BIODIVERSITAS
Volume 24, Number 3, March 2023
Pages: 1493-1500

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d240319

Population structure and distribution of the endangered *Vatica diospyroides* in Southern Thailand to inform its conservation strategies

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Manuscript received: 27 December 2022. Revision accepted: 6 February 2023.

Abstract. *Srisawat T, Maneenoon K, Wuttipong P, Thitithanakul S, Pechwang J, Wongchana K, Chumkaew P, Ratchareon W. 2023. Population structure and distribution of the endangered* Vatica diospyroides *in Southern Thailand to inform its conservation strategies. Biodiversitas 24: 1493-1500. Vatica diospyroides* Symington is an endemic and rare dipterocarp species. It is listed as Endangered under the IUCN Red List due to its decreasing population. It has been the subject of a wide range of medicinal studies, but there is no prior survey of its population. This study was conducted to investigate the population structure and distribution of *V. diospyroides* in the lowland Tapi River floodplain, Surat Thani, southern Thailand, covering in-situ (VAT01-VAT04) and ex-situ (VAT05-VAT06) areas. The total count method was employed over the entire studied area to assess the conservation status of *V. diospyroides*. The number and location of trees, height level and Circumference at Breast Height (CBH) were recorded and the relationship between plant height and CBH and evidence of threats were analyzed. In total 4,535 and 508 trees were recorded in the in-situ and ex-situ conservation areas, respectively. Height ranges of 1.1-5.0 m and 5.0-10.0 m were dominant among trees in the in-situ and ex-situ areas, respectively. Classes of 0-1.0 and 5.1-50.0 cm were the dominant CBH in the in-situ and ex-situ areas, respectively. The VAT03-VAT05 had normal stem growth pattern and scattered distribution with large trees classified by plant height and CBH. The population of *V. diospyroides* in the ex-situ conservation area were blended in vegetation within the protected area (VAT05) and a private area (VAT06). No threats were detected in the in-situ conservation area, except for the need to protect from humans, but management is necessary in the ex-situ area. This study has revealed the patterns of *V. diospyroides* composition and structure variations in southern Thailand to help species conservation and protection. The findings of this study imply that the conservation status and definite size of this tree species should be revised.

Keywords: Dipterocarpaceae, Nong Thung Thong, population, survey, *Vatica diospyroides*

INTRODUCTION

Malay Peninsula is one the most biologically diverse areas in Southeast Asia, and is a global hotspot of species diversity with over 50,000 flora species (Hughes 2017; Middleton et al. 2019; Westwood et al. 2021). Over 57% of the species have distribution patterns restricted to specific zones within the peninsula (Guan and Yen 2000) that is included in the Sundaic subregion (all parts of Malaysia, Sumatra, Java, and Borneo). Southern Thailand is an area geographically located on the Malay Peninsula. It has landscape and vegetation conditions similar to those of the peninsular Malaysia and receives plenty of annual rainfall from both the southwest and northeast monsoons (Suraprasit et al. 2019).

In the tropical Asia, the most important timber family is Dipterocarpaceae (Guan and Yen 2000; Rana et al. 2009; Cvetković et al. 2017). About 17 genera with more than 600 species of this family are known to have geographical distribution in tropical Africa, Asia, and South America; yet the largest number and most newly described dipterocarps are found in Southeast Asia (Ashton 2015). Among them, more than 66.7% (360 species) are threatened with extinction and categorized as Vulnerable (VU), Endangered (EN), or Critically Endangered (CR) based on the Red List of Threatened Species by the International Union for Conservation of Nature (Primananda et al. 2022). Dipterocarps are also common in most tropical forests of the Malay Peninsula. In Southern Thailand, 8 genera with 63 species of Dipterocarpaceae have been recorded (Pooma 2002; Poopath et al. 2014), while 157 species are found in peninsular Malaysia (Guan and Yen 2000), including 31 of the Critically Endangered species (Chua et al. 2022). This family consists of 32 species in the genus *Vatica* (Ummul-Nazrah et al. 2018) some of which are categorized as Critically Endangered (CR) and threatened species (Robiansyah et al. 2021).

Vatica diospyroides Symington is an endemic and extremely rare species. It is native and only occurs on the lowland river-floodplain area in Southern Thailand.

Although four locations in southern Thailand have been recorded as geographic range for this taxa (Pooma et al. 2017), most conservation efforts have been focused at Nong Thung Thong non-hunting area because that is where the population density and distribution of this species are the highest. This region is considered one of the rare ecosystems threatened by an array of annual seasonal events, such as extreme flooding and severe drought (Srisawat et al. 2013; Pattarakulpisutti and Mitchell 2022). Flooding at the end of rainy season in the floodplain area is very significant in structuring plant population, community, and biodiversity (Richards et al. 2020). In the Nong Thung Thong forest, within habitat patches, *V. diospyroides* exhibits fruiting stage related to period and level of flooding, and its seed dispersal relies on floating. Because a climate anomaly hit Thailand in 2009 with severe and long drought until August 2010 (Srisawat et al. 2012), unusual blossoming of *V. diospyroides* occurred. Aside from the climate, the species is also threatened by habitat loss as some areas in the floodplain habitat have been converted into agricultural land (Forest ranger, pers. comm.). Therefore, *V. diospyroides* has a high conservation concern, and it is now listed as Endangered under the IUCN Red List because of its decreasing population and habitat loss (Pooma et al. 2017). Moreover, due to being famous as a medicinal plant (Srisawat and Jongkraijak 2013; Srisawat et al. 2014; Boukaew et al. 2017; Chothiphirat et al. 2019) and with strong fragrance properties of the flowers (Srisawat et al. 2013), there is a high demand for use in the perfume industries and in drug discovery programs: thus this species may have a high risk of extinction.

Only one ex-situ collection has been officially managed by the Royal Forest Department (BGCI 2017). Living collection of this taxa both in-situ and ex-situ should be in the focus of conservation strategies. No current estimate of *V. diospyroides* population or its distribution in the Nong Thung Thong forest is available due to the lack of taxonomic survey work. Thus, there is a need for dependable and specific information on *V. diospyroides*, including the composition of population, growth structure, as well as the dominance, abundance and distribution of this taxa. This is the first report on the endangered and threatened species of *V. diospyroides*, with scope limited to assessing the population level and the distribution pattern in both in-situ and ex-situ conservation areas. We expect that the results of this study could provide a basis to public's awareness and better understanding of the population and distribution of *V. diospyroides*, which then affect conservation strategies determined by state actors of the country.

MATERIALS AND METHODS

Description of the study area

In-situ conservation

The in-situ conservation area was partitioned into 4 sub-areas. The first sub-area was Chan Ka Pho Water Park (sub-area VAT01) of about 0.4 km^2 located in the vicinity of Tapi River, Khian Sa District, Thailand. The rest of the sub-areas were located in the Nong Thung Thong non-hunting area of Khian Sa District, in Surat Thani Province (Department of National Parks, Wildlife and Plant Conservation) with sub-areas of VAT02, VAT03 and VAT04 having an in-situ conserved lowland river-floodplain of about 61.50 km^2 size (Figure 1) (Information and Communication Technology Center 2018). The entire area is protected following the Notification of Ministry of Agriculture and Cooperatives, B.E. 1975 (according to the Wildlife Preservation and Protection Act, B.E. 1960). The rare *V. diospyroides* population is completely protected in the 61.50 km^2 area (Figure 1).

Ex-situ conservation

The ex-situ study area had two sub-areas of ex-situ conservation for this species. Firstly, the Surat Thani Silvicultural Research Station (Royal Forest Department) (sub-area VAT05) located in Khao Tha Phet non-hunting area, Muang District, Surat Thani, with an extent of 4.65 km^2 (Information and Communication Technology Center 2018); and the second was a private garden (sub-area VAT06) (Ban Na Doem District, Surat Thani, Thailand) of 0.5 km^2 size. Both areas were established to preserve *V. diospyroides* cultivation before the year 2000.

Data collection procedure

We used the total count or comprehensive method following non-sampling approach within the entire study area assuming 100 percent detection of this plant (Regan 2004). This complete listing of *V. diospyroides* took a team of field workers with 3 years of data collection to completion (2019-2021). The following data for each plant were recorded; GPS coordinates (Lat Lon, DM and WGS84), plant height category based on exponential growth (0-1.0, 1.1-5.0, 5.1-10.0 and >10.0 m) by using clinometer, Circumference at Breast Height (CBH) class consistent with exponential growth (0.01-1.0, 1.1-5.0, 5.1-50.0, 50.1-100.0 and >100.0 cm) recorded at 1.3 m above the ground by wrapping a metric tape around the circumference, number of plants, and pictures of plant morphology were deposited in the RSPG database (for full project name please see the Acknowledgements). Environmental disturbances in the form of forest fire, drought, flood level, and human and insect attacks within the in-situ conservation area were also recorded.

Data analysis

To simply understand the density of *V. diospyroides* spatially within the in-situ and ex-situ areas, we used offline MAPinr to map all *V. diospyroides* occurrences in the entire study area. We completed the total number count of *V. diospyroides* to obtain a 100 percent population survey of this plant. To show the level of occurrences, we generated a graph that included the count of tree occurrences by height level and CBH class. To analyze stem growth, relationships of tree height and CBH, linear mixed model analysis was applied to these data (Sumida et al. 2013).

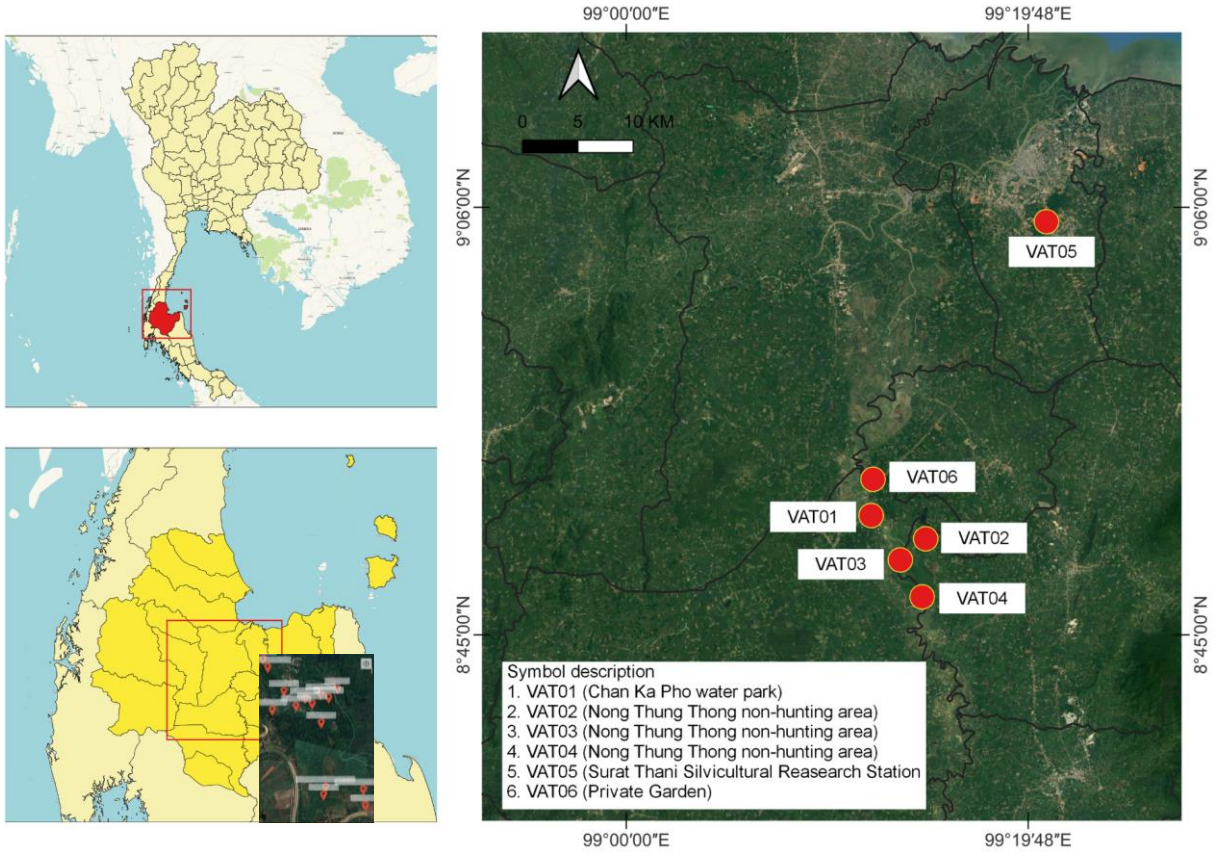

Figure 1. Map of the sampling/survey locations showing the area of distribution and localities of *V. diospyroides* population in Surat Thani Province, Thailand. Notes: VAT01-VAT04 are in-situ conservation areas, and VAT05-VAT06 are ex-situ conservation areas. The symbol on Google Map shows an example of existing individual *V. diospyroides* using MAPinr. The multiple pins on Google Map and picture morphology are not shared because the resources of this species are confidential and controlled under RSPG-PSU notification

RESULTS AND DISCUSSION

Population structure and distribution of *V. diospyroides*

From our observational survey that took three years, we found that the actual tree size of *V. diospyroides* can be classified as a large tree. Such large trees were distributed in the in-situ conservation areas with an average height of 16 m. From the total 5,043 recorded individual trees, mostly the *V. diospyroides* were clustered with a population of 4,535 in-situ, and scattered with a population of 508 ex-situ in the conservation areas, respectively (Tables 1 and 2). We did not know the ages of old trees, but we assumed the tallest plants with largest CBH are the oldest. The largest tree with CBH of 302 cm and a height of 35.12 m was found in VAT03 of the in-situ conservation area. The lower CBH classes and height levels on average were assumed to be younger trees. The tree size of *V. diospyroides* in ex-situ areas (VAT05-VAT06) was lesser (average 12 m height with 115 cm CBH) compared to those in-situ. Proportions of population by height level and CBH class are shown in Tables 1 and 2.

The structural composition indicates that the in-situ conservation area had a larger number of individuals at the low growth classes (0.1 to 1.1 cm CBH and 1.1 to 5.1 m height range) compared to the medium and high growth classes, whereas in the ex-situ conservation area the majority of individuals fell in the medium growth classes (5.1 to 50 cm CBH and 5.1 to 10 m height level) (Figure 2). Height level and CBH class in the structure models of *V. diospyroides* in the in-situ conservation area revealed that this species has a decreasing trend in the relative dominance of trees at low, medium, and high levels (or classes) as shown in Figure 3. The average height and CBH of *V. diospyroides* show higher average growth in the in-situ than those of ex-situ. Seedling grown at low growth class (0-1.0 m height range) was not found in some sub-areas, namely VAT02 and VAT06.

The relationship between plant height and CBH

Across the studied sites, there were different patterns of relationship between plant height and CBH, as shown in Figure 4. In the in-situ conservation area, the maximum CBH was greater than100 cm, and with the increase in height, the tree CBH also slowly increased in some sub-area. Thin tree trunk of *V. diospyroides* (tall but with a thin trunk) was mostly found at VAT01 and VAT02 sub-areas. The *V. diospyroides* in both VAT01 and VAT02 areas had low to medium R^2 (0.5245 and 0.4752, respectively). CBH was the main driver of various levels in height among VAT03, VAT04, and VAT05, resulting in the highest R^2

(0.8207, 0.8263 and 0.7202, respectively). The *V. diospyroides* in these areas grows in near optimal conditions, promoting taller and thicker tree trunks. In VAT06, the solid lines show the trend given by y = 0.0424x + 4.9587 having the poorest R^2 (0.2135) among the linear fits. The *V. diospyroides* population in this sub-area was cultivated mixed with orchard crops, such as mango and mangosteen.

Factors which negatively affect the current population

Based on the observations, we identified several factors that may negatively affect the population of *V. diospyroides* in its habitat (Figure 5). The small population size of this taxa is subject to biotic and abiotic effects reducing population density, especially to effects of annual flooding, drought, and insect attacks. Potential climate change effects can further decrease population growth rates.

Table 1. Numbers (and percentages) of *V. diospyroides* trees located in the studied areas classified by height range (m)

Area	Type of conservation	Number of trees (percent) in each height range			
		0.01-1.0 m	1.1-5.0 m	5.1-10.0 m	>10.1 m
Water park (VAT01)	In-situ	21 (3.68)	317 (55.52)	116 (20.31)	117 (20.49)
Nong Thung Thong (VAT02)	In-situ	0 (0.0)	246 (23.98)	284 (27.68)	496 (48.34)
Nong Thung Thong (VAT03)	In-situ	455 (24.85)	765 (41.78)	204 (11.14)	407 (22.23)
Nong Thung Thong (VAT04)	In-situ	64 (3.47)	535 (29.03)	83 (4.50)	1161 (63.00)
Silvicultural Research Station (VAT05)	Ex-situ	37 (11.38)	121 (37.23)	105 (32.31)	62 (19.08)
Private garden (VAT06)	Ex-situ	0 (0.0)	61 (33.88)	100 (55.55)	19 (10.55)

Table 2. Numbers (and percentages) of *V. diospyroides* trees located in the studied areas classified by CHB (cm)

Area	Type of conservation	Number of trees (percent) in each CBH class				
		0-1.0 cm	1.1-5.0 cm	5.1-50.0 cm	50.1-100.0 cm	>100.1 cm
Water park (VAT01)	In-situ	222 (35.18)	60 (9.51)	203 (32.17)	78 (12.36)	68 (10.78)
Nong Thung Thong (VAT02)	In-situ	227 (21.70)	5 (0.48)	397 (37.95)	267 (25.53)	150 (14.34)
Nong Thung Thong (VAT03)	In-situ	751 (41.02)	360 (19.66)	337 (18.41)	198 (10.81)	185 (10.10)
Nong Thung Thong (VAT04)	In-situ	134 (12.80)	382 (36.49)	168 (16.05)	186 (17.76)	177 (16.90)
Silvicultural Research Station (VAT05)	Ex-situ	71 (21.65)	31 (9.45)	181 (55.18)	45 (13.72)	0 (0.0)
Private garden (VAT06)	Ex-situ	0 (0.0)	2 (1.11)	131 (72.78)	40 (22.22)	7 (3.89)

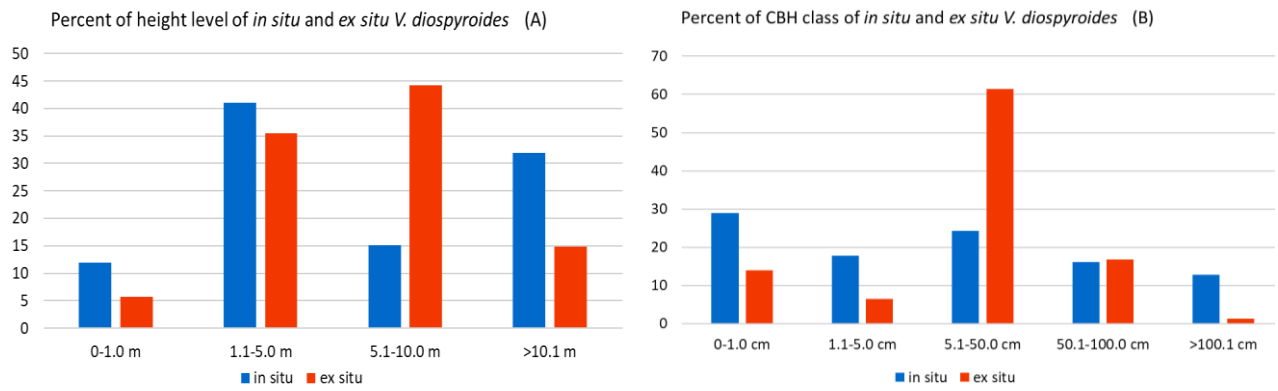

Figure 2. Proportions by height range (A) and CBH (B) for *V. diospyroides* populations located in the in-situ conservation areas (VAT01-VAT04) and in the ex-situ conservation areas (VAT05-VAT06)

Discussion

The current conservation status of *V. diospyroides* is Endangered (EN) according to the IUCN Red List (Pooma et al. 2017) with decreasing number of native mature individuals in lowland forests of peninsular Thailand (Smitinand 1966). The restricted habitat of this species has been heavily disturbed over the last decade by effects of climate change, poor management, and the lack of plant conservation activities (Westwood et al. 2021). Climate change related events, including changes in temperature, rainfall, and natural disasters, have significantly impacted the reproduction and habitat loss of species (Habibullah et al. 2022).

The flowering season of this taxa in Thailand usually occurs regularly once a year (December to February) followed by fruiting and seed dispersal in February to April, which is concurrent with the flooding period in the floodplain habitat. After a severe drought in 2009, the plant did not bloom for 2 years (Srisawat and Jongkraijak 2013). Flowering of this taxa is considered rare with uncertain blooms in the habitat: for example, the flowering of *V. diospyroides* is asynchronously produced by mature individuals or might not take place at all. Unfortunately, only little is known about the response of *V. diospyroides* seeds to flooding time in terms of seed viability and nutrient composition in the soil-water environment. Dipterocarpaceae species are mostly threatened with extinction as ecosystem functions of their habitat are decreasing (Luo et al. 2022). The loss of ecosystem functions in the habitat of *V. diospyroides* may lead to the conclusion that population of this taxa continues to decrease.

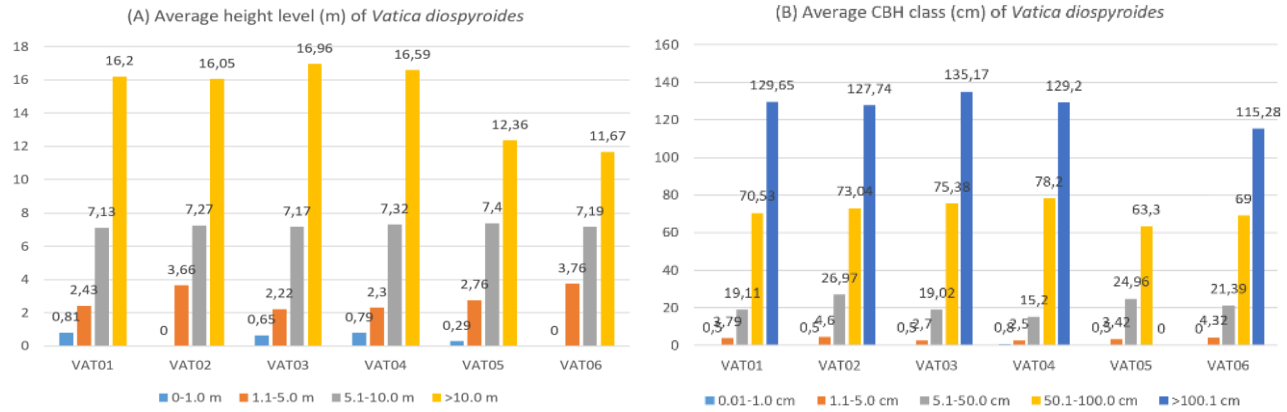

Figure 3. Average height (A) and average CBH (B) levels of *V. diospyroides* located at VAT01-VAT06

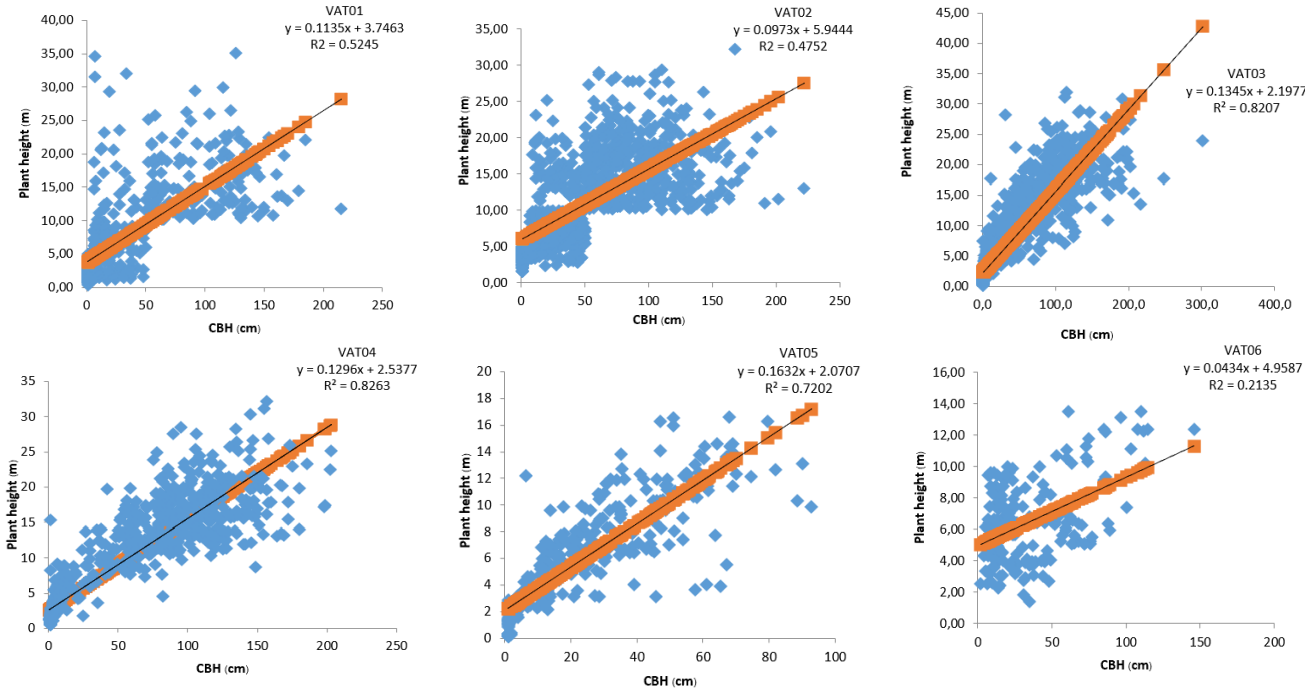

Figure 4. Linear regression results for *V. diospyroides* showing relationship between plant height (m) and CBH (cm) in the 6 studied subareas (VAT01-VAT06)

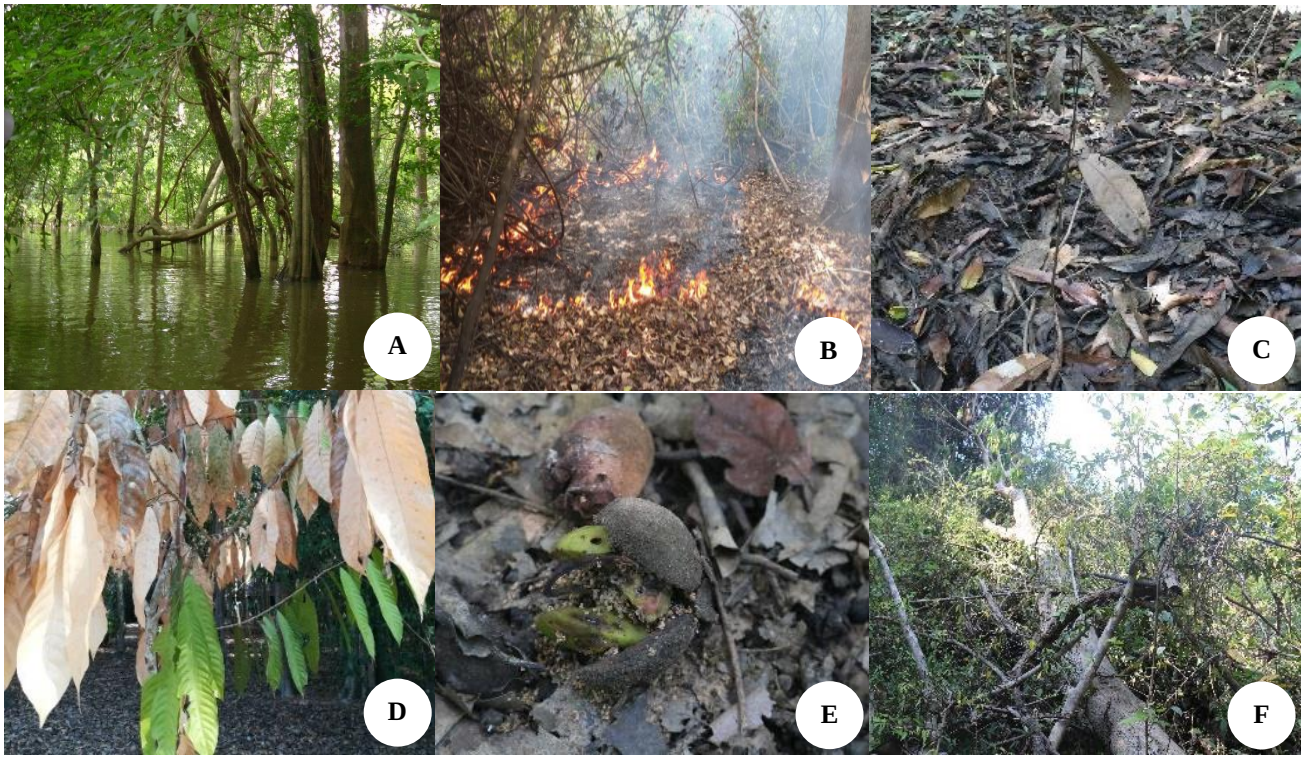

Figure 5. Several factors that likely affect the structure and size of *V. diospyroides* population: A. Heavy flooding, B. Forest fire, C. Seedling die, D. Drought, E. Insect attack, F. Lightning

For conservation program of threatened plants in Dipterocarpaceae family, lacking accurate population information of the species will result in misguided decision-making by the IUCN. Therefore, before development of conservation actions (species management, *ex-situ* conservation, genome resource bank, and habitat protection) for this taxa, we provide accurate population information based on comprehensive approach with total count of all trees of this taxa, for a specific important study area. Previous studies have shown the number counts of individuals of some species in the genus *Vatica* native to Southeast Asia, for example 280 individuals of *V. bantamensis* (Robiansyah and Hamidi 2019), 179 individuals of *V. cauliflora* (Robiansyah et al. 2021), 71 individuals of *V. venulosa* (Primananda et al. 2022), and 196 individuals of *V. chinensis* (Sanil et al. 2022). In our study, we confirmed 5,043 individuals of *V. diospyroides* in both in-situ and ex-situ conservation areas. Not all the trees had the same growth rate because some have reached up to 30 m in their lifetimes, while some will never grow taller than 10 m. Clustered distributions were found in places where resources are patchy (i.e. VAT01 and VAT02, representative of north and north-east sections of the Nong Thung Thong forest). Scattered distribution could promote normal stem growth pattern with high number of larger trees in the habitat (in VAT03 and VAT04), representative of central and southern parts of the Nong Thung Thong forest, whereas VAT05 is the best ex-situ conservation area under management by the Royal Forest Department. These are the minimum basic data used for the scoring of conservation status and for developing strategies to protect and conserve this rare and endemic species (Guan and Yen 2000) and the remaining habitat of the species.

The *V. diospyroides* is previously defined to be a 'small tree' using a tree height of <15 feet at maturity (Smitinand 1966). However, based on our observations, the actual classification of *V. diospyroides* by size should be revised, because the average height of mature individuals is 16 m (52.49 feet) with 130 cm CBH. The maximum height reached 35.12 m (115.22 feet) and CBH of 302 cm (or equivalent to 96.1 cm diameter at breast height or DBH). Dipterocarpaceae is commonly classified into small or large size classes. The most dominant larger *V. diospyroides* tree is the comparative tree size in the Nong Thung Thong forest. Thus, the taxa should be classified as a 'large tree' with average DBH of >50.8 cm or 20 inches and >40 feet or 12.192 m height as the large tree criteria. The large *V. diospyroides* trees were mostly observed in the *in-situ* conservation area with proportion of 20-60% and 10% for height level and CBH classes, respectively. Thus, *V. diospyroides* may be a species in the large tree category, though plant maturity naturally relates to the size.

The linear regression between tree height and CBH in VAT03, VAT04 and VAT05 indicates a strong, significant relationship (R^2>0.70, p<0.05), justifying their use for determining pattern of stem growth (Sumida et al. 2013). Variations in population structure and stem growth pattern of endangered species may result from various factors, such as disturbance severity from effects of climate change

between sites, habitat degradation, severe habitat fragmentation (Tang et al. 2011; Finger et al. 2012; Roque et al. 2017), and threats from humans (Pooma et al. 2017). Thus, the extent of available habitats with highly specific requirements by this species is a significant factor. We suggest that other factors, such as environmental heterogeneity, biotic factors, or soil characteristics, may be driving VAT03, VAT04 and VAT05 to be diverse hotspots of *V. diospyroides* density. The lowland dipterocarp forests in peninsular Thailand should be the primary focus of the sustainable management of tropical rainforests. Since the taxa is threatened by humans gathering flowers or fruit for many purposes, including the increased ethnobotanical use of this family (Use et al. 2016), new planting and re-planting of appropriate *Vatica* species in ex-situ conservation should be conducted extensively (Widiyatno et al. 2020).

In conclusion, a comprehensive analysis of the *V. diospyroides* occurrences within our study region revealed specific locations with limited numbers of trees. Although this species within our project area is protected, the trees are still vulnerable to threats, such as flooding, forest fire, and insect or human attacks, increased disturbances, and habitat fragmentation. Management and monitoring of *V. diospyroides* within the protected areas requires continuous sampling to reach current biodiversity goals and to inform future management decisions. Understanding the reproductive performance of this taxa in its habitat is critical to inform conservation efforts. The management of plant propagation and re-planting in ex-situ conservation forest should be pursued. Based on the evidence reported here, new studies and actions on conservation, protection and propagation are required.

ACKNOWLEDGEMENTS

In memoriam of Miss Waranyu Ratchareon, former head of Suratthani Silvicultural Research Station (Royal Forest Department) who was a leader in ex-situ conservation of *V. diospyroides*. The authors are thankful to Associate Professor Dr. Seppo Karrila for kindly editing this manuscript; and to forest rangers, Somsak Saipankaew, Narit Chandoem, Phuriwat Nakjan, Soraya Punjuban, Apisit Thongead and Nontawan Rungsawat for field assistance. This project is under the Plant Genetic Conservation Project under the Royal Initiative of Her Royal Highness Princess Maha Chakri Sirindhorn conducted by the Prince of Songkla University, Thailand (RSPG-PSU) (SIT600362S).

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