Forest Dynamics and Tree Distribution Patterns in Dry Evergreen Forest, Northeastern, Thailand

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ABSTRACT

Deforestation based on anthropogenic activities is the main cause of biological diversity loss. This study clarified forest dynamics after intermediate disturbances and detected the tree distribution pattern in a dry evergreen forest (DEF). A 1 hectare (ha) permanent plot was set up in a lowland DEF in 2002 and all trees with a diameter at breast height (DBH) larger than 4.5 cm were tagged, measured and identified. Tree monitoring was done in 2009 and 2016. In addition, the permanent plot was expanded to 3 ha, for studying the tree distribution pattern and all trees with DBH greater than 2 cm were included and their coordinates also recorded during 2016. The forest dynamics during 2002 to 2016 showed the net recruitment rate was higher than the mortality rate (2.58 and 2.35 %/year, respectively); however, it varied among periods. The mortality rate in the second period (2009-2016) was greater than in the first period (2002-2009), with rates of 4.71 and 2.64 %/year, respectively, due to disastrous flooding in 2003. A clumped distribution pattern based on the Morisita index was detected for all selected species, indicating habitat heterogeneity in which the physical environments were patched and induced the clumped distribution.

1. INTRODUCTION

Tropical forest communities are globally recognized for having the highest biological diversity covering a wide geographic range and also for their productivity (Cao et al., 2006; Houghton, 2002; Myers et al., 2000). These forests are the source of ecosystem services including preservation of biotic components and regulating soil erosion (Armenteras et al., 2009; Naidu and Kumar, 2016). In recent years, tropical forests have become noticeably degraded (Laurance, 1999; Naidu and Kumar, 2016) due to natural disasters such as forest fire, drought and flooding (Osman, 2013) and particularly from anthropogenic disturbances, such as transportation development and agricultural expansion (Anitha et al., 2010). These causes of overexploitation combine to form one of the largest environmental and economic problems around the world and also have resulted in rapid loss of tropical forests (Mani and Parthasarathy, 2006; Naidu and Kumar, 2016). Therefore, study on forest regeneration and succession processes, especially after disturbances, provides important ecological knowledge for the application of effective tropical forest conservation and management, particularly in understanding the tree distribution patterns associated with ecological niches. Furthermore, the changes in forest ecosystems related with land use changes affect the variability of environmental factors which are mandatory for tree establishment. Thus, to monitor such events, long term ecological research (LTER) is very important to identify the forest dynamics and their influences.

The study of forest dynamics requires LTER based on permanent plots (Bunyavejchewin, 1999) to monitor and evaluate the effects of environmental changes or some disturbances on the plant communities (Condit et al., 1996; Laurance et al., 2004; Mohandass and Davidar, 2009). It provides information on growth, mortality and recruitment in forests (Feeley et al., 2011). In addition, the study of plant communities within a tree census plot has been done more frequently in the topics, especially, tree distribution patterns-regular, random and clumped (Bunyavejchewin et al., 2003; Lan et al., 2009). The distribution pattern can be produced by social interaction within populations, by the structure of the physical environment, or by a combination of the two. Such study is important in developing a conservation strategy (Austin, 2002; Lim et al., 2008) and changes in each distribution pattern can be used to detect major adaptations in the ecosystem (Alados et al., 2003; Lim et al., 2008). Therefore, this is critical in terms of determining the status and understanding the ecology of plant communities as well as their conservation value (Lee and Williams, 2002; Lim et al., 2008).

In Thailand, LTER has been undertaken in many forest types, which generally have been located in relatively undisturbed protected areas (Baker et al., 2005; Bunyavejchewin, 1999; Marod et al., 1999; Sahunalu, 2010). However, less LTER was found in the disturbed areas, in particular, the dry evergreen forest, DEF, which are commonly converted into agricultural areas due to good soil fertility and water condition (Marod and Kutintara, 2009). Therefore, a study of forest dynamics in the DEF after disturbance should be established with a high priority. The information obtained on biological diversity and the regeneration process of tree species will be applied in the restoration program.

DEF is one type of tropical forest found in Thailand, where it is widespread and mostly located in the northeast in protected areas (Chairuangsirikul, 1986; Marod and Kutintara, 2009). DEF is very important both economically and ecologically, due to the high number of products from timber species and the distinctive biotic communities (Bunyavej-chewin, 1999). Some DEF areas in preservation forest have been disturbed because they are adjacent to a local community and readily impacted on by human activities. For example, some areas of DEF in Wang Nam Khiao Forestry Research and Training Station, Wang Nam Khiao district, Nakhon Ratchasima province have been disturbed by road construction. Thus, the current study aimed to clarify the forest dynamics, particular forest regeneration after intermediate disturbance, and to detect the tree distribution patterns in a permanent plot of DEF.

2. METHODOLOGY

2.1 Study site

The study was conducted in DEF on the Wang Nam Khiao Forestry Research and Training Station, Wang Nam Khiao district (14° 30′ N, 101° 55′ E), Nakhon Ratchasima province, Northeastern Thailand. It is located along Highway Number 304 and about 300 km from Bangkok. The altitudinal range is from 250 to 762 m.a.s.l (Niamrat, 2003). The climate is tropical with rainfall mainly occurring from July to October, while less rain falls in the remaining 8 months. The mean annual rainfall is ca. 1,100 mm/year and the mean monthly temperature is 27.3ºC (Sakaerat Environmental Research Station, 2015).

The prevailing forests consist of the DEF, mixed deciduous forest (MDF) and deciduous dipterocarp forest (DDF). The DEF is mostly found on lowland sites adjacent to streams and has a high number of species (Eiadthong, 2000). However, the forest structure and species composition has been disturbed after the road construction of Highway Number 304. Nowadays, this forest is under a natural recovery process.

2.2 Methods

In 2002, a 1 ha (100 m × 100 m) permanent plot was established in the lowland DEF and was divided into subplots (10 m × 10 m). All trees with diameter at breast height (DBH, at 1.30 m) ≥ 4.5 cm were tagged, measured and identified based on Smitinand (2014). Tree monitoring was carried out at 7 year intervals (2009 and 2016). In addition, the permanent plot was expanded into 3 ha (150 m × 200 m) in 2016 in order to cover the lowland and the highland altitudinal gradients for analysis of tree distribution patterns. All trees with DBH ≥ 2 cm were included and the position of each tree was recorded. Thus, the analyses of forest structure, composition and tree distribution patterns were based on all woody plants, DBH ≥ 2 cm; however, the forest dynamics were considered only for woody plants with DBH ≥ 4.5 cm in the initial 1 ha plot data.

2.3 Data analysis

The forest structure and species composition were described in terms of the number of stems, dominant species and basal area (Oliveira et al., 2014). The dominant species were defined according to the relative frequency, relative dominance, relative density and importance value (IV) which were estimated following Kent (2012) for all species by separating them into two groups: saplings (2 cm ≤ DBH < 5.0 cm) and trees (DBH ≥ 5 cm). The Shannon-Wiener index (H') was analyzed following Shannon and Weaver (1949).

The forest dynamics were characterized using annualized mortality (M) and recruitment (R) following Sherman et al. (2012) according to the equations:

$$M\ (\%) = 100 \times (ln\ (N_0) - ln\ (N_s))/t$$
$$R\ (\%) = 100 \times (ln\ (N_t) - ln\ (N_s))/t$$

where N_t and N_0 are the size of the population at time t and time 0, respectively, and N_s is the number of survivors at time t. The relative growth rate (RGR) of species was calculated using the equation following Sherman et al. (2012):

$$RGR\ (\%) = 100 \times (ln\ (DBH_{t2}) - ln\ (DBH_{t1}))/(t_2 - t_1)$$

where DBH is the diameter at breast height (1.3 m) of an individual tree at time $t_2 - t_1$ divided by the number of years between census periods. The paired t-test was used in order to compare the two measurement period (2002-2009 and 2009-2016) in term of the mean RGR at $p < 0.05$.

The distribution patterns of saplings and trees were considered for species with more than 80 individuals (Lan et al., 2009) based on the Morisita index (I_δ) following Morisita (1959):

$$I_\delta = \sum n_i(n_i\text{-}1)/N(N\text{-}1)q$$

where n_i is the number of individuals in each quadrat, N is the total number of individuals, q is the number of quadrats for a given quadrat size and I_δ is a measure of the distribution pattern with $I_\delta < 1$ if the individuals are regularly distributed, where $I_\delta = 1$ if there is a random distribution and $I_\delta > 1$ if the individuals are clumped. The smallest quadrat size was achieved by subdividing the 3 ha plot into square quadrats with sides of $(0.181)^2 \times 200$ m (i.e., the x-axis length) and $(0.209)^2 \times 150$ m (i.e., the y-axis length) yielding quadrats of 6.55 m × 6.55 m (42.90 m^2). Larger quadrat sizes were obtained by doubling the length of the quadrat sides (Bunyavejchewin et al., 2003). Quadrat sizes ranged from 42.9 m^2 to 2,745.8 m^2. The statistical test of randomness (F test) was used to test the significance of departures for all quadrat sizes (spatial scales) at $p < 0.05$.

3. RESULTS AND DISCUSSION

3.1 Forest structure and species composition

Within the 3 ha permanent plot, there were 4,810 individuals (DBH ≥ 2 cm), consisting of 150 species that belonged to 119 genera and 46 families. The tree density and basal area (BA) for DBH ≥ 5 cm were 806 individual/ha and 24.18 m^2/ha, respectively. Tree diversity based on the Shannon-Wiener index was high (H' 4.04). Considering the species regeneration on sapling and tree stages, the dominant tree species based on the importance value (IV) established high dense sapling such as *Dipterocarpus alatus*, *Streblus asper*, *Hydnocarpus ilicifolia*, and *Markhamia stipulata* (Table 1 and Table 2). Indicating these species had regenerated well. However, many dominant sapling species were pioneers of shrub habit, *Cleistanthus papyraceus*, *Streblus ilicifolius* and *Clausena guillauminii* (Table 2), indicating some disturbances had occurred in this area. This species composition was also similar to that reported by Laurance et al. (1998) who found that forest disturbances resulted in an increase in the number of pioneer and secondary species and also inhibited the growth of native species.

Table 1. Dominant tree species in the DEF at Wang Nam Khiao Forestry Research and Training Station.

Species	Density (individual/ha)	BA (m^2/ha)	Min DBH (cm)	Max DBH (cm)	Mean DBH (cm)	IV (%)	Habit
Pterocarpus macrocarpus	54	4.07	5.31	84.13	26.90	27.83	T
Dipterocarpus alatus	32	4.14	5.00	246.72	25.40	25.20	T
Streblus asper	44	0.47	5.02	31.98	10.25	11.31	T
Hydnocarpus ilicifolia	42	0.46	5.00	26.79	10.51	11.20	ST
Microcos tomentosa	37	0.73	5.06	39.04	14.50	11.08	T
Markhamia stipulata	32	0.50	5.06	41.81	12.50	9.72	T
Leucaena luecocephala	31	0.49	5.06	36.50	12.68	9.50	S/ST
Holoptelea integrifolia	17	1.14	5.06	105.57	20.93	9.44	T

Table 1. Dominant tree species in the DEF at Wang Nam Khiao Forestry Research and Training Station (cont.).

Species	Density (individual/ha)	BA (m^2/ha)	Min DBH (cm)	Max DBH (cm)	Mean DBH (cm)	IV (%)	Habit
Wrightia arborea	27	0.59	5.09	56.95	13.85	9.15	ST
Lagerstroemia calyculata	16	0.63	5.22	60.77	19.89	7.11	T
other species (110)	472	10.96				168.49	
Total	806	24.18				300	

T = Tree; ST = Shrubby tree; S/ST = Shrub or Shrubby tree

Table 2. Dominant sapling species in the DEF at Wang Nam Khiao Forestry Research and Training Station.

Species	Density (individual/ha)	BA (m^2/ha)	Min DBH (cm)	Max DBH (cm)	Mean DBH (cm)	IV (%)	Habit
Cleistanthus papyraceus	117	0.08	2.01	4.93	2.81	30.43	S
Streblus asper	62	0.05	2.04	4.99	3.17	23.83	T
Hydnocarpus ilicifolia	45	0.04	2.02	4.96	3.31	17.62	ST
Aphanamixis polystachya	37	0.03	2.04	4.80	3.05	12.88	T
Streblus ilicifolius	32	0.02	2.05	4.55	2.94	10.98	S/T
Memecylon ovatum	28	0.03	2.11	4.96	3.46	10.53	S/T
Clausena guillauminii	29	0.03	2.01	4.93	3.22	10.45	S
Markhamia stipulata	22	0.02	2.07	4.77	3.26	9.31	T
Dipterocarpus alatus	22	0.02	2.05	4.99	3.38	9.27	T
Mallotus philippensis	22	0.02	2.03	4.93	2.92	9.19	S/T
other species (95)	375	0.32				155.51	
Total	792	0.65				300	

T = Tree; ST = Shrubby tree; S/T = Shrub or Tree; S = Shrub

3.2 Forest dynamics

The BA of trees with DBH ≥ 4.5 cm in the 1 ha permanent plot tended to increase in the first 7-year measurement period as the gain rate was higher than the loss rate. However, the BA in the second period (2009-2016) was loss (5.72 m^2/ha) than half compare to the first period (2002-2009) with value of 2.66 m^2/ha. The species number varied between periods and was highest in 2009. In contrast, the stem density decreased due to the high mortality rate in both periods (Table 3). However, the net mortality and recruitment during the 14-year period were relatively balanced (2.58 and 2.35 %/year, respectively). In October 2003, torrential rain occurred in the study area (Sakaerat Environmental Research Station, 2003) resulting in flooding and damage to some species in the permanent plot. As a result, there was high mortality of native species, particular *Diospyros mollis* mostly along the river bank. In addition, the death of large trees (*Dipterocarpus alatus* and *Melia azedarach*) through blowdown also initiated in the occasional death of nearby small trees, which created large gaps in the plot. This situation created an opportunity for pioneer species, particular shrub and shrubby tree species, to grow up and become very dense. Thus, this accounted for the doubling in the recruitment rates in the second period. However, the mortality during the second period was two times higher than in the first period. This high mortality was mainly due to increased mortality in the small size class (4.5 cm < DBH < 20 cm), in particular, within the areas where high recruitment had occurred. Indicating a natural thinning process among recently recruited trees began in the latter period. Thus, not only the anthropogenic disturbances but also natural disasters such as flooding can be crucial factors which impact forest regeneration. Changes in the forest regeneration process in tropical forests are affected by various natural disturbances, for example, forest fires prohibited tree regeneration in mixed deciduous forest and deciduous dipterocarp forest (Marod et al., 1999; Sahunalu, 2010), windthrow caused gaps (Bunyavejchewin, 1999) and drought reduced stocking (Feeley et al., 2011). The current research found that flooding was the main cause restricting forest regeneration, particularly for native species.

Table 3. Summary data of the DEF at Wang Nam Khiao Forestry Research and Training Station.

	2002		2009		2016	2002–2016
BA (m^2/ha)	22.52	-	25.71	-	26.29	-
Loss	-	2.66	-	5.72	-	4.19
Gain	-	5.84	-	6.30	-	6.07
Tree density	813	-	791	-	763	-
M (%/year)	-	2.64	-	4.71	-	2.58
R (%/year)	-	2.17	-	4.16	-	2.35
Number of species	79	-	90	-	83	-

During the 14-year period, the relationship between the mortality and recruitment rates of individual tree species with more than 10 stems differed among the species and periods. Some species had higher recruitment than mortality, such as *Leucaena leucocephala* (ll), *Streblus asper* (sa), *Aphanamixis polystachya* (apo) and *Adenanthera pavonina* (ap), while species such as *Diospyros mollis* (dm), *Antidesma sooptepense* (as) and *Melia azedarach* (ma) had high mortality throughout the study period (Figure 1), indicating that various adaptive traits of species can be promoted due to disturbance events. After flooding in the first period, large gaps occurred, particular along river banks and increased light conditions were detected (personal observation). The pioneer species *Leucaena leucocephala*, which prefers high light intensity, had drastically increased in number. This species is classified as an invasive alien species and its establishment prohibited the regeneration of native species (Marod et al., 2012). Intermediate disturbances not only supported pioneer species regeneration but also some native species such as *Adenanthera pavonina* and *Aphanamixis polystachya*. Thus, coexisting species in disturbed areas can be found. In contrast, the flooding disaster prohibited the regeneration of native species such as *Diospyros mollis*, indicating the importance of intermediate disturbances in maintaining tree diversity in this forest (Baker et al., 2005; Connell, 1978).

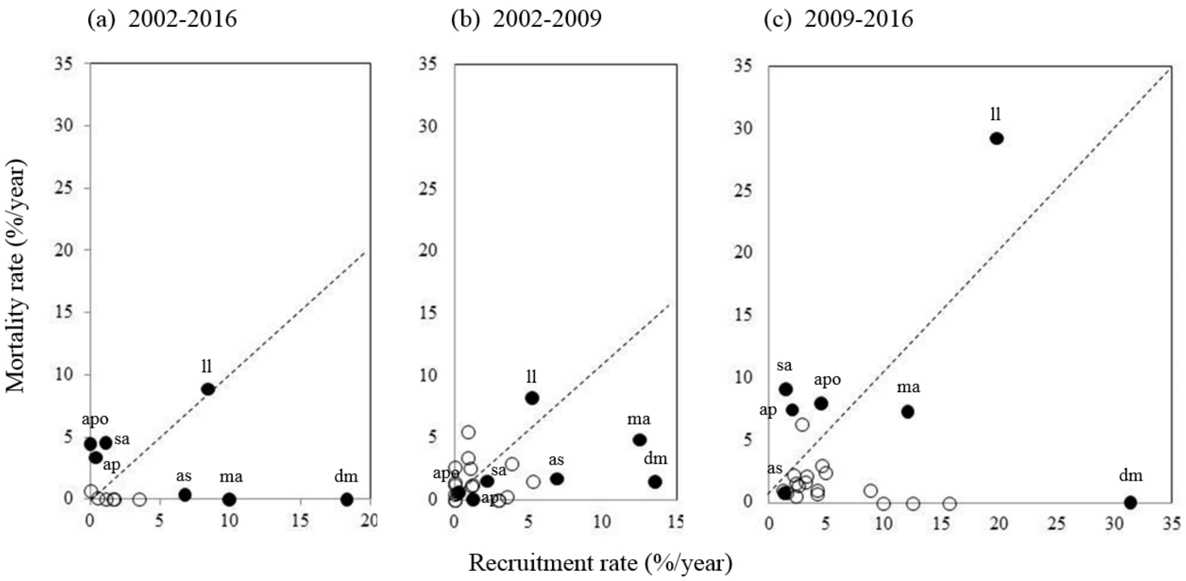

Figure 1. Relationships between recruitment and mortality rates during the 14-year period (a) while (b) and (c) represent the first and the second period, respectively. ll: *Leucaena leucocephala*; sa: *Streblus asper*; apo: *Aphanamixis polystachya*; ap: *Adenanthera pavonina*; dm: *Diospyros mollis*; ma: *Melia azedarach*; as: *Antidesma sooptepense*.

The mean relative growth rate (RGR) of all tree species (DBH ≥ 4.5cm) throughout the study period was 1.57 %/year and varied among periods. The RGR in the first period was slightly lower than in the second period (1.82 %/year and 1.94 %/year, respectively). The RGR in this study is similar to that reported by Sherman et al. (2012) who found that the range of RGR in tropical forest is 0-2 %/year. In addition, the mean RGR of *Afxelia xylocarpa*, *Leucaena leucocephala* and *Mallotus philipensis* showed no significant differences. During the first period, the top canopy and middle canopy species had approximately similar RGR values (Figure 2(a)), while in the second period, the RGR of the middle canopy species, particularly *Senna spectabilis*, *Cinnamomum iners*, *Mallotus philipensis* and *Leucaena leucocephala*, were relatively higher than the top canopy species (Figure 2(b)), even though these species had a lower RGR in the first period. This indicated that the environmental influence changed due to disturbance which provided good opportunities to support the growth of middle canopy species. Furthermore, species of *Afxelia xylocarpa* had similar RGR values in both periods. This species is a late successional tree (Artsamat, 2005) and its growth was straight throughout the periods, suggesting the disturbances would not affect the growth of this species. Thus, disturbance not only maintained the tree diversity (Baker et al., 2005) but also provided suitable environments for plant growth (Schnitzer and Carson, 2001).

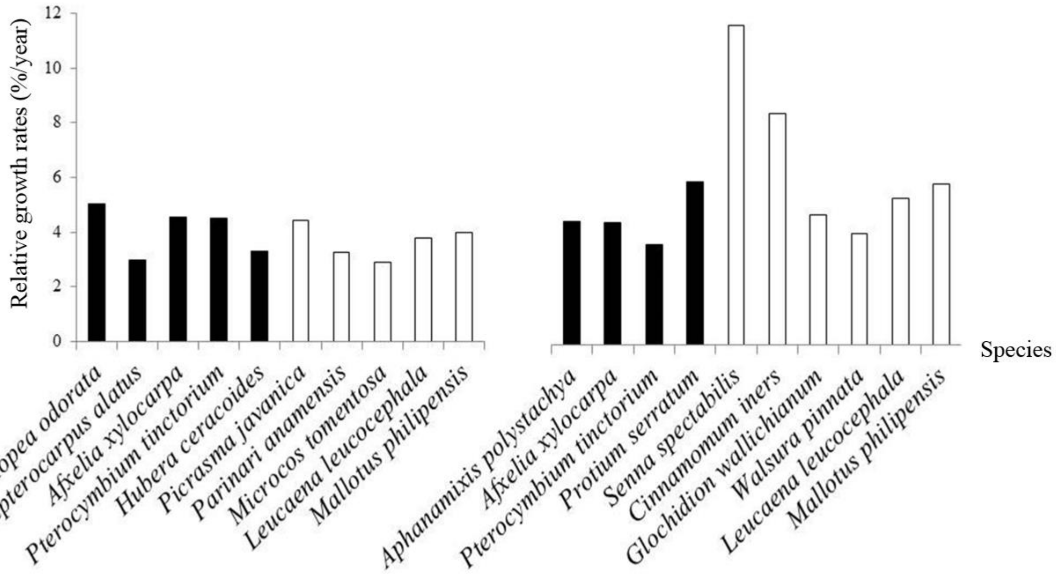

Figure 2. Relative growth rates of the top-10 species in the first (a), and the second (b) period. Filled and unfilled columns indicate top and middle canopy species, respectively.

3.3 Distribution pattern

The Morisita index showed that all selected species were clumped ($I_{\delta} > 1$) and were significantly different in all expanded quadrat sizes (Table 4). The clumped pattern varied among species and stages, sapling and tree. It trended to decrease when expanded quadrats, indicated the intensities of spatial aggregation had decreased. Moreover, the intensity of aggregation for *Cleistanthus papyraceous* saplings was greater than for other species.

A clumped pattern is usually found in tree species in tropical forests and can be influenced by limited dispersal and ecological niches based on environmental factors (Luo et al., 2009; Elias et al., 2011). In the current study, most species were mainly dispersed by wind due to their seeds having a modified structure, such as *Pterocarpus macrocarpus*, *Dipterocarpus alatus* and *Wrightia arborea* (Ashton, 1969; Suzuki and Ashton, 1996). However, this kind of dispersal typically promotes random rather than clumped regeneration. Therefore, the aggregation in these species may have resulted from habitat differentiation. *Dipterocarpus alatus* and *Apanamixis polystachya* were relatively distributed on the lowland nearby streams similar to others reports (Bunyavejchewin et al., 2003; Kumar et al., 2014;

Saldanha and Nicolson, 1976), while *Pterocarpus macrocarpus*, *Wrightia arborea* and *Markhamia stipulata* mostly occupied at the intermediate altitudes where the soil texture was a sandy clay loam. In contrast, *Hydnocarpus ilicifolia* and *Memecylon ovatum* were mostly found on highland and steep slopes. This indicated that habitat differentiation is very important in determining the species distribution pattern (Chu et al., 2014; Miyamoto et al., 2003).

Table 4. Morisita index values for tree and sapling species at difference scales. Significantly different (F test; $p < 0.05$) distributions are in bold. Absence of values indicates that the number of individuals was less than 80.

Species	Quadrat size (m^2)			
	42.9	171.6	686.4	2,745.8
Pterocarpus macrocarpus				
Sapling	-	-	-	-
Tree	**5.00**	**4.22**	**2.81**	**1.45**
Cleistanthus papyraceus				
Sapling	**31.36**	**17.22**	**9.83**	**3.74**
Tree	-	-	-	-
Streblus asper				
Sapling	**5.18**	**2.77**	**1.90**	**1.09**
Tree	**10.93**	**5.87**	**3.05**	**1.17**
Hydnocarpus ilicifolia				
Sapling	**4.20**	**3.26**	**2.64**	**2.26**
Tree	**6.84**	**5.65**	**5.63**	**2.86**
Dipterocarpus alatus				
Sapling	-	-	-	-
Tree	**4.96**	**3.69**	**3.03**	**1.65**
Markhamia stipulata				
Sapling	-	-	-	-
Tree	**5.44**	**4.68**	**1.91**	**2.07**
Aphanamixis polystachya				
Sapling	**10.30**	**6.32**	**3.07**	**2.98**
Tree	-	-	-	-
Leucaena leucocephala				
Sapling	-	-	-	-
Tree	**6.17**	**3.57**	**2.65**	**1.92**
Microcos tomentosa				
Sapling	-	-	-	-
Tree	**10.17**	**4.63**	**2.83**	**1.27**
Memecylon ovatum				
Sapling	**14.95**	**13.08**	**5.91**	**2.46**
Tree	-	-	-	-
Clausena guillauminii				
Sapling	**11.25**	**8.82**	**6.50**	**2.23**
Tree	-	-	-	-
Wrightia arborea				
Sapling	-	-	-	-
Tree	**5.09**	**2.80**	**2.86**	**1.22**
Streblus ilicifolius				
Sapling	**13.59**	**7.81**	**5.46**	**2.59**
Tree	-	-	-	-

In addition, some researchers have reported the effect of disturbance factors on the clumped pattern in tree species (Bunyavejchewin et al., 2003; Elias et al., 2011), due to disturbances influencing the environmental factors in the area; for example, a high light intensity resulting from a dead tree that provides suitable conditions for plant recovery. On the current study site, flooding and former road construction may have been reasons for the environmental changes, resulting in the strong aggregation of *Streblus asper*, *Leucaena leucocephala* and *Microcos tomentosa*. These are pioneer species in the DEF which could have become well-established after gap creation (Schnitzer and Carson, 2001). In particular, there was strong clumping of trees and saplings in *Streblus asper*. Furthermore, *Cleistantus papyraceous*, *Streblus ilicifolius* and *Clauseana guillaumini* are small shrubby trees species which had high intensities of sapling aggregation. Thus, this result indicated that the disturbances that occurred and resulted in environmental changes would be important in determining the clumped pattern.

4. CONCLUSIONS

High species diversity (150 species from 119 genera and 46 families) was found on the Wang Nam Khiao Forestry Research and Training Station. Intermediate disturbances by flooding and large tree fell down strongly affected forest dynamics in which high mortality and recruitment were found after disturbance. Gap creation not only increases species growth, but also maintains pioneer species in the DEF. In addition, a clumped pattern was found in the disturbed areas, indicating habitat heterogeneity as a result of the physical environment being patchy. Thus, intermediate disturbances are important in inducing spatial heterogeneity and internal dynamics which help in forest regeneration.

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REFERENCES

Alados CL, Pueyo Y, Giner ML, Navarro T, Escos J, Barroso F, Cabezudo B, Emlen JM. Quantitative characterization of the regressive ecological succession by fractal analysis of plant spatial patterns. Ecological Modelling 2003;163(1-2):1-17.

Anitha K, Joseph S, Chandran RJ, Ramasamy EV, Prasad SN. Tree species diversity and community composition in a human-dominated tropical forest of Western Ghats biodiversity hotspot, India. Ecological Complexity 2010;7(2):217-24.

Armenteras D, Rodríguez N, Retana J. Are conservation strategies effective in avoiding the deforestation of the Colombian Guyana Shield? Biological Conservation 2009;142(7):1411-9.

Artsamart N. Comparison of Planting Techniques of *Azadirachta indica* A. Juss. var. *siamensis* Valeton and *Afzelia xylocarpa* (Kurz) Craib at Saraburi Province. [dissertation]. Bangkok, Thailand, Kasetsart University; 2005. [In Thai]

Ashton PS. Speciation among tropical forest trees: some deductions in the light of recent evidence. Biological Journal of the Linnean Society 1969;1(1-2):155-96.

Austin MP. Spatial prediction of species distribution: an interface between ecological theory and statistical modelling. Ecological Modelling 2002;157(2-3):101-18.

Baker PJ, Bunyavejchewin S, Oliver CD, Ashton PS. Disturbance history and historical stand dynamics of a seasonal tropical forest in western Thailand. Ecological Monographs 2005;75(3):317-43.

Bunyavejchewin S. Structure and dynamics in seasonal dry evergreen forest in northeastern Thailand. Journal of Vegetation Science 1999;10(6):787-92.

Bunyavejchewin S, LaFrankie JV, Baker PJ, Kanzaki M, Ashton PS, Yamakura T. Spatial distribution patterns of the dominant canopy dipterocarp species in a seasonal dry evergreen forest in western Thailand. Forest Ecology and Management 2003;175(1-3):87-101.

Cao M, Zou X, Warren M, Zhu H. Tropical forests of Xishuangbanna, China. Biotropica 2006;38(3):306-9.

Chairuangsirikul T. Structure of the Dry Evergreen Forest in Thailand. [dissertation]. Bangkok, Thailand: Kasetsart University; 1986. [In Thai]

Chu G, Wang M, Zhang S. Spatial patterns and associations of dominant woody species in desert–oasis ecotone of South Junggar Basin, NW China. Journal of Plant Interactions 2014;9(1):738-44.

Condit R, Hubbell SP, Lafrankie JV, Sukumar R, Manokaran N, Foster RB, Ashton PS. Species-area and species-individual relationships for tropical trees: a comparison of three 50-ha plots. Journal of Ecology 1996;84:549-62.

Connell JH. Diversity in tropical rain forests and coral reefs. Science 1978;199(4335):1302-10.

Eiadthong W. Flora List in Sakaerat Biosphere Reserve and Forestry Field Training Station. [dissertation]. Bangkok, Thailand: Department of Forest Biology, Faculty of Forestry, Kasetsart University; 2000. [In Thai]

Elias R, Dias E, Pereira F. Disturbance, regeneration and the spatial pattern of tree species in Azorean mountain forests. Community Ecology 2011;12(1):23-30.

Feeley KJ, Davies SJ, Perez R, Hubbell SP, Foster RB. Directional changes in the species composition of a tropical forest. Ecology 2011;92(4):871-82.

Houghton RA. Temporal patterns of land-use change and carbon storage in China and tropical Asia. Science in China (Series C) 2002;45(Supp):10-7.

Kent M. Vegetation Description and Data Analysis: A Practical Approach. Oxford, United States of America: John Wiley and Sons; 2012.

Kumar R, Prasanna KT, Gowda B. Evaluation of *Aphanamixis polystachya* (Wall.) R. Parker as a potential source of biodiesel. Journal of Biochemical Technology 2014;3(5):128-33.

Lan G, Zhu H, Cao M, Hu Y, Wang H, Deng X, Zhou S, Cui J, Huang J, He Y. Spatial dispersion patterns of trees in a tropical rainforest in Xishuangbanna, southwest China. Ecological Research 2009;24(5): 1117-24.

Laurance WF. Reflections on the tropical deforestation crisis. Biological Conservation 1999;91(2-3):109-17.

Laurance WF, Ferreira LV, Rankin-de Merona JM, Laurance SG. Rain forest fragmentation and the dynamics of Amazonian tree communities. Ecology 1998;79(6):2032-40.

Laurance WF, Oliveira AA, Laurance SG, Condit R, Nascimento HEM, Sanchez-Thorin AC, Lovejoy TE, Andrade A, D'Angelo S, Ribeiro JE. Pervasive alteration of tree communities in undisturbed Amazonian forests. Nature 2004;428(6979):171-5.

Lee OHK, Williams GA. Spatial distribution patterns of Littoraria species in Hong Kong mangroves. Hydrobiologia 2002;481(1-3):137-45.

Lim Y, Na S-T, Lee S-J, Cho KH, Shin H. Spatial distribution patterns and implications for conservation of *Scrophularia takesimensis* (Scrophulariaceae), an endangered endemic species on Ulleung Island, Korea. Journal of Plant Biology 2008;51(3):213-20.

Luo Z, Ding B, Mi X, Yu J, Wu Y. Distribution patterns of tree species in an evergreen broadleaved forest in eastern China. Frontiers of Biology in China 2009;4(4):531-8.

Mani S, Parthasarathy N. Tree diversity and stand structure in inland and coastal tropical dry evergreen forests of peninsular India. Current Science 2006;90:1238-46.

Marod D, Duengkae P, Kutintara U, Sungkaew S, Wachrinrat C, Asanok L, Klomwattanakul N. The influences of an invasive plant species (*Leucaena leucocephala*) on tree regeneration in Khao Phuluang Forest, northeastern Thailand. Kasetsart Journal (Natural Science) 2012;46:39-50.

Marod D, Kutintara U, Yarwudhi C, Tanaka H, Nakashisuka T. Structural dynamics of a natural mixed deciduous forest in western Thailand. Journal of Vegetation Science 1999;10(6):777-86.

Marod D, Kutintara U. Forest Ecology. Bangkok, Thailand: Department of Forest Biology, Faculty of Forestry, Kasetsart University. 2009. [In Thai]

Miyamoto K, Suzuki E, Kohyama T, Seino T, Mirmanto E, Simbolon H. Habitat differentiation among tree species with small-scale variation of humus depth and topography in a tropical heath forest of Central Kalimantan, Indonesia. Journal of Tropical Ecology 2003;19(1):43-54.

Mohandass D, Davidar P. Floristic structure and diversity of a tropical montane evergreen forest (shola) of the Nilgiri Mountains, southern India. Tropical Ecology 2009;50(2):219-29.

Morisita M. Measuring of the dispersion of individuals and analysis of the distribution patterns. Memoirs of the Faculty of Science, Kyushu University, ser E (Biology) 1959;2:215-35.

Myers N, Mittermeier RA, Mittermeier CG, Da Fonseca GAB, Kent J. Biodiversity hotspots for conservation priorities. Nature 2000;403(6772):853-8.

Naidu MT, Kumar OA. Tree diversity, stand structure, and community composition of tropical forests in Eastern Ghats of Andhra Pradesh, India. Journal of Asia-Pacific Biodiversity 2016;9(3):328-34.

Niamrat W. Seedling Establishment of Climax Species under the Eucalyptus Plantation and Open Site at Wang Nam Khiew Forestry Student Training Station, Amphoe Wang Nam Khiew, Changwat Nakhon Ratchasima. [dissertation]. Bangkok, Thailand, Kasetsart University; 2003. [In Thai]

Oliveira APd, Schiavini I, Vale VSd, Lopes SdF, Arantes CdS, Gusson AE, Júnior JAP, Dias-Neto OC. Mortality, recruitment and growth of the tree communities in three forest formations at the Panga Ecological Station over ten years (1997-2007). Acta Botanica Brasilica 2014;28(2):234-48.

Osman KT. Forest Soils: Properties and Management. Chittagong, Bangladesh: Springer Science and Business Media; 2013.

Sahunalu P. Dynamics of size structure and tree population over 16 years in the long-term dynamics plot of Sakaerat deciduous dipterocarp forest, Northeastern, Thailand. Journal of Forest Management 2010;4(7):19-32.

Sakaerat Environmental Research Station. Meteorological observations [Internet]. 2003 [cited 2017 Dec 20]. Available from: http://www.tistr.or.th/sakaerat/ Meteorlogical.

Sakaerat Environmental Research Station. Meteorological observations [Internet]. 2015 [cited 2017 Nov 12].

Available from: http://www.tistr.or.th/sakaerat/ Meteorlogical.

Saldanha CJ, Nicolson DH. Flora of Hassan District, Karnataka, India. New Delhi, India: Amerind Publishing Company; 1976.

Schnitzer SA, Carson WP. Treefall gaps and the maintenance of species diversity in a tropical forest. Ecology 2001;82(4):913-9.

Shannon CE, Weaver W. The Mathematical Theory of Communication. Illinois, United States of America: University of Illinois Press; 1949.

Sherman RE, Fahey TJ, Martin PH, Battles JJ. Patterns of growth, recruitment, mortality and biomass across an altitudinal gradient in a neotropical montane forest, Dominican Republic. Journal of Tropical Ecology 2012;28(5):483-95.

Smitinand T. Thai Plant Names. Bangkok, Thailand: Department of National Parks, Wildlife and Plant Conservation; 2014. [in Thai]

Suzuki E, Ashton PS. Sepal and nut size ratio of fruits of Asian Dipterocarpaceae and its implications for dispersal. Journal of Tropical Ecology 1996;12(6): 853-70.