SITE INDEX OF SIAMESE ROSEWOOD (*Dalbergia cochinchinensis* Pierre) IN PLANTATIONS OF THAILAND

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ABSTRACT

Currently, decreased productivity of Siamese rosewood (*Dalbergia cochinchinensis* Pierre) is a problem due to illegal logging and the guidelines to manage this prevention being may be insufficient. Forest plantations should be promoted to achieve sustainable wood production for this species. Site index (SI) is a measure that can be used to predict forest productivity to identify appropriate sites for planting Siamese rosewood. The objective of the current study was to predict the SI for Siamese rosewood in Thailand. A sample of 78 temporary plots at 26 sites in 16 provinces of Thailand was selected to construct a site index curve with a base age of 30 yr. The results showed that the mean age of Siamese rosewood was 28 yr (between 13 and 55 yr), the mean diameter at breast height (DBH) was 20.03 cm (between 7.99 and 33.80 cm), and the mean dominant height was 20.79 m (between 7.32 and 24.82 m). The SI equation was: SI = $e(\ln H_{do}-12.476(A^{-1}-A_b^{-1}))$ with an R^2 value of 0.406 at $p < 0.0001$ (chosen as 30 yr in the present study). The equation indicated that 14, 18, 22, 26, and 30 m trees belonged to site classes I, II, III, IV, and V**,** respectively. Although in natural forest, Siamese rosewood is distributed in dry evergreen and mixed deciduous forests, in the present study, several sites in areas under both in situ and ex situ conservation were in the good and very good site categories. Thus, both areas can be used to plant Siamese rosewood and increase its productivity.

Keywords: Siamese rosewood, Site index, Temporary plot

INTRODUCTION

Siamese rosewood (*Dalbergia cochinchinensis* Pierre) is generally found in the dry evergreen and mixed deciduous forests (Veesommai & Kavduengtain 2004) at elevations between 100 and 775 m above sea level (Eiadthong & Tangmitcharoen 2015). This species is native to Thailand, Cambodia, Laos, and Vietnam. Over the years, this species has been severely affected by illegal logging, due to the quality of its hardwood and high durability, leading to a gradual reduction in its numbers (Cadena 2014). It was under the "vulnerable" category and red listed as a threatened species by the International Union for Conservation of Nature (IUCN) (IUCN, 2008), leading to a high demand of its wood and high price (Forest Research and Development Bureau 2010). This has been the prime reason affecting the numbers of Siamese rosewood trees.

According to a survey by the Royal Forest Department of Thailand (2015), the price of Siamese rosewood heartwood was USD 30,000/m^3 on the black market. Such a high price provided sufficient motivation for illegal logging in both natural forest and plantations. In 2014, 1,823 $m^3$of Siamese rosewood was seized by the Thai government. The lawsuits filed for illegal logging of Siamese rosewood have increased while productivity has decreased every year in Thailand (Department of National Parks, Wildlife and Plant Conservation 2015). A similar situation exists for other threatened species with similar hardwood characteristics, such as *Dalbergia oliveri* Gamble ex Prain and *Pterocarpus macrocarpus* Kurz (Internal Security Operations Command 2014). The diminishing number of individual trees of such species is of grave concern and needs to be dealt with urgently. Plantations can play an important role in the success of reviving these species. Several economically viable species, including Siamese rosewood, have been promoted in certain areas by the Thai government. Two distinct procedures have been applied: 1), in situ conservation areas (conservation of ecosystems and natural habitats and maintenance and recovery of the population that allows the species to exist in the natural environment and in the case of domesticated or cultivated plant species in an environment in which those species have developed special properties); and 2) ex situ conservation (conservation of plant genetic resources outside the natural habitat). The current methods being used for selecting areas where this planting Siamese rosewood need to be improved and implemented in the future. (Tangmitcharoen 2013)

Site index (SI) is one of the measures used to predict forest productivity, wood volume, and the potential rate of growth (Hanson *et al.* 2002). The relationship between dominant height and age was used to construct a site index curve by Mayhew & Newton (1998). There are several techniques for determining SI such as: (1) the proportion curve or guide curve method; (2) the parameter prediction method; and (3) the different equation method (Clutter *et al*. 1983). In Thailand, the proportion curve method has been used for assessing and predicting the site quality of *Tectona grandis* L.f. (Forestry Research Center 1669) and *Eucalyptus camaldulensis* Dehnh. plantations in the lower northeastern parts (Insaun 2009) and *Acacia mangium* Willd. plantation in Trat province(Jumwong 2006). Siamese rosewood research has also focused on other dimensions such as inventory, ecology, growth and yield. The prediction of SI for Siamese rosewood is yet to be undertaken. Thus, the objective of the current research was to summarize the growth characteristics and develop a SI for Siamese rosewood found in plantations in Thailand.

MATERIALS AND METHODS

Study site and data collection

Thailand is a tropical country located between 5^0 37" N and $20^0$27" N latitude and 97° 22" E and 105° 37" E longitude. The annual rainfall ranges between 1,200 and 1600 mm and the mean annual rainfall is 1,587 mm. The mean annual temperature is around 27^0 C (Thai Meteorological Department 2014). The study was conducted in Siamese rosewood plantations owned by the Royal Forest Department of Thailand (RFD) and the Forest Industry Organization (FIO).

Table 1 Summary of 26 Siamese Rosewood study sites in Thailand used in the study.

No	Plantation	Province	Region	Code	latitude	longitude
1	Kam Phaeng Phet Silvicultural Research Station	Kamphaengphet	N	KPP1	16° 33’	99° 30’
2	Kam Phaeng Phet Silvicultural Research Station	Kamphaengphet	N	KPP2	16° 34’	99° 30’
3	Kam Phaeng Phet Silvicultural Research Station	Kamphaengphet	N	KPP3	16° 33’	99° 30’
4	Phit Sa Nu Lok Silvicultural Research Station	Phitsanulok	N	PNL	16° 50’	100° 53’
5	In Tha Khin Silvicultural Research Station	Chiangmai	N	ITK	19° 9’	98° 56’
6	Tha Tum Silvicultural Research Station	Surin	NE	TT	15° 18’	103° 45’
7	Nong Khu Silvicultural Research Station	Surin	NE	NK	14° 41’	103° 45’
8	Huai Tha Silvicultural Research Station	Sisaket	NE	HT1	14° 52’	104° 26’
9	Huai Tha Silvicultural Research Station	Sisaket	NE	HT2	14° 52’	104° 26’
10	Pha Nok Khao Silvicultural Research Station	Khon Kaen	NE	PNK	16° 50’	101° 56’
11	Loei Forestry and Forest Products Research Center	Loei	NE	LOEI	16° 52’	101° 56’
12	Udon Tha Ni Forest Nursery Center	Udon Thani	NE	UD	16° 50’	102° 56’
13	Mu Si Silvicultural Research Station	Nakhon Ratchasima	NE	MS1	14° 30’	101° 25’
14	Mu Si Silvicultural Research Station	Nakhon Ratchasima	NE	MS2	14° 30’	101° 25’
15	Ka La Sin Silvicultural Research Station	Kalasin	NE	KLS	16° 28’	103° 24’
16	Dong LanSilvicultural Research Station	Khon Kaen	NE	DL	16° 49’	101° 59’
17	Huai Rang Plantation	Trat	E	HR	12° 26’	102° 33’
18	Tha Kum Noboru Umeda Plantation	Trat	E	TK1	12° 22’	102° 40’
19	Tha Kum Noboru Umeda Plantation	Trat	E	TK2	12° 23’	102° 39’
20	Tha Kum Noboru Umeda Plantation	Trat	E	TK3	12° 23’	102° 39’
21	Rat Cha Bu Ri Silvicultural Research Station	Ratchaburi	C	RBR	13° 34’	99° 44’
22	Central Silvicultural Research center	Kanchanaburi	C	PK1	14° 24’	98° 55’
23	Central Silvicultural Research center	Kanchanaburi	C	PK2	14° 24’	98° 55’
24	Thong Pha Phum Silvicultural Research Station	Kanchanaburi	C	TPP	14° 42’	98° 39’
25	Southern Silvicultural Research center	Songkhla	S	PT	7° 1’	100° 17’
26	Sai Thong Silvicultural Research Station	Prachuap Khiri Khan	S	ST	10° 59’	99° 27’

Note: Regions as identified by the Thai Meteorological Department are: “N” is north, “NE” is northeast, “E” is east, “C” is central, and “S” is south.

Twenty-six sites were selected from16 provinces distributed throughout Thailand (Table 1 and Figure 1). Three temporary sample plots were selected per site (78 temporary sample plots in total). Each temporary plot was 0.16 ha in size and the diameter at breast height over bark (DBH) at 1.30 m above ground and total height (H), of all trees in the plot, were measured. Meteorological data from the Thai Meteorological Department for the sample sites are shown in Table 2.

Table 2 Meteorological data for the study sites.

No.	Station name	Average temperature (°C)	Average relative humidity (%)	Rainfall (mm/yr)	Study sites
1	Phitsanulok	28.1	74.2	1399	PNL
2	Kamphaengphet	28.5	76.8	1372	KPP1,KKP2,KKP3
3	Chiangmai	27.2	71.3	1158	ITK
4	Pakchong Agromet	26.4	73.3	1206	MS1,MS2
5	Thatom	27.9	74.1	1313	TT
6	Surin	27.7	72.4	1454	NK
7	Sisaket Agromet	27.7	74.8	1420	HT1,HT2
8	Loei	26.9	73.2	1310	Loei
9	Kalasin	27.2	72.0	1340	KLS
10	Khon Kaen	27.7	70.4	1196	PNK,DL
11	Udonthani	27.5	71.1	1338	UD
12	Trat	27.9	81.4	4988	HR,TK1,TK2,TK3
13	Ratchaburi	28.6	78.1	1067	RBR
14	Kanchanaburi	29.0	70.4	1104	PK1,PK2
15	Thong Phaphum	28.1	78.5	1827	TPP
16	Prachuap Khiri Khan	28.8	76.3	1056	ST
17	Hatyai	28.3	79.4	1793	PT

Determination of SI equation

The height of the tree is important in the creation of the SI but the mean height of a stand is usually sensitive to age, site, class and stand density. Thus, the dominant height is normally used to represent a stand and specifically mean height of the 100 tallest trees/ha is most widely used to construct an SI (Alder 1980). In this case, the SI equation was constructed using the top 16 tallest trees per plot (plot size of 0.16 ha). There are several techniques for determining the SI. However, the current study only had access to data derived from temporary plots and consequently, the guide curve method was used (Alder1980) based on equation (1) and the SI equation was constructed using equation (2).

$$\ln(H_{do}) = \text{In}b_0+b_1A^{-k} \quad \text{......(1)},$$

$$SI = e(\ln(H_{do})+ b_1 (A^{-1}-A_b^{-1})) \quad \text{......(2)},$$

where H_{do} is the dominant height, ln is the natural logarithm, b_0 and b_1 are regression coefficients, A is the stand age, k = 1, SI is the site index, e is the natural exponent, and A_b is the base age (chosen as 30 yr in the present study).

Based on equation 2, 5 site classes were used (I, II, III, IV, and V) indicating very poor, poor, moderate, good, and very good sites, respectively. The upper and lower bounds for each SI class were determined using simple interpolation and extrapolation in the Excel software package (Microsoft Corp.; Redmond, CA, USA).

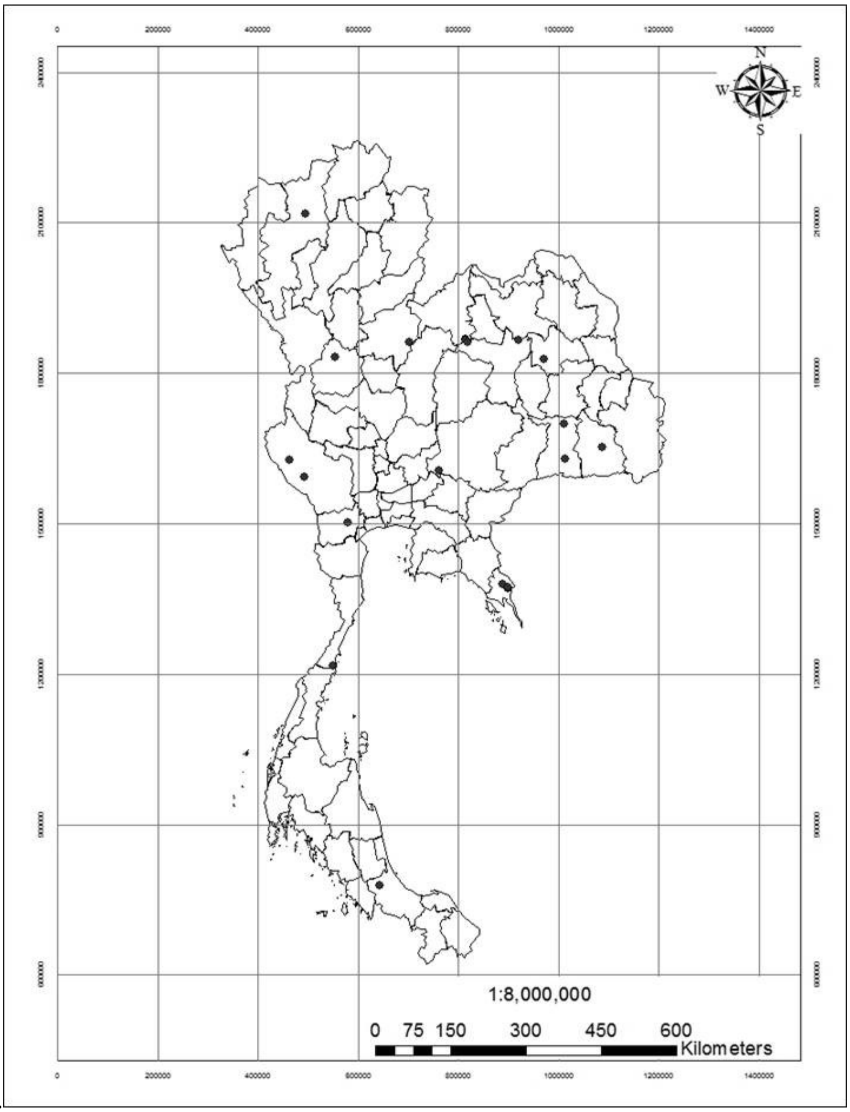

Figure 1. Location of Siamese rosewood study sites in Thailand.

RESULTS AND DISCUSSION

The growth characteristics of Siamese rosewood, as determined from 26 sites, are presented in Table 3. The mean age was 28 yr (between 13 and 55 years), mean DBH was 20.03 cm (between 7.99 and 33.80 cm), mean H was 16.48 m (ranging between 6.18 and 23.20 m), and the mean H_{do} was 20.79 m (ranging between 7.32 and 24.82 m). The mean DBH, H and H_{do} of the TT plantation were lowest (see Table 1 for identification of the plantation abbreviations used). Both the highest mean DBH and mean H were in the KLS plantation and the highest mean of H_{do} was in the PNL plantation. The stand mean dominant heights for KLS and PNL were similar (24.18 and 24.82 m, respectively) despite their stand ages being rather different (42 and 27 years, respectively). This could be interpreted as the younger stand age alone indicating site suitability which is not necessarily correct. Thus, the methodology for assessing the appropriate site using the site index had to decrease the bias associated with the different-aged stands.

The SI equation for Siamese rosewood obtained using the proportional curve method at a base age of 30 yr was $SI = e(\ln H_{do} - 12.476(A^{-1} - A_b^{-1}))$ with an R^2 value of 0.406 and $p < 0.0001$. Five stratification levels were used based on site classes I through V for H values of 14, 18, 22, 26, and 30 m, respectively. Figure 2 shows that a 30 year old Siamese rosewood tree with a dominant height of 22 m belonged to site class III. This stand was predicted as a moderate site for planting. Likewise, we also determined the best site planting (class V) for which trees had to be 30 m tall at age 30 yr. In contrast, trees on poorer sites (site I) were only 14 m tall at age 30 yr.

Table 3. Growth characteristics of Siamese rosewood in plantations located at 26 sites in Thailand.

No	Site code	Age (yr)	DBH ± SD (cm)	H ± SD (m)	H_{do} ± SD (m)
1	TT	13	7.99 ± 3.94	6.18 ± 2.65	7.32 ± 2.22
2	RBR	22	23.42 ± 7.48	14.06 ± 3.30	14.55 ± 3.00
3	NK	25	13.23 ± 5.66	10.78 ± 3.85	16.03 ± 2.40
4	HT1	25	18.38 ± 6.06	14.58 ± 3.56	17.55 ± 1.49
5	HT2	25	21.02 ± 8.27	16.64 ± 4.13	17.43 ± 3.03
6	PNK	54	31.59 ± 7.16	22.64 ± 4.83	22.92 ± 4.70
7	LOEI	55	18.34 ± 6.07	17.42 ± 4.68	22.14 ± 2.43
8	UD	20	14.18 ± 5.73	13.82 ± 4.95	17.50 ± 4.13
9	KPP1	23	18.43 ± 7.30	16.72 ± 3.93	20.62 ± 1.90
10	MS1	28	21.15 ± 6.15	16.74 ± 3.18	20.02 ± 1.16
11	MS2	28	15.41 ± 6.29	13.96 ± 4.63	20.72 ± 2.38
12	HR	30	20.49 ± 7.92	16.21 ± 5.57	22.72 ± 2.61
13	TK1	32	25.06 ± 10.62	17.58 ± 6.16	23.53 ± 2.52
14	TK2	35	22.21 ± 8.48	15.82 ± 5.36	22.04 ± 1.74
15	TK3	36	25.40 ± 9.18	15.09 ± 5.25	21.38 ± 2.01
16	KLS	42	33.80 ± 9.92	23.20 ± 5.02	24.18 ± 4.94
17	PK2	18	18.39 ± 7.17	15.69 ± 4.64	20.71 ± 1.74
18	PK1	21	16.99 ± 7.65	15.09 ± 4.98	20.72 ± 1.53
19	KPP2	23	21.11 ± 7.07	19.47 ± 5.13	23.86 ± 2.38
20	KPP3	23	20.65 ± 9.55	17.54 ± 6.68	24.35 ± 1.96
21	PT	26	20.29 ± 8.14	18.24 ± 5.45	23.08 ± 0.90
22	PNL	27	15.97 ± 6.83	17.93 ± 5.45	24.82 ± 1.22
23	TPP	27	25.55 ± 11.14	20.01 ± 5.26	24.30 ± 1.28
24	ST	28	19.18 ± 7.67	19.64 ± 4.62	24.42 ± 1.15
25	DL	16	16.66 ± 5.68	16.06 ± 3.42	19.89 ± 1.92
26	ITK	20	15.85 ± 6.89	17.30 ± 5.16	23.60 ± 2.16

The number of study sites in the classifications were 1, 6, 9, 8, and 2 for SI classes I, II, III, IV, and V, respectively (Table 3). The lower and upper bounds of a very poor site class were 12.00 and 15.99 m, respectively, thus, the TT plantation was in this category. On the other hand, the lower and upper bounds of a very good site were 28.00 and 32.00m, respectively, and the DL and ITK plantations were in this category. In this study, most of the measured sites were in either the moderate or good site classes. Even though the growth rate based on DBH, H, and H_{do} of KLS and PNL were satisfactory, the results showed that DL and ITK were very good sites for Siamese rosewood compared at the base age of 30 years.

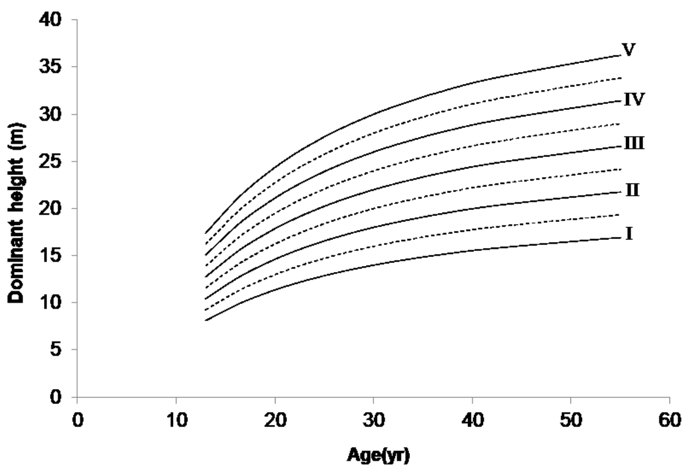

Figure 2. SI curves for Siamese rosewood in Thailand, where the dotted lines indicate the upper and lower bounds for each class based on simple interpolation/extrapolation.

Table 3 Site class, SI, and bounds at base age 30 yr of Siamese rosewood in Thailand, where the last column indicates the class according to site quality.

Site class	SI	Number of study sites	Lower limit (m)	Upper limit (m)	Site Code
I (very poor)	14	1	12.00	15.99	TT
II (poor)	18	6	16.00	19.99	RBR, NK, HT1, HT2, PNK, LOEI
III (moderate)	22	9	20.00	23.99	UD, KPP1, MS1, MS2, HR, TK1, TK2, TK3, KLS
IV (good)	26	8	24.00	27.99	PK2, PK1, KPP2, KPP3, PT, PNL, TPP, ST
V (very good)	30	2	28.00	32.00	DL, ITK

Kliangpibool (2012) reported the suitable age for Siamese rosewood logs was between 18 and 25 yr at the price was USD 530 to 1,000/ha. However, the valuation of Siamese rosewood does not depend only on the quantity as the economic valuation of hardwood is important too. Kuasakun (2017) determined that the heartwood percentage of Siamese rosewood at the Mu Si Silvicultural Research Station (MS) was 68.30% while the SI for MS1 and MS2 were moderate site. In contrast, the heartwood percentage of Siamese rosewood at In Tha Kin Silvicultural Research Station (ITK) was 21.97 while the SI of ITK in the present study indicated it was a very good site; nevertheless, the increasing heartwood should result with increasing age as well (Visaratana, 2016)

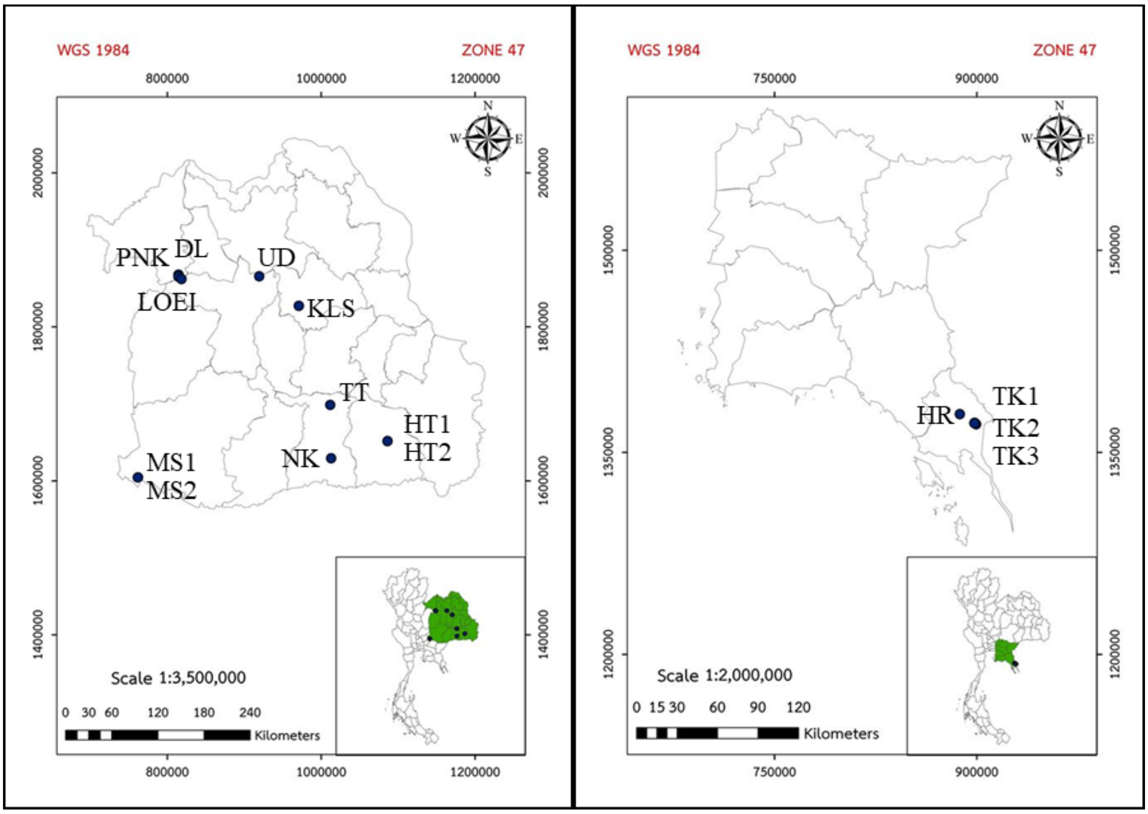

Figure 3. In situ study sites of Siamese rosewood in northeastern and eastern Thailand

The natural distribution of Siamese rosewood is in the dry evergreen and mixed deciduous forests where located northeastern and eastern Thailand (Figure 3). Both regions have in situ conservation areas in which were located the study sites HR, TK1, TK2, and TK3 in the eastern, and TT, NK, HT1, HT2, PNK, LOEI, UD, MS1, MS2, KLS, and DL in the northeastern regions. Several sites in the in-situ conservation areas were not as appropriate as plantation sites as in the ex-situ conservation areas. The better ex situ sites were PK1, PK2, KPP1, KPP2, PT, PNL, TPP, ST, and ITK and were determined to be in the good and very good site classes (IV and V, see Figure 4).

Suanpaga & Boonyuan (2016) compared the growth of eight appropriate tree species for planting in the Songkhla province, southern Thailand (an ex-situ conservation area for Siamese rosewood). Based on their results, they recommended Siamese rosewood and three other species (*Dipterocarpus alatus* Roxb, *Xylia xylocarpa* (*Roxb*.) Taub. var. kerrii (Craib & Hutch.) I. C. Nielsen, and *Azadirachta excelsa* (Jack) Jacobs).

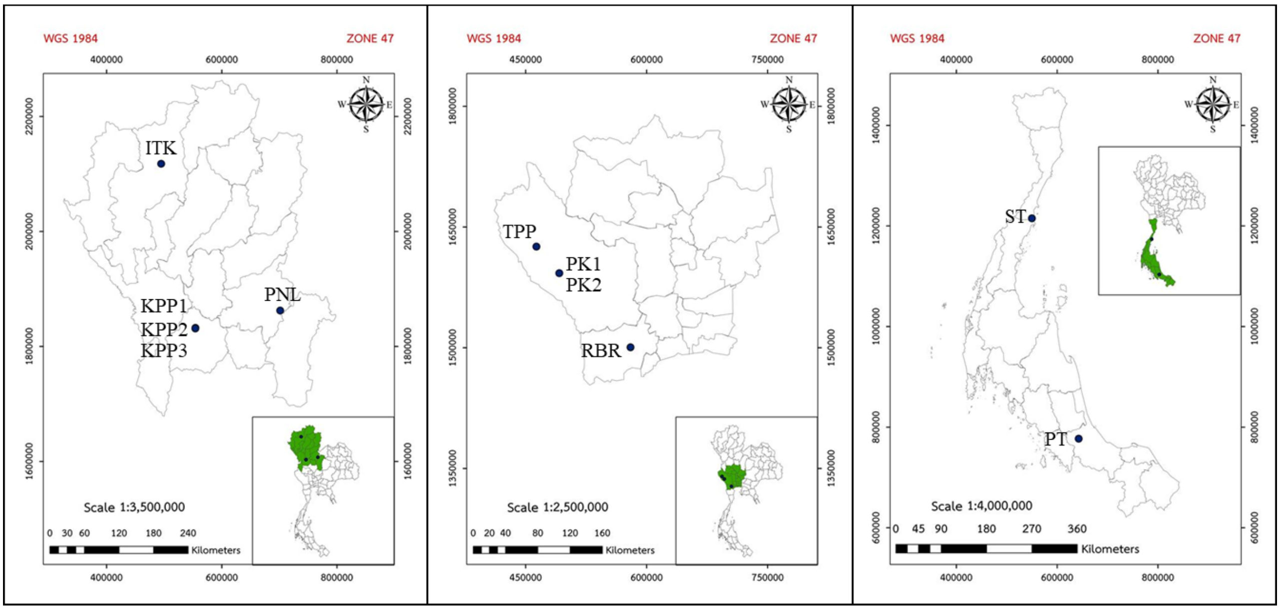

Figure 4. Ex situ study site of Siamese rosewood in northern, central, and southern Thailand

Illegal logging has continued (Sudsakorn 2012) and so plans to increase sustainable productivity need to consider prevention and promotion. Chaipunya (2016) considered three aspects to maintain sustainable production from current stands: preventing illegal rosewood logging, preventing transportation, and preventing export of logs or wood products. In addition, Vissaratana et al. (2016) presented a case to promote both forest management and silvicultural techniques via plantations located on good sites to provide increasing productivity and economic value. Siamese rosewood can fix nitrogen through *Rhizobium* bacteria that can increase the health of ecological systems by fixing nutrients for use also by other species (Mungklarat 2001) and to improve soil fertility for reforestation purposes (So 2010). With regard to the current study, several sites in the ex-situ conservation area belonged to either the good or very good site classes. Thus, both ex-situ and in-situ conservation areas can be used for plantation purposes to increase productivity.

CONCLUSION

A site index curve and equation are necessities for Thailand forestry to support Siamese rosewood plantations dating back more than 50 yr; however, extensive research commenced only recently. As a result, knowledge is still lacking of the site requirements for plantations of this species. Based on the growth characteristic of Siamese rosewood at 26 sites, five SI classes were constructed with most sites in the moderate site class. The SI equation developed in this study can be applied to help avoid planting of Siamese rosewood on inappropriate low quality sites and place more emphasis on identifying higher quality sites for plantation establishment. Several sites in the ex-situ conservation area belonged either to the good or very good site classes. Thus, both ex-situ and in-situ conservation areas can be used for plantation purposes to increase productivity.

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