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SITE INDICATOR SPECIES FOR PREDICTING THE PRODUCTIVITY OF TEAK PLANTATIONS IN PHRAE PROVINCE, THAILAND**

NARINTHORN JUMWONG[1], CHONGRAK WACHRINRAT[2*], SARAWOOD SUNGKAEW[3] AND ATCHARA TEERAWATANANON[4]

[1]*Faculty of Forestry, Kasetsart University, Bangkok 10900, Thailand*
[2]*Department of Silviculture, Faculty of Forestry, Kasetsart University, Bangkok 10900, Thailand*
[3]*Department of Forest Biology, Faculty of Forestry, Kasetsart University, Bangkok 10900, Thailand*
[4]*Natural History Museum, Pathum Thani 12120, Thailand*

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ABSTRACT

Site quality assessment is critically important in any tree planting activity as it may serve a range of management functions such as, optimizing productivity estimates of forest plantations. This study aimed to evaluate the site quality, using plant indicators species, for three teak plantations located in Northern Thailand belonging to the Forest Industry Organization (FIO). Twenty-four sample plots were chosen to cover all the growth classes within the age range of 6-39 years. The site index of teak was established by using the anamorphic technique which is based on dominant height and age at a base age of 30 years, divided into 3 site index classes as 24, 21, and 18, as good, moderate, and poor site quality, respectively. Associated species, the native species that are tree and shrub habits, were surveyed in the 24 plots and indicator species were classified using the Indicator Species Analysis (ISA) and Two Way Indicator Species Analysis (TWINSPAN). The relationship between indicator species and environmental factors was analyzed by the Generalized Linear Model (GLM). The associated species was classified into 76 species with 21 families. The results of ISA indicated the significant indicator species under the good site class were *Streblus ilicifolius*, *Lagerstroemia floribunda*, *Dalbergia cana* and *Lagerstroemia calyculata*; while *Schleichera oleosa* and *Dalbergia nigrescens* were presented under poor site class, respectively. The results from TWINSPAN supported *Streblus ilicifolius*, *Lagerstroemia floribunda* and *Schleichera oleosa* were obvious indicators. Each indicator species distribution influenced by various relationships with environmental factors, which soil pH and N were the main factors to distribute all indicator species to 3 relationships. First, the indicator species positively associated with soil pH and negatively associated with N were *Streblus ilicifolius* and *Dalbergia nigrescens*. Second, the indicator species positively associated with soil pH and N were *Lagerstroemia floribunda* and *Schileichera oleosa*. Third, the indicator species negatively associated with soil pH and positively associated N were *Dalbergia cana* and *Lagerstroemia calyculata*. The GLM analysis revealed P, Ca and elevation influenced indicator species distribution. As of writing, this is the first study on species indicators for suitable sites of teak in Thailand. Meanwhile, in the absence of confirmatory studies, these indicators can be used as guide for farmers interested in planting teak. In bare lands, the farmer can apply these indicator species to determine the site quality based on the species' past appearance.

Keywords: productivity, site indicator species, site quality, Teak plantation, Thailand

INTRODUCTION

Teak (*Tectona grandis* L.f.) plantations were established 112 years ago by the Royal Forest Department (RFD) and more than 50 years ago by the Forest Industry Organization (FIO) in order to replenish the timber resources in Thailand (Kijkar 2000). Initially, the teak plantations were grown naturally in the natural forest, especially in the northern part of Thailand; however, with technology improvements, these plantations were expanded externally (Thueksathit 2006).

*Corresponding author, e-mail: fforcrw@ku.ac.th
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Since timber yield strongly depends on forest site quality, determination of site quality is one primary step in the intensive management of forest land (Davis 1987; Skovsgaard & Vanclay 2008). Based on site and yield information, a forest manager can estimate the future wood supplies and make realistic decisions about future costs and benefits of intensive management, land acquisition and industrial investment (Carmean 1977; Clutter *et al.* 1983).

For over 50 years, Thailand has performed site quality assessments using the site index (SI) (Boonthawee 1968; Chanpaisang 1977; Papata 2001; Prempanichnukul 2001; Srisuksai 2001). It is determined using a direct method defining the actual growth as an average of the heights of the dominant and co-dominant trees at a given base age in a single-species and evenly-aged stand (Ford-Robertson 1971). The same site can produce different site indices, as may be influenced by the environmental factors. However, the indirect or soil-site measurement uses the soil, topography and climatic factors in an area to correlate with the site index, growth, or yield, estimated from the trees in each plot (Sahunalu 1970; Srisuksai 2001).

Site quality assessments of Teak plantations are based both on site index and soil survey methods. The site index method, however, needs records of teak growth in each site. It is difficult to evaluate the site quality and productivity of teak sites that lack teak growth record and of those newly established teak plantations. As tree heights and many other site properties are difficult to measure, the plant indicator species is determined based on the measurement of indicative variables such as the appearance or composition of ground vegetation (Vanclay 1992). This study attempts to develop a practical site productivity indicator by using plant indicator species to evaluate the site quality and describe the effects of all environmental factors.

MATERIALS AND METHODS

Studied Sites and Sampling Plots

The study was conducted in year 2013 on those teak plantations which apply similar management techniques and are maintained by the Forest Industry Organization (FIO) in the Phrae Province, Northern Thailand. The planted areas in all plantations were divided according to the year of planting. The three plantations selected from a total of 12 teak plantations managed by FIO, included the Wang Chin (WC), Khun Mae Kham Mee (KM) and Mae Sa-Roy (MS) plantations (Fig. 1). These plantations covered a wide range of growth rates, tree age sizes, age classes and were classified as 6-10, 11-15, 16-20, 21-25, 26-30 and > 30-years old (Table 1). The elevation of the study areas ranged from 100-700 m above the mean sea level. The topography varied among sites with undulating area from flat to hilly. The soil texture is either sandy clay loam or clay type derived from a parent rock consisting of limestone (Table 2).

Using a dominant height growth covering 5 site index classes, 24 temporary sample plots were randomly established in the selected study sites managed by the Forestry Research Center in 1997 (Forestry Research Center 1997) and distributed into 6 age classes. All plots were studied for their soil properties during the year 2000 (Sakurai *et al.* 2002).

Data Collection

Data were collected during the rainy season (August-November 2013), in which the highest density of associated species was observed. Twenty-four temporary sample plots of 40 x 40 m were established and then divided into sub-plots of 10 x 10 m where bamboos were measured. Inside the plots, the heights of 16 dominant and co-dominant trees were measured using a haga altimeter. The diameters at breast height (DBH) of all the trees were measured by a diameter tape. Five subplots of 4 x 4 m were set up for saplings observation at the corners and in the middle of the 40 x 40 sample plot (Fig. 2). The frequency and density of each species' sapling plant was also estimated.

Site Index Analysis

The site index for teak was determined using the anamorphic site index method (Prasomsin 1991). The method defines an average height for a given age, which is commonly taken as 30 years for teak rotation. The tree selection was done based on the dominant height, as this

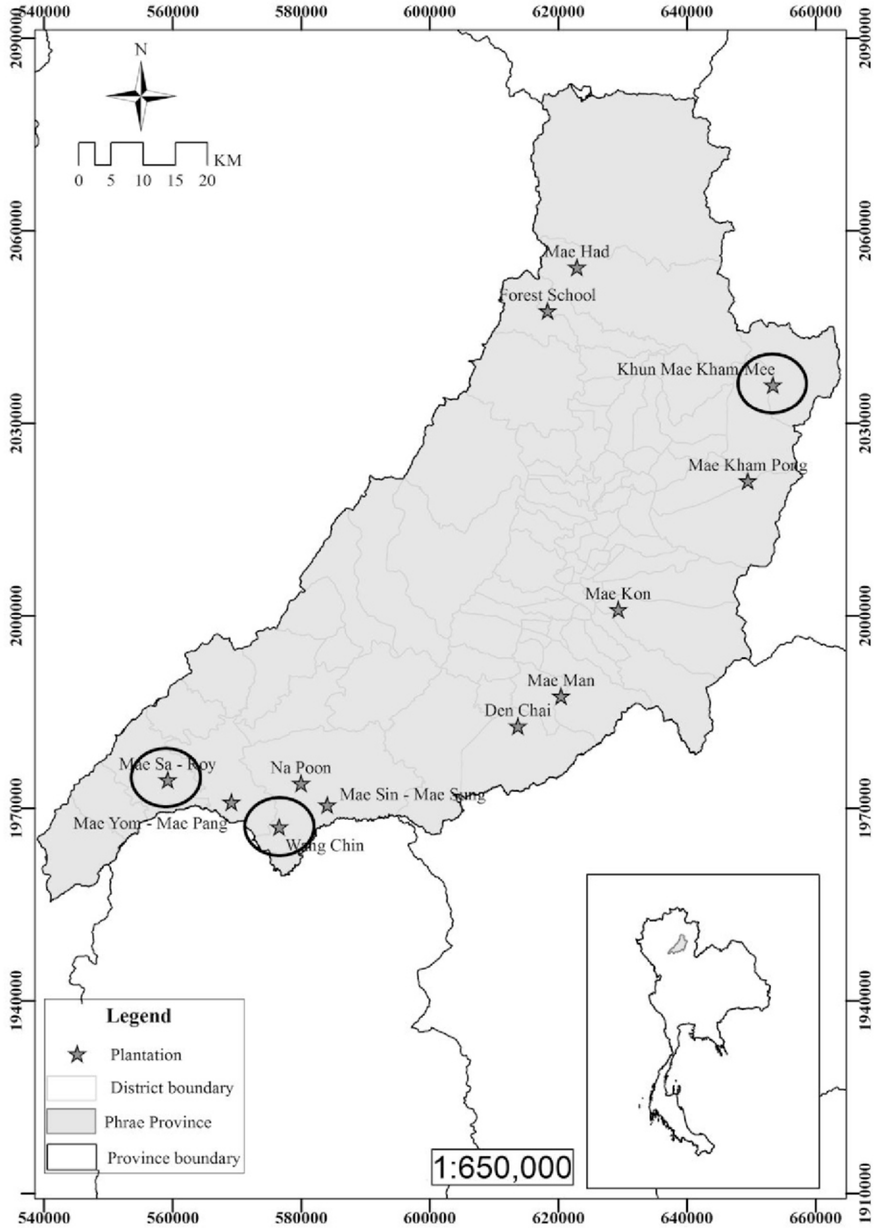

Figure 1 Location of the three study areas, Khun Mae Kham Mee (KM) plantation, Wang Chin (WC) plantation and Mae Sa-Roy (MS) plantation as indicated by circles

Table 1 Age classes of Teaks in the twenty-four sample plots selected from Khun Mae Kham Mee (KM), Wang Chin (WC) and Mae Sa-Roy (MS) plantations

Age class (yr)	Site index[a] 8	11	14	17	20	Total
6-10			**1** (1)	**1** (1)	**2** (2)	**4** (4)
11-15			**1** (1)	**1** (1)		**2** (2)
16-20					**1** (1)	**1** (1)
21-25		**2** (2)		**1** (2)	**2** (2)	**5** (6)
26-30	**1** (1)	**3** (5)	**3** (4)			**7** (10)
> 30		**0** (3)	**2** (8)	**2** (5)	**1** (4)	**5** (20)
Total	**1** (1)	**5** (10)	**7** (14)	**5** (9)	**6** (9)	**24** (43)

Notes: [a] as reported by the Forestry Research Center (1997); the highlighted numbers indicate the sample plots and the number in brackets are the existing plots.

Table 2 The environmental conditions (topography and soil properties at 0 and 20 cm soil depth) at the 24 sample plots from Khun Mae Kham Mee plantation (KM), Mae Saroy plantation (MS) and Wang Chin plantation (WC)

No	Plot	Topography		Soil depth (cm)	Soil properties						
		Slope (%)	Elevation (m)		pH	N (%)	P (mg P/kg)	Ca	K	Mg	Na
								---------- cmol(+)/kg ------------			
1	KM75	50	498.20	0	5.24	1.10	3.86	4.99	0.21	1.04	0.30
				20	5.66	2.20	2.28	7.56	0.26	3.33	0.23
2	KM81	20	348.00	0	6.04	1.20	3.37	9.99	0.21	1.90	0.26
				20	5.79	1.00	1.07	9.03	0.10	1.43	0.28
3	KM85	45	550.00	0	6.11	1.70	18.86	7.00	0.34	1.29	0.27
				20	5.89	1.10	1.48	4.27	0.14	1.03	0.28
4	KM83	0	432.30	0	6.53	2.10	12.47	14.85	0.41	3.27	0.32
				20	6.21	1.40	0.73	10.64	0.14	2.31	0.35
5	KM78	35	426.10	0	6.08	2.20	2.84	13.64	0.28	4.82	0.35
				20	5.59	1.60	0.85	6.72	0.11	3.73	0.25
6	KM05	0	441.00	0	5.93	1.80	4.28	9.07	0.37	3.55	0.11
				20	5.51	1.20	0.79	4.92	0.13	2.86	0.32
7	KM02	0	432.30	0	5.93	1.80	4.28	9.07	0.37	3.55	0.11
				20	5.51	1.20	0.79	4.92	0.13	2.86	0.32
8	KM04	5	453.70	0	5.93	1.80	3.55	9.38	0.30	4.23	0.32
				20	5.60	0.60	0.70	6.36	0.13	2.58	0.29
9	KM01	10	458.20	0	5.93	1.80	3.55	9.38	0.30	4.23	0.32
				20	5.60	0.60	0.70	6.36	0.13	2.58	0.29
10	MS87	5	164.00	0	5.89	1.50	7.25	5.20	0.31	3.18	0.21
				20	5.44	0.90	1.70	2.87	0.08	2.11	0.28
11	MS83	2	136.20	0	5.22	1.30	3.58	2.13	0.21	1.46	0.27
				20	4.91	1.00	1.04	1.20	0.12	0.62	0.29
12	MS80	5	147.40	0	5.39	1.20	3.07	3.54	0.19	1.79	0.28
				20	5.36	0.80	1.80	1.87	0.11	2.39	0.32
13	MS86	35	175.80	0	5.93	1.80	7.54	8.08	0.44	2.21	0.30
				20	5.06	1.90	1.56	4.85	0.25	1.56	0.29
14	MS82	20	185.30	0	5.69	1.10	2.33	2.99	0.20	2.13	0.26
				20	5.23	0.90	1.97	1.77	0.22	0.80	0.29
15	MS84	30	135.70	0	5.90	1.10	13.29	3.88	0.21	1.72	0.23
				20	5.24	0.80	1.64	1.90	0.14	1.00	0.32
16	WC06	2	142.60	0	5.39	1.20	3.07	3.54	0.19	1.79	0.28
				20	5.36	0.80	1.80	1.87	0.11	2.39	0.32
17	WC83	30	125.90	0	5.22	1.30	3.58	2.13	0.21	1.46	0.27
				20	4.91	1.00	1.04	1.20	0.12	0.62	0.29
18	WC82	15	128.20	0	5.69	1.10	2.33	2.99	0.20	2.13	0.26
				20	5.32	0.80	0.86	1.40	0.14	2.07	0.27
19	WC79	3	177.20	0	6.26	0.90	3.34	7.19	0.30	3.08	0.20
				20	5.60	0.80	0.65	5.09	0.16	4.02	0.30
20	WC89	0	142.00	0	5.74	1.30	5.36	4.01	0.16	2.05	0.20
				20	5.06	0.80	1.40	1.08	0.10	1.03	0.27
21	WC90	3	178.90	0	5.31	1.40	4.37	7.61	0.17	4.75	0.32
				20	5.14	0.90	1.23	2.56	0.09	3.91	0.28
22	WC07	0	155.20	0	5.39	1.20	3.07	3.54	0.19	1.79	0.28
				20	5.36	0.80	1.80	1.87	0.11	2.39	0.32
23	WC92	35	139.90	0	5.52	1.10	6.90	3.09	0.19	1.17	0.26
				20	5.27	0.50	4.14	0.47	0.14	0.45	0.26
24	WC93	30	118.80	0	5.91	1.60	13.16	5.11	0.47	2.65	0.34
				20	5.19	0.90	1.17	2.52	0.17	1.28	0.11

Notes: Numbers after the plantation's abbreviation indicate the planted year (19XX/20XX), for examples: WC92 is a sample plot in Wang Chin plantation that was planted in year 1992; WC06 is a sample plot in Wang Chin plantation that was planted in year 2006;
EC = electrical conductivity, N = total nitrogen, C = organic carbon, P = available phosphorus, Ca = exchangeable calcium, K = exchangeable potassium, Mg = exchangeable magnesium, Na = exchangeable sodium.

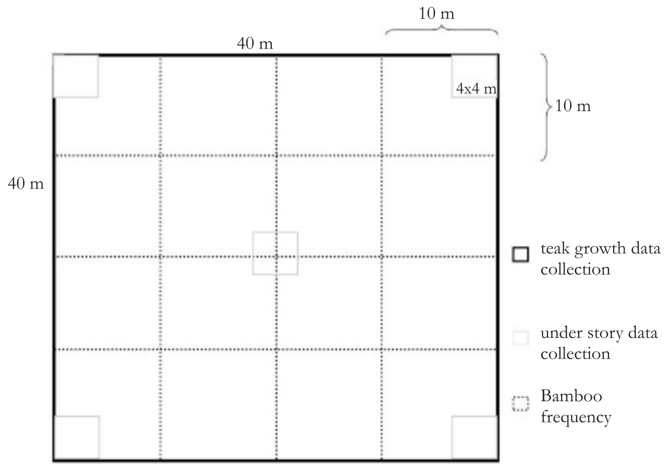

Figure 2 The experimental design for data collection

measure is relatively stable and robust over a large range of managed stand densities (Steve 2001; Herrera-Fernández *et al.* 2004). Many stands had a dominant height and base age of 30-years at the time which the experiment was conducted. A scatter plot between heights and ages was fitted with a best-fit curve, along with higher and lower envelope curves with a shape similar to the guiding curves (Donald 1971) and classified into 3 classes as having a good, moderate, or poor site quality.

Classification of the Associated Species Characteristics

The 24 sample plots or stands were analyzed to describe the associated species life in the teak plantation. In each stand, all the associated species in the five sub-plots (4 x 4 cm each) were identified based on Smitinand (2014) and recorded, including its life form. The analysis of associated species characteristics was important value index (IVI).

Analysis of Plant Indicator Species

Indicator species was determined using Indicator Species Analysis (ISA): an analysis of the relationship between important index values (IVI), which refer to species occurrence and their abundance, from a set of sampled sites which were site quality classes (good, moderate and poor). The significant associated species with $p < 0.05$ were indicator species of the site. Two Way Indicator Species Analysis (TWINSPAN) used to confirm the obvious indicator species. Available in PC-ORD version 6.08 developed for windows (McCune & Mefford 2011).

Relationship between Indicator Species and Environmental Factors

A Generalized linear model (GLM) technique was applied to determine the relationships of indicator species distribution with environmental factors (Table 2). The GLM expands the general linear model so that the dependent variable (number of each indicator species) is linearly related to the covariates (environmental factors) via a specified link function which was natural log in this study.

RESULTS AND DISCUSSION

Site Index of Teak

Site index of teak was divided into 3 site classes, with 24, 21 and 18, indicating a good, moderate, and poor site quality, respectively (Fig. 3 and Table 3). The number of plots that were related to good, moderate, and poor site quality was 9, 8 and 7, respectively.

The dominant height of teak trees, aged 30-years, represented in the poor, moderate and good quality sites, was 18, 21 and 24 m, respectively. In a teak plantation in northern Thailand, the site quality had influenced the 30-year old teak height, 10 m (poor), 20 m (moderate), and 30 m (good) (Kaosa-Ard 1991). This study results indicated that the site quality for teak plantation in Phrae Province was relatively higher than the overall values reported in the northern Thailand, particular, for the poor and moderate site quality. On the other hand, the tree height for the good site class was lower than that previously reported. These results substantiated that of Chanpaisang (1997) where the teak height at a base age of 30-years, were classified it into 5 site qualities, 14 m (very poor), 17 m (poor), 20 m (moderate), 23 m (good) and 26 m (very good). The variability in the average DBH, average dominant height, and merchantable volume of teak was relatively high for each of the site index classes (Table 1). In sample plots with poor site quality, such as MS83, it was observed that the average DBH was higher than in those plots with good site quality (WC83). This was a direct result of silvicultural management, in which selective thinning was done at ages 15 and 22 years, to promote optimum growth of the remaining trees. Thus, it is important to select a good site with intensive management to grow teak.

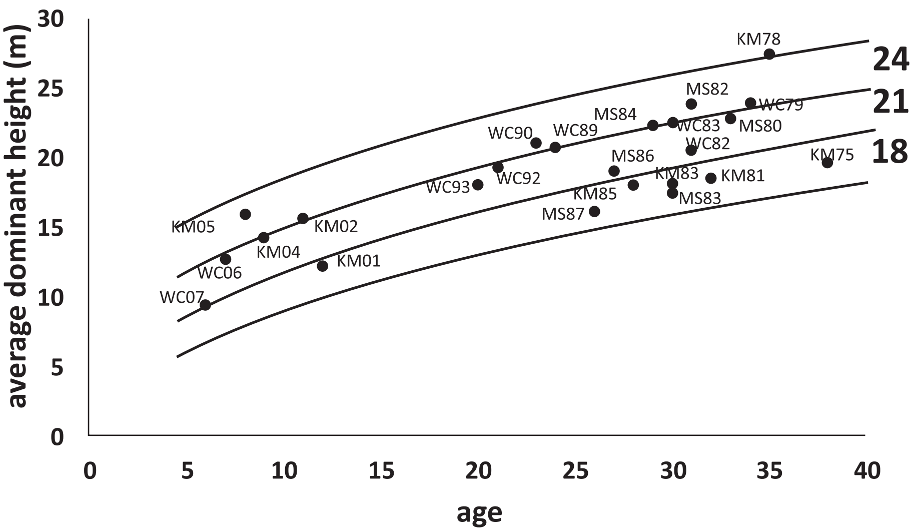

Figure 3 Site index classes for teak in the three plantations located in Phrae Province, Thailand
Notes: KM = Khun Mae Kham Mee plantation; MS = Mae Saroy plantation; WC = Wang Chin plantation; Numbers 24, 21, and 18 = site quality classes.

Table 3 Site index (SI), site quality (SQ) classes and related growth characteristics of Teak plantations at Phrae Province, Thailand

SI (SQ)	No	Plot	Age (yr)	Tree/ha	H (m)	DBH (cm)	Mean Annual Increment (MAI)	
							H (m)	DBH (cm)
24 (good)	1	KM05	8	612	15.95	12.66	1.99	1.58
	2	KM02	11	687	15.60	15.92	1.42	1.45
	3	MS84	22	331	22.30	17.61	1.01	0.80
	4	WC90	23	650	21.00	16.86	0.91	0.73
	5	WC89	24	806	20.60	16.51	0.86	0.69
	6	WC83	30	343	22.50	17.20	0.75	0.58
	7	MS82	31	306	23.80	20.49	0.77	0.66
	8	WC79	34	300	23.90	26.32	0.70	0.77
	9	KM78	36	137	27.40	29.49	0.76	0.82
21 (moderate)	1	WC07	6	450	9.44	10.91	1.57	1.82
	2	WC06	7	487	12.70	10.74	1.81	1.53
	3	KM04	9	475	14.21	16.51	1.58	1.83
	4	WC93	20	481	18.00	15.62	0.90	0.78
	5	WC92	21	543	19.22	17.96	0.92	0.86
	6	MS86	27	281	19.00	27.66	0.70	1.02
	7	WC82	31	175	20.50	23.27	0.66	0.75
	8	MS80	33	393	22.80	13.50	0.69	0.41

Table 3 (Continued)

18	1	KM01	12	762	12.70	12.82	1.06	1.07
(poor)	2	MS87	26	837	16.05	15.60	0.62	0.60
	3	KM85	28	581	17.99	19.59	0.64	0.70
	4	KM83	30	262	17.49	22.79	0.60	0.64
	5	MS83	30	312	18.10	19.19	0.58	0.76
	6	KM81	32	293	18.50	23.95	0.58	0.75
	7	KM75	39	137	19.60	18.51	0.50	0.47

Notes: Numbers indicate the planted year (19XX/20XX);
KM = Khun Mae Kham Mee plantation; MS = Mae Saroy plantation; WC = Wang Chin plantation.

Associated Species Characteristics

In this study, the associated species is native species with only tree and shrub. From the exploration of three Teak plantations in Phare Province, it was found that all associated species in 24 sample plots comprised of 76 species belonging to 21 families. All the sample unit was found in seedling and sapling stages. Most of the associated species comprised of trees (51 species). The dominant family was Fabaceae (previously Leguminosae), with a total of 15 species, followed by Malvaceae (6 species) and Phyllanthaceae (6 species).

IVI was calculated by summing up the relative density and relative frequency. The top five with the highest IVI were *Cratoxylum formosum* (20.86), *Clerodendrum chinense* (13.24), *Lepisanthes rubiginosa* (11.15), *Oroxylum indicum* (10.25) and *Dalbergia lanceolaria* (9.4). The species composition and IVI of associated species are shown in Table 3.

Table 3 Relative density (RD), relative frequency (RF) and important value index (IVI) of associated species

No	Scientific name	Family	RD (%)	RF (%)	IVI
1	*Cratoxylum formosum*	Hypericaceae	13.43	7.43	20.86
2	*Clerodendrum chinense*	Lamiaceae	10.59	2.65	13.24
3	*Lepisanthes rubiginosa*	Sapindaceae	3.71	7.43	11.15
4	*Oroxylum indicum*	Bignoniaceae	3.53	6.73	10.25
5	*Dalbergia lanceolaria*	Fabaceae	6.51	2.83	9.34
6	*Vitex canescens*	Lamiaceae	4.95	4.07	9.02
7	*Bridelia ovata*	Phyllanthaceae	6.00	2.12	8.13
8	*Ficus hispida*	Moraceae	4.35	3.36	7.72
9	*Croton stellatopilosus*	Euphorbiaceae	3.62	3.72	7.34
10	*Barringtonia acutangula*	Lecythidaceae	2.84	3.72	6.56
11	*Millettia brandisiana*	Fabaceae	3.62	2.48	6.10
12	*Pterocarpus macrocarpus*	Fabaceae	3.67	2.30	5.97
13	*Mitragyna rotundifolia*	Rubiaceae	1.92	3.19	5.11
14	*Streblus ilicifolius*	Moraceae	3.25	1.24	4.49
15	*Fernandoa adenophylla*	Bignoniaceae	1.10	2.83	3.93
16	*Hymenodictyon orixense*	Rubiaceae	1.24	2.65	3.89
17	*Grewia eriocarpa*	Malvaceae	1.47	2.12	3.59
18	*Xylia xylocarpa*	Fabaceae	1.28	2.30	3.58
19	*Dalbergia cultrata*	Fabaceae	1.37	1.95	3.32
20	*Sterculia guttata*	Malvaceae	1.79	1.24	3.03
21	*Lagerstroemia floribunda*	Lythraceae	1.65	1.24	2.89
22	*Smilax sp.*	Smilacaceae	1.97	0.88	2.86
23	*Diospyros malabarica*	Ebenaceae	0.73	1.59	2.33
24	*Millettia leucantha*	Fabaceae	1.24	1.06	2.30
25	*Bauhinia saccocalyx*	Fabaceae	1.05	1.24	2.29
26	*Markhamia stipulata*	Bignoniaceae	0.64	1.42	2.06
27	*Terminalia nigrovenulosa*	Combretaceae	0.69	1.24	1.93
28	*Lagerstroemia calyculata*	Lythraceae	0.50	1.42	1.92
29	*Schleichera oleosa*	Sapindaceae	0.64	1.24	1.88
30	*Artocarpus sp.*	Moraceae	0.55	1.06	1.61
31	*Albizia odoratissima*	Fabaceae	0.37	1.24	1.61
32	*Dalbergia nigrescens*	Fabaceae	0.50	1.06	1.57
33	*Dalbergia cana*	Fabaceae	0.50	1.06	1.57
34	*Albizia lucidior*	Fabaceae	0.60	0.88	1.48
35	*Casearia grewiifolia*	Salicaceae	0.46	0.88	1.34

Table 3 (Continued)

36	*Bombax anceps*	Malvaceae	0.27	1.06	1.34
37	*Streblus asper*	Moraceae	0.60	0.71	1.30
38	*Cassia fistula*	Fabaceae	0.60	0.71	1.30
39	*Vitex peduncularis*	Lamiaceae	0.41	0.88	1.30
40	*Helicteres isora*	Malvaceae	0.23	1.06	1.29
41	*Wrightia arborea*	Apocynaceae	0.27	0.88	1.16
42	*Antidesma ghaesembilla*	Phyllanthaceae	0.41	0.71	1.12
43	*Anogeissus acuminata*	Combretaceae	0.41	0.53	0.94
44	*Microcos paniculata*	Malvaceae	0.41	0.53	0.94
45	*Croton poilanei*	Euphorbiaceae	0.23	0.53	0.76
46	*Broussonetia papyrifera*	Moraceae	0.32	0.35	0.67
47	*Morinda tomentosa*	Rubiaceae	0.14	0.53	0.67
48	*Irvingia malayana*	Irvingiaceae	0.27	0.35	0.63
49	*Clausena harmandiana*	Rutaceae	0.09	0.53	0.62
50	*Ardisia polycephala*	Primulaceae	0.23	0.35	0.58
51	*Holarrhena pubescens*	Apocynaceae	0.05	0.53	0.58
52	*Diospyros castanea*	Ebenaceae	0.37	0.18	0.54
53	*Vitex pinnata*	Lamiaceae	0.32	0.18	0.50
54	*Terminalia glaucifolia*	Combretaceae	0.14	0.35	0.49
55	*Alstonia scholaris*	Apocynaceae	0.14	0.35	0.49
56	*Catunaregam sp.*	Rubiaceae	0.14	0.35	0.49
57	*Litsea glutinosa*	Lauraceae	0.14	0.35	0.49
58	*Quercus kerrii*	Fabaceae	0.09	0.35	0.45
59	*Homalium tomentosum*	Salicaceae	0.09	0.35	0.45
60	*Siphonodon celastrineus*	Celastraceae	0.09	0.35	0.45
61	*Antidesma bunius*	Phyllanthaceae	0.09	0.35	0.45
62	*Cratoxylum cochinchinense*	Hypericaceae	0.23	0.18	0.41
63	*Dalbergia ovata*	Fabaceae	0.09	0.18	0.27
64	*Dalbergia oliveri*	Fabaceae	0.09	0.18	0.27
65	*Terminalia pierrei*	Combretaceae	0.09	0.18	0.27
66	*Adenanthera microsperma*	Fabaceae	0.09	0.18	0.27
67	*Knema globularia*	Myristicaceae	0.09	0.18	0.27
68	*Millingtonia hortensis*	Bignoniaceae	0.05	0.18	0.22
69	*Glochidion assamicum*	Phyllanthaceae	0.05	0.18	0.22
70	*Pterospermum semisagittatum*	Malvaceae	0.05	0.18	0.22
71	*Lagerstroemia duperreana*	Lythraceae	0.05	0.18	0.22
72	*Sterculia sp.*	Malvaceae	0.05	0.18	0.22
73	*Canarium subulatum*	Burseraceae	0.05	0.18	0.22
74	*Diospyros mollis*	Ebenaceae	0.05	0.18	0.22
75	*Glochidion sphaerogynum*	Phyllanthaceae	0.05	0.18	0.22
76	*Flueggea virosa*	Phyllanthaceae	0.05	0.18	0.22
	Total		100.00	100.00	200.00

Plant Indicator Species

The results from the ISA significantly indicated indicator species ($p < 0.05$) that were *Streblus ilicifolius*, *Dalbergia cana* and *Lagerstroemia floribunda* for good site. For poor site, the indicator species were *Schleichera oleosa* and *Dalbergia nigrescens* (Table 4). ISA could not indicate indicator species for moderate site.

The results of TWINSPAN supported the results of ISA which three indicator species were found to define site quality of teak. *Streblus ilicifolius* and *Lagerstroemia floribunda* were strong indicator species for good site in KM. *Schleichera oleosa* was strong indicator species for poor site in KM (Fig. 4).

In Thailand, this is the first study of indicator species and site quality of teak. There was no information to compare the results with specific site quality from previous works, therefore discussion considered following the important value of these indicator species from previous works. The results of indicator species analysis both of ISA and TWINSPAN were in correspondence with Boonsri (2016) who found *Dalbergia nigrescens* and *Schleichera oleosa* were dominant species at KM. Forest Industry Organization (2016) reported *Schleichera oleosa* was dominant species in Mae Moh Forest Plantation, Lampang.

Table 4 The significant plant indicator species from ISA

Site class	Indicator SPP	p-Value	Significance level		
			Bonferroni correction	Sequential Bonferroni	False Discovery Rates
3 plantations					
Good site	*Streblus ilicifolius*	*	0.00089	0.00089	0.00089
Good site	*Lagerstroemia floribunda*	*	0.00089	0.00091	0.00179
Good site	*Dalbergia cana*	*	0.00089	0.00093	0.00268
Poor site	*Schleichera oleosa*	*	0.00089	0.00094	0.00357
Poor site	*Dalbergia nigrescens*	*	0.00089	0.00096	0.00446
Khun Mae Kham Mee Plantation (KM)					
Good site	*Lagerstroemia calyculata*	*	0.00128	0.00128	0.00128
Good site	*Dalbergia cana*	*	0.00128	0.00132	0.00256
Wang Chin Plantation (WC)					
Good site	*Streblus ilicifolius*	*	0.00054	0.00227	0.00227
Mae Saroy Plantation (MS);		No indicator species			

Note: * $p < 0.05$.

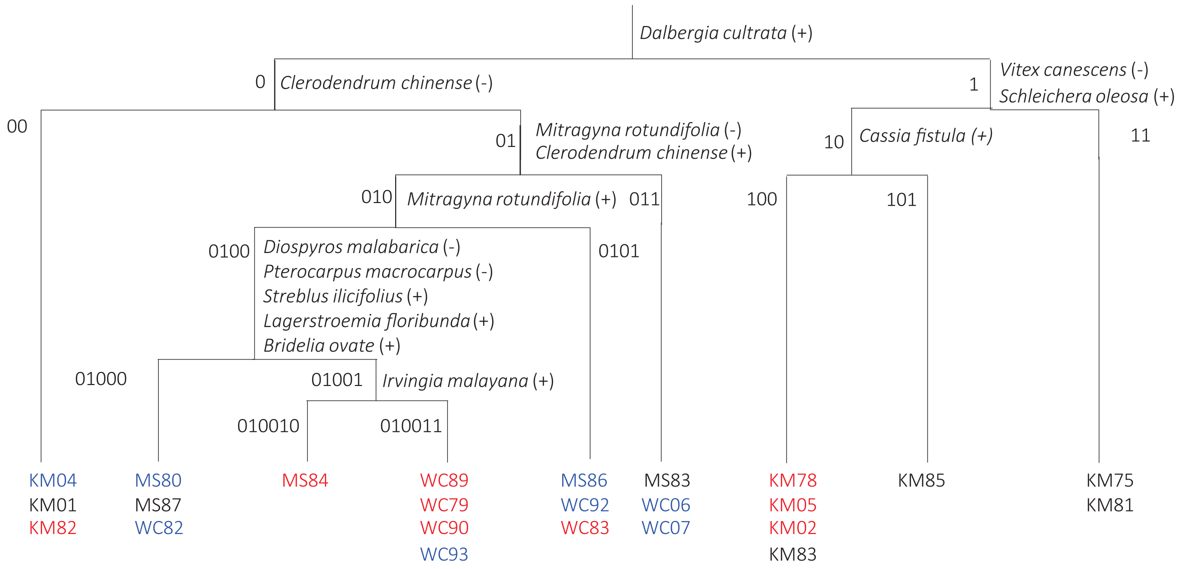

Figure 4 The indicator species for each division from TWINSPAN

Notes: For the sample plot red alphabets indicate a good site, blue indicates a moderate site and black indicates a poor site; 0 = negative group; 1 = positive group; (+) = right hand sub-group; (-) = leaf hand sub-groups.

Table 5 Generalized linear model (GLM) analysis of the relationships between indicator species distribution and environmental factors

Indicator species	Plantation	Site quality	pH	N	P	Ca	Elevation
Streblus ilicifolius	KM/WC	Good	3.38**	-39.43*	26.53**	3.64	
Dalbergia cana	KM/WC	Good	-96.12	14.52			-0.13
Lagerstroemia calyculata	KM/WC	Good	-112.00	25.53			0.21
Lagerstroemia floribunda	MS/WC	Good	10.23**	20.42*	4.60**		
Schileichera oleosa	KM	Poor	1.50	0.16			
Dalbergia nigrescens	KM	Poor	2.56	-0.96	-3.24		

Notes: * $p < 0.05$; ** $p < 0.01$;
The values in the various columns are model regression coefficient.

Relationship between Indicator Species and Environmental Factors

Soil pH and N were the main factors to distribute all indicator species to 3 relationships. First, the indicator species positively associated with soil pH and negatively associated with N were *Streblus ilicifolius* and *Dalbergia nigrescens*. Second, the indicator species positively associated with soil pH and N were *Lagerstroemia floribunda* and *Schileichera oleosa*. Third, the indicator species negatively associated with soil pH and positively associated N were *Dalbergia cana* and *Lagerstroemia calyculata*. The GLM analysis revealed P, Ca and elevation influenced indicator species distribution (Table 5).

Streblus ilicifolius was indicator species of good site which the result of ISA computed from data sets of three plantations: KM, MS and WC. From the survey found that *Streblus ilicifolius* was found in KM and WC. The distribution of *Streblus ilicifolius* was statistically significant positively associated with soil pH and P and negatively associated with N. Furthermore, tend to find *Streblus ilicifolius* in areas with high calcium content.

Dalbergia cana and *Lagerstroemia calyculata* were indicator species of good site which found in KM and WC. The spatial distribution was not statistically significant with environmental factors ($p > 0.05$). The distribution was negatively associated with soil pH and positively associated with N. By the time, *Dalbergia cana* was negatively associated with elevation but *Lagerstroemia calyculata* was positively associated with elevation.

Lagerstroemia floribunda was indicator species of good site which found in MS and WC. The distribution was statistically significant positively associated with soil pH, N and P.

Schileichera oleosa and *Dalbergia nigrescens* were indicator species of poor site in KM. The spatial distributions were not statistically significant with environmental factors ($p > 0.05$). The distribution of *Schileichera oleosa* was positively associated with soil pH and N. The distribution of *Dalbergia nigrescens* was positively associated with soil pH and negatively associated with N and P.

CONCLUSION

Based on the anamorphic site index method, Indicator Species Analysis (ISA) and Two Way Indicator Species Analysis (TWINSPAN) of the three Teak plantations in Phrae province, Thailand, the site indices at base age 30 year old teak trees could be divided into 3 classes, namely; 24 for good, 21 for moderate, and 18 for poor site quality. The significant indicator species in the 3 site index classes derived from ISA ($p < 0.05$) are *Streblus ilicifolius, Dalbergia cana*, *Lagerstroemia floribunda* and *Lagerstroemia calyculata* for good site. For poor site, the indicator species were *Schleichera oleosa* and *Dalbergia nigrescens*. The results of TWINSPAN supported the results of ISA which three indicator species are obvious indicator species i.e., *Streblus ilicifolius* and *Lagerstroemia floribunda* and *Schleichera oleosa* for poor site, especially in KM. Finally, since this study is the first of its kind, it is recommended that the site indicator species analysis be done in other teak areas to substantiate this study results. Meanwhile, in the absence of confirmatory studies, the farmers can apply this current finding and determine the site quality based on the past or present appearance of the indicator species.

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