

THE EFFECT OF LEUCAENA ON NATIVE SPECIES OF MIXED DECIDUOUS FOREST FRAGMENTS IN NORTHEASTERN THAILAND

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Abstract

Leucaena (*Leucaena leucocephala* (Lam.) de Wit.), a leguminous invasive exotic plant is often present in tropical fragmented forests. This study was conducted in the green area of Suranaree University of Technology (SUT) in Northeastern Thailand to evaluate the relationship between *Leucaena* abundance and native plant species (tree and climber) diversity. Species data of the entire line transects were ranked according to Importance Value Index (IVI) to describe overall species distribution within fragments for trees, saplings, and seedlings separately. Random 80 m segments of nine line transects were selected within 9 selected forest fragments to record species diversity and abundance in a standardized manner. Generalized linear mixed model (GLMM) comparisons among the Shannon diversity index and species richness (as native species diversity variables) were modeled dependent upon *Leucaena* stem density and propagule pressure (as *Leucaena* abundance variables). The cluster diagram of similarity between species abundance and comparison of Sorenson similarity index (β diversity among fragments) did not reveal a significant relationship between native species diversity and *Leucaena* abundance based on fragments. Rank abundance curves showed establishment of secondary native species under the *Leucaena* dominant canopy. As the result of IVI ranking, same six native species were at the top in tree, sapling, and seedling stages. Thus, at SUT *Leucaena* may be acting as nurse crop (or even a pioneer species) in severely disturbed mixed deciduous forest fragments.

Keywords: Diversity index, forest fragments, invasive plants, *Leucaena leucocephala*

Introduction

In Thailand, forest fragmentation has resulted from population expansion over the last three decades (Fox *et al.*, 1995) which has resulted in biodiversity reduction (Pattanaibool and Dearden, 2002). Trisurat *et al.* (2010) predicted that the highest deforestation was expected to occur in the southernmost regions of northern Thailand. *Leucaena* (*Leucaena leucocephala* (Lam.) de Wit.),

is a leguminous tree, native to Central America with strong resistance to dry and poor soil conditions (Kuo, 2003), thus it has been categorized as one of the 100 most harmful invasive species globally (Lowe *et al.*, 2000). Natural forest ecosystems are negatively and positively affected by exotic invasive species but not properly understood (Stinson *et al.*, 2006). Exotic invasive species adversely affect to

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the native tree species diversity while altering species composition (Siderhurst *et al.*, 2012). Furthermore, exotic invasive species are vastly influenced by altering soil chemical properties via bulky biomass accumulation (Kamo *et al.*, 2008). Marod *et al.* (2012) found that *Leucaena* restricting natural forest regeneration by its invasive growing habit which reduces light transmittance to the forest floor. But several studies were revealed that *Leucaena* passively facilitated regeneration of native dry forest plant species (Costa and Durigan, 2010; Bai *et al.*, 2015) and with control measures (Francis and Parrotta, 2006; Gong and Tang, 2016) in highly disturbed landscapes.

Leucaena was introduced for reforestation purposes in Thailand due to its tolerance to withstand strong seasonal climate shifts (Yige *et al.*, 2012) in areas with degraded sub-tropical dry forests (Peter *et al.*, 2003). Suranaree University of Technology (SUT) is in Nakhon Ratchasima Province, Northeastern Thailand and was established July 27, 1990. 1,120 hectares of degraded mixed deciduous forest area (Lamotte *et al.*, 1998) of the Huay Ban Yang Reservoir was allocated to the establishment (<http://web.sut.ac.th/>) and in 2018, Google Earth Pro images (Imagery date: 11.16.2016) showed 34% of the area was covered by 26 secondary forest fragments that could have regrown as a result of limited anthropogenic activities for nearly 25 years since establishment of the University (Figure 1). The campus has 383 plant species including one species of cycad, 308 dicot species and 74 monocot species (Wara-Aswapati *et al.*, 2001).

Almost of the fragments already had been severely disturbed by agricultural activities thus, invaded by exotic invasive species *Leucaena* to varying degrees. Our study aimed to investigate the effects of *Leucaena* on the native plant community. We hypothesized that high abundance and diversity

of native species would be resulted in lower abundance of *Leucaena* and low abundance and diversity of native species would be the result of high abundance of *Leucaena* between fragments.

Materials and Methods

Study Site

Field research was conducted in 9 forest fragments within Suranaree University of Technology (SUT) campus (14° 52' 22.5" N, 102° 1' 25.32" E, 252 - 233 m above sea level) located at Muang District, in Nakhon Ratchasima Province of Northeastern Thailand (Figure 1). The area is mostly flat terrain. SUT satellite images (dated: 11.16.2016) from Google Earth pro were used to determine areas and perimeter of the existing forest fragments. Arc Map (10.3) and field inspections were then used to determine fragment boundaries, prior to evaluating the *Leucaena* distribution (Figure 1).

Among 26 fragments within SUT premises, 9 fragments (named as A to I) were selected mainly based on anthropogenic activities, proximity and area. Fragments with less ongoing anthropogenic activities (ex: garbage and landfill dumping) and at least distance of 100 m from each other were considered to avoid spatial autocorrelation among the community variables (Legendre, 1993). Area of the fragments were also concerned which varied from smallest (2.4 ha) to largest (36.97 ha).

One transect per each fragment was selected according to Kaiser (1983) the widest distance from south to north (north faced). The UTM coordinates of the south end of each line transect varied between 80 to 627 m in length were loaded to GPS navigator (Gramin GPSmap64s) using Arc Map (ESRI, 2011) and demarcated at the edge of each fragment (Table 1). Based on the shortest transect length of 80m at fragment I among 9 fragments, 80 m segments of other 8 fragments were randomly selected according to generate random numbers using function of R statistical software (R Core Team, 2017) (Table 1).

Data Collection

From 2017.07.04 to 2017.09.06, direction to north from south, totally 2.38 km length of line transects were measured which length varies between 80 to 627 m, shown in Table 1 (Wheater *et al.*, 2011), woody plants (excluding herbs and palms) were counted and identified to the lowest possible taxonomic level (usually species). Diameter at breast height (DBH) was measured and recorded within three distinct categories: 1) trees - DBH greater than or equal to 4.5 cm and total height over or equal to 1.3 m; 2) saplings - DBH between 1-4.4 cm and total height over or equal to 1.3 m; and 3)



Figure 1. Map of SUT and forest fragments within the SUT premises, select fragments (yellow outline) and line transects along widest distance (red line). (Source: Google maps (2017) and modified from Arc Map)

Table 1. Total transect lengths with randomly selected segments (random number in bolded) based on smallest length of 80 m in fragment I, universal transverse Mercator (UTM) coordinates of the (X and Y axis) south end of line transects

Fragment	Area (ha)	Perimeter (m)	Total length of transect (m)	Randomly selected 80 m transect segment	UTS coordinates of line transect	
					Point X	Point Y
A	2.40	691.77	160	100-160, 0-20	179,877.342	1,646,869.495
B	17.91	3,155.62	270	210-270, 0-10	178,604.530	1,647,573.867
C	36.97	3,752.18	627	420-500	180,167.741	1,645,692.452
D	15.82	2,659.87	306	190-270	178,731.193	1,647,101.196
E	5.11	1,006.25	178	40-120	178,731.618	1,647,101.274
F	2.40	666.00	140	120-140, 0-60	179,605.479	1,646,931.282
G	6.43	1,421.58	180	120-180, 0-20	178,885.661	1,648,225.720
H	12.40	1,453.79	440	30-110	179,146.850	1,647,326.400
I	2.75	776.99	80	0-80	179,101.915	1,647,394.684

Table 2. Comparison of fixed effects in generalized linear mixed models (GLMM) based on likelihood ratio test, using the ANOVA function. Full model with fixed effect with null model that lack of fixed effect and fragment as the random effect. Best fitted model was bolded

Model	Rank	DF	AIC	Δ AIC	LogLik	Deviance
sha_ind ~ 1 (Null)	1	3	96.465	0.00	-45.232	90.465
sha_ind ~ prop_pre	2	4	98.229	1.584	-45.115	90.229
sha_ind ~ leu_stden	3	4	98.464	1.999	-45.232	90.464
sp_rich ~ 1 (Null)	1	3	240.95	0.00	-117.47	234.95
sp_rich ~ leu_stden	2	4	242.54	1.59	-117.27	234.54
sp_rich ~ prop_pre	3	4	242.77	1.82	-117.39	234.77

seedlings - DBH less than 1 cm and height over 15 cm (Marod *et al.*, 2012). At least one herbarium specimen was collected per species per transect for validation purposes and species identification by the specialist.

S Statistical Analyses

To describe overall species composition, distribution and occurrence of SUT forest fragments; species data of entire 2.38 km line transects were ranked according to Importance Value Index (IVI) based on weightage of the use of frequency, density and abundance (Bhadra and Pattanayak, 2016; Dash *et al.*, 2020) for seedlings, saplings and trees separately. Randomly selected 80m line transects segment species data were used to statistical analysis to test hypothesis.

Species data of nine 80m segments were used to statistical analysis. Shannon Wiener Diversity Index, Sorenson similarity index (β diversity), native species abundance and evenness were considered as representatives of native species composition. Leucaena stem density and propagule pressure (individuals above 2.5 cm DBH) were selected as measures of the invasive species abundance and density. Box plots for Leucaena density and native species diversity were used to visualize and overview of the data distribution among fragments (Ferreira *et al.*, 2016). To evaluate the relationship between Leucaena abundance and

native species diversity, the mean values of each variable were applied in generalized linear mixed models (GLMM, lme4 package). Shannon Wiener Diversity Index and species richness were used as dependent variables; Leucaena stem density and Leucaena propagule pressure as fixed effects while fragments as a random effect (Bates *et al.*, 2015). Each full model was compared with null model that lack the fixed effects using likelihood ratio test of the Anova function (Faraway, 2005) and the best-fit model was determined based on smallest Δ AIC value. Rank abundance curves were constructed with and without Leucaena to compare species evenness and abundance (Vegan package) and Sorenson similarity indexes between seedlings, saplings and trees to evaluate differences among β diversity between fragments (vegdist package: Jurasinski *et al.*, 2009). Cluster diagrams of similarity between species abundance from the 9 fragments based on Ward's average distance method (hclust package) (Oksanen, 2015) was also used to determine correlation between Leucaena stem density and native species abundance of each fragment. Box plots were used to visualize the relationship of Leucaena stem diversity and Leucaena propagule pressure with Shannon Index, and species richness of 9 fragments (ggplot2 package). R statistical software version 3.0.2 was used for analysis and significance level was set at $\alpha < 0.05$.

Table 3. Comparison of *Leucaena* stem density (%) (brackets) and Sorenson similarity indexes (B diversity) between seedlings, saplings and trees (1st, 2nd and 3rd lines of each row) of the 9 fragments (A to I) as the equation of $(A+B-2*J)/(A+B)$, where A, B= number of species in site A and site B, respectively, and J = number of shared species (Oksanen, 2015) Values > 0.6 are bolded

	A (0.00)	B (39.05)	C (43.01)	D (88.46)	E (98.43)	F (100.00)	G (70.49)	H (67.73)
B (39.05)	0.67 1.00 1.00							
C (43.01)	0.87 0.67 1.00	0.78 0.50 1.00						
D (88.46)	0.60 0.60 1.00	0.57 0.71 1.00	0.64 0.43 1.00					
E (98.43)	0.53 1.00 1.00	0.64 0.60 1.00	0.75 0.60 1.00	0.69 0.50 0.33				
F (100.00)	0.68 1.00 1.00	0.69 0.60 1.00	0.60 0.60 1.00	0.60 0.50 0.00	0.67 0.00 0.33			
G (70.49)	0.56 1.00 1.00	0.50 0.78 1.00	0.78 0.78 1.00	0.43 0.50 0.33	0.45 0.67 0.50	0.69 0.67 0.33		
H (67.73)	0.50 1.00 1.00	0.43 0.56 1.00	0.82 0.56 1.00	0.63 0.75 0.50	0.69 0.66 0.60	0.73 0.66 0.50	0.57 0.80 0.60	
I (72.61)	0.75 1.00 1.00	0.60 0.67 1.00	0.43 0.67 1.00	0.50 0.60 0.00	0.78 0.33 0.33	0.45 0.33 0.00	0.60 0.71 0.33	0.67 0.71 0.50

Table 4. List of trees (DBH ≥ 4.5 cm and total height ≤ 1.3 m) found in SUT fragments from line transects in species name with IVI values. *Leucaena leucocephala* (Lam.) de Wit was bolded

No	Species name	IVI
1	<i>Leucaena leucocephala</i> (Lam.) de Wit	107.01
2	<i>Bauhinia saccocalyx</i> Pierre	29.88
3	<i>Maerua siamensis</i> (Kurz) Pax	21.01
4	<i>Combretum quadrangulare</i> Kurz	16.44
5	<i>Diospyros rhodocalyx</i> Kurz	15.33
6	<i>Sindora siamensis</i> Teijsm. ex Miq.	11.55
7	<i>Azadirachta indica</i> A.Juss.	9.66
8	<i>Colona auriculata</i> Craib	8.93
9	<i>Ziziphus cambodiana</i> Pierre	8.93
10	<i>Ziziphus oenoplia</i> (L.) Mill.	8.93
11	<i>Albizia lebbek</i> (L.) Benth.	5.93
12	<i>Anthocephalus chinensis</i> Hassk.	5.93
13	<i>Dalbergia nigrescens</i> Kurz	5.93
14	<i>Hymenopyramis brachiata</i> Wall. ex Griff.	5.93
15	<i>Lannea coromandelica</i> (Houtt.) Merr.	5.93
16	<i>Morinda tomentosa</i> B.Heyne ex Roth	5.93
17	<i>Olax psittacorum</i> Vahl	5.93
18	<i>Tamarindus indica</i> L.	5.93
19	<i>Xylia xylocarpa</i> (Roxb.) Taub.	5.93

Results

From 2.38 km line transects data, 1,370 individuals including 126 trees, 270 saplings, and 974 seedlings of 46 taxa and 24 families were identified and ranked based on IVI values for tree, sapling, and seedling (Tables 4, 5, and 6). Exclude *Leucaena*, same six native species were at the top in tree, sapling and seedling categories (*Bauhinia saccocalyx*, *Maerua siamensis*, *Combretum quadrangulare*, *Diospyros rhodocalyx*, *Sindora siamensis* and *Azadirachta indica*), 78.6% species were common

between saplings and seedlings while 50% between trees and saplings.

Box plots of *Leucaena* density (*Leucaena* stem density and propagule pressure) against native species diversity (Shannon Index and species richness) clearly visualized the skewed data distribution pattern among fragments (Figure 2). According to the GLMM results which were compared native species diversity (represented by Shannon Index and species richness as dependent variables) against *Leucaena* abundance (represented by *Leucaena* stem density and propagule pressure as fixed effects) and fragments as a random effect for

Table 5. List of saplings (DBH between 1-4.4 cm and total height ≥ 1.3 m) found in SUT fragments from line transects in species name with IVI values. *Leucaena leucocephala* (Lam.) de Wit was bolded

No	Species name	IVI
1	<i>Leucaena leucocephala</i> (Lam.) de Wit	97.48
2	<i>Ziziphus oenoplia</i> (L.) Mill.	20.54
3	<i>Oxalys psittacorum</i> Vahl	15.03
4	<i>Diospyros rhodocalyx</i> Kurz	14.48
5	<i>Azadirachta indica</i> A.Juss.	14.22
6	<i>Maerua siamensis</i> (Kurz) Pax	13.41
7	<i>Bauhinia saccocalyx</i> Pierre	12.59
8	<i>Carissa spinarum</i> L.	10.33
9	<i>Dalbergia nigrescens</i> Kurz	6.90
10	<i>Harrisonia perforate</i> (Blanco) Merr.	6.90
11	<i>Hymenopyramis brachiata</i> Wall. ex Griff.	6.90
12	<i>Pterocarpus macrocarpus</i> Kurz	6.90
13	<i>Bridelia glauca</i> Blume	6.63
14	<i>Combretum quadrangulare</i> Kurz	6.63
15	<i>Colona auriculata</i> Craib	5.19
16	<i>Azalia xylocarpa</i> (Kurz) Craib	3.47
17	<i>Albizia lebbekoides</i> (DC.) Benth.	3.47
18	<i>Buchanania lanzan</i> Spreng.	3.47
19	<i>Caesalpinia godefroyana</i> Kuntze	3.47
20	<i>Cratogeomys cochinchinense</i> (Lour.) Blume	3.47
21	<i>Flacourtia indica</i> (Burm.f.) Merr.	3.47
22	<i>Litsea glutinosa</i> (Lour.) C.B.Rob.	3.47
23	<i>Microcos tomentosa</i> Sm.	3.47
24	<i>Senna garrettiana</i> (Craib) Irwin & Garneby	3.47
25	<i>Sindora siamensis</i> Teijsm. ex Miq.	3.47
26	<i>Streblus asper</i> Lour.	3.47
27	<i>Vitex glabrata</i> R.Br.	3.47

randomly selected nine 80m segments, null models without fixed effects (*Leucaena* stem density and propagule pressure) were selected as best fitted with lowest ΔAIC value (Table 2) emphasized that native species diversity was not affected by *Leucaena* abundance which was further graphically visualized by Figure 2. According to rank abundance curves of the fragments with and without *Leucaena* (Figure 3), *Leucaena* (60%) was the highly abundance species in fragments followed far below by *Sindora siamensis* (10%), *Combretum quadrangulare* (5%) and other 3 species (*Oxalys psittacorum*, *Bridelia glauca* and *Diospyros rhodocalyx*) indicated by the steep gradient but when *Leucaena* was excluded, a gradual distribution of richness and evenness was expressed by the native species. Cluster dendrogram of similarity between species abundance of 9 fragments (Figure 4) also emphasized this phenomenon. If *Leucaena* abundance has any effect, native diversity of fragments with nearly close values of *Leucaena* stem density should be at the same cluster but, fragment H, I, and G (*Leucaena* stem density 67.73%, 72.61% and 70.49%) positioned at different levels. Fragment F and E (100% and 98.43%) as well as B and C (39.05% and 43.01%) shown the same results of dissimilarities. According to Table 3, comparing combinations of fragment similarity (β diversity) of seedlings, saplings and trees, value 1.0 similarities were reported in 37.5% occasions while >0.60 similarities

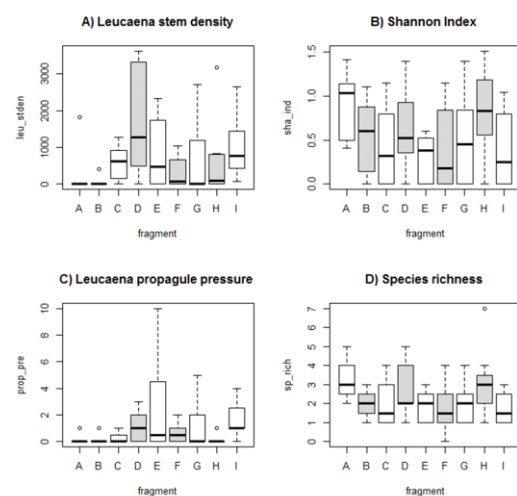


Figure 2. Box plot showing A: *Leucaena* stem diversity, B: Shannon Index, C: *Leucaena* propagule pressure, and D: species richness in 9 fragment ID (A to I). The horizontal line crossing the box in the center represents the median, the box represents the 25th and the 75th percentiles. The vertical line outside the box represents the minimum and maximum values

in 87.5% occasions between 9 fragments. 9.4% of zero similarity was in only 3 occasions (between fragment I, D, I, F, and F, E).

Table 6. List of seedlings (DBH <1 cm and height >15 cm) found in SUT fragments from line transects in species name with IVI values. *Leucaena leucocephala* (Lam.) de Wit was bolded

No	Species name	IVI
1	<i>Leucaena leucocephala</i> (Lam.) de Wit	103.94
2	<i>Combretum quadrangulare</i> Kurz	29.36
3	<i>Sindora siamensis</i> Teijsm. ex Miq.	21.19
4	<i>Bauhinia saccocalyx</i> Pierre	14.36
5	<i>Oxalys psittacorum</i> Vahl	14.00
6	<i>Ziziphus oenoplia</i> (L.) Mill.	9.79
7	<i>Diospyros rhodocalyx</i> Kurz	9.66
8	<i>Azadirachta indica</i> A.Juss.	9.21
9	<i>Bridelia glauca</i> Blume	7.77
10	<i>Dalbergia nigrescens</i> Kurz	5.35
11	<i>Caesalpinia godefroyana</i> Kuntze	5.14
12	<i>Maerua siamensis</i> (Kurz) Pax	5.00
13	<i>Harrisonia perforate</i> (Blanco) Merr.	4.23
14	<i>Carissa spinarum</i> L.	3.78
15	<i>Litsea glutinosa</i> (Lour.) C.B.Rob.	3.78
16	<i>Polyalthia cerasoides</i> (Roxb.) Benth. ex Bedd.	3.78
17	<i>Croton persimilis</i> Mull.Arg.i	3.55
18	<i>Wrightia arborea</i> (Dennst.) Mabb.	3.55
19	<i>Flacourtia indica</i> (Burm.f.) Merr.	3.32
20	<i>Senna garrettiana</i> (Craib) Irwin & Garneby	3.32
21	<i>Cratogeomys cochinchinense</i> (Lour.) Blume	2.77
22	<i>Memecylon caeruleum</i> Jack	2.77
23	<i>Microcos tomentosa</i> Sm.	2.77
24	<i>Pterocarpus macrocarpus</i> Kurz	2.77
25	<i>Albizia lebbek</i> (L.) Benth.	2.77
26	<i>Abrus precatorius</i> L.	1.99
27	<i>Millingtonia hortensis</i> L.	1.99
28	<i>Pterolobium integrum</i> Craib	1.99
29	<i>Albizia lebbekoides</i> (DC.) Benth.	1.99
30	<i>Naringi crenulata</i> (Roxb.) Nicolson	1.99
31	<i>Ochna integerrima</i> (Lour.) Merr.	1.99
32	<i>Phyllanthus reticulatus</i> Poir.	1.99
33	<i>Cansjera rheedii</i> Gmel	1.99

Discussion

There was no evidence for the impact of *Leucaena* abundance (stem density) on native species diversity based on GLMM results (Table 2 and Figure 4), cluster diagrams (Figure 4), β diversity comparisons (Table 3) and box plot visualization (Figure 2). IVI ranking results of the native species abundance of total line transects (Tables 4, 5, and 6) (Bargali *et al.*, 2011), similarities of β diversity among fragments (Table 3) and occurrence of native species in all (tree, sapling and seedling) stages (Tables 4, 5, and 6) also strengthen this argument. This could be because severely disturbed fragments had been left alone since 1990 (about 25 years) and developed as the secondary forests. Diversity and dominance measures are often unrelated in small (<5 ha) fragment sizes (Table 1) and perimeter (Tripathi and Reynald, 2010) as well as in young forest fragments (Munguia-Rosas and Montiel, 2014) and edge effect could be a major contributor to bias in our study (Wekesaa *et al.*, 2019). In small fragments, the most important driving force of species composition is thought to be light intensity and competition

for light (Montgomery and Chazdon, 2002). Similarities among fragments (instead of extent) elaborated unite in species composition within the same landscape (Laurance *et al.*, 2007). The Rank abundance curves showed that although *Leucaena* is currently dominant in SUT forests (60% of all individuals measured) (Figure 3) native species are survived underneath the *Leucaena* canopy (Yeom and Kim, 2011; Caballero and León-Cortés, 2012). In time, native species may replace *Leucaena* as the dominant species on SUT fragments especially because *Leucaena* is capable of fixing nitrogen which can improve the soil for other trees (Hogberg and Kvarnstrom, 1982). Rank abundance curves (Figure 3) showed that native species are survived underneath the *Leucaena* dominated canopy (Yeom and Kim, 2011; Caballero and León-Cortés, 2012) of SUT fragments might be the effect of nitrogen fixing capability of *Leucaena* which improve soil fertility for natives (Hogberg and Kvarnstrom, 1982). Marod *et al.* (2012) publicized that seedlings of native species could be able to germinate under *Leucaena* canopy but unable to survived up to mature individuals. But IVI value rankings revealed the same six native species are capable to be

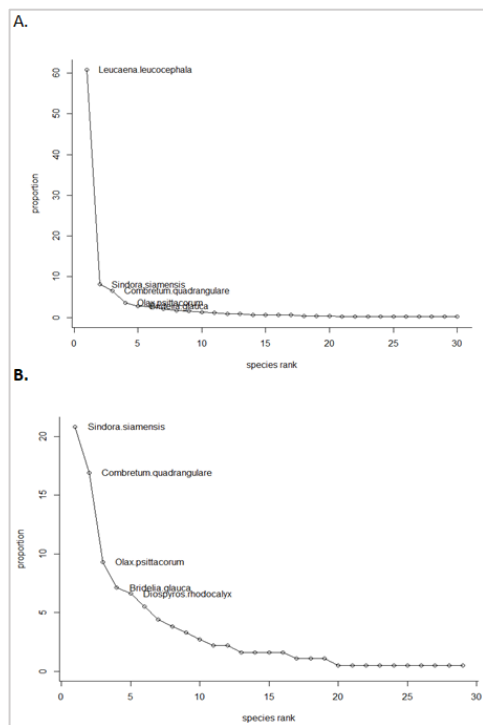


Figure 3. Rank abundance curve of the fragments with *Leucaena* (A) and without (B) shown species abundance and evenness, species rank (total no of species) in x and proportion (species abundance / total abundance) in y axis

dominated at stages of seedling sapling and tree (Tables 4, 5, and 6) which emphasized native species have a potential to survive up to a mature individuals. Thus, *Leucaena* may in fact be acting as a nurse crop (Dordel *et al.*, 2011; Balasundaran and Ali, 1987) in such highly disturbed mixed deciduous forest fragments that native species might lack the potential to properly establish without soil reclamation (Badayos *et al.*, 2017). Instead of a hindrance, perhaps *Leucaena* is facilitating forest restoration in highly disturbed landscapes (Francis and Parrotta, 2006; Costa and Durigan, 2010; Bai *et al.*, 2015; Gong and Tang, 2016).

Conclusions

This paper demonstrates in young, small forested areas, *Leucaena* abundance does not dramatically impact the diversity and abundance of native species. However, as this paper did not evaluate virgin forest for comparison, we can only make stipulations based on the locality at-hand.

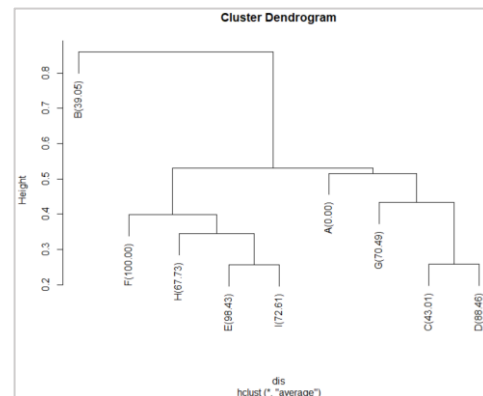


Figure 4. Cluster diagram of similarity between species abundance of 9 fragments based on Ward's average distance method. Correlation between dissimilarities and similarities = 0.92 and, *Leucaena* stem density of each fragment is displayed in brackets

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