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Original Article

Impact of Ecological Factors on the Distribution of *Vanilla siamensis* Rolfe ex Downie (Orchidaceae: Vanilloideae) in Tropical Forest at Khao Soi Dao Wildlife Sanctuary, Chantaburi, Thailand

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ABSTRACT: Some species of the pantropical orchid genus *Vanilla* are widely used in a variety of industries, including food, pharmaceuticals, cosmetics, tobacco and traditional crafts. *Vanilla siamensis* Rolfe ex Downie is a leafy vine endemic to Thailand. Ecological factors affecting the distribution of *V. siamensis* are still unknown. This study aims to examine the distribution of *V. siamensis* in natural conditions as well as to investigate the impact of environmental factors on its distribution in forest ecosystems. In order to achieve the proposed objectives, a study was conducted in a tropical moist forest at Khao Soi Dao Wildlife Sanctuary. The plant community and environmental factors where *V. siamensis* occurs were assessed in two study sites. At each site, two plots (10 m×50 m) were set up near waterfalls (NWA) and in adjacent forest areas (AFA).

A total of 66 species of woody plants were recorded in the study plots. Higher values for importance value index (IV) were found for *Pterygota alata* (Roxb.) R.BR., *Diospyros defectrix* H.R. Fletcher, *Strombosia ceylanica* Gardner, *Alchornea rugosa* (Lour.) Mull. Arg., and *Diospyros transitoria* Bakh. The highest number of tree species, number of individuals, Shannon diversity index and evenness were found at the NWA compared to the AFA. A total of 19 woody plant species act as support trees of *V. siamensis* in the plant families Malvaceae, Annonaceae and Achariaceae. The results showed that *V. siamensis* might possible well adapted in the NWA study zone which contained a higher level of soil moisture content compared to the AFA. All results revealed that the distribution of *V. siamensis* in the study areas could be impacted by tree hosts. All tree host species have a larger diameter at breast height and thicker and softer bark when compared with non-tree hosts.

KEY WORDS: orchid, host specificity, epiphyte, natural forest

INTRODUCTION

The genus *Vanilla* has a pantropical distribution (Medina *et al*., 2009; Hernandez-Ruiz *et al*., 2016), containing the notable species *V. planifolia* Jacks. ex Andrews and *V. pompona* Schiede from the tropical Americas and the hybrid *V. × tahitiensis*, that are used in a variety of industries, including food, pharmaceuticals, cosmetics, tobacco and traditional crafts (Medina *et al*., 2009). Extracts of *V. siamensis*, a leafy vine endemic to Thailand (Cameron,

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2011a; Pedersen *et al*., 2011), exhibit the characteristic effects of a natural bone-promoting compounds such as phytoestrogen (Wanachantararak, 2012). In spite of being a distinctive species of pharmacological interest, detailed information on the distribution, ecology, and biology of *V. siamensis* is sparse. An understanding of the role of the various ecosystem components in terms of its survival and colonization would be beneficial for its conservation and potential utilisation.

Vanilla is unusual amongst other orchids in that it germinates in the soil and then climbs up a tree hosts by use of adherent roots, eventually becoming epiphytic after losing contact with the soil (Cameron, 2011b). As such, the species appear to possess the ability to colonize a range of tree species (Zimmerman and Olmsted, 1992; Muñoz *et al*., 2003; Bergstrom and Carter, 2008), although in the case of *V. siamensis* isolated large trees seem to be favored (Patel, 1996; Harrison *et al*., 2003; Muñoz *et al*., 2003; Bergstrom and Carter, 2008). Information on the distribution, identity and size of host trees for *V. siamensis* and other species of *Vanilla remains* fragmentary.

The aim of this study was to investigate the impact of environmental factors on the distribution of *V. siamensis* in forest ecosystems. Specifically, we aimed to examine the degree to which *V. siamensis* is host specific and/or size class dependant under natural condition; in addition, the diversity and composition of the vegetation at various elevational levels were analysed.

MATERIALS AND METHODS

The study was conducted in the Khao Soi Dao Wildlife Sanctuary (KSD-WS), Chanthaburi, Thailand (Fig. 1a), chosen for harboring easily accessible populations of *V. siamensis.* The forest at the study site of the Khao Soi Dao waterfall is classified as a tropical moist forest. We divided the sample plots into two areas, namely, upper areas (UP) located at 439 m above sea level (asl) and lower areas (LW) located at 372 m asl (Fig. 1b). At each study area, two permanent plots (10 m×50 m) were constructed near waterfall areas (NWA) and in adjacent forest areas (AFA) at a distance of at least 20 m from each other. In every sample plot, five quadrats of 10m×10m were constructed for plant sampling and measurement of environmental factors (Fig. 1c). Field work was conducted over a 1-year period from November 2016 to July 2017.

Plant Sampling

All trees possessing a stem diameter of 1.3 m at breast height were examined for each study plot; data recorded included the species name, diameter and tree height by using the Haga hypsometer. The presence or absence of *V. siamensis* and its host tree species were also recorded (Fig. 2a-2d). Herbarium specimens were collected and identified using various regional floras and were deposited in the Forest Herbarium, Bangkok (BKF).

Measurement of Environmental Factors

Soil temperature and moisture content were randomly measured in the study plots at four sampling areas in each study site. Soil temperature was measured at a depth of 10 cm in the soil with a Drip-Proof Type Digital Thermometer (MODEL PC-9215; SATO, Tokyo, Japan). Soil moisture content was also measured at a depth of 10 cm in the soil with a moisture sensor (Theta Probe type ML2x; Delta-T Devices Ltd., Cambridge, UK). Surface temperature of the host tree was measured, comprising the trees that supported the *Vanilla* vines at each study site. All environmental factors were measured in daytime between 09:00 to 17:00.

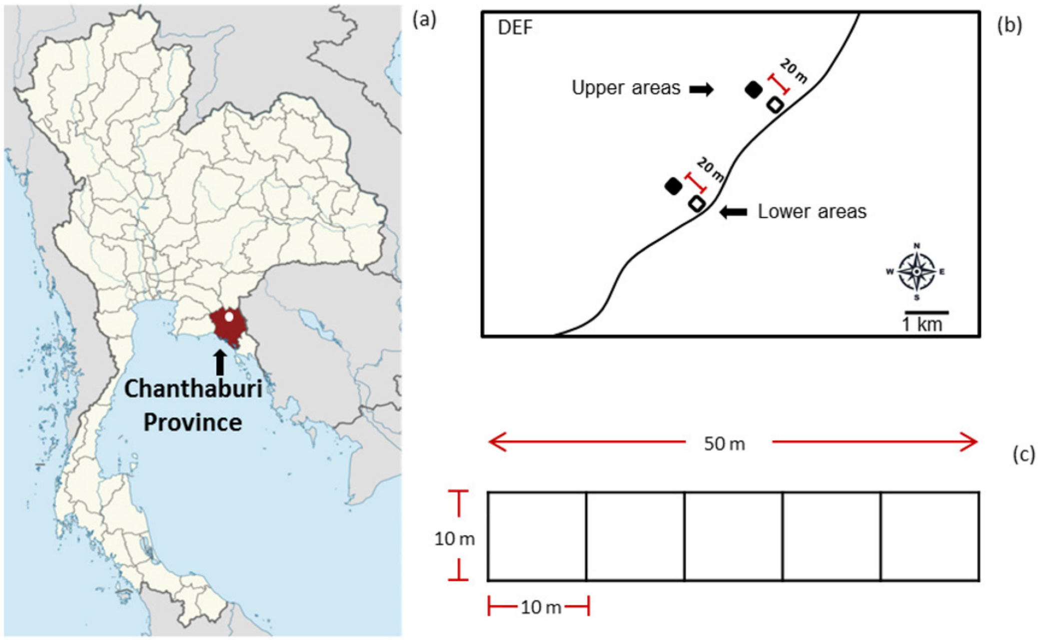

Figure 1 (a-b). The study site in the Khao Soi Dao Waterfall, which is located in a Dry evergreen forest (DEF) Khao Soi Dao Wildlife Sanctuary, Chanthaburi, Thailand. (b) The sample plots (50 m×10 m) were set up near waterfall areas (□ ; white square) and adjacent to forest areas (■; black square), and (c) 5 quadrats of 10 m×10 m size were set up in every sample plot.

Data Analysis

The tree community was characterized using (1) richness (*i.e.* number of species), (2) Shannon diversity index (*H′*), (3) Evenness index (*E*), and (4) Importance Value (IV) index of tree species. *T*-tests were conducted to assess the differences in mean values of richness, number of tree individuals, *H′* and *E* at lower sites (LW) and upper sites (UP).

Importance Values (IV) are referred to as the importance percentage. The importance value, or the importance percentage, gives an overall estimate of the importance of a plant species i in the community. It is calculated by: IVi = RDi+ RFi + RCi. Here, RDi is the relative density, RFi the relative frequency, and RCi the relative dominance (expressed as basal area) of species i.

t-tests were used to compare the means of richness, diameter (DBH), number, and height of host trees for *V. siamensis* between the LW and the UP.

Difference of soil temperature and moisture content between the LW and the UP were also assessed through *t*-tests. *T*-test was used to compare differences in means of soil temperature and moisture content among study areas (*i.e.* the UP and the LW), and study plots (*i.e.* the NWA and the AFA).

T-test were performed with SPSS Ver. 20.0.0 for Windows (SPSS Inc., Chicago, IL, USA). Shannon diversity index (*H′*) and Evenness index (*E*) were evaluated with PAST: Paleontological statistics software package version 3.0

Figure 2 (a-b) Flower of *V. siamensis* and (c-d) its host trees (*Pterocybium tentorium*).

RESULTS

Plant Community

Of a total of 134 individual trees recorded in the plots, 66 species of woody plants belonging to 60 genera in 34 families were identified from the forest (Appendix 1). At the upper site (UP), the most dominant tree species was *Hydnocarpus ilicifolia* King (320), followed by *Pterocymbium tinctorium* (Blanco) Merr. (190), *Orophea polycarpa* A.DC. (160), *Murraya paniculata* L.Jack (140), and *Diospyros variegata* Kurz (120) (Appendix 2). At the lower site (LW), the most dominant tree species was *Alchornea rugosa* (Lour.) Mull. Arg. (180 individuals/ha), followed by *Strombosia ceylanica* Gardner (150) *Diospyros defectrix* H.R. Fletcher. (130), *D. transitoria* Bakh. (120), and *Pterygota alata* (Roxb.) R.Br. (60) (Appendix 3).

Importance Value index was calculated for each study site separately. At UP, higher values of IV were found for *Hydnocarpus ilicifolia* King (62.0), *Pterocymbium tinctorium* (Blanco) Merr. (27.3), *Dalbergia oliveri* (25.3), *Diospyros variegata* Kurz (22.6) and *Murraya paniculate* (L.) Jack (20.9) (Appendix 2). At LW higher values of IV were found for *Pterygota alata* (31.03), *Diospyros defectrix* (23.83), *Strombosia ceylanica* (22.44), *Alchornea rugose* (21.33) and *D. transitoria* (20.65) (Appendix 3).

While the greatest richness of tree species, number of individuals, Shannon diversity index, and evenness were found near waterfall areas

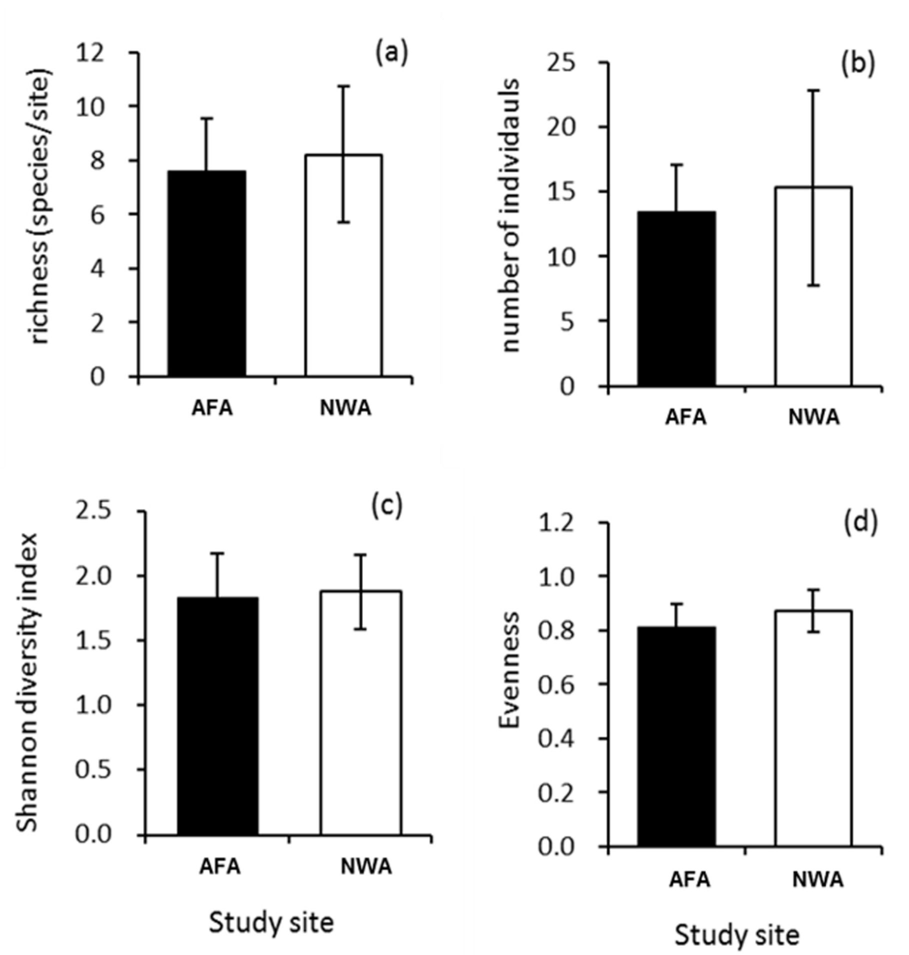

Figure 3. Mean (±SE) of (a) richness of tree species, (b) number of individuals, (c) Shannon diversity index and (d) evenness of plant community at adjacent forest areas (AFA; black bar) and near waterfall areas (NWA; white bar).

(NWA); compared with adjacent to forest areas (AFA), these differences were not statistically significant (*t*-test; $P > 0.05$; Fig.3a-3d).

Host Trees for *Vanilla siamensis*

Of the 287 individual trees surveyed, those that hosted *V. siamensis* represented 10.5 % (n=30) of woody plants (Table 1). Tree species from the family Malvaceae accounted for 28.1% of all host trees, followed by Annonaceae (15.3%) and Achariaceae (10.3%).

The highest number of tree host species was found in the upper sites (3.4 ±1.6 SE hosting trees per quadrat) as compared with the lower sites (1.6 ±1.0 SE); however, the difference was not statistically significant (*t*-test; t (9) = 2.0, $P > 0.05$. Table 1; Fig.4a). The greatest number of individual tree hosts was recorded at the upper sites (6 ±3.70 SE), compared with the lower sites (1.6 ±1.03 SE), however, again difference was not significant (*t*-test; t (9) = 2.1, $P > 0.05$. Table 1; Fig.4b). The results suggest that neither species richness nor abundance of host trees is a key factor in terms of the abundance of *V. siamensis* in the study area, KSD-WS.

The diameter at breast height (DBH) of host trees was significantly higher at the lower sites (36.6 ±10.79 SE) than at the upper sites (8.4 ±1.04 SE; *t*-test; t (36) = 24.3, $P < 0.001$;

Table 1. List of host trees for *V. siamensis*, and number of individuals found near waterfall areas (NWA) at lower and upper sites.

Family/ species	number of individuals	
	lower site	upper sites
Achariaceae		
Hydnocarpus ilicifolia King	0	4
Annonaceae		
Miliusa mollis Pierre var. mollis	0	2
Orophea polycarpa A. DC.	0	4
Bignoniaceae		
Markhamia stipulata (Wall.)	1	1
Mayodendron igneum (Kurz) Kurz	0	1
Combretaceae		
Terminalia nigrovenulosa Pierre	0	1
Dipterocarpaceae		
Dipterocarpus alatus Roxb. ex G. Don	1	0
Ebenaceae		
Diospyros defectrix H. R. Fletcher	0	1
Diospyros transitoria Bakh.	1	0
Diospyros variegata Kurz	0	1
Euphorbiaceae		

Table 1. (Continued).

Family/ species	number of individual	
	lower site	upper site
Alchornea rugosa (Lour.) Müll. Arg.	1	0
Fabaceae		
Millettia leucantha Kurz var. leucantha	0	1
Malvaceae		
Pterocymbium tinctorium (Blanco) Merr.	0	11
Meliaceae		
Aglaia edulis (Roxb.) Wall.	1	0
Myrtaceae		
Syzygium syzygioides (Miq.) Merr. & L. M. Perry	1	0
Phyllanthaceae		
Bischofia javanica Blume	1	0
Rhizophoraceae		
Carallia brachiata (Lour.) Merr.	1	0
Rutaceae		
Murraya paniculata (L.) Jack	0	1
Vitaceae		
Tetrastigma leucostaphylum (Dennst.) Alston	0	2
Total species of host tree	8	12
Total number of host tree	8	30

Fig.4c). The height of the tree hosts was also significantly higher at the lower sites (23.8 ±4.51 SE) than at the upper sites (7.7 ±0.80 SE; *t*-test; t (36) = 24.3, P < 0.001; Fig.4d).

Environmental Factors

Soil temperature was significantly higher in the upper sites (27.7 Celsius ±0.6 SD) than at the lower sites (25.2 ±0.3 SD; t (36) = 14.3, P = 0.09; Table 2). Soil temperature was also significantly higher at the AFA than at the NWA (*t*-test; *t* (36) = 19.3, P <0.001; Fig. 5a).

Soil moisture was significantly higher in the upper sites (5.3% ±0.7 SD) than the lower sites (3.4 ±0.5 SD; P < 0.001). The difference was found for sampling areas, in which soil moisture was significantly higher at the NWA than the AFA (*t*-test; *t* (36) = 24.1, P < 0.001; Fig. 5b). Surface temperature for host trees was higher in the upper sites (28.1 ± 0.4 SD) compared to the lower sites (27.4±0.6 SD). Surface temperature for host trees was also significantly higher at the NWA than at the AFA (*t*-test; t (36) = 18.9, P < 0.001; Fig. 5c).

DISCUSSION

The plant communities where *Vanilla siamensis* occurs contain a diverse flora. However, there were no differences in tree and shrub species

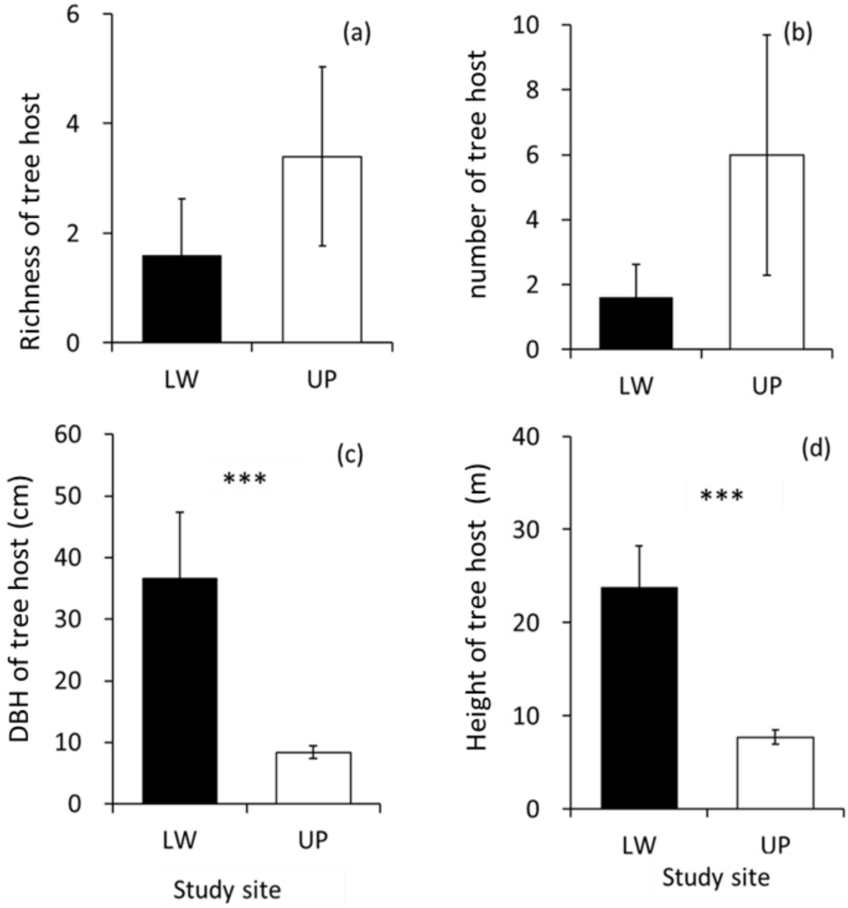

Figure 4. Mean (±SE) of (a) species, (b) number of individuals, (c) diameter at breast height (DBH) and (d) high of tree host at lower sites (LW) and upper site (UP).

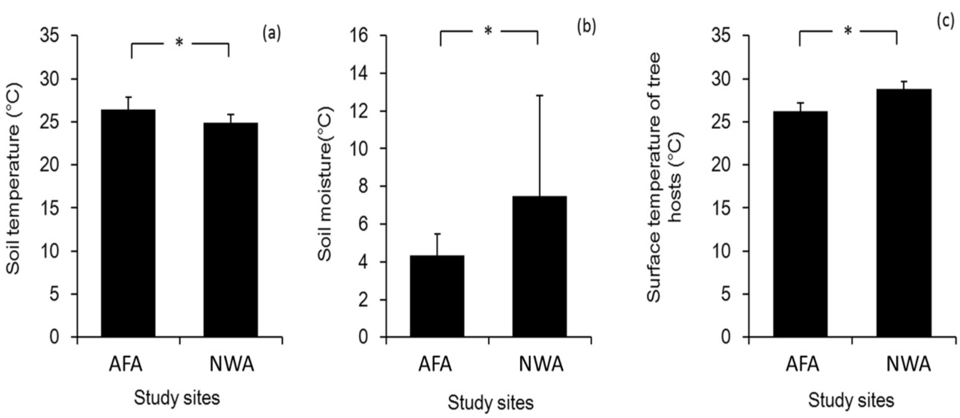

Figure 5. Mean (±SE) of (a) soil temperature, (b) soil moisture and (c) surface temperature of host tree at adjacent forest areas (AFA) and near waterfall areas (NWA). Significant values are indicated with an asterisk for * = P<0.001.

composition between areas near waterfalls (NWA) and adjacent forest areas (AFA). At the same time, a significant difference in the number of individuals of *V. siamensis* was found. The results showed that more individuals of *V. siamensis* were found at the upper areas when compared with the lower areas, which was the case for both NWA and AFA. These results suggest that the level of species richness and number of individual *Vanilla* plants may not explain the distribution of *V. siamensis*. On the other hand, a larger number of *V. siamensis* vine can be found at higher elevations and near waterfalls, especially in association with the host tree *Pterocymbium tinctorium*. From the data collected, these areas have a higher level of soil moisture content compared with adjacent forest areas. These results show that the distribution of *V. siamensis* in the study areas could be related to a higher level of moisture content near waterfalls and also to the position of host trees, as has been reported for other hemi-epiphytes (Patel, 1996; Harrison *et al*. 2003; Bergstrom *et al*., 2008), and Muñoz *et al*., (2003) who reported that three epiphytic ferns showed preferences for large-sized trees, whereas frequency of occurrence of three common vines was independent of host tree size.

According to the present study, micro-site factors, in particular species of host tree and their bark characteristics, are among the key variables that relate to the occurrence of *V. siamensis*. A greater incidence of *V. siamensis* was found on 19 woody plant species of the plant families Malvaceae, Annonaceae and Achariaceae. These trees have thick and soft bark on the lower part of tree trunk and smooth bark in the upper part of tree trunk. Bark structure might be a factor influencing the climbing habit of *V. siamensis* as it is found in other groups of vascular epiphytes (Wyse and Burns, 2011; Zhao *et al*., 2015). The most common host tree is *P. tinctorium* (Malvaceae: Sterculioidae), known in Thailand as Phor E Gae, where it is a significant timber tree growing to about 45 m tall. The straight, cylindrical bole can be 90 cm in diameter and unbranched for up to 30 m (Brown, 1920). The trees are grown in plantations as well as in the wild for local use as a source of fiber, wood and dyestuff. The fibers obtained from the bark are used to make rope. The bark is used to improve the dying of cotton cloth black, due to the presence of tannins. The white wood is light and very soft, and is used for construction, matches, veneer and pulp (Brown, 1920).

All host trees found in this study have a large diameter at breast height (DBH). In the study area, *V. siamensis* can attains lengths of 8 to 25 m, with internodes 5 to 10 cm long. These results suggest that larger DBH and height of host trees are potentially important factors that influence the presence of *V. siamensis* in natural conditions (Köster *et al*., 2011)

Observation of various *Vanilla* vines in the wild, as well as in cultivation, suggests that none seem to be host-specific, but that they do prefer certain host trees that have a favorable type of bark and belong to a distinct size class. *V. siamensis* in the wild is predominantly located near the edge of waterfalls, within a forest habitat. They prefer areas with high content of organic matter, high soil moisture and humidity. At the edge of a waterfall, within a forest, the branches of 45 meter-tall *P. tinctorium* trees maintain constant shade, neither too intense nor too weak, which is favorable for the development and flowering of *V. siamensis*. *Vanilla siamensis* does not have to compete with the *P. tinctorium* for water and nutrients, but obtains these mainly from the bark of *P. tinctorium*, where it is always moist. This encourages the further development of *V. siamensis.* The terrain slopes gradually underneath the trees to retain the humus generated by them. At Khao Soi Dao, away from the edge of the waterfall areas, the ground is flat below the trees where the forest soil is well drained to prevent flooding. The choice of host tree is important as it must protect the *Vanilla* vines from the heat of the sun or from the wind, so as not to compete for water supply and nutrients.

It would be interesting to investigate if seed dispersal of *V. siamensis* is another factor that helps explain the variations in occurrence of this species in its habitat. In the course of our studies, we have been able to observe *Vanilla* seeds in the faeces of small mammals, especially civet species. It is well known that these nocturnal mammals can act as seed dispersers in the wild (Corlett, 1998; Corlet, 2002; Nakashima *et al*., 2010). If Vanilla is only dispersed by such small mammals, their occurrence may be linked to the behavior of these animals. This would clearly have implications for the conservation of these plants.

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Appendix 1. Plant species list.

	Botanical Name	Species code	Family Name	Habit
1	*Hydnocarpus ilicifolia* King	*Hydnocarpus ilicifolia*	Achariaceae	ST
2	*Mangifera cochinchinensis* Engl.	*Mangifera cochinchinensis*	Anacardiaceae	T
3	*Alphonsea boniana* Finet & Gagnep.	*Alphonsea boniana*	Annonaceae	T
4	*Miliusa mollis Pierre* var. mollis	*Miliusa mollis*	Annonaceae	ST
5	*Orophea polycarpa* A. DC.	*Orophea polycarpa*	Annonaceae	S/ST
6	*Uvaria wrayi* (King)	*Uvaria wrayi*	Annonaceae	C
7	*Willughbeia edulis* Roxb.	*Willughbeia edulis*	Apocynaceae	C
8	*Wrightia coccinea* (Roxb.) Sims	*Wrightia coccinea*	Apocynaceae	T
9	*Markhamia stipulata* (Wall.)	*Markhamia stipulata var. pierrei*	Bignoniaceae	T
10	*Mayodendron igneum* (Kurz) Kurz	*Mayodendron igneum*	Bignoniaceae	T
11	*Capparis* sp.	*Capparis* sp.	Capparaceae	C
12	*Gonocaryum lobbianum* (Miers) Kurz	*Gonocaryum lobbianum*	Cardiopteridaceae	ST
13	*Glyptopetalum sclerocarpum* M. A. Lawson	*Glyptopetalum sclerocarpum*	Celastraceae	S/ST
14	*Garcinia vilersiana* Pierre	*Garcinia vilersiana*	Clusiaceae	ST
15	*Combretum album* Pers.	*Combretum album*	Combretaceae	C
16	*Terminalia nigrovenulosa* Pierre	*Terminalia nigrovenulosa*	Combretaceae	T
17	*Neuropeltis racemosa* Wall.	*Neuropeltis racemosa*	Convolvulaceae	C
18	*Dipterocarpus alatus* Roxb. ex G. Don	*Dipterocarpus alatus*	Dipterocarpaceae	T
19	*Dipterocarpus turbinatus* C. F. Gaertn.	*Dipterocarpus turbinatus*	Dipterocarpaceae	T
20	*Shorea guiso* (Blanco) Blume	*Shorea guiso*	Dipterocarpaceae	T
21	*Diospyros defectrix* H. R. Fletcher	*Diospyros defectrix*	Ebenaceae	T

Appendix 1. (Continued)

	Botanical Name	Species code	Family Name	Habit
22	*Diospyros transitoria* Bakh.	*Diospyros transitoria*	Ebenaceae	T
23	*Diospyros variegata* Kurz	*Diospyros variegata*	Ebenaceae	T
24	*Alchornea rugosa* (Lour.) Müll. Arg.	*Alchornea rugosa*	Euphorbiaceae	S/ST
25	*Cleidion javanicum* Blume	*Cleidion javanicum*	Euphorbiaceae	S/T
26	*Croton persimilis* Müll. Arg.	*Croton persimilis*	Euphorbiaceae	S/ST
27	*Falconeria insignis* Royle	*Falconeria insignis*	Euphorbiaceae	T
28	*Macaranga indica* Wight	*Macaranga indica*	Euphorbiaceae	ST/T
29	*Mallotus peltatus* (Geisel.) Müll. Arg.	*Mallotus peltatus*	Euphorbiaceae	S/ST
30	*Dalbergia oliveri* Gamble ex Prain	*Dalbergia oliveri*	Fabaceae	T
31	*Dendrolobium lanceolatum* (Dunn) Schindl.	*Dendrolobium lanceolatum*	Fabaceae	S
32	*Erythrina subumbrans* (Hassk.) Merr.	*Erythrina subumbrans*	Fabaceae	T
33	*Millettia leucantha* Kurz var. leucantha	*Millettia leucantha*	Fabaceae	T
34	*Saraca declinata* (Jack) Miq.	*Saraca declinata*	Fabaceae	ST
35	*Cryptocarya albiramea* Kosterm.	*Cryptocarya albiramea*	Lauraceae	T
36	*Strychnos minor* Dennst.	*Strychnos minor*	Loganiaceae	C
37	*Microcos tomentosa* Sm.	*Microcos tomentosa*	Malvaceae	T
38	*Pterocymbium tinctorium* (Blanco) Merr.	*Pterocymbium tinctorium*	Malvaceae	T
39	*Pterygota alata* (Roxb.) R. Br.	*Pterygota alata*	Malvaceae	T
40	*Scaphium affine* (Mast.) Pierre	*Scaphium affine*	Malvaceae	T
41	*Sterculia hypochra* Pierre	*Sterculia hypochra*	Malvaceae	T
42	*Memecylon caeruleum* Jack var. caeruleum	*Memecylon caeruleum*	Melastomataceae	S

Appendix 1. (Continued)

	Botanical Name	Species code	Family Name	Habit
43	*Memecylon intermedium* Blume	*Memecylon intermedium*	Melastomataceae	T
44	*Aglaia edulis* (Roxb.) Wall.	*Aglaia edulis*	Meliaceae	T
45	*Aglaia spectabilis* (Miq.) S. S. Jain & Bennet	*Aglaia spectabilis*	Meliaceae	T
46	*Dysoxylum cyrtobotryum* Miq.	*Dysoxylum cyrtobotryum*	Meliaceae	T
47	*Walsura pinnata* Hassk.	*Walsura pinnata*	Meliaceae	T
48	*Artocarpus chama* Buch.-Ham.	*Artocarpus chama*	Moraceae	T
49	*Ficus heterostyla* Merr.	*Ficus heterostyla*	Moraceae	S/T
50	*Knema latericia* Elmer	*Knema latericia subsp. Ridleyi*	Myristicaceae	S/T
51	*Syzygium siamense* (Craib) Chantar. & J. Parn.	*Syzygium siamense*	Myrtaceae	T
52	*Syzygium syzygioides* (Miq.) Merr. & L. M. Perry	*Syzygium syzygioides*	Myrtaceae	T
53	*Strombosia ceylanica* Gardner	*Strombosia ceylanica*	Olacaceae	T
54	*Galearia maingayi* Hook. f.	*Galearia maingayi*	Pandaceae	T
55	*Bischofia javanica* Blume	*Bischofia javanica*	Phyllanthaceae	T
56	*Carallia brachiata* (Lour.) Merr.	*Carallia brachiata*	Rhizophoraceae	T
57	*Canthium coffeoides* Pierre ex Pit.	*Canthium coffeoides*	Rubiaceae	S/ST
58	*Hymenodictyon orixense* (Roxb.) Mabb.	*Hymenodictyon orixense*	Rubiaceae	T
59	*Atalantia monophylla* (L.) DC.	*Atalantia monophylla*	Rutaceae	ST
60	*Clausena harmandiana* (Pierre) Pierre ex Guillaumin	*Clausena harmandiana*	Rutaceae	S
61	*Murraya paniculata* (L.) Jack	*Murraya paniculata*	Rutaceae	S/ST
62	*Casearia calva* Craib	*Casearia calva*	Salicaceae	T
63	*Xerospermum noronhianum* (Blume) Blume	*Xerospermum noronhianum*	Sapindaceae	T

Appendix 1. (Continued)

	Botanical Name	Species code	Family Name	Habit
64	*Picrasma javanica* Blume	*Picrasma javanica*	Simaroubaceae	T
65	*Tetrameles nudiflora* R. Br.	*Tetrameles nudiflora*	Tetramelaceae	T
66	*Tetrastigma leucostaphylum* (Dennst.) Alston	*Tetrastigma leucostaphylum*	Vitaceae	C

Appendix 2. Importance Value (IV) of plant species at upper site.

no.	Botanical names	no.tree (tree)	no. plot (plot)	sum Ba (m2)	density (tree/Rai)	density (tree/ha)	frequency (%)	Dominance (m2/ha)	RD (%)	RF (%)	RBa (%)	IV
1	*Hydnocarpus ilicifolia*	32	8	0.7490	51.20	320.00	80.00	7.49	20.92	10.81	30.34	62.07
2	*Pterocymbium tinctorium*	19	4	0.2358	30.40	190.00	40.00	2.36	12.42	5.41	9.55	27.38
3	*Dalbergia oliveri*	1	1	0.5771	1.60	10.00	10.00	5.77	0.65	1.35	23.38	25.38
4	*Diospyros variegata*	12	4	0.2311	19.20	120.00	40.00	2.31	7.84	5.41	9.36	22.61
5	*Murraya paniculata*	14	6	0.0901	22.40	140.00	60.00	0.90	9.15	8.11	3.65	20.91
6	*Wrightia coccinea*	11	6	0.0619	17.60	110.00	60.00	0.62	7.19	8.11	2.51	17.81
7	*Orophea polycarpa*	16	4	0.0402	25.60	160.00	40.00	0.40	10.46	5.41	1.63	17.49
8	*Clausena harmandiana*	7	5	0.0213	11.20	70.00	50.00	0.21	4.58	6.76	0.86	12.19
9	*Terminalia nigrovenulosa*	4	3	0.0941	6.40	40.00	30.00	0.94	2.61	4.05	3.81	10.48
10	*Miliusa mollis*	4	4	0.0085	6.40	40.00	40.00	0.08	2.61	5.41	0.34	8.36
11	*Diospyros transitoria*	2	2	0.0867	3.20	20.00	20.00	0.87	1.31	2.70	3.51	7.52
12	*Markhamia stipulata* var. pierrei	3	2	0.0415	4.80	30.00	20.00	0.41	1.96	2.70	1.68	6.34
13	*Memecylon caeruleum*	3	2	0.0281	4.80	30.00	20.00	0.28	1.96	2.70	1.14	5.80
14	*Millettia leucantha*	3	2	0.0190	4.80	30.00	20.00	0.19	1.96	2.70	0.77	5.43
15	*Tetrastigma leucostaphylum*	2	2	0.0213	3.20	20.00	20.00	0.21	1.31	2.70	0.86	4.87
16	*Atalantia monophylla*	2	2	0.0210	3.20	20.00	20.00	0.21	1.31	2.70	0.85	4.86
17	*Diospyros defectrix*	2	2	0.0132	3.20	20.00	20.00	0.13	1.31	2.70	0.53	4.54
18	*Memecylon intermedium*	2	2	0.0091	3.20	20.00	20.00	0.09	1.31	2.70	0.37	4.38
19	*Sterculia hypochra*	1	1	0.0387	1.60	10.00	10.00	0.39	0.65	1.35	1.57	3.57
20	*Mayodendron igneum*	1	1	0.0252	1.60	10.00	10.00	0.25	0.65	1.35	1.02	3.02
21	*Hymenodictyon orixense*	2	1	0.0062	3.20	20.00	10.00	0.06	1.31	1.35	0.25	2.91
22	*Falconeria insignis*	1	1	0.0161	1.60	10.00	10.00	0.16	0.65	1.35	0.65	2.66
23	*Erythrina subumbrans*	1	1	0.0075	1.60	10.00	10.00	0.08	0.65	1.35	0.31	2.31
24	*Microcos tomentosa*	1	1	0.0074	1.60	10.00	10.00	0.07	0.65	1.35	0.30	2.30
25	*Canthium coffeoides*	1	1	0.0030	1.60	10.00	10.00	0.03	0.65	1.35	0.12	2.13
26	*Glyptopetalum sclerocarpum*	1	1	0.0047	1.60	10.00	10.00	0.05	0.65	1.35	0.19	2.19
27	*Alphonsea boniana*	1	1	0.0028	1.60	10.00	10.00	0.03	0.65	1.35	0.11	2.12
28	*Strychnos minor*	1	1	0.0024	1.60	10.00	10.00	0.02	0.65	1.35	0.10	2.10
29	*Saraca declinata*	1	1	0.0021	1.60	10.00	10.00	0.02	0.65	1.35	0.09	2.09
30	*Willughbeia edulis*	1	1	0.0019	1.60	10.00	10.00	0.02	0.65	1.35	0.08	2.08
31	*Capparis* sp.	1	1	0.0017	1.60	10.00	10.00	0.02	0.65	1.35	0.07	2.07
	Total	153	74	2.47	244.80	1530.00	740.00	24.69	100.00	100.00	100.00	100.00

Appendix 3. Importance Value (IV) of plant species at lower site.

no.	Botanical names	no.tree (tree)	no. plot (plot)	sum Ba (m2)	density (tree/Rai)	density (tree/ha)	frequency (%)	Dominance (m2/ha)	RD (%)	RF (%)	RBa (%)	IV
1	*Pterygota alata*	6	5	0.9833	9.60	60.00	50.00	9.83	4.48	5.95	20.60	31.03
2	*Diospyros defectrix*	13	9	0.1627	20.80	130.00	90.00	1.63	9.70	10.71	3.41	23.83
3	*Strombosia ceylanica*	15	5	0.2525	24.00	150.00	50.00	2.52	11.19	5.95	5.29	22.44
4	*Alchornea rugosa*	18	5	0.0928	28.80	180.00	50.00	0.93	13.43	5.95	1.94	21.33
5	*Diospyros transitoria*	12	6	0.2171	19.20	120.00	60.00	2.17	8.96	7.14	4.55	20.65
6	*Dipterocarpus alatus*	1	1	0.7241	1.60	10.00	10.00	7.24	0.75	1.19	15.17	17.11
7	*Atalanti*+M:Ra monophylla	3	2	0.4589	4.80	30.00	20.00	4.59	2.24	2.38	9.62	14.24
8	*Millettia leucantha*	4	3	0.1846	6.40	40.00	30.00	1.85	2.99	3.57	3.87	10.42
9	*Gonocaryum lobbianum*	6	3	0.1099	9.60	60.00	30.00	1.10	4.48	3.57	2.30	10.35
10	*Aglaia edulis*	5	3	0.0798	8.00	50.00	30.00	0.80	3.73	3.57	1.67	8.98
11	*Bischofia javanica*	2	2	0.2118	3.20	20.00	20.00	2.12	1.49	2.38	4.44	8.31
12	Markhamia stipulata	3	1	0.1684	4.80	30.00	10.00	1.68	2.24	1.19	3.53	6.96
13	*Saraca declinata*	4	3	0.0124	6.40	40.00	30.00	0.12	2.99	3.57	0.26	6.82
14	*Pterocymbium tinctorium*	1	1	0.2100	1.60	10.00	10.00	2.10	0.75	1.19	4.40	6.34
15	*Galearia maingayi*	2	1	0.1535	3.20	20.00	10.00	1.53	1.49	1.19	3.22	5.90
16	*Cleidion javanicum*	3	2	0.0587	4.80	30.00	20.00	0.59	2.24	2.38	1.23	5.85
17	*Dysoxylum cyrtobotryum*	2	2	0.0796	3.20	20.00	20.00	0.80	1.49	2.38	1.67	5.54
18	*Macaranga indica*	1	1	0.1699	1.60	10.00	10.00	1.70	0.75	1.19	3.56	5.50
19	*Xerospermum noronhianum*	2	2	0.0608	3.20	20.00	20.00	0.61	1.49	2.38	1.27	5.15
20	*Artocarpus chama*	3	2	0.0130	4.80	30.00	20.00	0.13	2.24	2.38	0.27	4.89
21	*Knema latericia* subsp. Ridleyi	2	2	0.0423	3.20	20.00	20.00	0.42	1.49	2.38	0.89	4.76
22	*Walsura pinnata*	2	2	0.0123	3.20	20.00	20.00	0.12	1.49	2.38	0.26	4.13
23	*Scaphium affine*	3	1	0.0205	4.80	30.00	10.00	0.20	2.24	1.19	0.43	3.86
24	*Aglaia spectabilis*	1	1	0.0543	1.60	10.00	10.00	0.54	0.75	1.19	1.14	3.08
25	*Croton persimilis*	1	1	0.0479	1.60	10.00	10.00	0.48	0.75	1.19	1.00	2.94
26	*Casearia calva*	1	1	0.0408	1.60	10.00	10.00	0.41	0.75	1.19	0.86	2.79
27	*Mallotus peltatus*	2	1	0.0047	3.20	20.00	10.00	0.05	1.49	1.19	0.10	2.78
28	*Garcinia vilersiana*	1	1	0.0367	1.60	10.00	10.00	0.37	0.75	1.19	0.77	2.70
29	*Tetrameles nudiflora*	1	1	0.0347	1.60	10.00	10.00	0.35	0.75	1.19	0.73	2.66
30	*Atalantia monophylla*	1	1	0.0172	1.60	10.00	10.00	0.17	0.75	1.19	0.36	2.30
31	*Dendrolobium lanceolatum*	1	1	0.0123	1.60	10.00	10.00	0.12	0.75	1.19	0.26	2.19
32	*Combretum album*	1	1	0.0064	1.60	10.00	10.00	0.06	0.75	1.19	0.13	2.07
33	*Cryptocarya albiramea*	1	1	0.0061	1.60	10.00	10.00	0.06	0.75	1.19	0.13	2.06
34	*Picrasma javanica*	1	1	0.0057	1.60	10.00	10.00	0.06	0.75	1.19	0.12	2.06

Appendix 3. (Continued)

no.	Botanical names	no.tree (tree)	no. plot (plot)	sum Ba (m2)	density (tree/Rai)	density (tree/ha)	frequency (%)	Dominance (m2/ha)	RD (%)	RF (%)	RBa (%)	IV
35	*Syzygium siamense*	1	1	0.0041	1.60	10.00	10.00	0.04	0.75	1.19	0.09	2.02
36	*Shorea guiso*	1	1	0.0035	1.60	10.00	10.00	0.04	0.75	1.19	0.07	2.01
37	*Mangifera cochinchinensis*	1	1	0.0034	1.60	10.00	10.00	0.03	0.75	1.19	0.07	2.01
38	*Ficus heterostyla*	1	1	0.0031	1.60	10.00	10.00	0.03	0.75	1.19	0.07	2.00
39	*Willughbeia edulis*	1	1	0.0031	1.60	10.00	10.00	0.03	0.75	1.19	0.07	2.00
40	*Uvaria wrayi*	1	1	0.0030	1.60	10.00	10.00	0.03	0.75	1.19	0.06	2.00
41	Dipterocarpus turbinatus	1	1	0.0024	1.60	10.00	10.00	0.02	0.75	1.19	0.05	1.99
42	*Syzygium syzygioides*	1	1	0.0022	1.60	10.00	10.00	0.02	0.75	1.19	0.05	1.98
43	*Neuropeltis racemosa*	1	1	0.0017	1.60	10.00	10.00	0.02	0.75	1.19	0.04	1.97
	Total	134	84	4.77	214.40	1340.00	840.00	47.72	100.00	100.00	100.00	300.00