The Influences of an Invasive Plant Species (*Leucaena leucocephala*) on Tree Regeneration in Khao Phuluang Forest, Northeastern Thailand

Dokrak Marod [1, 2*], Prateep Duengkae[1], Utis Kutintara[1], Sarawood Sungkaew[1], Chongrak Wachrinrat [2], Lamthai Asanok[3] and Narongchai Klomwattanakul[4]

ABSTRACT

The influence of Leucaena (*Leucaena leucocephala*) on tree regeneration was studied in a natural forest in the Khao Phuluang Ecotourism Development Project, northeastern Thailand. In total, three belt transects of 10×150 m were established perpendicular to the edge of the remnant forest (RF) and Leucaena plantation (LP) to study the changes in vegetation structure and species composition along a gradient from the RF into the adjacent LP. The vegetation transect census recorded the living numbers of seedlings, saplings and trees, excluding lianas, and the stem diameter and height were measured for saplings and trees. Light and soil conditions were also investigated.

The results showed that the species composition in the LP was very low and only 16 species of 16 genera in 11 families were found. Leucaena had a high stem density and basal area cover of 1,196.7 stems.ha^{-1} and 13.92 m^2.ha^{-1}, respectively. The high density created a closed canopy which reduced the relative light intensity measured as mean $\pm$ SD on the floor ($18.5 \pm 5.5\%$) which was similar to that of the RF ($15.56 \pm 2.8\%$). The distribution of the diameter at breast height of Leucaena fitted a negative exponential growth curve function ($r^2 = 0.94$), indicating the species had successful natural regeneration which was not only from seedlings but also from coppiced stems. The natural regeneration of native species from the RF towards the LP was highly significantly (ANOVA, $P < 0.001$) different for both the stem density and species number. The stem densities of trees, saplings and seedlings of native species were greater in the RF than in the LP. In addition, not only the native climax species but also pioneer species had less success in establishment in the LP. This would suggest that Leucaena plays an important role in restricting natural forest regeneration by its invasive growing habit which reduces light transmittance to the forest floor.

Keywords: invasive species, forest restoration, edge effect, natural regeneration, vegetation dynamics

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[1]   Department of Forest Biology, Faculty of Forestry, Kasetsart University, Bangkok 10900, Thailand.
[2]   Center for Advanced Studies in Tropical Natural Resources, Kasetsart University, Bangkok 10900, Thailand.
[3]   Department of Agroforestry, Maejo University Phrae Campus, Phrae 54140, Thailand.
[4]   Khoa Phuluang Ecotourism Development Project, Klong Somboon village, Wang Namkhiew district, Nakhon Ratchasima 30150, Thailand.
*   Corresponding author, e-mail: dokrak.m@ku.ac.th

INTRODUCTION

Invasive plant species are problematic globally and are now considered as one of the main threats to the world's biodiversity (Lonsdale, 1999; Williamson, 1999; Mooney and Hobbs, 2000). An invasive plant is any exotic species characterized by aggressive natural spreading into a new place, a new environment or within the same ecosystem with a different role (GISP, 2004; Mason *et al.*, 2009). This role might be negative and could affect ecosystems (Vitousek and Walker, 1989; Rejmanek and Richardson, 1996). The colonization and establishment of an invasive plant species represents a unique form of disturbance. Many studies have shown alterations in community structure and ecosystem function following invasion by an exotic species (for example, Vitousek and Walker, 1989; Lesica and Miles, 2001). Invasive plant species may function differently from those that are already present in a system (Orians, 1986; Vitousek *et al.*, 1996) such as, by changing germination sites, by affecting surface microclimates and by creating situations where one species alters or introduces symbiotic associations between plants and microbes, which may subsequently facilitate or deter the establishment of others (Vitousek and Walker, 1989). Invasion success depends on the ecological attributes of the invading plant, the characteristics of the invasion site and a range of stochastic short-term events (Hobbs and Humphries, 1995; Davis *et al.*, 2000). The spread of invasive species is now recognized as one of the greatest threats to the ecological and economic well being of the planet (GISP, 2004). For instance, invasive alien plants pose an increasing threat to the composition and structure of natural communities across the globe (Cronk and Fuller, 2001).

Deforestation and degraded forest are now serious environmental problems in Thailand. Vast expanses of original forest have been converted into pasture and agricultural fields, often under shifting cultivation, with subsequent abandonment of the temporary sites (Brown and Lugo, 1990; Chapman and Chapman, 1999; Marod *et al.*, 2003). The causes of forest degradation have varied from poor harvesting methods, shifting agriculture following logging, and forest fires, among others. In the past, Thailand's government through the Royal Forest Department (RFD) has tried to solve the problem usually by establishing single-species plantations, especially fast exotic growing species such as *Acacia mangium, A. auriculaeformis, Azadirachta indica* and *Eucalyptus camaldulensis* (Khemnark, 1994). The natural succession process after plantation establishment has allowed some native and non-native pioneer species to migrate into the area and become successfully established through to the climax stage. Recently, however, the idea of restoring original forest ecosystems has rapidly gained interest. RFD is actively promoting "enrichment planting" using a wide range of native tree species and a random planting pattern.

Leucaena (*Leucaena leucocephala*) was introduced for reforestation purposes in Thailand due to its tolerance to a wide range of annual rainfall (500–3,500 mm) and its ability to withstand strong seasonal climates with a dry season of 6–8 mth (Cronk and Fuller, 2001). It has been classified as a shade-intolerant species because it needs high light intensity for establishment. In general, the light requirements and tolerance to shading of seedlings are the major features that have been used to classify forest tree species into two ecological groups: 1) species that are shade-intolerant or pioneer, and 2) species that are shade-tolerant or late-succession (Bazzaz and Pickett, 1980; Swaine and Whitmore, 1988). Leucaena used to be promoted also for tropical forage purposes (Shelton and Brewbaker, 1994) because it produces nutritional food for livestock. However, the leaves and seeds of Leucaena contain an amino acid called mimosine (Matthews and Brand, 2004) that can be poisonous to other plants which has resulted in it being able to invade

riverbanks, roadsides, cultivated land, waste land and also forest margins. It produces extensive areas that are unusable and inaccessible and also threatens native plants. Recently, Leucaena has been widely regarded as a global, invasive, alien species (GISP, 2004). Contrarily, considering its impact on human and related activities, this plant used to be designated as the "miracle tree" because it could be utilized in a variety of ways, including, forage, firewood, timber, human food, green manure, shade and erosion control. However, its leaves, which are high in protein and vitamin A, and the edible seeds contain the amino acid mimosine and could be toxic if consumed in large quantities (Shelton and Brewbaker, 1994). Farmers also consider this species to be an agricultural weed which is almost impossible to uproot completely. The impact of Leucaena on invaded ecosystems has not been well documented (GISP, 2004; Matthews and Brand, 2004), even though it has been shown that the tree can displace native species under its canopy, which is relatively close, resulting in surface soil that is often free of vegetation. A better understanding of the causes, patterns, consequences and management options associated with this threat to biodiversity is needed in order to guide managers, policy makers and researchers and to raise general public awareness.

This study considered the differences in vegetation structure and composition along a transect from the natural forest interior toward a Leucaena plantation. The main objective was to clarify the influences of Leucaena on the tree regeneration dynamics along the remnant forest-Leucaena plantation edge.

Study area

The study was carried out in the Khoa Phuluang Ecotourism Development Project forest, situated on the southwestern edge of the Korat plateau in Nakhon Ratchasima province, northeastern Thailand (N 15°13′166″ and E 101°10′319″), during May–October 2010. The topography of the study area is mountainous terrain with an altitude range from 280 to 800 m above sea level and slopes of 10–30%. The soil is mainly derived from sandstone of the Phra Wihan formation of the Khorat group (Moormann and Rojanasoonthorn, 1972). The upper soil texture is mostly sandy loam, clay loam and sandy clay loam (Bunyavejchewin, 1986). From 2006 to 2010, the annual mean temperature was 26.5 °C and the annual mean precipitation was 1,019 mm (Sakaerat Environmental Research Station, 2011). There is a distinct dry season from November to February (Figure 1). The prevailing forest mainly consists of dry evergreen forest (DEF) and deciduous dipterocarp forest, mostly in response to altitude and soil type distribution (Bunyavejchewin, 1986; Sahunalu and Dhanmanonda, 1995). The original DEF has been heavily invaded and cleared for agriculture during the last two decades (Srisawas et al., 1991).

MATTERIAL AND METHODS

**Site selection and vegetation sampling**

To investigate the species composition, sampling was undertaken in LP aged 15 and 5 yr. Three sampling plots, 20 × 50 m, were established with two of the plots set up in the 15 yr-old LP and one in the 5 yr-old LP. The 5yr-old stand originated from an old LP stand that had been clearcut and allowed to regenerate naturally.

Each plot was divided into 10 × 10 m frame quadrats and within each quadrat, subquadrats of 4 × 4 m and a further single 1 × 1 m were established in a corner for woody plant structure analysis. Woody plant species were counted, identified and measured using diameter at breast height (DBH) and total height for three distinct categories; 1) seedlings (total height less than 1.3 m), 2) saplings (DBH less than 4.5 cm and total height over or equal to 1.30 m) and 3) trees (DBH greater than or equal to 4.5 cm and total

height over 1.30 m) in the 1 × 1 m, 4 × 4 m and 10 × 10 m quadrats, respectively. In addition, climbing and herbaceous plants were also observed in all 1 × 1 m subquadrats.

To study the influences of Leucaena on the regeneration of native tree species, three belt transects of 10 × 150 m (Figure 2) were laid out running from the interior of the remnant forest (RF, -50 m to 0 m) through near-to-edge (nLP, 0 m to 50m) and distant-to-edge (dLP, 50 m to 100m) in the LP. Each transect consisted of 15 contiguous

10 × 10 m frame quadrats, distributed over RF (5 quadrats) and LP (10 quadrats), with 45 frame quadrats in total. The representative sample sites were selected on the basis of the presence of LP adjacent to the DEF. All woody species of trees, saplings and seedlings, were counted, identified and measured using the procedure described above. Stratification of the vegetation structure was based on the randomly selected belt transect sample.
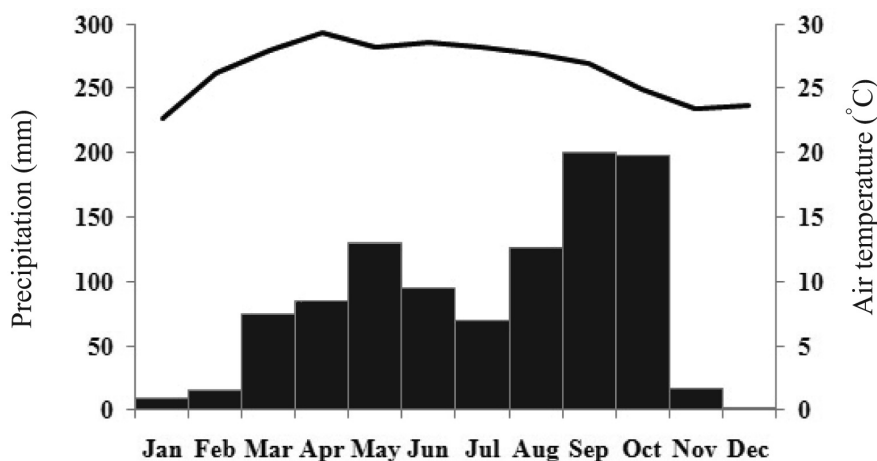
Figure 1 Average monthly values for precipitation (bar graph) and air temperature (line) from 2006 to 2010 at Sakaerat Environmental Research Station, Nakhon Ratchasima Province. (Source: Sakaerat Environmental Research Station, 2011)
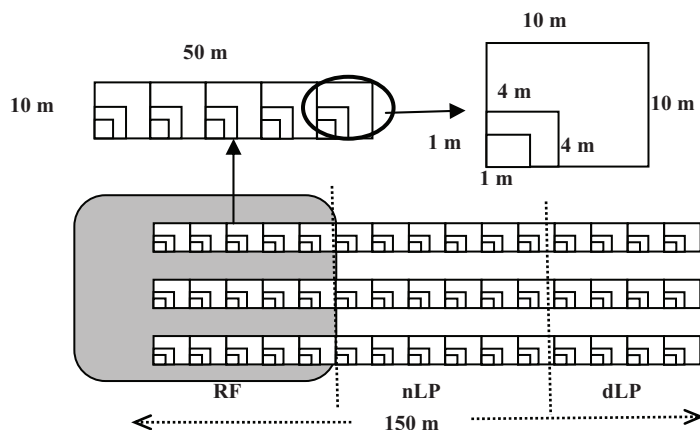
Figure 2 Layout of belt transects of 10 × 150m, with three transects established along the remnant forest (RF) into near-to-edge and distant-to-edge of Leucaena plantation (nLP and dLP, respectively).

Sampling environmental influences

In order to study the influences of Leucaena on environmental changes, the soil and light conditions were randomly investigated; 15 soil samples were collected from each of three sites—in the DEF, LP and in the open area. Both the physical and chemical properties of all soil samples were analyzed at the Department of Soil Science, Faculty of Agriculture, Kasestsart University. The results of the soil analysis from the three sites were then compared to describe the changes after reforestation using Leucaena. Soil depths, especially of the A and B layers of the soil profile (about 50 cm below the surface) were also measured on all three sites.

A total of 45 hemispherical photos were taken looking up vertically using a fish-eye lens at the same locations where the soil samples had been collected on each site. The relative light intensity (RLI) was analyzed by the FEW52b program (Ishizuka and Kanazawa, 1991). In addition, the variations in light intensity along the RF into the LP were investigated using the hemispherical photos in every quadrat of 10×10 m for all belt transects (a total of 45 photos).

Data analysis

To analyze the changes in vegetation structure and species composition, each set of 5 continuous 10×10 m subquadrats was combined into one plot according to its location in RF, nLP or dLP, resulting in 15 subquadrats for each category. In each of the 15 subquadrats, stem density (number of stems per area) was calculated for the

seedlings, saplings and trees. Analysis of variance (ANOVA) was used to evaluate differences in stem density and basal area (Sokal and Rohlf, 1981). Forest-to-edge vegetation profiles were drawn to illustrate changes in the forest structure moving from the RF into nLP and dLP, respectively.

RESULTS

Environmental changes

Differences in the soil properties of the top soil layers, especially the A layer (0−20 cm), between the three sites were significant ($P < 0.05$). Greater soil depth was found in the DEF, 12.5 ± 1.2 cm (mean ± SD), followed by the LP and the open area, with depths of 7.5 ± 1.8 and 5.6 ± 2.2 cm, respectively. The soil texture in the DEF and LP was sandy clay loam and clay loam, respectively, while the open area texture consisted of only sand. The amount of litter on the forest floor in the DEF and LP was high and similar, (0.69 ± 0.18 and 0.72 ± 0.14 kg.m^{-2}, respectively), while it was very low in the open area (0.15 ± 0.08 kg.m^{-2}). Differences in soil properties, particularly soil organic matter at the three sites were highly significant ($P < 0.001$). The highest nutrient content was found in the DEF followed by the LP and the open area, respectively, (Table 1). However, the LP and DEF were similar in soil pH, with both having a lightly acidic soil. In contrast, the open area had a strongly acidic soil (Table 1).

The analysis of RLI from the hemispherical photos taken at the three sites showed significant

Table 1 Soil properties between three sites: open area, Leucaena plantation (LP) and dry evergreen forest (DEF) in Khoa Phuluang forest, northeastern Thailand. (Mean ± SD).

Site	Soil texture	pH	OM (%)	P (mg.kg^{-1})	K (mg.kg^{-1})	Ca (mg.kg^{-1})	Mg (mg.kg^{-1})
Open area	S	4.7±0.2	1.6±0.5	3.9±0.9	55.2±20.5	504.0±40.9	129.5±53.2
LP	SCL-CL	6.2±0.5	2.3±0.3	31.1±9.9	193.7±23.2	3725.4±1237.2	181.1±65.3
DEF	CL	5.8±0.5	4.1±0.3	10.6±1.8	214.4±29.3	1409.8±181.1	334.9±22.8

S = sandy; SCL = sandy clay loam; CL = clay loam. OM = Soil organic matter.

(P < 0.01) differences. The highest RLI was found in the open area (98.59 ± 1.2%) followed by the LP and DEF (18.5 ± 5.5 and 15.56 ± 2.8%, respectively). In contrast, there was no significant difference along the gradient of RF to nLP and dLP, with values of 18.19 ± 2.5, 20.27 ± 2.6 and 21.65 ± 1.5%, respectively.

Vegetation structure and species composition in LP

The species composition in the LP was very low with only 16 species from 16 genera in 11 families. Leucaena had a high stem density and basal area cover, with 1,196.7 stems.ha^{-1} and 13.92 m^2.ha^{-1}, respectively. It formed dense, monospecific thickets and created a closed canopy in the area. Under such shade, only a few native species were found (Table 2). The maximum canopy height inside the RF (-50 to 0 m) ranged from 20 to 27 m. On the other hand, the vegetation height of both nLP and dLP ranged from 10 to 15

m and was dominated by Leucaena (Figure 3).

The DBH class distribution of Leucaena was analyzed and it fitted a negative exponential growth curve function (r^2 = 0.95, Figure 4). There was a large number of trees in the small size class (4.5–13.5cm), especially on the site that had been clear cut and re-established itself by stem coppicing until aged 5yr, where the small-sized stocking was 1,110 stems.ha^{-1}. In contrast, all of the native trees and shrubby trees were concentrated solely in the smallest size class (4.5–7.5cm), with a stocking of 83 stems.ha^{-1}.

Regeneration along the edge of RF toward LP

The differences in the stem densities of native trees, saplings and seedlings, including pioneer species, were highly significant (ANOVA, P < 0.001) in the RF but no significant differences were detected in the LP (Figure 5A). The stem density of trees was about 1,660 stems.ha^{-1} and rapidly decreased in the nLP and dLP to 103.33

Table 2 Species composition, tree density and basal area cover of Leucaena plantation in Khoa Phuluang forest, northeastern Thailand.

Species	Family	Habit	Density (stems.ha^{-1})	Basal area (m^2.ha^{-1})
Leucaena leucocephala	Fabaceae	T	1,196.70	13.92
Milllettia leucantha	Fabaceae	T	66.67	0.22
Sampantaea amentiflora	Euphobiaceae	ST	46.67	0.11
Diospyros mollis	Ebenaceae	T	43.33	0.42
Maerua siamensis	Capparaceae	ST	23.33	0.07
Clausena wallichii	Rutaceae	S	13.33	0.04
Pterocarpus macrocarpus	Fabaceae	T	10.10	0.02
Terminalia pierrei	Combretaceae	T	6.67	0.02
Atalantia monophylla	Rutaceae	S	6.67	0.02
Afzelia xylocarpa	Fabaceae	T	6.67	0.02
Murraya paniculata	Rutaceae	S	3.33	0.04
Zollingeria dongnaiensis	Sapindaceae	T	3.33	0.04
Lagerstoemia duperreana	Lythraceae	T	3.33	0.03
Walsura trichostemon	Meliaceae	ST	3.33	0.01
Sterculia foetida	Sterculiaceae	T	3.33	0.01
Streblus ilicifolius	Moraceae	S	3.33	0.01

T = Tree; ST = Shrubby tree; S = Shrub.

and 46.66 stems.ha^{-1}, respectively. Saplings and seedlings also followed the same pattern as the trees (Figure 5A). However, native trees such as *Lagerstoemia duperreana*, *Afzelia xylocarpa* and *Pterocarpus macrocarpus* could grow to the sapling stage only in the nLP where they had a low stocking density of 113 stems.ha^{-1}. High stem densities of shrubs and shrubby trees were found, primarily belonging to shade-tolerant species such as *Sampantaea amentiflora*, *Maerua siamensis*, *Clausena wallichii*, *Atalantia monophylla*, *Murraya paniculata* and *Streblus ilicifolius* (Table 2). The mature trees of *Leucaena leucocephala* were distributed only in the LP, and low seedling and sapling densities were found under their shade (Figure 5B).

The different numbers of native species of trees, saplings and seedlings along the forest
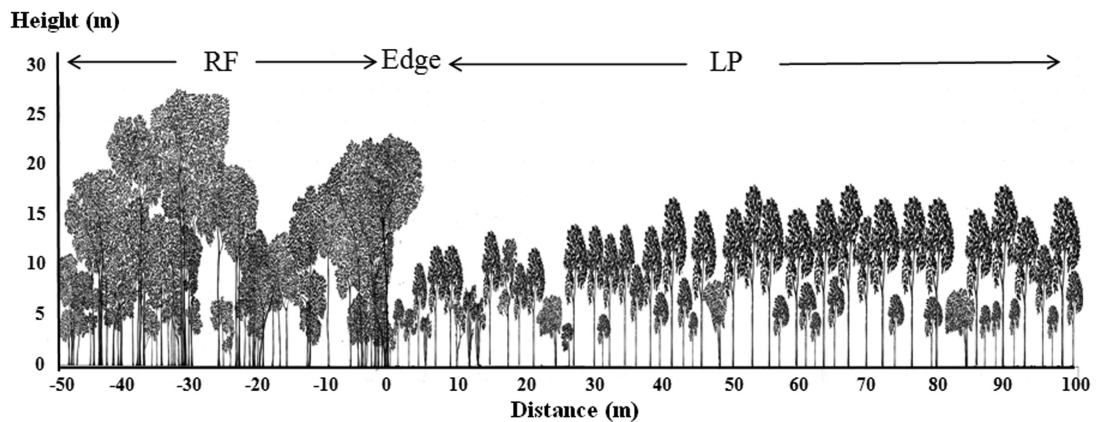
Figure 3 Schematic profile diagrams and horizontal stem distributions of belt transects of 10 × 150 m along gradient distant from remnant forest (RF) toward Leucaena plantation (LP).
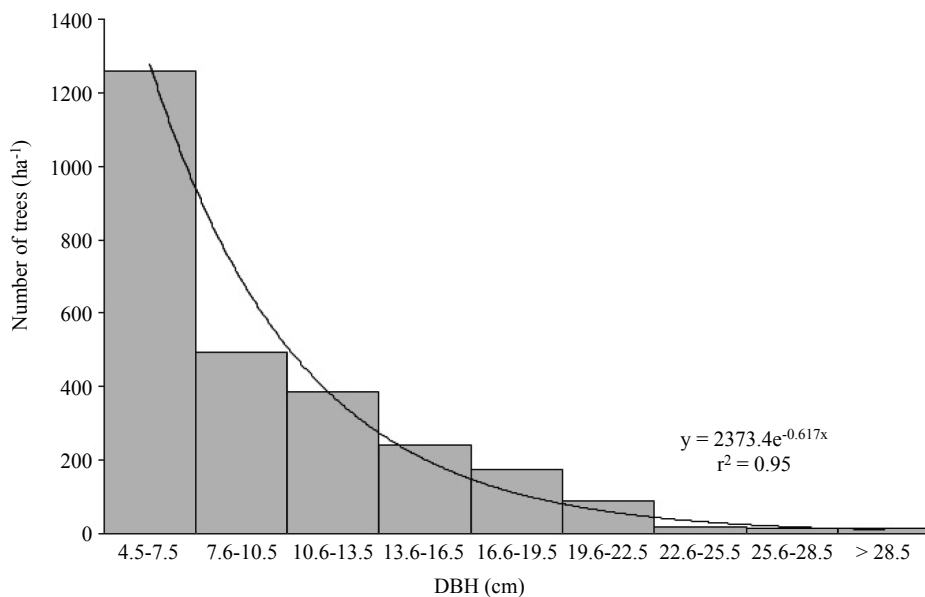
Figure 4 DBH distribution of *Leucaena leucocephala* in Leucaena plantation, Khoa Phuluang, northeastern Thailand.

edge were highly significantly (ANOVA, $P <$ 0.001) and were greater in the RF than in the nLP and dLP. The highest species number was found in the tree category (Figure 6A) being higher in the RF than in the nLP and dLP, with values of 39.25 ± 3.5, 10.6 ± 4.5 and 5.4 ± 2.6 species, respectively. This similar pattern was also found in the native saplings and seedlings (Figure 6A). However, there was there was no difference in the numbers of pioneer species among trees, saplings and seedlings (Figure 6B).
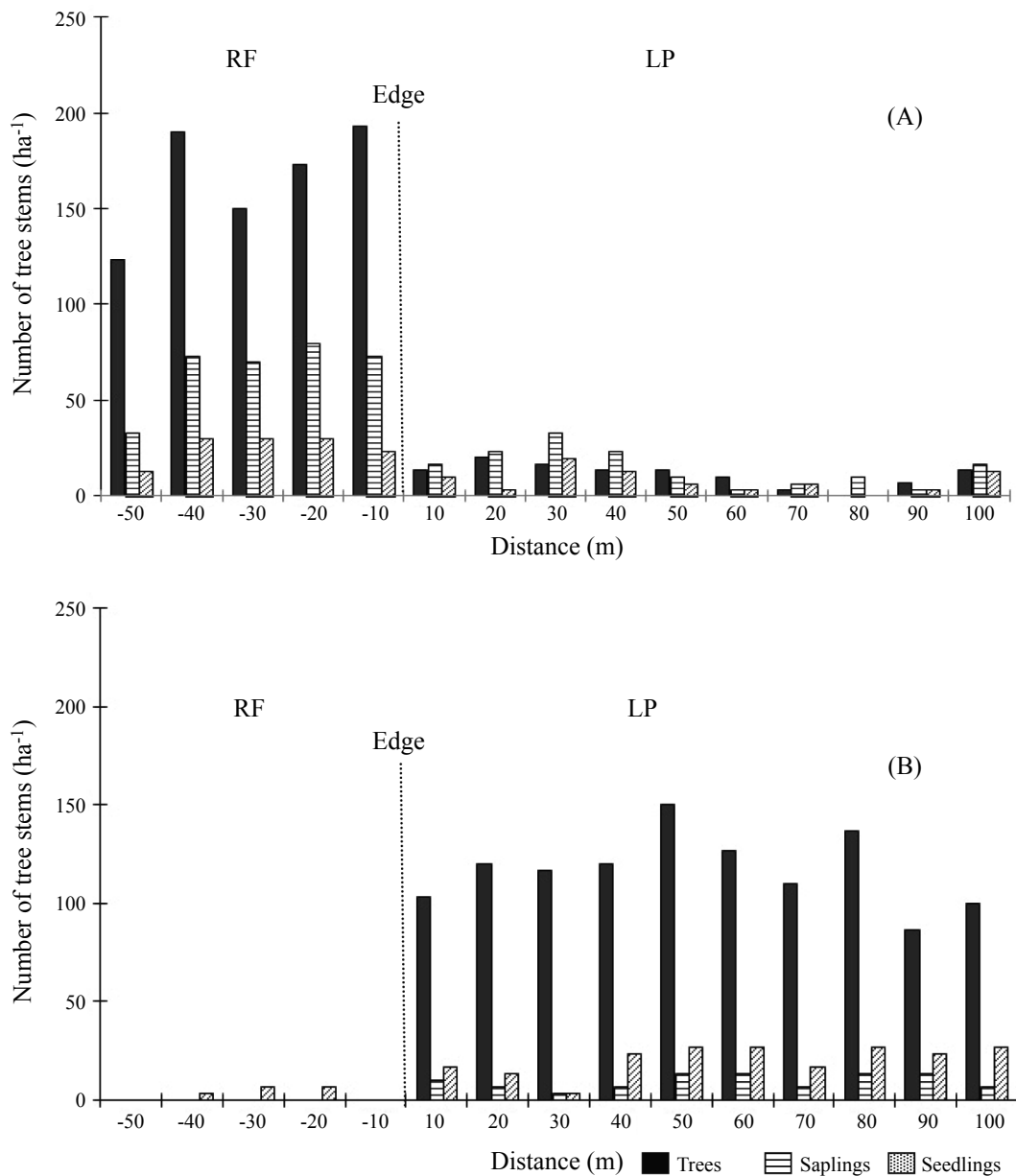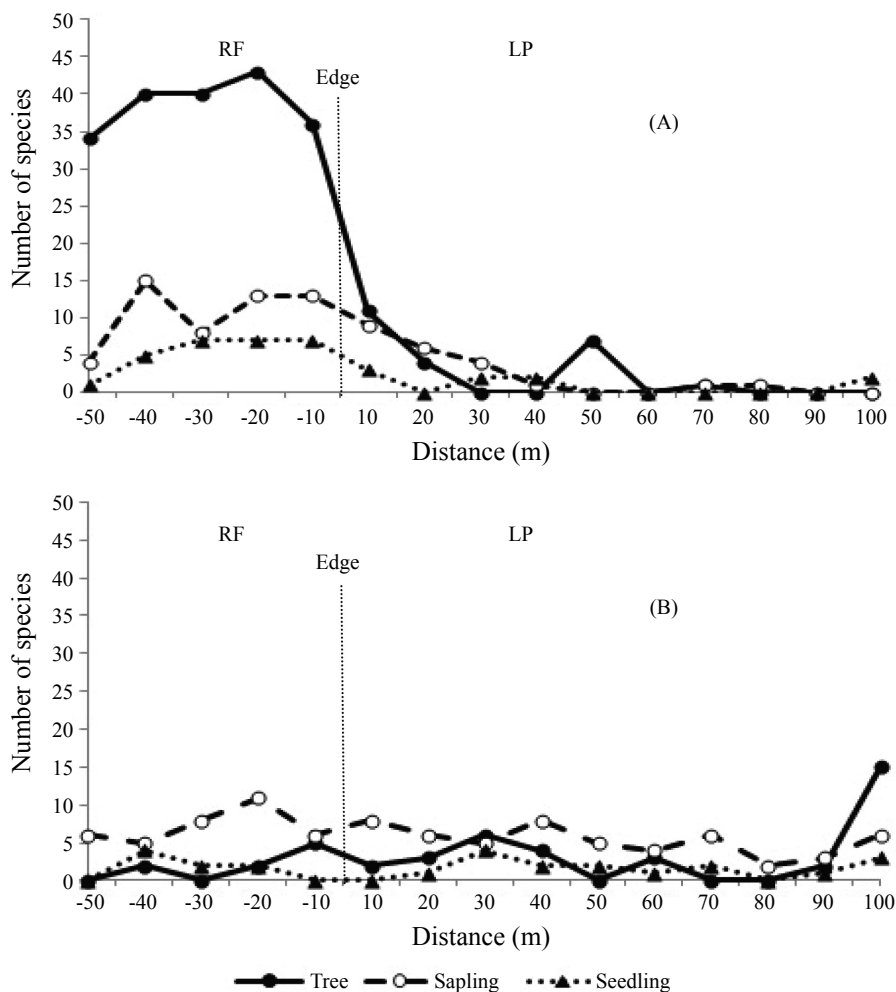

Figure 5 Distribution of stem numbers along remnant forest (RF) interior to edge and to the exterior distance of a Leucaena plantation (LP) for: (A) native tree species; and (B) *Leucaena leucocephala*.

DISCUSSION

A gradual change in vegetation was reported from the edge of RF bordering agricultural land (Pattanavibool and Dearden, 2002; Fukushima *et al.*, 2008). The vegetation structure and species composition along the RF-edge gradient changed from an assemblage of high density canopy and subcanopy trees in the RF and decreased in open areas and less dense stands at the edge. In contrast, the small sapling density slightly increased in an abandoned field (Laurance *et al.*, 1998; Sizer and Tanner 1999). The results from the present study

showed that forest regeneration along the gradient from RF to LP presented a similar picture to that of these reported studies. However, Leucaena not only influenced forest regeneration but also environmental changes. The forest regeneration of native tree species was low in the nLP and dLP, with 103.33 and 46.67 stems.ha^{-1}, compared to the RF, with 1,660 stems.ha^{-1}, while the RLI in the DEF was low and similar to that in the LP that had been clear cut at age 5 yr, which was a product of the resultant deep shade. The analysis of the RLI showed that on the forest floor under the DEF and LP (especially in the 5 yr-old clear cut plot), the

Figure 6 Distribution of species numbers along a remnant forest (RF) interior to edge and to exterior distance for: (A) native species; and (B) and pioneer species.

density from the regrowth may be higher than that of the original trees before cutting (Guevarra *et al.*, 1978). The low light transmittance may reduce the seed germination and the growth of native and pioneer species (Lovejoy *et al.*, 1986; Jose *et al.*, 1996; Marod *et al.*, 2004). These phenomena may prohibit a natural succession process after reforestation towards mature forest (Kappelle *et al.*, 1996; Hobbs, 2000). The results showed that there was a low amount of succession of native and pioneer species in the LP (Figure 5). In addition, the strong allelopathic potential in Leucaena because of its leaves containing toxic chemicals may inhibit the germination and growth of other trees (Chou and Kuo, 1986).

Furthermore, Leucaena produces a large number of seeds every year that can remain viable in the soil for many years (Chou and Kuo, 1986). Small seedlings may germinate from the soil seed bank several years after the removal of Leucaena trees (Kuo, 2003). Thus, it can easily establish in abandoned areas, and become a pure stand in a few years. The present study found that the DBH class distribution of Leucaena fitted a negative exponential growth function indicating that it had a good regeneration process which was further supported by the high success rate of Leucaena through its establishment and invasion of many places, especially open areas in Thailand. Because of this, GISP (2004) mentioned that it is a difficult task to rehabilitate an ecosystem which has been invaded or planted by invasive alien species such as Leucaena.

CONCLUSION

Leucaena formed dense, monospecific thickets with a high stem density (1,196.7 stems.ha^{-1}), resulting in a closed canopy. Thus the Leucaena canopy directly influenced a reduction in light transmittance on the soil surface and the low light conditions may be a crucial environmental factor preventing the seed germination and growth

of pioneer and native species. In the shade, the RLI was reduced (18.5 ± 5.5%) to a level similar to that in the DEF (15.56 ± 2.8%). Forest regeneration under the LP was very low. In the nLP and dLP, not only low numbers of native species (10.6 ± 4.5 and 5.4 ± 2.6, respectively) but also low stem densities (103.33 and 46.67 stems.ha^{-1}, respectively) were found,

Thus, Leucaena plays an important role in prohibiting natural forest regeneration by its invasive growth reducing essential environmental resources. However, the planting of Leucaena also has some positive effects on the improvement of soil properties and an increased amount of litter on the ground. Further research should be undertaken to learn more about the ecological characteristics of Leucaena, in order to find the most efficient method of preventing its future invasion, and of rehabilitating ecosystems where it has already colonized.

ACKNOWLEDGEMENTS

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