establishing, and promoting the registration of private small-scale *D. cochinchinensis* and/or *D. oliveri* plantations in Choam Ksant district. The resulting mapping also provided the means for differentiating whether harvested trees of *D. cochinchinensis* or *D. oliveri* originated in natural forests or in forest plantations.

III. Plant Species Accounts

3.1 *Dalbergia cochinchinensis*

Local name: Kranhung
Scientific name: *Dalbergia cochinchinensis* Pierre ex Laness., *Dalbergia* spp. (Burma rosewood)
Family: Fabaceae
Sub-family: Faboideae
Commercial Grade - Cambodia: Luxury
CITES status of protection: Annex II
IUCN Red List: Vulnerable[4] (VU)

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[2] D. Fekedulegn, M. Mac Siurtain, and J. Colbert, "Parameter estimation of nonlinear growth models in forestry;" Silva Fennica, vol. 33, no. 4, pp. 327-336; 1999.

[3] Universal Transverse Mercator (UTM) is a system for assigning coordinates to locations on the surface of the Earth.

[4] IUCN Red List. *Dalbergia cochinchinensis* (Siamese Rosewood). Retrieved on 04 May 2020, from: https://www.iucnredlist.org/search?query=Dalbergia%20cochinchinensis&searchType=species

3.1.1 Species Biology

Dalbergia cochinchinensis is a large tree reaching 30 m in height and 60 cm in dbh. Its bark is light yellow and its canopy is ramified. It usually has about 7-9 oval leaflets, which are pinnately compound. Its inflorescence is axillary with white flowers and its pod is flat, 5-6 cm long and 1 cm wide, consisting of 1 or 2 seeds (Tan Dung, 1996). It grows sparsely in deciduous and semi-deciduous forests at altitudes ranging from 0-1200 m (Cambodia Tree Seed Project, 2003), but it is mainly concentrated at 400-500 m (Chính *et al.*, 1996). It is considered to be an intermediate pioneer species that is characterised by rapid growth during its younger stages and slower growth during its older stages (So, 2000). It can attain a height of up to 35 m with a dbh of up to 90 cm (Hartvig *et al.*, 2015) and it is capable of regenerating after coppicing (Van Sam *et al.*, 2004). *D. cochinchinensis* prefers fertile and deep sandy clay or calcareous soil along streams (Sareth, 2002 in CTSP, 2003). It flowers from March to August and it fruits from September to December (Van Sam *et al.,* 2004). Its heartwood is a brown-red color with prominent veins (Hien and Phong, 2012), making it one of the most sought-after of the rosewoods (EIA, 2014). Natural regeneration of the species is often poor (CoP16 Prop. 60).

3.1.2 National Distribution and Trend

Dalbergia cochinchinensis is native to Cambodia, Vietnam, Laos, and Thailand. In Cambodia, the species is found in Kampong Thom, Preah Vihear, Ratanakiri, Pursat, Siem Reap, Kratie, Koh Kong, Stung Treng, and Modulkiri provinces (Sareth, 2002). The species requires rainfall that ranges from 1,200 to 1,650 mm per year. It can tolerate shade even when it is young, but it needs plenty of sunlight to grow and it adapts to the dry season. It can survive on most soils (Joker, 2000). The population size of *D. cochinchinensis* in Cambodia is unknown. The largest remaining population was reported to be a seed source in Siem Reap province (Theilade *in litt.* to UNEP-WCMC, 2018). That population was considered to be fairly well protected, although some trees were reported to have been felled with the remainder having dbh's of 20-25 cm (Theilade *in litt.* to UNEP-WCMC, 2018). The second largest population was reported to be in Leap Kuy Community Forest in Kampong Speu province. It consists of 200 trees found in a natural forest that extends across 107 ha (Theilade *in litt.* to UNEP-WCMC, 2018).

3.1.3 Seed Sources and Seed Collection

There is a number of identified seed sources of *D. cochinchinensis* that was established in natural forests in Koh Kong, Rattanakiri, Pursat and Siem Reap provinces by the CTSP in the early 2000's (CTSP, 2003). One of the primary seed sources is in Siem Reap province (Sre Noy commune, Varin district), where it is well protected under the evergreen forest in which it resides. Seeds of *D. cochinchinensis* may also be sourced from Leap Kuy Community Forest (CF) in Phnom Sruoch district, Kampong Speu province.

This species produces flowers in May and June with the fruits ripening in November and January (CTSP, 2003). In Laos, flowering occurs from March to August, while fruiting occurs from September to December (Sam *et al.,* 2004). Its pod is long and tapering and there are 1 or 2 seeds in each fruit. One kg of seed contains about 35,000 seeds (Joker, 2000). The maturity of the seeds can be recognized when the pod becomes dark brown. The fruits are often collected as soon as the color turns from green to yellow in order to avoid damage from insects. The pods may be collected by cutting or shaking the branches so that the pods fall to the ground. Covering the ground with canvas around the base assists in the collection of the seeds more easily (Joker, 2000).

3.1.4 Growth

A 5-year-old *D. cochinchinensis* planted in Kbal Chay Watershed Protection Area in Phreah Sihanouk province had reached 6.7 cm in diameter and 5.7 m in height at the time of measurement (So *et al.,* 2010). On the basis of empirical observations collected by measuring in 2013, an 18-year-old *D. cochinchinensis* had reached 13.67 m in height and 29.63 cm. in diameter.

3.2 *Dalbergia oliveri*

Local name: Neang Nuon
Scientific name: *Dalbergia oliveri* Gamble & Prain
Family: Fabaceae
CITES status of protection: Annex II
IUCN Red List: Endangered[5] (EN)

3.2.1 Species Biology

Dalbergia oliveri is a large tree growing up to 30 m in height (Dy Phon, 2000) and 90 cm in diameter (Tan Dung, 1996). Its bark is gray and its branches are stout and slightly pubescent. Its leaves are pinnately compound having 13 to 17 leaflets, but occasionally 9-11 or 19-21 leaflets. Its inflorescence, which is corymbose-paniculate, axillary or nearly terminal, is 10-20 cm long and 7.5-15 cm wide. The inner part of its flower is white and its fruit is flat, 6-7 cm long and 1.7 cm wide, consisting of 1 seed, although sometimes the pod may have 2 or 3 seeds.

3.2.2 National Distribution and Trend

This species is native to Cambodia, Laos, Thailand, and Vietnam (Dy Phon, 2000). In Cambodia, the species is sparsely found in Kratie, Preah Vihear, Kampong Thom, Ratanakiri, Stung Treng, Pursat and Siem Reap provinces. It occurs individually or in groups of 5-10 trees and it is found in evergreen forests or semi-evergreen forests dominated by *Lagerstroemia* and Dipterocarp species. The presence of the species ranges below 900 m and it is normally found near streams and in foothills. The tree is able to grow under the shade when young, but it has to be exposed to more sunlight when mature. *D. ovileri* can produce large amounts of seeds, but natural regeneration is usually low because of poor germination and survival rates. It generally grows slowly under both natural and plantation conditions.

3.2.3 Seed Sources and Seed Collection

Seeds of *D. oliveri* may be collected from a number of identified seed sources in natural forests, including in Pal Hal commune, Tbeng Meanchey district, Preah Vihear province, or in Prognel commune, Phnom Kravanh district, Pursat province (CTSP, 2004). The remnant forest surrounding Boeung Yak Loam in Rattanakiri province is home to a number of mature trees of *D. oliveri* where seed collection is possible.

In Cambodia, the tree starts flowering during May to July and the fruit becomes ripe from November to January. The seed is orthodox and can be stored in cool dry places for several years. It is brown with an oval shape that is 10 mm long and 6 mm wide. There are about 6,100 seeds per kilogram (CTSP, 2003). The young pods of the species are green, but will turn a dark brown when ripening. The fruits must be collected immediately when they start to mature to protect them from damage from insects. The best season for seed collection is in December and January (CTSP, 2003).

3.2.4 Growth

Based on an empirical study conducted in Cambodia (Narong & Sobon, 2014), a 16-year-old *D. oliveri* reached 11 m in height and 24 cm in dbh.

IV. Results and Discussion

4.1 Forest Habitats and Geographic Features

Choam Ksant district, a biodiversity hotspot, contains a mosaic of forests that are characterized by geographic reliefs with a wide range of altitudes and natural streams. It is home to biodiversity resources that are native to the area, including many species of wild fauna and flora.

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[5] IUCN Red List. *Dalbergia cochinchinensis* (Siamese Rosewood). Retrieved on 04 May 2020. From https://www.iucnredlist.org/search?query=Dalbergia%20cochinchinensis&searchType=species

The study area extends over 376,941 ha of land and includes these different types of forest cover (2014):

- Evergreen Forest: 54,589 ha (14.5%)
- Semi-Evergreen Forest: 44,294 ha (11.8%)
- Deciduous Forest: 204,449 ha (54.2%)
- Forest Regrowth: 337 ha (0.1%)
- Bamboo: 4,929 ha (1.3%)
- Rubber Plantations: 189 ha (0.1%)
- Non-forest Land: 68,154 ha (18.1%)

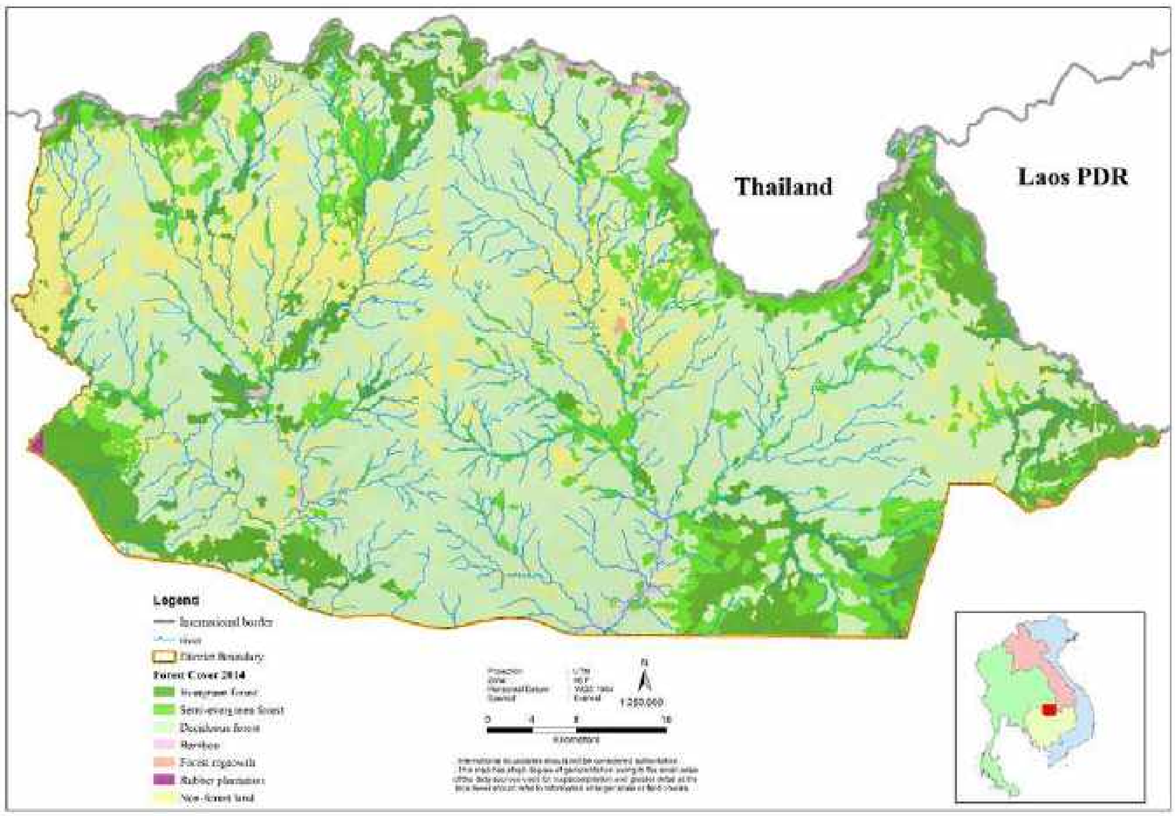


Figure 7. Forest cover of Choam Ksant district, the study area, in 2014.

The study area has an average annual rainfall ranging from 1,301-1,594 mm, with an average number of days of rain per year of 97. The average annual temperature is 32.94º C with a maximum of 35.24º C and a minimum of 25.99º C. The humidity depends on the rainfall, but average humidity per year is 73.55% (FA, 2016).

Most parts of the study area's open dry deciduous forest lies in the low flat plains, while its mixed deciduous forest, semi-evergreen forest, and evergreen forest are generally found on the hills or in areas that are not completely waterlogged as a result of the heavy rainfall (Figure 8 and 9).

Figure 8. Structure of evergreen forest and semi-evergreen forest in the study area.

Figure 9. Structure of mixed deciduous forest and open dry deciduous forest in the study area.

One-third of the area's land ranges from 46 to 75 m (asl) in elevation; another one-third ranges between 75 and 95 m (asl); with the remaining one-third, which lies primarily along the border in the North, ranging between 95 and 802 m (asl) (Figure 10).

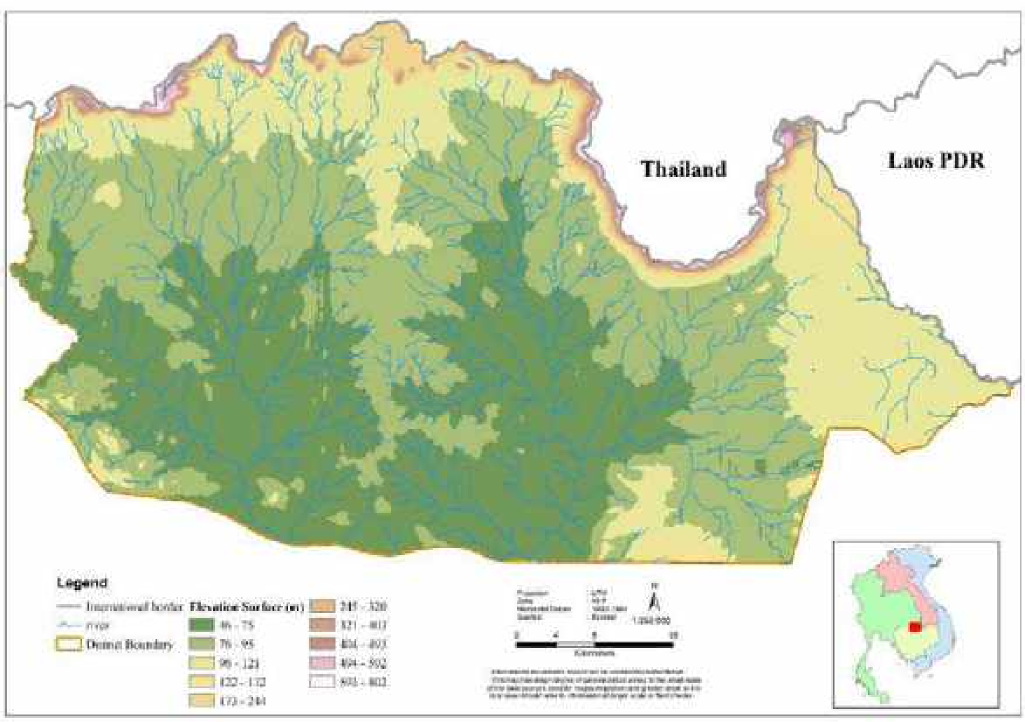


Figure 10. Elevation of the study area.

Most of the study area has a gentle slope that ranges from 0 to 7.24%, with some slopes ranging from 7.25 to 25.34%. It is only the hillsides along the trans-boundary area between Cambodia and Thailand that have steep slopes that range from 25.35 to 132% (Figure 11).

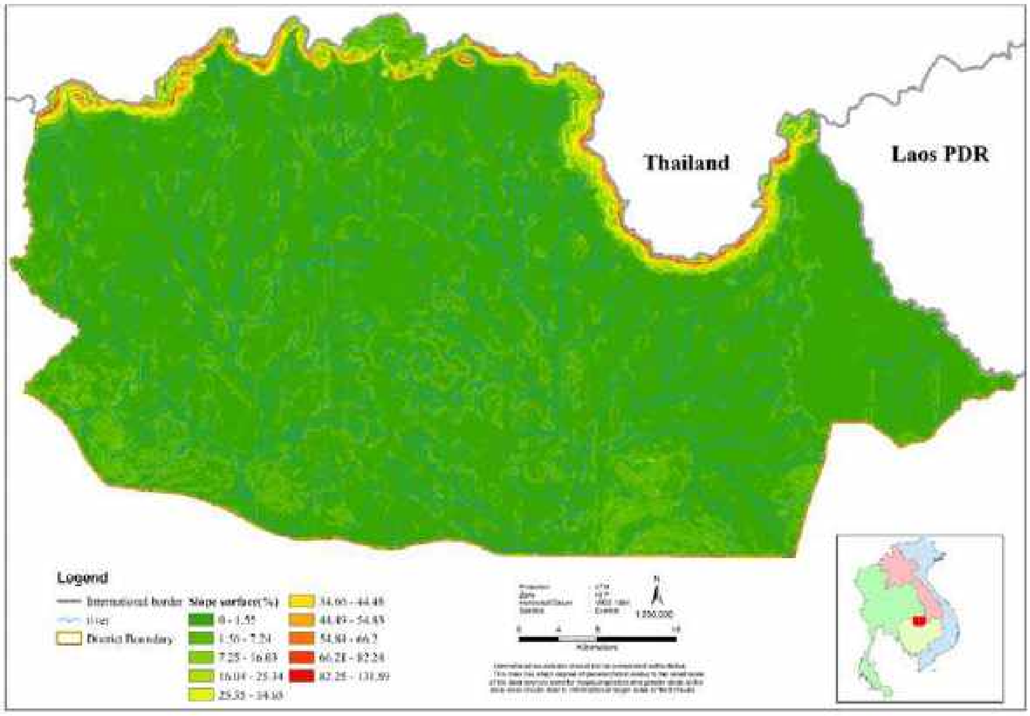


Figure 11. Surface slope of the study area.

4.2 NDVI of Actual Flora Plots

There were 63 flora plots established in semi-evergreen forest and 23 plots established in mixed deciduous and dry deciduous forests. Although all of the plots were referenced to the NDVI, which ranged from 0.4 to 0.7, as determined in the design of the sampling of the flora plots, the actual plots could have been affected by recent changes in land use, as well as by the inaccessibility of some of the plots because of concerns with land mines along the border and the steepness of the slopes of the Dangrek Mountain range that lies along the trans-boundary area between Cambodia and Thailand. The locations of most of the actual plots were, nevertheless, situated within 1 km of the original systematic plot designations.

With the exception of 18 plots whose NDVIs were affected by land use changes and some deviations associated with the ground survey, the NDVIs of the actual flora plots in deciduous forests ranged from 0.31 to 0.57, with an average of 0.41, while the corresponding NDVIs of the actual flora plots in semi-evergreen forests ranged from 0.31 to 0.68, with an average of 0.47.

4.3 Timber Species

There were 72 timber species recorded in the 86 flora plots used in undertaking the systematic field survey. Those consisted of 8 species of Luxury Grade, 19 species of Grade 1, 8 species of Grade 2, 9 species of Grade 3, and 28 species of Ungraded timber (Annex 1). That categorization was based on the 'Declaration on Prohibited Forest Products and Non-timber Forest Products' that was promulgated by the Cambodian Ministry of Agriculture, Forestry and Fisheries in 2005.

There were 52 of the 72 species (72%) that were recorded in plots of semi-evergreen forest and 47 species (65%) located in plots of mixed deciduous and dry deciduous forest. Of the 72 species, 42 (58%) were reported to be used as traditional medicinal plants, while 13 (18%) were classified as edible plants.

The occurrence of *D. cochichinensis* was reported in 5 of the 86 plots (5.8%), while *D. oliveri* was recorded in 7 of the plots (8.1%).

4.4 *Dalbergia cochichinensis*

4.4.1 Population Density and Diameter Distribution of *D. cochinchinensis*

The population density of *D. cochinchinensis* was estimated on the basis of its presence in the plots and subplots that were established according to the relative positions illustrated in Figure 5. Seedlings of *D. cochinchinensis* were defined as plants with a height < 1 m and DBH < 5 cm; saplings as plants with a height > 1 m and a DBH < 5 cm. The volume assessments of *D. cochinchinensis* were restricted to those trees with a DBH ≥ 5 cm. Since *D. cochinchinensis* was recorded most often in mixed deciduous forests and dry deciduous forests, the population estimates and estimates of wood volume were determined from trees in those two forest types.

Table 4. Population density of *D. cochinchinensis* in natural forest habitats.

	DBH < 5 cm		*Density (trees/ha), DBH ≥ 5 cm*								
	Seedlings/ha	Saplings/ha	5-10 cm	10-15 cm	15-20 cm	20-30 cm	30-40 cm	40-50 cm	> 50 cm	**Sub Total**	**Grand Total**
Average	**87.209**	**23.256**	2.326	0.155	0.155	-	-	-	-	**2.636**	**113.10**
S.E.	*±49.754*	*±12.118*	*±2.326*	*±0.155*	*±0.155*	-	-	-	-	*±2.636*	*±64.51*

The average population density of *D. cochinchinensis* was 113.1± 64.5 plants/ha, which reflects a relatively high variability. Of those 113.1 plants/ha, moreover, 87.2 plants/ha, on average, were seedlings and 23.3 plants/ha, on average, were saplings. There were only 2.6 plants/ha with diameters ≥ 5 cm (Table 4).

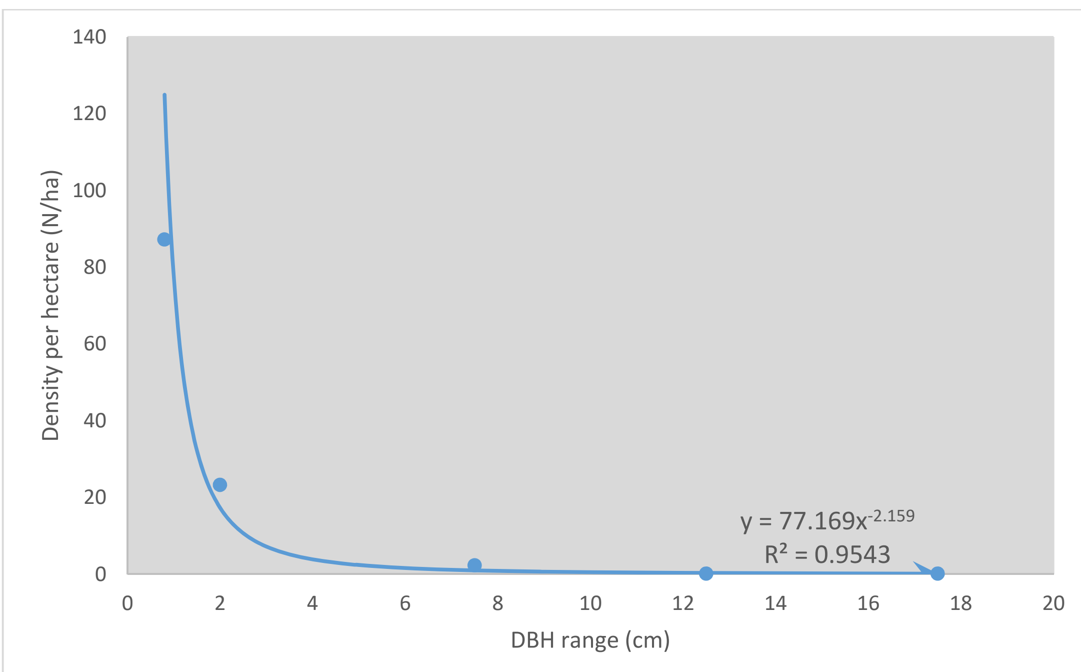


Figure 12. The population density and diameter distribution represented in the reverse J-shap curve for *D. cochinchinensis.*

Figure 12 illustrates *D. cochinchinensis*'s negative exponential relationship between population density and diameter distribution, which approximates a standardized reverse J-shap curve. This relationship represents the underlying structural conditions conducive to the reproductive sustainability of the species occurring in natural forest habitats. The maximum DBH that was recorded for *D. cochinchinensis* in natural habitats was only 20 cm, however, which, together with the very low average wood volume of *D. cochinchinensis* (0.139 m^3/ha) (Table 5), underscore the requirement for more effective conservation efforts if the species is to continue to survive in its natural forest habitat in Cambodia.

Table 5. Volume of *D. cochinchinensis* in natural forest habitats.

	Volume (m^3/ha)							
	5-10 cm	10-15 cm	15-20 cm	20-30 cm	30-40 cm	40-50 cm	> 50 cm	**Total**
Average	0.104	0.016	0.019	-	-	-	-	**0.139**
S.E.	*±0.104*	*±0.016*	*±0.019*	-	-	-	-	*±0.139*

4.4.2 Observed Population Size and Structure of D. cochinchinensis

The recorded population density and structure of *D. cochinchinensis* accounted for the occurrence of every plant that was recorded and counted from preliminary spot checks, observations of planted trees, and systematic surveys conducted in the study area in Choam Ksant district. Collectively, there were no more than 30 trees of *D. cochinchinensis* per diameter class that were recorded, with the average number of trees per dbh steadily declining from about 7 to 1 over the range of the diameter classes (Figure 13).

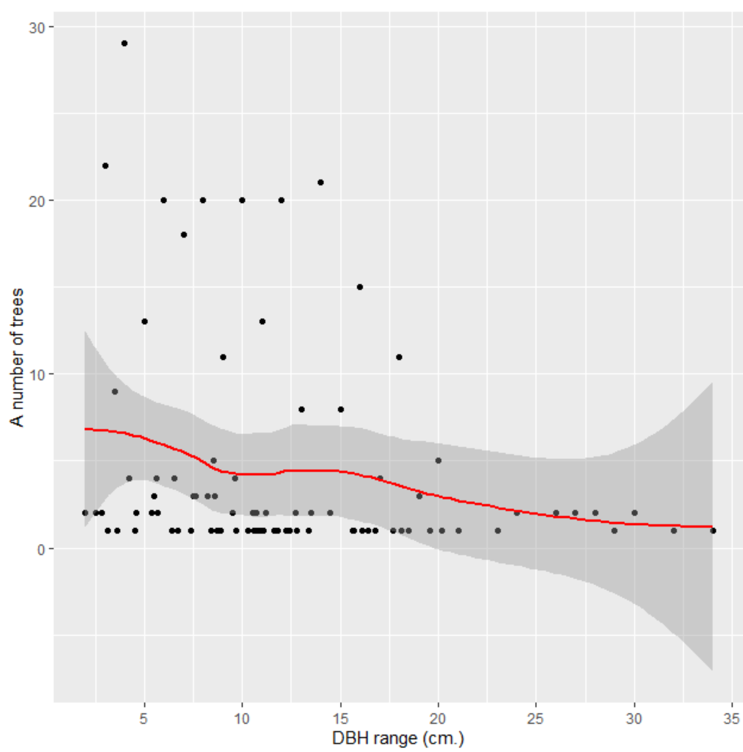


Figure 13. Population trend of *D. cochinchinensis* recorded in both natural habitats and forest plantings.

4.4.3 Natural Distribution of *D. cochinchinensis*

In assessing the natural distribution of *D. cochinchinensis* in forest habitats, correlation tests were conducted using various plausible covariates, or those factors most likely to influence the occurrence of the species. Possible covariates included elevation, slope, the NDVI, and forest type. The tests were performed using observations from 133 locations established in systematic plots and where preliminary spot checks were performed (Table 6).

Table 6. Association tests (Chi-Square tests, n =133).

No.	*Parameter*	*(P)*	*Contingency Coefficient (R)*	*Mean*	*Min-Max*	*Standard Deviation*
1	Elevation	0.139	0.617	133.1	55-321	± 57.91
2	Slope	0.217	0.707	2.83	0.015-21.33	± 4.86
3	NDVI Index	0.387	0.707	0.35	0.09-0.62	± 0.13
4	Forest Type (field notes)	0.000**	0.318			
5	Forest Type (2014 National data)	0.000**	0.358			

Notes: ** significant (P < 0.001)

The results of the correlation tests revealed that there was a significant relationship between occurrences of *D. cochinchinensis* and forest type (P < 0.001) on the basis of the use of both field records and national data (Forest Cover 2014), although that significance was tempered to some extent by a coefficient of determination, or R^2, of only 0.101 or 0.128, respectively. That is, even though the distribution of *D. cochinchinensis* may occur in some other locations, it is primarily limited to forest habitats, especially deciduous forests. Nevertheless, not all occurrences of *D. cochinchinensis* would be expected to be in deciduous forests since dry deciduous forests with their open spaces and waterlogged conditions during the rainy season would not be particularly conductive to supporting the occurrences of *D. cochinchinensis*. That reasoning suggests that geographical characteristics beyond forest types may also influence its distribution in natural habitats.

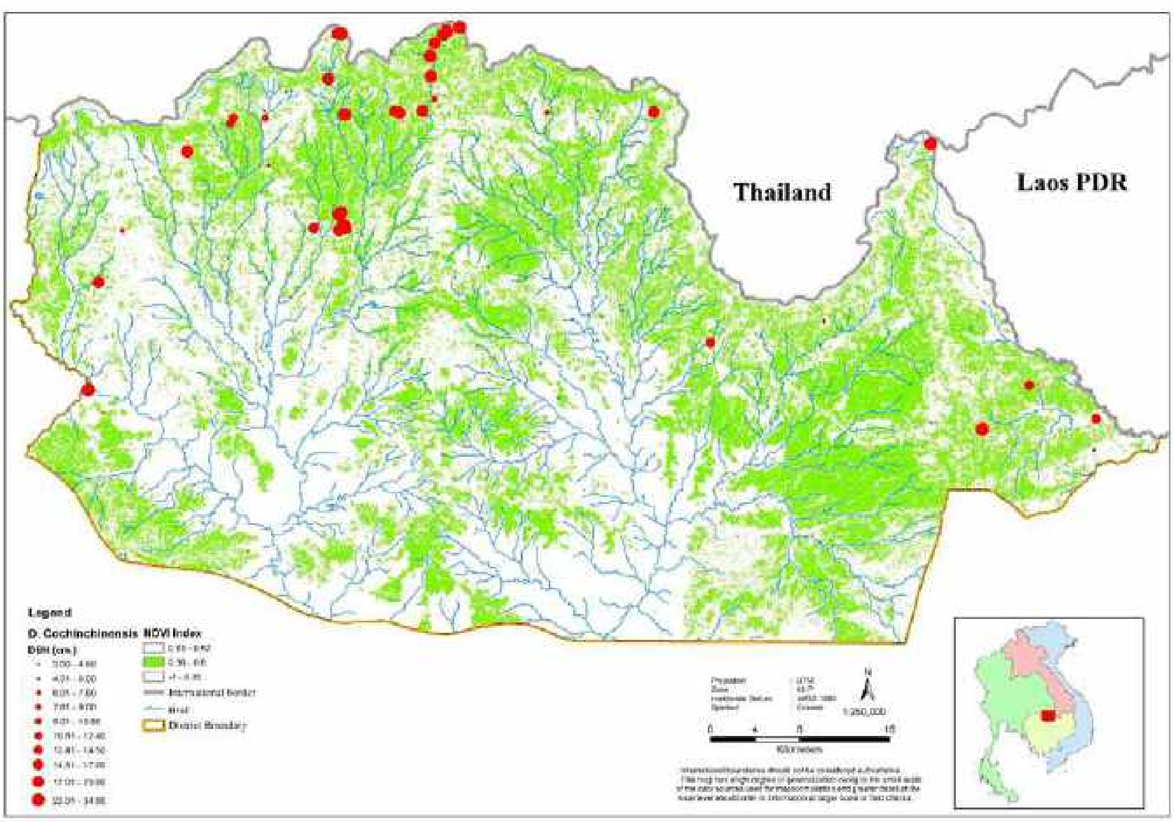


Figure 14. Distribution of *D. cochinchinensis* recorded in natural forest habitats and its probable ranges in association with the NDVI.

That assertion is supported by indication that while the association tests indicated that there was no significant correlation between the occurrence of *D. cochinchinensis* and either elevation or slope, there was no evidence of its occurrence at elevations below 70 m above sea level. That result corresponds with the geographical characteristics of the flat plains of open dry deciduous forests that are situated at altitudes less than 70 m with slopes that are less than 5%, which are often waterlogged in the rainy season.

Similarly, while the NDVI reflects different forest types, the test results indicated that there was no significant correlation between the NDVI and the distribution of the species. Land use changes have nevertheless resulted in the appearance of small forest patches, and deviations of ground surveys from precisely-defined locations of flora plots could have affected the NDVI in those locations. It was observed that most of the locations with the NDVI ranging between 0.1 and 0.35 provided evidence of the presence of the species as small seedlings that were observed at those sites. Those occurrences provide support for the likelihood that most, if not all, of those locations were formerly mixed or dry deciduous forests that have since either been selectively logged, resulting in forest fragmentation, or have been clear cut.

The distribution of *D. cochinchinensis* may, thus, more probably occur over a suitable habitat range that extends along streams, gentle slopes with well-drained soils at elevations > 70 m (asl), with an average elevation of 107 m, and mixed deciduous or dry deciduous forests with the NDVI ranging from 0.35 to 0.62. The map provided in Figure 14 demonstrates that occurrences of *D. cochinchinensis* were, indeed, primarily reported in the forest landscape along the trans-boundary area between Cambodia and Thailand, with some distribution in the eastern and western parts of Choam Ksant district, as well.

Figure 15. *D. cochinchinensis* growing in its natural habitat - a small patch of fragmented riparian forest along the stream where the NDVI was < 0.35.

4.4.4 Growth Pattern of *D. cochinchinensis*

The mean annual increment (MAI) refers to the average annual growth that can be computed for volume, weight, or other related measures up to the time of measurement or projection. The MAI may be calculated for a tree or a stand of trees, and if for the latter, it represents the growth rate per unit area per year. The MAI changes over the life of a tree or a stand of trees, exhibiting slow growth rates initially, higher rates of growth during mid-life, and declining growth rates at older ages. To estimate the annual increment of wood volume requires the values of the MAI and the Current Annual Increment (CAI) (Peter B. et al., 2009), which are defined in the following relationships:

$\text{MAI} = \left(\frac{\text{Volume per ha}}{\text{Age of stand}}\right)$; CAI = (volume at the end of a year – volume at the beginning of the year)

Since the stands of trees of *D. cochinchinensis* in natural forests are not even-aged, the Chapman-Richards growth model of nonlinear regression, which assists in projecting increments of tree diameters and ages, was used for assessing the growth correlation between the diameters and ages of *D. cochinchinensis* trees. It is expressed in the following manner:

Nonlinear regression model:

A	k	p
17	0.3	5

Parameters:

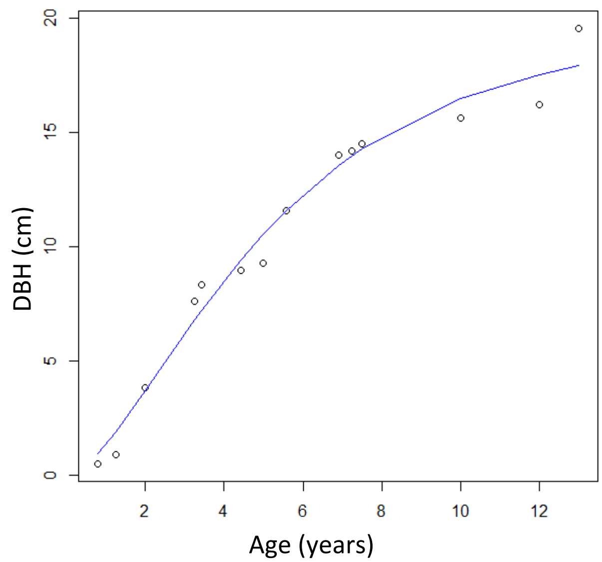
	Estimate	Std. Error	t value	Pr(>|t|)	
a	19.27241	1.40136	13.753	2.83e-08	***
b	0.24592	0.05924	4.151	0.00161	**
c	1.74715	0.39832	4.386	0.00109	**

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual sum-of-squares: 10.35

Number of iterations to convergence: 7

Achieved convergence tolerance: $1.874e^{-06}$



$y = 17\,(1 - e^{-0.3x})^5$

Figure 16. Growth correlation between age and DBH of *D. cochinchinensis*.

where y = DBH; x = age in years

The model seems not to fit precisely with the hypothesis that Narong & Sobon (2014) specified in their empirical observation that an 5-year-old *D. cochinchinensis* and another 18-year-old *D. cochinchinensis* could reach 6.7 cm and 29.63 cm in diameter, respectively, since the model indicated a more rapid growth with ages ranging from 1 to 8 years old; a slower rate at ages from 8 to 12 years old; a very slow growth rate from 13 years old onward.

Table 7. Projected annual increments per hectare of *D. cochichinensis* over the next 10 years.

DBH classes	*Average Ages*	*Density*	***Growth per tree***	*year 1*	*year 2*	*year 3*	*year 4*	*year 5*	*year 6*	*year 7*	*year 8*	*year 9*	*year 10*
Seedling	1	87.209	*Ages (years)*	2	3	4	5	6	7	8	9	10	11
			DBH growth (cm.)	0.32	1.25	2.83	4.81	6.89	8.85	10.57	12.01	13.17	14.09
			Wood volume growth (m3)	0.000	0.000	0.000	0.000	0.046	0.056	0.067	0.078	0.087	0.095
Sapling	1.25	23.256	*Ages (years)*	2.25	3.25	4.25	5.25	6.25	7.25	8.25	9.25	10.25	11.25
			DBH growth (cm.)	0.48	1.59	3.30	5.33	7.40	9.30	10.95	12.32	13.42	14.28
			Wood volume growth (m3)	0.000	0.000	0.000	0.039	0.048	0.059	0.070	0.080	0.089	0.097
5-10cm.	4.25	2.326	*Ages (years)*	5.25	6.25	7.25	8.25	9.25	10.25	11.25	12.25	13.25	14.25
			DBH growth (cm.)	5.33	7.40	9.30	10.95	12.32	13.42	14.28	14.95	15.46	15.85
			Wood volume growth (m3)	0.039	0.048	0.059	0.070	0.080	0.089	0.097	0.104	0.115	0.119
10-15cm.	6	0.155	*Ages (years)*	7	8	9	10	11	12	13	14	15	16
			DBH growth (cm.)	8.85	10.57	12.01	13.17	14.09	14.80	15.35	15.76	16.08	16.31
			Wood volume growth (m3)	0.056	0.067	0.078	0.087	0.095	0.102	0.114	0.118	0.122	0.124
15-20cm.	12.5	0.155	*Ages (years)*	13.5	14.5	15.5	16.5	17.5	18.5	19.5	20.5	21.5	22.5
			DBH growth (cm.)	15.57	15.93	16.20	16.41	16.56	16.67	16.76	16.82	16.87	16.90
			Wood volume growth (m3)	0.116	0.120	0.123	0.126	0.127	0.129	0.130	0.130	0.131	0.131
			Total wood volume growth	***0.118***	***0.141***	***0.167***	***1.111***	***5.320****	***6.474***	***7.712***	***8.907***	***9.993***	***10.908***
		0.139	**CAI (m^3 /h/year)**		0.022	0.027	0.943	4.209	1.154	1.238	1.195	1.087	0.915

*Note: *The estimates of wood volume were applied to trees with a DBH > 5 cm.*

The results of using the model for projecting the mean annual wood volume growth over the next 10 years that are presented in Table 7 seem to be indicative of annual increments of growth of *D. cochinchinensis* that are consistent with a pattern of slower growth during the first 4 years of growth, from 0.022 m^3/ha in the second year to 0.943 m^3/ha in the fourth year. That is the result of not including trees with a dbh < 5 cm into the wood volume formula, however, as rapid growth of 4.209 m^3/ha occurs in the fifth year as many of those trees whose dbh's become > 5 cm are included into the formulation. The growth of wood volume subsequently starts to steadily decrease, however, to < 1 m^3/ha in the last year of the projection. In spite of the fact that the trees are growing broader and taller, the model reflects the slower growth of those trees. It is as the result of that slower growth and the apparent sparseness of its population density in natural forests that the conservation of the genetic resources of *D. cochinchinensis* in natural forests should be of considerable concern.

4.4.5 Artificial Propagation of *D. cochinchinensis*

Aside from the natural scatter of *D. cochinchinensis* observed in mixed deciduous forests and dry deciduous forests, there has been a movement to plant this species on both private and public land, including school grounds, gardens, and pagodas. There are some individuals who have planted various species of trees that are native to this area on private land and *D. cochinchinensis* is one of the most desirable of those species. There have not been many trees of such species planted in plantations, however, because of limited yard space and uncertainties associated with the success of the plantings. Local villagers prefer planting the trees with other local high-value commercial timber species along the front fences of yards. The surveys conducted in the study indicate that at least 30 households have planted at least a few trees of *D. cochinchinensis* with ages ranging from 1 to 5 years. A vast majority, in general, have used seedlings for those plantings, which have been primarily sourced from (1) local Forestry Administration nurseries, (2) other governmental institutions' nurseries, such as those of the Preah Vihear Authority, (3) seedlings regrown naturally from stumps embedded in the ground from nearby forests, and (4) other sources, such as friends, neighbors, relatives, and colleagues.

In considering the seed sources of those plantings, small amounts of seeds might have been collected in natural habitats, but a majority of the seeds were believed to have been imported from Thailand. It was recorded that trees from the seeds sourced from Thailand that were about 10 years old were reported to have not yet flowered, while those sourced from the seeds of native trees seem to mature at around 5-6 years old.

The principal purposes of *D. cochinchinensis* plantings have been to: (1) conserve genetic resources of *D. cochinchinensis,* (2) maintain those resources for the use of prospective generations, (3) contribute to the protection of local high-value commercial timber species, (3) provide shade in house yards, and (4) protect endangered tree species.

Figure 17. Some planted trees of *D. cochinchinensis* in local villagers' yards and along front fences and in primary school yards.

On public land, a considerable number of *D. cochinchinensis* trees have been planted along fences, in open yards to provide shade, and in gardens of schools, pagodas, local military offices, and commune offices (Figure 17). There are about seven hundred of the trees along the road to Preah Vihear temple that were planted by local Forestry Administration units and some of those were reported to have been regrown naturally and protected by the Preah Vihear Authority. The Forestry Administration Division and Sub-governmental district authorities have also shared opportunities for local people to participate in planting trees during annual Arbor Day ceremonies.

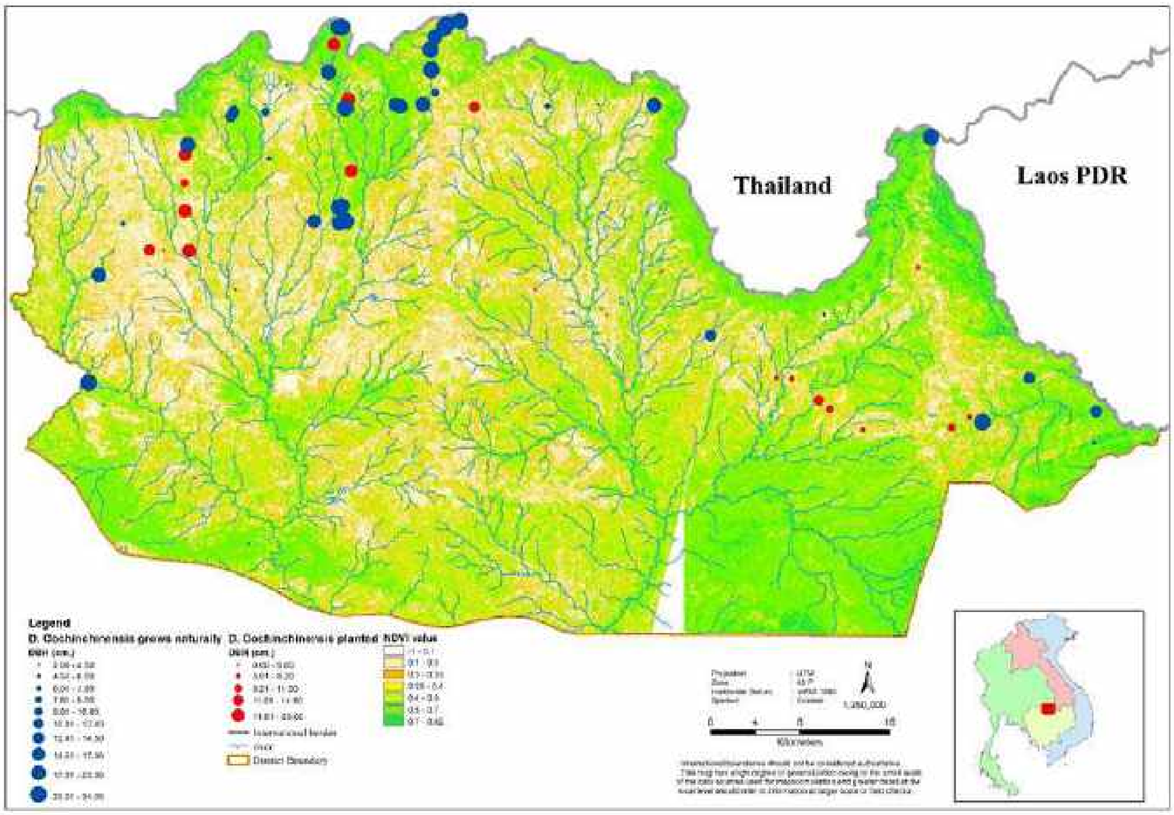


Figure 18. The distribution of *D. cochinchinensis* in natural forests and through artificial propagation.

Figure 18 delineates the distribution of *D. cochinchinensis* by DBH classes in both natural habitats and by means of plantings. In natural forests, the maximum DBH recorded was 34 cm., while the maximum DBH recorded in planted areas was 20 cm. The distribution of planted *D. cochinchinensis* seems to be the most common amid occurrences in natural habitats (Table 8).

Table 8. Observed *D. cochinchinensis* planted in Choam Ksant district.

No.	Easting	Northing	# Trees	DBH Range (cm)	Height Range (m)	Planting Year	Planting System	Note
1.	469992	1588649	700	1.4 - 22.07	2.1 - 9.0	2013	Plantation	By FA
2.	469945	1588650	17	6.0 - 16.00	4.2 - 8.5	2015	Mixed tree species Plantation	By UNESCO
3.	463783	1589629	350	0.48 - 14.00	0.8 - 4.6	2015-2019	Mixed tree species Plantation	Abor day
4.	455351	1583710	15	10.83 - 19.00	7.0 - 9.0	2013	Living fence	Household
5.	455691	1575034	1	22.21	9	2003 *	Living fence	Household
6.	469424	1583400	6	11.0 – 16.00	7.4 – 9.0	2007	Living fence	Household
7.	470231	1582191	15	5.0 – 15.00	4.0 – 8.0	2007 - 2017	Living fence	Household
8.	469361	1578367	6	1.0 – 13.14	1.0 – 6.0	2013 – 2019	Living fence	Household
9.	469786	1580783	3	7.0 – 10.80	5.5 – 6.0	2015	Living fence	Household
10.	485247	1587430	4	9.24 – 15.76	7.0 – 8.5	Unknown	Living fence	Household

No.	Easting	Northing	# Trees	DBH Range (cm)	Height Range (m)	Planting Year	Planting System	Note
11.	487773	1588012	3	10.83 – 12.90	7.5 – 8.0	2008	Living fence	Household, fruited
12.	502224	1566465	5	3.12 – 5.32	2.6 – 5.3	2016	Living fence	Household, fruited
13.	526668	1559673	10	4.49 – 11.15	2.0 – 7.5	2015	Living fence	Household, fruited
14.	517138	1559155	2	7.64 – 14.97	NA	2013 - 2015*	Living fence	Household, fruited
15.	516002	1658867	4	7.01 – 12.99	6.0 – 6.5	2012 - 2015*	Living fence	Household, fruited
16.	513126	1560755	2	14.01 – 18.06	6.5 – 7.5	2014 - 2016*	Living fence	Household, fruited
17.	512472	1561203	2	6.21 – 7.01	4.5 – 6.0	Unknown	Living fence	Household, fruited
	Total		**1,145**					

Note: * Since the local villagers may not remember well when their trees were planted, the exact planting year may not be accurate; FA = Forestry Administration.

There were at least 17 locations visited where approximately1,145 trees of *D. cochinchinensis* had been planted.

4.4.6 Threats and Biological Risks of *D. cochinchinensis*

Threats and biological risks refer to all of the disturbances and biological vulnerabilities that have the ability to affect the reproduction, resilience capacities, and natural growth of *D. cochinchinensis,* which can result in either mortality or increased vulnerability.

Those threats and biological risks are exemplified in the study area in Choam Ksant district. It is one of the areas that suffer the most from intermittent occurrences of violent confrontations between Cambodia and Thailand and, as a result, several thousand troops, as well as their families, have been allowed to settle along the border in social land concessions. Since those settlers regularly enter the surrounding forest areas to collect forest products, as well as non-timber forest products, the vulnerability of high-value commercial timber species has become severe and increased the levels of threat and endangerment that are posed to those species by these incursions.

The inventory results of the study divulge various forms of disturbances, as well. Those encompass droughts, forest fires, unregulated selective logging, and the creation of patches of fragmented forest that are associated with natural and human-induced activities. There were 86 flora plots established in the study area and, of those, at least 60% were reported to have been completely burned as the result of the long droughts that are experienced every year during the dry season and the spread of the fires over extensive areas of mixed and dry deciduous forest. There was another 30% of the plots that were recorded to be partly burned, particularly those that were located in mixed deciduous forest (Figure 19). Understory plants, which include *D. cochinchinensis,* are, thus, prone to burning every year, which would have a deleterious effect on the successful germination of *D. cochinchinensis* seedlings and saplings from the stump.

Figure 19. Dry and mixed deciduous forests in the study area susceptible to annual burning.

There were 45 plots, accounting for 52% of the total plots, that had been selectively logged with only the stumps, trunks, and embedded roots of several large-diameter, high-value commercial timber species that included *Pterocarpus pedatus,* Pierre, *Afzelia xylocarpa* (Kurz), *Xylia dolabriformis* Benth. and *Sindora cochinchinensi,* Baill remaining. The plots where *D. cochinchinensis* exists were reported to have been selectively logged, as well. It is inarguable that even the remaining roots embedded in the ground of *D. cochinchinensis* may be collected by the local people in consideration of their commercial value, even though they are aware that it is highly restricted by law, which increases the severity of the vulnerability of the species in natural habitats. Such a situation occurs throughout almost the entire study area, except on the mountain range along the trans-boundary area where the critical danger of landmines deters access to the area by locals and is prohibited by the military. Each of these disturbances impedes the natural regrowth ability of *D. cochinchinensis* in the habitats distinguished in the study and reduces its survival rate.

While it is recognized that *D. cochinchinensis* flowers during May-June and its fruits ripen from November until January (CTSP, 2003) (Figure 20), it is not clear at what age and of what size dbh an individual tree of *D. cochinchinensis* starts to flower. Some individual trees may become mature at an early age with a small dbh, while others may mature much later or during a period when its dbh has become relatively large. Since it was not until the germination of seedlings from seeds of *D. cochinchinensis* or its natural regrowth from stumps embedded in the ground that individual trees were observed and recorded in this study, there is still much that remains to be learned about seed dispersal and pollination during the reproductive cycle of *D. cochinchinensis*. There were a few local villagers who said that they used to collect seeds of *D. cochinchinensis* from mother trees with a dbh > 25 cm for germinating and planting, however, rather than collecting them from stumps since they thought those would not survive.

Figure 20. *D. cochichinensis* trees observed to be fruiting during the period that preliminary spot checks were conducted in December 2019 at Bos Sbov pagoda, adjacent to the trans-boundary area between Cambodia and Thailand.

In this study, the reproductive pattern of *D. cochinchinensis* was categorized by dbh class. Early maturity was defined as the period when an individual tree with dbh < 15 cm starts to flower; medium maturity as the period when an individual tree with a dbh ranging from 15-30 cm starts to flower; and late maturity as the period when an individual tree with dbh > 30 cm starts to flower. One of the monks in Bos Sbov pagoda reported that there were a few trees of *D. cochinchinensis* with a dbh of 15 cm that had started to flower a few years ago and that its seeds could be collected annually, which suggested its early maturity and fruiting. Some local villagers reported that their planted tree species of *D. cochinchinensis* with diameters ranging from 13-15 cm had also started to flower 3 years previously (at 5 years old) and that this was most probably due to the fact that they had collected seedlings of the species regrown naturally from stumps and roots embedded in the ground to plant. It may therefore be inferred that the flowering of *D. cochinchinensis* could occur in early maturity every year in natural forests in the study area.

Figure 21. Planted trees of *D. cochinchinensis* that were sourced from regrowth of stumps and roots and were native to local forests that started to flower and fruit at 5-6 years old.

The increasingly severe risk associated with the apparent flowering and fruiting pattern of this local species is that the majority of seeds that are currently used for planting *D. cochinchinensis* have been sourced from Thailand and those seeds are not considered to be prepared to flower and fruit until late maturity at ages of 10, or even 15, years old. This may increase the risk to the species, considering that it has a long reproduction cycle and it has become less commonly planted locally where its genetic conservation has been largely ignored. This risk has been compounded by the realization that it is extremely difficult, if not practically impossible, to differentiate those trees that are native to the local forest.

4.5 *Dalbergia oliveri*

4.5.1 Population Density and Diameter Distribution of *D. oliveri*

The population density of *D. oliveri*, as with *D. cochinchinensis,* was estimated on the basis of its presence in the plots and subplots that were established according to the relative positions illustrated in Figure 5. Seedlings of *D. oliveri* were defined as plants with a height < 1 m and a DBH < 5 cm; saplings as plants with a height > 1 m and a DBH < 5 cm. The volume assessments of *D. oliveri* were restricted to those trees with a DBH ≥ 5cm. Since *D. oliveri* was recorded most often in deciduous forests, mixed deciduous forests, and semi-evergreen forests, the population estimates and estimates of wood volume were determined from trees in those two forest habitats (deciduous and semi-evergreen).

Table 9. Population density of *D. oliveri* in natural forest habitats.

Forest Type	*Seedlings/ha*	*Saplings/ha*	*5-10 cm*	*10-15 cm*	*15-20 cm*	*20-30 cm*	*30-40 cm*	*40-50 cm*	*> 50 cm*	***Sub Total***	**Grand Total**
Average in DF	198.41	95.24	-	0.21	0.21	0.42	-	-	-	**0.85**	**294.50**
S.E.	*198.41*	*59.16*	-	*0.21*	*0.21*	*0.30*	-	-	-	0.72	**258.29**
Average in SF	-	69.57	-	-	-	0.58	-	-	-	0.58	**70.14**
S.E.	-	*0.14*	-	-	-	*0.58*	-	-	-	0.58	**0.72**
Overall Average	**145.35**	**88.37**	**-**	**0.16**	**0.16**	**0.47**	**-**	**-**	**-**	**0.78**	**234.50**
S.E.	**145.35**	**45.55**	**-**	**0.16**	**0.16**	**0.27**	**-**	**-**	**-**	**0.58**	**191.48**

The overall average population density of *D. oliveri* was 234.5 ± 191.5 plants/ha, which, as with *D. cochinchinensis*, reflects a relatively high variability. Of those 234.5 plants/ha, moreover, 145.4 plants/ha, on average, were seedlings and 88.4 plants/ha, on average, were saplings. There were only 0.8 plants/ha with diameters ≥ 5 cm (Table 9).

The average population density of *D. oliveri* in the deciduous forests was 294.5 ± 258.3 plants/ha and, of those 294.5 plants/ha, 198.4 plants/ha, on average, were seedlings and 95.2 plants/ha, on average, were saplings. There were only 0.8 plants/ha with diameters ≥ 5 cm.

The average population density of *D. oliveri* in the semi-evergreen forests was 70.1 ± 0.7 plants/ha and, of those 70.1 plants/ha, 69.6 plants/ha, on average, were saplings. There were no seedlings and only 0.6 plants/ha with diameters ≥ 5 cm.

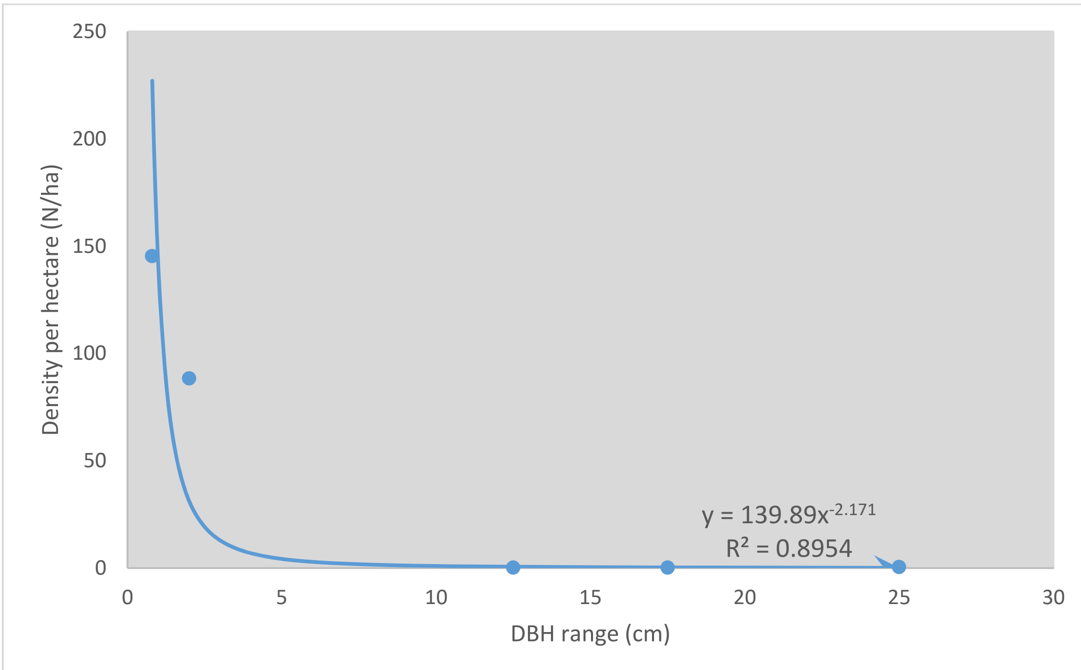


Figure 22. The population density and diameter distribution represented in the reverse J-shap curve for *D. oliveri*.

Figure 22 illustrates *D. oliveri's* negative exponential relationship between population density and diameter distribution, which approximates a standardized reverse J-shaped curve. Despite the presence of this relationship, the sustainability of the species seems to be very much threatened by the small number of large DBH trees – less than one per hectare - that were observed during field observations in natural forest habitats. Those observations provide compelling evidence that the harvesting of the species should be strictly prohibited while every effort is made to protect remaining mother trees.

Table 10. Volume of *D. oliveri* in natural forest habitats.

	Volume (m^3/ha)							
Forest Type	5-10 cm	10-15 cm	15-20 cm	20-30 cm	30-40 cm	40-50 cm	> 50 cm	**Total**
Average in DF	-	0.150	0.031	0.127	-	-	-	**0.308**
S.E.	-	*0.150*	*0.031*	*0.090*	-	-	-	*0.271*
Average in SF	-	-	-	0.197	-	-	-	**0.197**
S.E.	-	-	-	*0.197*	-	-	-	**0.197**
Overall Average	**-**	**0.015**	**0.022**	**0.146**	**-**	**-**	**-**	**0.183**
S.E.	-	*0.015*	*0.022*	*0.084*	-	-	-	**0.121**

The requirement to prohibit harvesting to protect remaining mother trees is borne out by the measure of the average wood volume of *D. oliveri* in its natural forest habitats, which was only 0.308 m^3/ha in deciduous forests and 0.197 m^3/ha in semi-evergreen forests (Table 10).

4.5.2 Observed Population Size and Structure of *D. oliveri*

The recorded population density and structure of *D. oliveri* accounted for the occurrence of every plant that was recorded and counted from preliminary spot checks, observations of planted trees, and systematic surveys conducted in the study area in Choam Ksant district. Collectively, there were no more than 18 trees of *D. oliveri* per diameter class that were recorded, with the average number of trees per dbh settling in at about 2.5 (Figure 23). In natural forests, the maximum DBH recorded was 30 cm., while only a tree with a DBH of 25 cm. was recorded as planted by local villagers. The distribution of planted *D. oliveri* seems to be limited to a range of natural habitats..

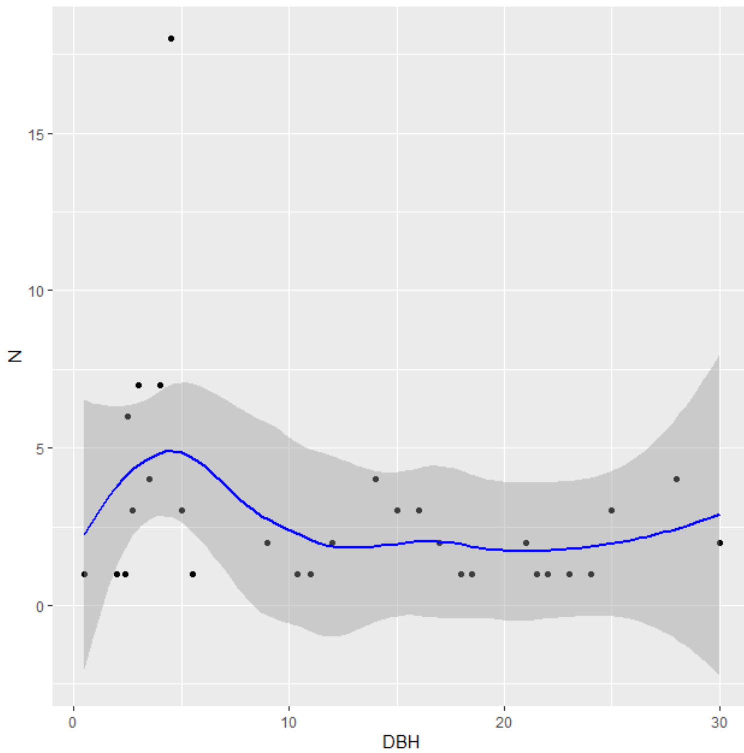


Figure 23. Population trend of *D. oliveri* recorded in both natural habitats and forest plantings.

4.5.3 Natural Distribution of *D. oliveri*

In assessing the natural distribution of *D. oliveri* in forest habitats, correlation tests were conducted using various plausible covariates, or factors that are most likely to influence the occurrence of the species. Possible covariates included elevation, slope, the NDVI, and forest type. The tests were performed using observations from 118 locations established in systematic plots and where preliminary spot checks were performed (Table 11).

Table 11. Association tests (Chi-Square tests, n =118).

No.	*Parameter*	*(P)*	*Contingency Coefficient (R)*	*Mean*	*Min-Max*	*Standard Deviation*
1	Elevation (m)	0.023*	0.627	92.67	56-182	±20.33
2	Slope (%)	0.022*	0.707	1.35	0.001-11.32	±2.011

3	NDVI Index	0.431	0.707	0.47	0.12-0.70	±0.17
4	Forest Type (field notes)	0.656	0.041			
5	Forest Type (2014 National data)	0.001**	0.340			

Note: * significant (P < 0.05)

The results of the correlation tests revealed that while there were no significant relationships between occurrences of *D. oliveri* and either the NDVI or the forest type on the basis of the use of field records, there were significant relationships with elevation and with slope (P < 0.05), as well as with forest type on the basis of the use of national data (P < 0.01). These results suggest that the distribution of *D. oliveri* would be expected to be observed across different natural forest habitat types, but primarily limited to certain ranges of altitude, slope, and specific forest types, including steep slopes, such as those found in the alleys of hills, or in the upper elevations of the Dang Rek Mountain range along the trans-boundary area between Cambodia and Thailand. It was reported by an officer of the Preah Vihear Authority that his colleagues used to collect the seeds of this species next to the Preah Vihear temple on a flat top of Dang Rek Mountain.

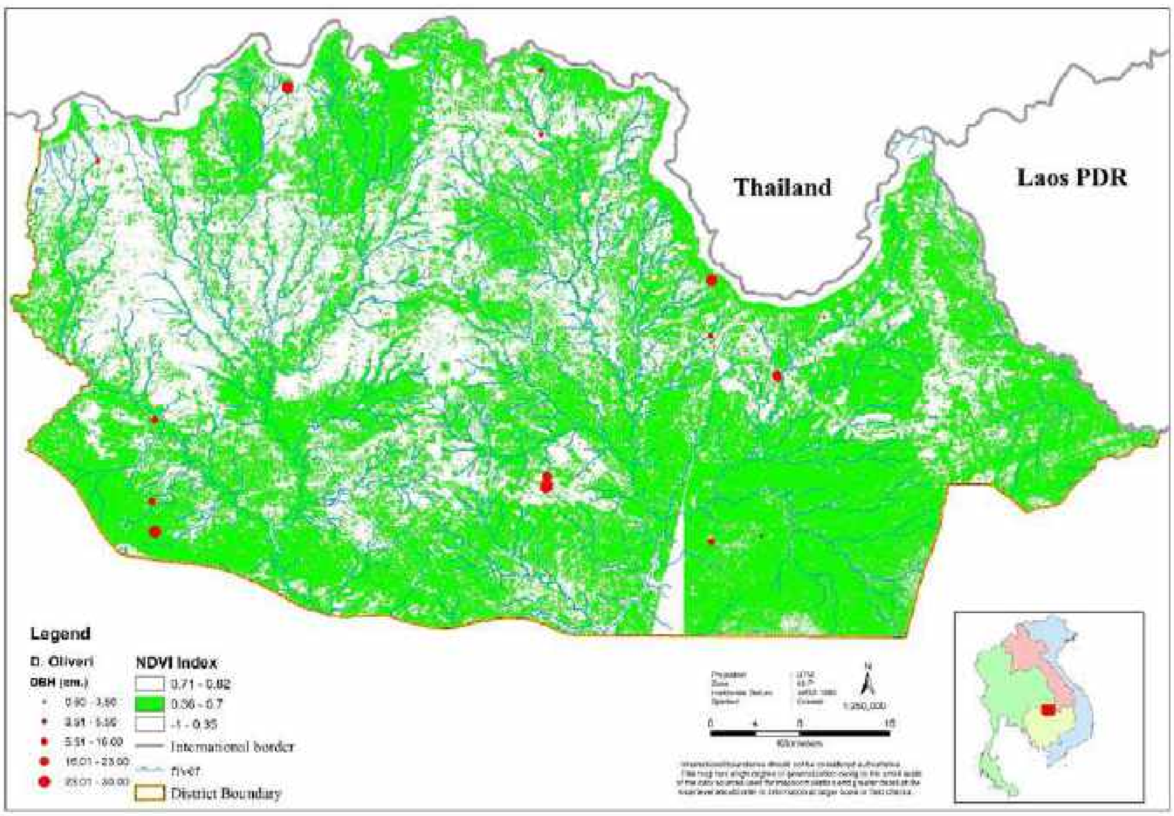


Figure 24. The distribution of *D. oliveri* recorded in natural forest habitats and its probable range in association with the NDVI.

Figure 25. *D. oliveri* growing with its stump embedded in the ground in semi-evergreen forest with an NDVI > 0.6 and a tall tree of *D. oliveri* growing in a small patch of degraded riparian forest near a stream where the NDVI was < 0.35.

4.5.4 Growth Pattern of *D. oliveri*

The estimate of the mean annual increment of *D. oliveri* was not available because of data deficiencies, although Narong and Sobon (2013) had previously reported through field measurements that a 16-year-old *D. oliveri* could attain a height of 11 m with a DBH of 24 cm.

4.5.5 Artificial Propagation of *D. oliveri*

The distribution of *D. oliveri* recoded in the plots during the systematic survey, which was confirmed in the preliminary spot checks, revealed the rather sparse scattering of this species in natural forests.

Figure 26. Scattered trees of *D. oliveri* in the yard of the Neak Bous temple.

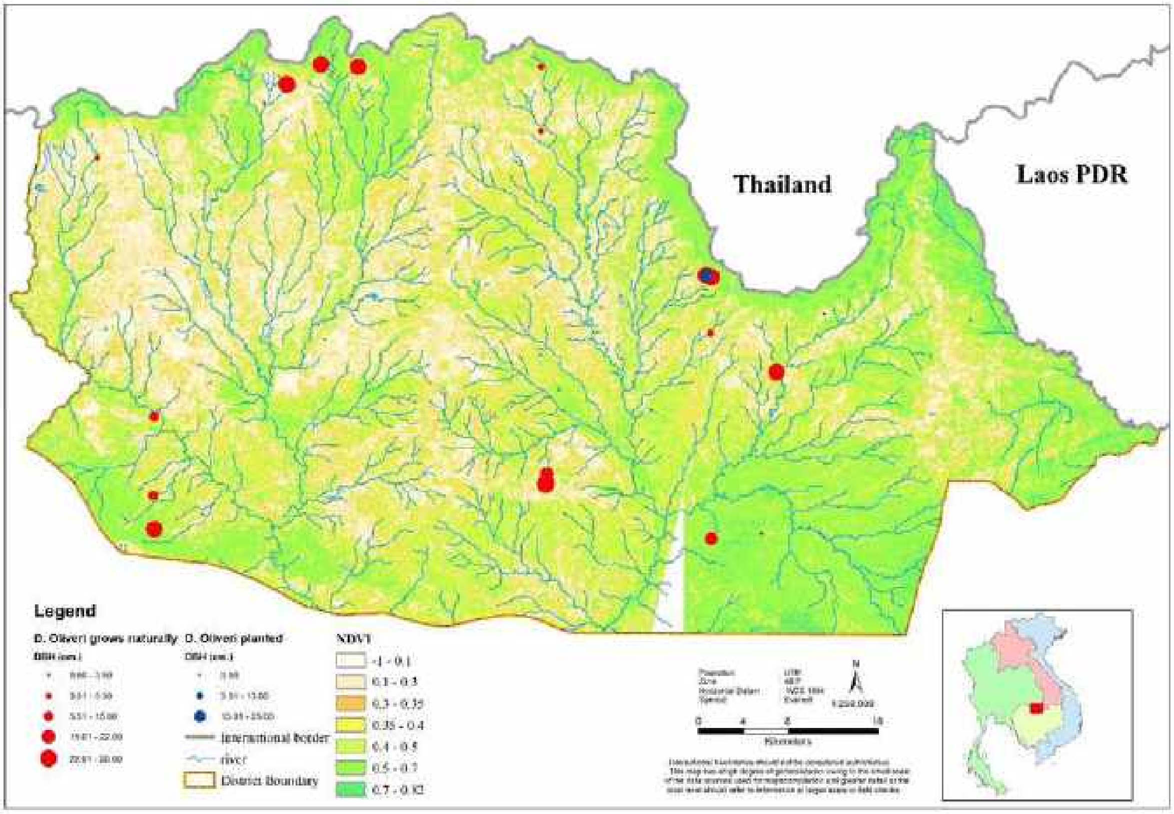


Figure 27. The distribution of *D. oliveri* recorded in both natural forest habitats and planted areas and its probable range in association with the NDVI.

4.5.6 Threats and Biological Risk of *D. oliveri*

Similar to the assessment conducted for *D. cochinchinensis,* the threats and biological risks of *D. oliveri* refer to all of the disturbances and biological vulnerabilities that have the ability to affect the reproduction, resilience capacities, and natural growth of *D. oliveri,* which can result in either mortality or increased vulnerability.

There were at least 60% of the 86 flora plots that were established in the study area that were reported to have been completely burned during the dry season when drought-related fires spread over extensive areas of mixed and dry deciduous forests (Figure 28). Understory plants, which include *D. oliveri,* are, as a result, prone to burning every year, which would have a deleterious effect on the successful germination of *D. oliveri* seedlings and saplings from the stump.

Figure 28. Remaining *D. oliveri* marked in a dry deciduous forest near a village that are highly susceptible to burning.

The unregulated selective logging conducted by local villagers has become a severe challenge affecting the sustainability of this species, as well, and even its stumps, trunks, and embedded roots were reported to be collected because of their commercial value.

The risk associated with the biological reproductive characteristics of *D. oliveri* is also becoming a serious threat. The officers of the Preah Vihear Authority reported that they collected the seeds from mother trees of this species growing naturally within the Preah Vihear temple complex on top of Dang Rek Mountain during the period from May to July, 2018, but that since that time none of those trees has flowered or fruited. Nor have any members of the survey teams confirmed having seen those trees flowering, which suggests that this species may not flower and fruit every year. This observation is supported by related reports of local villagers that *D. oliveri* generally flowers and fruit every couple of years after initially flowering. This reproductive pattern of *D. oliveri* may be especially influenced by its genetic characteristics growing in these habitat types. The result is that the seeds of *D. oliveri* are year-by-year becoming less-and-less available for collection, which threatens the species' genetic resources.

V. Conclusions

This report reflects on the project's primary objective, which was to undertake systematic field surveys to determine the population distribution, stocking levels, and diameter class distributions of *D. cochinchinensis* and *D. oliveri* in the Choam Ksant management district in Preah Vihear province. The biological risks, habitat specificity and vulnerabilities of those two species were also evaluated as a part of the study.

There were 63 flora plots established in semi-evergreen forest and 23 plots established in mixed deciduous and dry deciduous forests.

With the exception of 18 plots whose NDVIs were affected by land use changes and some deviations associated with the ground survey, the NDVIs of the actual flora plots in deciduous forests ranged from 0.31 to 0.57, with an average of 0.41, while the corresponding NDVIs of the actual flora plots in semi-evergreen forests ranged from 0.31 to 0.68, with an average of 0.47.

There were 72 timber species recorded in the 86 flora plots used in undertaking the systematic field survey, and of those 72 species, 52 (72%) were recorded in plots of semi-evergreen forest and 47 species (65%) located in plots of mixed deciduous and dry deciduous forest. The occurrence of *D. cochichinensis* was reported in 5 of the 86 plots (5.8%), while *D. oliveri* was recorded in 7 of those plots (8.1%)

The average population density of *D. cochinchinensis* was 113.1± 64.5 plants/ha and, of those 113.1 plants/ha, 87.2 plants/ha, on average, were seedlings and 23.3 plants/ha, on average, were saplings. There were only 2.6 plants/ha with diameters ≥ 5 cm.

D. cochinchinensis's negative exponential relationship between population density and diameter distribution approximates a standardized reverse J-shape curve, which represents the underlying structural conditions conducive to the reproductive sustainability of the species occurring in natural forest habitats. The maximum DBH that was recorded for *D. cochinchinensis* in natural habitats was only 20 cm, however, which, together with the very low average wood volume of *D. cochinchinensis* (0.139 m^3 /ha) underscores the requirement for more effective conservation efforts if the species is to continue to survive in its natural forest habitat in Cambodia.

In assessing the natural distribution of *D. cochinchinensis* in forest habitats, correlation tests were conducted using various plausible covariates, including elevation, slope, the NDVI, and forest type. The tests were performed using observations from 133 locations established in systematic plots and where preliminary spot checks were performed.

The results of those tests revealed that there was a significant relationship between occurrences of *D. cochinchinensis* and forest type ($P < 0.001$) on the basis of the use of both field records and national data (Forest Cover 2014), although that significance was tempered to some extent by a coefficient of determination, or R^2, of only 0.101 or 0.128, respectively. That is, even though the distribution of *D.*

cochinchinensis may occur in some other locations, it is primarily limited to forest habitats, especially deciduous forests. Nevertheless, not all occurrences of *D. cochinchinensis* would be expected to be in deciduous forests since dry deciduous forests with their open spaces and waterlogged conditions during the rainy season would not be particularly conductive to supporting the occurrences of *D.* cochinchinensis. Such reasoning suggests that geographical characteristics beyond forest types may also influence its distribution in natural habitats.

That assertion is supported by indications that while the association tests indicated that there was no significant correlation between the occurrence of *D. cochinchinensis* and either elevation or slope, there was no evidence of its occurrence at elevations below 70 m above sea level. That result corresponds with the geographical characteristics of the flat plains of open dry deciduous forests that are situated at altitudes less than 70 m with slopes that are less than 5%, which are often waterlogged in the rainy season.

Similarly, while the NDVI reflects different forest types, the test results indicated that there was no significant correlation between the NDVI and the distribution of the species. Land use changes have nevertheless resulted in the appearance of small forest patches, and deviations of ground surveys from precisely-defined locations of flora plots could have affected the NDVI in those locations. It was observed that most of the locations with the NDVI ranging between 0.1 and 0.35 provided evidence of the presence of the species as small seedlings that were observed at those sites. Those occurrences provide support for the likelihood that most, if not all, of those locations were formerly mixed or dry deciduous forests that have since either been selectively logged, resulting in forest fragmentation, or have been clear cut.

The distribution of *D. cochinchinensis* may, thus, more probably occur over a suitable habitat range that extends along streams, gentle slopes with well-drained soils at elevations > 70 m (asl), with an average elevation of 107 m, and mixed deciduous or dry deciduous forests with the NDVI ranging from 0.35 to 0.62. The occurrences of *D. cochinchinensis* were, indeed, primarily reported in the forest landscape along the trans-boundary area between Cambodia and Thailand, with some distribution in the eastern and western parts of Choam Ksant district, as well.

The results of projecting the mean annual growth over the next 10 years are indicative of annual increments of growth of *D. cochinchinensis* that are consistent with a pattern of rapid growth of all of the trees, including those < 5 cm, during the first 4 years of growth followed by a slower rate of growth during the following years.

In considering the seed sources of observed plantings, small amounts of seeds might have been collected in natural habitats, but a majority of the seeds were believed to have been imported from Thailand. It was recorded that trees from the seeds sourced from Thailand that were about 10 years old were reported to have not yet flowered, while those sourced from the seeds of native trees seem to mature at around 5-6 years old.

The principal purposes of *D. cochinchinensis* plantings are to: (1) conserve genetic resources of *D. cochinchinensis,* (2) maintain those resources for the use of prospective generations, (3) contribute to the protection of local high-value commercial timber species, (4) provide shade in house yards, and (5) protect endangered tree species.

Threats and biological risks can affect the reproduction, resilience capacities, and natural growth of *D. cochinchinensis,* which can result in either mortality or increased vulnerability. Those threats and biological risks are exemplified in the study area in Choam Ksant district. It is one of the areas that suffers the most from intermittent occurrences of violent confrontations between Cambodia and Thailand and, as a result, several thousand troops, as well as their families, have been allowed to settle along the border in social land concessions. Since those settlers regularly enter the surrounding forest areas to collect forest products, as well as non-timber forest products, the vulnerability of high-value commercial timber species has become severe and increased the levels of threat and endangerment that are posed to those species by these incursions.

The inventory results of the study divulge various forms of disturbances, as well. Those encompass droughts, forest fires, unregulated selective logging, and the creation of patches of fragmented forest that are associated with natural and human-induced activities. There were 86 flora plots established in the study area and, of those, at least 60% were reported to have been completely burned as the result of the long droughts that are experienced every year during the dry season and the spread of the fires over extensive areas of mixed and dry deciduous forest. There was another 30% of the plots that were recorded to be partly burned, particularly those that were located in mixed deciduous forest. Understory plants, which include *D. cochinchinensis,* are, as a result, prone to burning every year, which would have a deleterious effect on the successful germination of *D. cochinchinensis* seedlings and saplings from the stump.

There were 45 plots, accounting for 52% of the total plots, that had been selectively logged with only the stumps, trunks, and embedded roots of several large-diameter, high-value commercial timber species that included *Pterocarpus pedatus,* Pierre, *Afzelia xylocarpa* (Kurz), *Xylia dolabriformis* Benth. and *Sindora cochinchinensi,* Baill remaining. The plots where *D. cochinchinensis* exists were reported to have been selectively logged, as well. It is inarguable that even the remaining roots embedded in the ground of *D. cochinchinensis* may be collected by the local people in consideration of their commercial value, even though they are aware that it is highly restricted by law, which increases the severity of the vulnerability of the species in natural habitats. Such a situation occurs throughout almost the entire study area, except on the mountain range along the trans-boundary area where the critical danger of landmines deters access to the area by locals and is prohibited by the military. Each of these disturbances impedes the natural regrowth ability of *D. cochinchinensis* in the habitats distinguished in the study and reduces its survival rate.

D. cochinchinensis flowers during May-June and its fruits ripen from November until January (CTSP, 2003). It is not clear, however, at what age and of what size dbh an individual tree of *D. cochinchinensis* starts to flower, although it can be inferred from local reports that the flowering of *D. cochinchinensis* may occur in early maturity every year in natural forests in the study area. The increasingly severe risk associated with this apparent flowering and fruiting pattern is that the majority of seeds that are currently used for planting *D. cochinchinensis* have been sourced from Thailand and those seeds are not considered to be prepared to flower and fruit until late maturity at ages of 10, or even 15, years old. This may increase the risk to the species, considering that it has a long reproduction cycle and it has become less commonly planted locally where its genetic conservation has been largely ignored. This risk has been compounded by the realization that it is extremely difficult, if not practically impossible, to differentiate those trees that are native to the local forest.

The population estimates and estimates of wood volume of *D. oliveri* were determined from trees observed in deciduous and semi-evergreen forests. The overall average population density of *D. oliveri* was 234.5 ± 191.5 plants/ha. Of those 234.5 plants/ha, moreover, 145.4 plants/ha, on average, were seedlings and 88.4 plants/ha, on average, were saplings. There were only 0.8 plants/ha with diameters ≥ 5 cm.

The average population density of *D. oliveri* in the deciduous forests was 294.5 ± 258.3 plants/ha and, of those 294.5 plants/ha, 198.4 plants/ha, on average, were seedlings and 95.2 plants/ha, on average, were saplings. There were only 0.8 plants/ha with diameters ≥ 5 cm.

The average population density of *D. oliveri* in the semi-evergreen forests was 70.1 ± 0.7 plants/ha and, or those 70.1 plants/ha, 69.6 plants/ha, on average, were saplings. There were no seedlings and only 0.6 plants/ha with diameters ≥ 5 cm.

D. oliveri's negative exponential relationship between population density and diameter distribution approximates a standardized reverse J-shape curve, which represents the underlying structural conditions conducive to the reproductive sustainability of the species occurring in natural forest habitats. Despite the presence of this relationship, the sustainability of the species seems to be very much threatened by the relatively small number of large DBH trees – less than one per hectare - that were observed during field observations in natural forest habitats. Those observations provide compelling evidence that the harvesting of the species should be strictly prohibited while every effort is made to protect remaining mother trees. The requirement to prohibit harvesting to protect remaining mother trees is borne out by the measure of the average wood volume of *D. oliveri* in its natural forest habitats, which was only 0.308 m^3/ha in deciduous forests and 0.197 m^3/ha in semi-evergreen forests.

In assessing the natural distribution of *D. oliveri* in forest habitats, correlation tests were conducted using observations from 118 locations established in systematic plots and where preliminary spot checks were performed. The results of the tests revealed that while there were no significant relationships between occurrences of *D. oliveri* and either the NDVI or the forest type on the basis of the use of field records, there were significant relationships with elevation and with slope ($P < 0.05$), as well as with forest type on the basis of the use of national data ($P < 0.01$). These results suggest that the distribution of *D. oliveri* would be expected to be observed across different natural forest habitat types, but primarily limited to certain ranges of altitude and slope, and specific forest types, including steep slopes, such as those found in the alleys of hills, or in the upper elevations of the Dang Rek Mountain range along the trans-boundary area between Cambodia and Thailand. The distribution of *D. oliveri* recoded in the plots during the systematic survey, which was confirmed in the preliminary spot checks, revealed the rather sparse scattering of this species throughout natural forests.

Similar to the assessment conducted for *D. cochinchinensis,* the threats and biological risks of *D. oliveri* refer to all of the disturbances and biological vulnerabilities that have the ability to affect the reproduction, resilience capacities, and natural growth of *D. oliveri,* which can result in either mortality or increased vulnerability.

There were at least 60% of the 86 flora plots that were established in the study area that were reported to have been completely burned during the dry season when drought-related fires spread over extensive areas of mixed and dry deciduous forests. Understory plants, which include *D. oliveri,* are, thus, prone to burning every year, which would have a deleterious effect on the successful germination of *D. oliveri* seedlings and saplings from the stump.

The unregulated selective logging conducted by local villagers has become a severe challenge affecting the sustainability of this species, as well, and even its stumps, trunks, and embedded roots were reported to be collected because of their commercial value.

The risk associated with the biological reproductive characteristics of *D. oliveri* is also becoming a serious threat. Reports of local villagers, as well as the observations of the survey team, indicate that *D. oliveri* generally flowers and fruits every couple of years after initially flowering. This reproductive pattern of *D. oliveri* may be especially influenced by its genetic characteristics growing in these habitat types. The result is that the seeds of *D. oliveri* are year-by-year becoming less-and-less available for collection, which threatens the species' genetic resources.

Since there was only limited information available on D. oliveri both because of the sparseness of its presence in natural forest habitats, as well as the limited data available on artificial propagation by local villagers, *D. oliveri* would seem to be even more vulnerable than *D. cochinchinenis*, which underscores the immediacy of its genetic conservation

Responding to this imperative, the planting of both *Dalbergia* species should be incentivized and promoted in as many forms as available, including through the establishment of industrial plantations, household plantations, and agroforestry systems, as well as on public lands throughout its natural range.

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Annex I: List of Flora Species and Its Usages

N°	*Local Name*	*Khmer Name*	*Scientific Name*	*Family*	*Habitat*		*IUCN Red List*	*Medicinal Plant*	*Edible Plant*
					SF	**DF**			
			Luxury grade						
1	ក្រញូង	Kra Nhung	*Dalbergia cochinchinensis* Pierre.	Fabaceae	-	+	VU	√	
2	ក្រញូងស្វា	Kra Nhung Sav	*Dalbergia cultrate*	Leguminosae - Papilionoidae	-	+			
3	ច្រេស	Chres	*Albizia lebbeck, (L)* Benth.	Fabaceae	-	+		√	
4	ត្រយឹង	Tra yueng	*Diospyros helferi*, C.B.Clarke	Ebenaceae	+	-		√	
5	ធ្នង់	Thnong	*Pterocarpus pedatus*, Pierre	Papilionaceae	+	+	EN	√	
6	នាងនួន	Neang Noun	*Dalbergia oliveri* Gamble & Prain	Fabaceae	+	+	EN	√	√
7	បេង	Beng	*Afzelia xylocarpa*, (Kurz) Craib.	Caesalpiniaceae	-	+	EN	√	
8	អង្គត់ខ្មៅ	Angkot Khmao	*Diospyros bejaudii*, Lecomte.	Ebenaceae	-	+			
			Grade 1						
9	កកោះ	Krokoh	*Sindora cochinchinensis*, Baill.	Caesalpiniaceae	+	+	LC		√
10	ក្រឡាញ់	Kralanh	*Dialium cochinchinensis*, Pierre	Caesalpiniaceae	+	+			√
11	គគីខ្សាច់	KorKi	*Hopea pierrei*, Pierre	Dipterocarpaceae	+	-	VU	√	
12	ឈ្លីក	Chlik	*Terminalia alata*, F. Heyne ex Roth	Combretaceae	-	+		√	
13	ត្បែង	Tbeng	*Dipterocarpus obtusifolius*, Teysm.	Dipterocarpaceae	-	+	NT		
14	ត្រសេក	Trasek	*Peltophorum dasyrrhachis* Kurz, var	Caesalpiniaceae	+	+		√	
15	សំព័រ	Sam Por	*Artocarpus semperyirens*	Moraceae	-	+			
16	បុសនាគ	Bos Neak	*Mesua ferrea*, L.	Guttiferae	+	-		√	
17	ផ្ចឹក	Pchek	*Shorea obtusa*, Woll.	Dipterocarpacese	+	+	NT	√	
18	ពពូលអារ៉ែសេត្វ	Popul Arch Sat	*Vitex glabrata*	Verbenaceae	+	+	LC		
19	ពពូលថ្ម	Popul Thmar	*Vitex pinnata*	Verbenaceae	-	+	LC	√	
20	ពពូលបាយ	Popul Bay	*NA*	NA	+	-			
21	ពពេល	Popel	*Shorea roxburgshii*, G.Don.	Dipterocarpaceae	+	+			
22	ផ្ចឹករាំង	Pchek rang	*Shorea siamensis*	Dipterocarpaceae	-	+	LC		
23	សង្កូតត្នាត	Sangkout Thmart	*Stereospermum chelonoides*	Bignoniaceae	-	+			
24	សុក្រម	Sokram	*Xylia dolabriformis*, Benth.	Mimosaceae	+	+	LC	√	
25	ស្ពង់	Spong	*Tetrameles nudiflora*	Datiscaceae	+	-	LC	√	
26	ស្រឡៅ	Sralao	*Lagerstroemia calyculata*	Lythraceae	+	+			
27	ស្រឡៅជូរ	Sralao Chou	*Lagerstrocmia ovalifolia*	Lythraceae	-	+			
			Grade 2						
28	ខ្លុង	Khlong	*Dipterocarpus tuberculatus*, Roxb	Dipterocarpaceae	-	+	NT		
29	ខ្វាវ	Kvav	*Adina cordifolia*, Hook.f.	Rubiaceae	+	+		√	
30	ឈើទាល	Cheuteal	*Dipterocarpus alatus*, Roxb	Dipterocarpaceae	+	+	VU	√	
31	ឈើទាល នាងដែង	Cheuteal Neang Deng	*Dipterocarpus costatus*, Gaertn	Dipterocarpaceae	+	-	VU		
32	ត្បែង	Tbeng	*Dipterocarpus obtusifolius*, Teysm.	Dipterocarpaceae	+	+	NT		
33	ត្រាច	Trach	*Dipterocarpus intricatus*, Dyer.	Dipterocarpaceae	-	+	EN		

34	ផ្ដៀក	Phdeak	*Anishoptera costata*, Korth	Dipterocarpaceae	+	-		√	
35	ស្រគុំ	Srakum	*Mimusops elliptica*, Lecomt	Sapotaceae	-	+		√	
			Grade 3						
36	កណ្ដោល	Kandoal	*Careya sphoerica*, Pierre	Moraceae	+	+		√	
37	ក្របៅ	Kraboa	*Hydnocarpus annamensis*	Flacourtiaceae	-	+	VU		
38	ច្រម៉ាស់	Chhramas	*Vatica astotricha*, Dyer.	Dipterocarpaceae	+	-			
39	ធ្លក	Thlork	*Parinarium annamensis*, Hance	Rosaceae	+	+		√	
40	ប្រាំដំឡឹង	Bramdamleong	*Terminalia mucronata*, Graib ct Huth	Combretaceae	+	+			
41	ព្រីង	Pring	*Eugenia sp.*	Myrtaceaa	+	+	LC		√
42	ព្រូស	Prus	*Garcinia schefferi*, Pierre	Guttiferae	+	-			
43	ល្ងៀង	Lngeang	*Cratoxylon prunifolium*, Dyer.	Hypericaceae	+	+		√	√
44	ស្វាយព្រៃ	Svay Prey	*Mangifera duperreana*, Pierre	Anacardiaceae	+	-		√	
			Ungraded						
45	កន្ទួតព្រៃ	Kantout Prey	*Phyllanthus emblica*	Euphobiaceae	+	-		√	√
46	ខ្ទុំ	Khtoum	*Neonuclea sp*	Rubiaceae	+	+		√	
47	ក្រចាស់	Krachas	*NA*	NA	+	-			
48	ចារ	Char	*Butea monosperrna*	Leguminosae – Papilionoidae	+	-		√	√
49	ចំបក់	Cahmbak	*Irvingia malayana* Oliv,ex Benn.	Simaroubaceae	+	+	LC		√
50	ជើងគោ	Chueng ko	*Bauhinia variegate*	Leguminosae	+	-		√	
51	ជ្រៃ	Chrey	*Ficus rumphii*	Moraceae	+	+		√	
52	លាំងដៃ	Chey Plear	*Buchanania reticulata*	Anacardiaceae	-	+			√
53	ញព្រៃ	Nhor Prey	*Morinda tomentosa*	Rubiaceae	+	+		√	
54	ដកព	Dak por	*Markhamia stipulacea* var. pierrei	Bignoniaceae	+	-		√	
55	ដៃខ្លា	Dai Klar	*Gardenia angkoriensis*	Rubiaceae	+	-		√	
56	តាឡាត់	Talat	*Canarium album*	Burseraceae	+	-		√	
57	ត្របែកព្រៃ	Trabek Prey	*Lagerstroemia floribunda*	Lythraceae	+	+			
58	ពង្រ	Pongror	*Scheicheria trijuga*,Willd.	Sapindaceae	+	+		√	
59	ពោន	Pon	*Spondias pinnata*	Anacardiaceae	-	+		√	
60	ពព្លា	Poplear	*Grewia asiatica*, L.	Tiliaceae	+	+	LC	√	
61	ភ្វាស ឬភ្លង	Plong	*Memecylon acuminatum* var. tenuis	Melastomaceae	+	-	LC		
62	ភ្លូ	Plou	*NA*	NA	-	+			
63	មមាញ	Momeanh	*Cleome viscosa*	Capparidaceae				√	
64	រកា	Ro Kar	*Bombax ceiba or Bombax malabaricum*	Bombacacea	+	+		√	
65	ល្វៀង	Lveang	*Catunaregam tomentosa*	Rubiaceae	+	-		√	√
66	សង្កែ	Sangke	*Combrctum quadrangulare*	Combretaceae	+	+		√	
67	ស្តុកស្តៅ	Sduk Sdao	*Walsura villosa*	Meliaceae	-	+		√	
68	ស្តៅ	Sdao	*Azadirachta indica*	Meliaceae	+	-	LC	√	√
69	ស្នួល	Snoul	*Dalbergia nigrescens*	Leguminosae	+	-			√
70	ស្រម៉	Sramor	*Terminalia chebula*	Combretaceae	+	-		√	√
71	អង្ក្រង	Angkrong	*Zizyphus cambodiana*	Rhamnaceae	+	-		√	
72	អាចម៍សត្វ	Arch Sat	*Brownlowia emarginata*	Tiliaceae	+	-			
		Total			52	47		42	13

Percentage	72%	65%		58.33%	18.06%
VU = Vulnerable			5		
EN = Endangered			4		
NT = Near-threaten			4		
LC = Least Concern			11		

Note: + = presence; - = absence; √ = consumed by the locals

Annex II: List of planted *D. cochinchinensis* with selected measures for modelling with annual increment.

No.	Easting	Northing	DBH (cm.)	Height (m.)	Age (years)*
18.	463783	1589629	0.86	0.4	0.83
19.	463783	1589629	0.67	0.5	0.83
20.	463783	1589629	0.7	0.45	0.83
21.	463783	1589629	0.57	0.3	0.83
22.	463783	1589629	0.61	0.4	0.83
23.	463783	1589629	0.61	0.3	0.83
24.	463783	1589629	1.08	0.55	0.83
25.	463783	1589629	0.54	0.4	0.83
26.	463783	1589629	0.73	0.45	0.83
27.	463783	1589629	0.7	0.45	0.83
28.	463783	1589629	0.48	0.8	1.5
29.	463783	1589629	0.76	0.8	1.5
30.	463783	1589629	1.27	0.75	1.5
31.	463783	1589629	0.89	0.8	1.5
32.	463783	1589629	1.34	1	1.5
33.	463783	1589629	0.99	1.2	1.5
34.	463783	1589629	0.54	0.8	1.5
35.	463783	1589629	0.8	1	1.5
36.	463783	1589629	0.76	1.2	1.5
37.	469786	1580783	7.01	5	2
38.	470231	1582119	6.4	8	3
39.	470231	1582119	5.96	4	3
40.	469786	1580783	8.6	6	3
41.	502224	1566465	5.32	4	3
42.	502224	1566465	3.5	2.8	3
43.	502224	1566465	3.82	2.6	3
44.	502224	1566465	3.34	3	3
45.	502224	1566465	3.12	3	3
46.	526668	1559673	7.96	3.8	3.83
47.	526668	1559673	4.49	2	3.83
48.	526668	1559673	6.53	5.3	3.83
49.	526668	1559673	8.6	6.4	3.83
50.	526668	1559673	6.69	5	3.83
51.	526668	1559673	6.37	6	3.83
52.	526668	1559673	7.8	7.3	3.83
53.	517138	1559155	7.64		4
54.			8.28	4.2	4.08
55.	512472	1561203	6.21	5	4.08
56.	512472	1561203	7.01	4.5	4.08

No.	Easting	Northing	DBH (cm.)	Height (m.)	Age (years)*
57.	469992	1588649	6.21	3.8	5
58.	469992	1588649	7.8	5.5	5
59.	469992	1588649	7.96	4.5	5
60.	469992	1588649	8.73	4.2	5
61.	469992	1588649	4.17	3.4	5
62.	469992	1588649	7.83	5.3	5
63.	469992	1588649	7.77	5	5
64.	469992	1588649	6.85	5	5
65.	469992	1588649	6.5	4.2	5
66.	469992	1588649	9.81	8.2	5
67.	469992	1588649	8.18	7	5
68.	485247	1587430	9.24	7.5	5
69.	485247	1587430	11.46	7	5
70.	516002	1658867	11.15	6.5	5
71.	516002	1658867	7.01	6.2	5
72.	516002	1658867	11.15	6	5
73.	485247	1587430	15.03	7.5	6
74.	485247	1587430	15.76	8.5	6
75.	463783	1589629	7.17	4.3	6.42
76.	463783	1589629	7.01	4.2	6.42
77.	463783	1589629	6.82	4.2	6.42
78.	463783	1589629	7.61	3.8	6.42
79.	463783	1589629	13.79	4	6.42
80.	463783	1589629	7.48	4.6	6.42
81.	469361	1578367	16.83	5.5	6.75
82.	469992	1588649	15.61	9	7
83.	469992	1588649	18.15	9.3	7
84.	469992	1588649	15.61	9.5	7
85.	469992	1588649	14.17	7.5	7
86.	469992	1588649	16.08	8.5	7
87.	469992	1588649	15.92	8.5	7
88.	469992	1588649	15.54	7	7
89.	455351	1583710	14.01	9	7
90.	455351	1583710	14.14	8	7
91.	455351	1583710	16.56	7.2	7
92.	455351	1583710	16.56	7	7
93.	455351	1583710	14.97	7.2	7
94.	479173	1588121	19.43	10	10
95.	487773	1588012	21.74	7.5	12
96.	487773	1588012	22.9	8	13
97.	455691	1575034	25.21	10	15

Note: * the decimals refer to actual ages (years) and the months that are relative to 12 months.