BIODIVERSITAS
Volume 25, Number 9, September 2024
Pages: 3141-3153

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d250936

Effects of long-term fire protection on Deciduous Dipterocarp Forest dynamics in Northeastern Thailand

NATTAKARNDA DUANGON[1,2], CHONGRAK WACHRINRAT[3], CHATCHAI NGERNSAENGSARUAY[4], SATHID THINKAMPHEANG[1], SUTHEERA HERMHUK[5], JAKKAPHONG THONGSAWI[6], WONGSATORN PHUMPHUANG[8,9], ANUSORN KULLAWONG[7], ARERUT YARNVUDHI[8], DOKRAK MAROD[1,8,♥]

[1]Department of Forest Biology, Faculty of Forestry, Kasetsart University. 50 Phahonyothin Rd, Chatuchak District, Bangkok 10900, Thailand. Tel.: +66-2-579-0176, Fax.: +66-2-942-8107, ♥email: ffordrm@ku.ac.th

[2]Royal Forest Department. 61 Phahonyothin Rd, Chatuchak District, Bangkok 10900, Thailand

[3]Department of Silviculture, Faculty of Forestry, Kasetsart University. 50 Phahonyothin Rd, Chatuchak District, Bangkok 10900, Thailand

[4]Department of Botany, Faculty of Science, Kasetsart University. 50 Ngamwongwan Rd, Chatuchak District, Bangkok 10900, Thailand

[5]Faculty of Agricultural Production, Maejo University. Nong Han Sub-district, San Sai District, Chiang Mai Province 50290, Thailand

[6]Border Patrol Police Sub-division 41. Mueang Chumphon District , Chumphon Province 86000, Thailand

[7]Research Management and Academic Services Division, Kasetsart University. Chalermphakiat, Sakon Nakhon Province Campus, Mueang Sakon Nakhon District, Sakon Nakhon Province 47000, Thailand

[8]Cooperation Centre of Thai Forest Ecological Research Network, Department of Forest Biology, Faculty of Forestry, Kasetsart University. 50 Phahonyothin Rd, Chatuchak District, Bangkok 10900, Thailand

[9]Department of National Parks, Wildlife and Plant Conservation. 61 Phahonyothin Rd, Chatuchak District, Bangkok 10900,Thailand

Manuscript received: 5 August 2024. Revision accepted: 19 September 2024.

Abstract. *Duangon N, Wachrinrat C, Ngernsaengsaruay C, Thinkampheang S, Hermhuk S, Thongsawi J, Phumphuang W, Kullawong A, Yarnvudhi A, Marod D. 2024. Effects of long-term fire protection on Deciduous Dipterocarp Forest dynamics in Northeastern Thailand. Biodiversitas 25: 3141-3153.* Forest fires are a significant problem that is often unmanaged, particularly their effect on tree regeneration. We aimed to clarify the forest dynamics and effects of climbers on tree regeneration after fire protection in a Deciduous Dipterocarp Forest in Northeastern Thailand. In 2004, permanent plots of 4 ha were established, and all trees with a Diameter at Breast Height (DBH) larger than 4.5 cm were labeled, measured, and identified. Monitoring was conducted in 2017 and 2022 when all trees with a DBH of more than 2 and 1 cm, respectively, were included and measured. The 92 species comprised 72 genera and 35 families with low species diversity. Tree density and basal area (DBH≥1 cm) were 22.01 m^2 ha^{-1} and 1,740 stem ha^{-1}, respectively. The average recruitment rate was higher than the mortality rate throughout the study period (9.43 and 0.51 % y^{-1}, respectively). However, it varied between periods. Long fire protection from 2004 to 2017 promoted the highest tree recruitment (12.67 % y^{-1}, about 60 times to mortality rate) and regeneration of climbers on tree stems. It induced slightly higher mortality rates from 2017-2022, and approximately 18.87% of dead trees were damaged by dense climber cover. Our findings can help evaluate forest sustainability and support the planning of forest fire management strategies preserving species diversity in other tropical dry forests.

Keywords: Climbers, fire protection, long-term ecological research, size class distribution, tropical dry forests

INTRODUCTION

Tropical forests encompass <5% of Earth's terrestrial area (Dinerstein et al. 2017) and are the most biodiverse ecosystems (Lewis et al. 2015; Pillay et al. 2022). Tropical Dry Forests (TDFs) grow in regions with a markedly dry season, in which drought stress is indexed mostly by precipitation and temperature (Powers et al. 2018; Stan et al. 2021; Zou et al. 2021). Some tree species defoliate during the dry season, depending on the severity of the moisture deficit (Allen et al. 2017). The structure of a TDF is simpler than that of a tropical rainforest, with fewer tree strata and less luxuriant growth of climbing and herbaceous plants. Challenging dry conditions limit the number of species that can survive and thrive (Allaby 2006; Stan and Sanchez-Azofeifa 2019). Accounting for a large proportion (approximately 40%) of all tropical forests (Siyum 2020), TDFs are reported to play substantial roles in climate mitigation and adaptation measures by significantly contributing to global carbon stock (Kreier 2022) and supporting and regulating various ecosystem services (regulating local and global weather patterns, maintaining water cycles, and supporting complex food) (Artaxo et al. 2022). Despite their extensive coverage and manifold significance, TDFs are currently severely threatened by the interplay between anthropogenic and natural factors, including pressures from agricultural encroachment, climate change, fire, and population explosion (Djoudi et al. 2015; Sunderland et al. 2015; Lara-Reséndiz et al. 2024), which have a considerable impact on forest dynamics and carbon balance (Martínez-Vilalta and Lloret 2016). Nevertheless, they are still among the least studied ecosystems (Siyum 2020).

Apart from Mixed Deciduous Forest (MDF), Deciduous Dipterocarp Forest (DDF) is Thailand's central tropical deciduous forest. These two forests tended to have overlapping distributions, but DDF had a narrower covered area. It often occupies areas with severe drought, particularly in the dry season, and lateritic and sandy soils are characterized by dense rock-out crops with a low water retention capacity (Rundel et al. 2017; Hermhuk et al.

2020). Surface fires often occur during the dry season in these forest types, and it is an ecologically important factor that helps maintain certain types of plant communities in TDFs worldwide (Verma et al. 2017; Condé et al. 2019; De Andrade et al. 2020; Kaewsong et al. 2022; Zahed and Bączek-Kwinta 2023). Fire reduces protective vegetation and litter cover, heats the soil, intensifies light within the forest, and lowers soil moisture (Barlow et al. 2016; Marod et al. 2023; Pati et al. 2024). Consequently, it affects various stages of growth and development, including flowering, seed germination, seed dispersion, seedling establishment, and plant mortality (Verma et al. 2017; He et al. 2019; Neeraja et al. 2021). Adapting plants to fire-prone communities, including life forms and regeneration strategies, may promote their survival following a fire (Miller et al. 2019; Malasiya et al. 2022; Tangney et al. 2022). However, suppose the fire has a consistent frequency or occurrence every year. In that case, if the fire has a consistent frequency or occurrence every year, it can burn the biomass of all plants (herbs, climbers, and trees), increasing mortality, particularly at early stages, i.e., seedlings and saplings (Marod et al. 2002, 2004; Trouvé et al. 2020; Pati et al. 2024). Lower fire frequency may promote the establishment and increase the abundance of undergrowth and climber species (Schnitzer 2015; Trouvé et al. 2020; Nieman et al. 2022) which may prohibit the regeneration of these forests (Schnitzer 2015; Yang et al. 2018).

However, the interaction between climbers and tree regeneration under the influence of fire is not well documented, particularly based on long-term forest dynamics plot data. Therefore, this study aims to clarify forest dynamics, with an emphasis on the effects of fire protection and climbers on DDF. The practical application of this knowledge to fire management is crucial for ensuring sustainable plant diversity and conservation in other TDFs, making the research highly relevant and informative for our audience.

MATERIALS AND METHODS

Study area

The study was set up in the DDF at Kasetsart University Chalermphrakiat, Sakon Nakhon Province Campus, Thailand (16°45'-18°15'N 103°15'-104°30' E) (Figure 1). It is a lowland DDF ranging from 170-180 masl, which is located in Northeastern Thailand. The rainy season occurs from May to mid-October, with a mean annual precipitation of 1,300-2,000 mm. The mean temperature is 26.58°C, with January having the lowest and April having the highest temperature (22.35 and 29.12°C, respectively). The soil texture is sandy clay-loam, with a low soil bulk density and an available soil water capacity in the range of 34.37, capacity incent (Aramrak et al. 2017). In the DDF, the four stand clusters, based on a 50% similarity coefficient, were divided as follows: 1) *Pentacme siamensis* (Miq.) Kurz - *Shorea obtusa* Wall. stand or climax species stand, 2) *Aporosa villosa* (Lindl.) Baill. - *Buchanania lanzan* Spreng. stand, 3) *Peltophorum dasyrhachis* (Miq.) Kurz - *Cratoxylum formosum* (Jack) Benth. & Hook. fil. ex Dyer subsp. *pruniflorum* (Kurz) Gogelein stand, and 4) *C. formosum* subsp. *pruniflorum*-*Mitragyna hirsuta* Havil. stand (Marod et al. 2017). In the past, large trees were selected for cutting by local individuals, and they have been protected not only from illegal cutting but also from fire since 2004. At the same time, water drained into the DDF area during the rainy season, which increased the soil moisture content above that of the usual DDF. New environments not only support tree regeneration in different forest types, but also many climbers. Climbers grow rapidly, lean on the trunks of dominant species, and damage trees, leading to high mortality. However, fires occurred in 2004 and 2017 (Marod et al. 2017), and these fires were reprotected up to the present study.

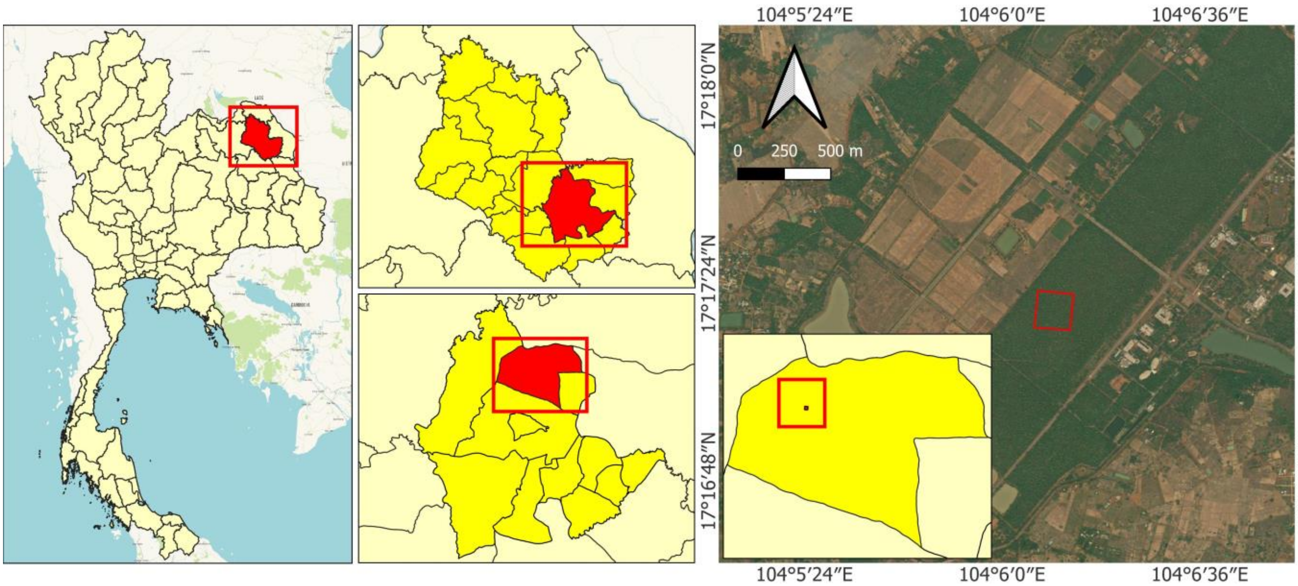

Figure 1. The location of the study area and 4 ha permanent plot in an abandoned area of DDF at Kasetsart University Chalermphrakiat, Sakon Nakhon Province Campus, Thailand

Methods

In 2004, a 4 ha (200 × 200 m) Permanent Sample Plot (PSP) was established in the DDF and divided into subplots (400 subplots, each subplot 10 × 10 m). All trees with a Diameter at Breast Height (DBH, at 1.30 m) ≥4.5 cm had their positions recorded in every subplot during field data collection, and were tagged, measured, and identified based on the methods by Smitinand (2014). Tree monitoring was carried out at 13-year (in 2017 after the fire) and 5-year intervals (in 2022 with 5-year fire protection), in which all trees DBH≥2 and 1 cm were included, respectively. During the recent 2022 monitoring, all climbers, depending on the host tree, were measured DBH (at 1.3 m from the ground) were recorded, for species identification of most climbers was not possible in the field. Therefore, specimens of unidentified species were collected, pressed, dried, and identification was made by botanists at Kasetsart University. In addition, damaged trunk characteristics (broken or dead) were recorded to detect the effect of climbers on tree regeneration.

In this paper, the forest structure and tree regeneration were based on all woody plants with DBH≥1 cm in 2022, while the forest dynamics were considered only for woody plants with DBH≥4.5 cm.

Data analysis

The species composition and forest structure were described in terms of the dominant species, number of stems, and basal area (De Oliveira et al. 2014). The species dominance was defined according to the relative dominance, relative density, relative frequency, and Importance Value Index (IVI), which were estimated following the methods by Kent (2012) for all species by separating them into two groups: saplings (1 cm≤DBH<4.5 cm) and trees (DBH≥4.5 cm).

The size class distribution for all species with at least 30 stems in the 4-ha plot was selected, which included all trees (DBH≥2.0 cm). The population structure across this size range reflects that of larger trees. The size class distribution of each species was defined by the families of probability mass functions fitted to the class frequency. To specifically select the most suitable family of mass distribution, the Anderson-Darling statistic (Anderson and Darling 1952; Liebscher 2016) and probability-probability plot (Chambers et al. 2017) were applied to determine the goodness-of-fit among families of the probability function. Subsequently, the optimal probability function was specified from the set of distribution functions (varied number of parameters) of the selected family using the likelihood ratio test and Akaike information criterion (Akaike 1998). The regeneration status of each tree species was predicted based on the size class distribution.

The Shannon-Wiener Index ($H^{/}$) was analyzed following Shannon and Weaver (1949) according to the equations:

$$H' = -\sum^{s}_{i=1} (Pi) \ln(Pi)$$

Where: Pi is the proportion (n/N) of individuals of one particular species found (n) divided by the total number of individuals found (N).

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

$$M\ (\%) = \frac{\ln(N_0) - \ln(N_S)}{t} \times 100,$$

$$R\ (\%) = \frac{\ln(N_t) - \ln(N_S)}{t} \times 100,$$

Where:

N_t, N_0: The population sizes at times t and 0, respectively

N_s : The number of survivors at time t

RESULTS AND DISCUSSION

Forest structure and species composition

The latest monitoring in 2022 showed that the total trees (DBH≥1 cm) in the DDF permanent sample plot was 4,273 stem ha^{-1}, consisting of 92 species, 72 genera, and 35 families, while the tree density and Basal Area (BA) for DBH≥4.5 cm were 1,740 stem ha^{-1} and 22.01 m^2 ha^{-1}, respectively. The intermediate tree diversity based on the Shannon-Wiener Index ($H^{/}$) was $H^{/}$=2.62. After fire protection, tree density tripled compared to other DDF in Southeast Asia (range of 400-600 stem ha^{-1}) (Bunyavejchewin 1979; Tuan et al. 2021; Ito et al. 2022). Considering mature tree species based on the IVI, DDF species such as *P. siamensis* and *S. obtusa* still dominated the top canopy layer (Table 1). However, we found other climax species (Tables 1 and 2) in the MDF, such as *Xylia xylocarpa* (Roxb.) W. Theob. var. *kerrii* (Craib & Hutch.) I. C. Nielsen and *Pterocarpus macrocarpus* Kurz (Marod et al. 1999), and *Adina cordifolia* (Roxb.) Brandisin Dry Evergreen Forests (DEF) (Muthupandiyan et al. 2019; Singh et al. 2022). In addition, *C. formosum* subsp. *Pruniflorum* has a high population density, particularly during the sapling stage. It had high regeneration after fire protection. A similar result was also reported in low fire frequency in the MDF, Northern Thailand (Chernkhunthod and Hioki 2020). The dominant species composition after fire protection differed from that of other DDF, which mostly belonged to the deciduous Dipterocarpaceae (Nguyen and Baker 2016; Larpkerna et al. 2017; Tuan et al. 2021; Kantasrtla et al. 2023). This indicates that long-term fire protection led to tree species composition shifting to other forest types in succession. The operation of drained water in the DDF increases the soil moisture content and induces the regeneration of evergreen species, such as *A. cordifolia*.

Regeneration of tree species

The characteristics of tree regeneration were explored using DBH class distributions. In total, 34 tree species with populations comprising more than 30 stems were analyzed. DBH classes followed two distributions: Negative Exponential (NE; reverse-J) and Polynomial (PO). Almost all tree species (24 species) were NE forms, while the rest were PO forms. The climax species in DDF in both the top canopy layer (*P. siamensis*, *S. obtusa*, and *Dipterocarpus tuberculatus* Roxb.) (Figures 2.A-2.C) and the middle canopy layer [*Lannea coromandelica* (Houtt.) Merr., *Gluta usitata* (Wall.) Ding Hou, and *Bridelia retusa* (L.) A. Juss] were distributed as PO forms (Table 3).

Table 1. Dominant tree species (DBH≥4.5 cm) in the DDF after fire protection at Kasetsart University Chalermphrakiat, Sakon Nakhon Province Campus, Thailand

Species	Density (stem ha^{-1})	BA (m^2 ha^{-1})	Min DBH (cm)	Max DBH (cm)	Mean DBH (cm)	IVI (%)	Growth form
Pentacme siamensis (Miq.) Kurz	407	11.08	4.68	34.54	17.76	86.37	T
Shorea obtusa Wall. ex Blume	288	2.92	4.62	28.68	10.34	40.97	T
Xylia xylocarpa (Roxb.) W. Theob. var. *kerrii* (Craib & Hutch.) I. C. Nielsen	298	1.51	4.51	26.80	7.41	35.93	T
Adina cordifolia (Roxb.) Brandis	130	1.23	4.50	47.78	9.74	20.87	T
Terminalia elliptica Willd.	97	0.79	4.62	24.86	9.43	16.38	T
Mitragyna hirsuta Havil.	68	0.30	4.50	21.29	6.88	11.41	T
Cratoxylum formosum (Jack) Benth. & Hook. f. ex Dyer subsp. *pruniflorum* (Kurz) Gogelein	75	0.39	4.62	27.06	7.23	11.19	T
Dipterocarpus tuberculatus Roxb.	42	0.55	4.65	28.58	11.81	8.87	T
Canarium subulatum Guillaumin	30	0.49	4.62	31.83	12.84	7.14	T
Buchanania lanzan Spreng.	33	0.25	4.62	23.24	9.04	6.51	T
Morinda tomentosa B. Heyne ex Roth	32	0.19	4.65	21.17	8.15	5.99	T
Aporosa villosa (Lindl.) Baill.	25	0.15	4.62	17.09	8.18	4.46	T
Pterocarpus macrocarpus Kurz	14	0.34	4.48	38.52	14.47	3.87	T
Diospyros castanea (Craib) H. R. Fletcher	18	0.06	4.62	18.11	6.26	3.12	T
Gluta usitata (Wall.) Ding Hou	13	0.26	6.18	29.76	15.13	3.05	T
Hymenodictyon orixense (Roxb.) Mabb.	15	0.10	4.62	27.02	8.41	2.98	T
Lannea coromandelica (Houtt.) Merr.	13	0.07	4.74	13.75	8.02	2.72	T
Phanera bracteata Benth.	15	0.12	4.65	19.45	9.37	2.36	WC
Strychnos nux-vomica L.	7	0.08	5.03	19.42	11.72	1.49	T
Bombax insigne Wall.	6	0.08	5.12	21.58	12.57	1.45	T
other species (53)	114	1.05				22.87	
Total	1,740	22.01				300	

Note: T: Tree; WC: Woody Climber; BA: Basal Area; DBH: Diameter at Breast Height; IVI: Importance Value Index

Table 2. Dominant sapling species (DBH<4.5 cm) in the DDF after fire protection at Kasetsart University Chalermphrakiat, Sakon Nakhon Province Campus, Thailand

Species	Density (stem ha^{-1})	BA (m^2 ha^{-1})	Min DBH (cm)	Max DBH (cm)	Mean DBH (cm)	IVI (%)	Growth form
Xylia xylocarpa (Roxb.) W. Theob. var. *kerrii* (Craib & Hutch.) I. C. Nielsen	546	0.34	1.00	4.49	2.62	57.26	T
Cratoxylum formosum (Jack) Benth. & Hook. f. ex Dyer subsp. *pruniflorum* (Kurz) Gogelein	531	0.24	1.00	4.49	2.23	46.70	T
Mitragyna hirsuta Havil.	327	0.19	1.00	4.44	2.53	36.39	T
Diospyros castanea (Craib) H. R. Fletcher	166	0.08	1.01	4.49	2.34	18.30	T
Adina cordifolia (Roxb.) Brandis	140	0.08	1.01	4.48	2.49	16.44	T
Buchanania lanzan Spreng.	89	0.05	1.01	4.33	2.43	12.85	T
Shorea obtusa Wall. ex Blume	74	0.07	1.32	4.48	3.37	12.45	T
Aporosa villosa (Lindl.) Baill.	67	0.04	1.02	4.45	2.42	9.41	T
Antidesma acidum Retz.	74	0.02	1.00	4.46	1.85	8.37	T
Hymenodictyon orixense (Roxb.) Mabb.	50	0.02	1.02	4.47	2.29	7.24	T
Peltophorum dasyrhachis (Miq.) Kurz	40	0.01	1.01	4.42	1.80	5.57	T
Morinda tomentosa B. Heyne ex Roth	24	0.02	1.07	4.43	2.84	4.48	T
Terminalia elliptica Willd.	24	0.02	1.14	4.46	3.17	4.48	T
Phanera bracteata Benth.	36	0.01	1.00	4.44	1.93	4.25	WC
Casearia grewiifolia Vent.	22	0.01	1.01	4.23	1.94	3.38	T
Canarium subulatum Guillaumin	19	0.01	1.06	4.46	2.92	3.30	T
Pavetta tomentosa Roxb. ex Sm. var. *glabrescens* (Kurz) Bremek.	25	0.01	1.00	3.82	1.87	3.28	T
Pterocarpus macrocarpus Kurz	17	0.01	1.04	4.34	2.53	3.15	T
Lagerstroemia cochinchinensis Pierre ex Laness.	24	0.01	1.06	4.14	2.57	3.10	T
Antidesma ghaesembilla Gaertn.	22	0.01	1.02	4.44	2.04	2.97	T
other species (68)	216	0.12				36.62	
Total	2,533	1.36				300	

Note: T: Tree; WC: Woody Climber; BA: Basal Area; DBH: Diameter at Breast Height; IVI: Importance Value Index

Table 3. List of species in 2022, DBH ≥2.00 cm, existed in 4-ha plot in the DDF at Kasetsart University Chalermphrakiat, Sakon Nakhon Province Campus, Sakon Nakhon Province, Thailand

Scientific name	Family	D	BA	RBA	DF	IVI	Growth form
Lannea coromandelica (Houtt.) Merr.	Anacardiaceae	0.002	0.309	0.334	PO	3.179	T
Spondias bipinnata Airy Shaw & Forman	Anacardiaceae	0.000	0.085	0.092	-	0.579	T
Buchanania lanzan Spreng	Anacardiaceae	0.009	1.157	1.247	NE	6.287	T
Semecarpus albescens Kurz	Anacardiaceae	0.000	0.005	0.005	-	0.253	T
Gluta usitata (Wall.) Ding Hou	Anacardiaceae	0.002	1.050	1.132	PO	3.444	T
Huberantha cerasoides (Roxb.) Chaowasku	Annonaceae	0.001	0.044	0.047	NE	2.354	T
Miliusa velutina (DC) Hook.f. & Thomson	Annonaceae	0.001	0.121	0.130	-	1.864	T
Wrightia arborea (Dennst.) Mabb.	Apocynaceae	0.000	0.002	0.002	-	0.242	T
Holarrhena pubescens Wall. ex G.Don	Apocynaceae	0.000	0.001	0.001	-	0.121	T
Stereospermum neuranthum Kurz	Bignoniaceae	0.001	0.307	0.331	PO	2.645	T
Oroxylum indicum (L.) Kurz.	Bignoniaceae	0.000	0.001	0.001	-	0.121	T
Bombax insigne Wall.	Bombacaceae	0.001	0.344	0.371	PO	2.174	T
Canarium subulatum Guillaumin	Burseraceae	0.005	2.016	2.173	NE	5.824	T
Salacia chinensis L.	Celastraceae	0.001	0.090	0.097	NE	0.823	T
Terminalia elliptica Willd.	Combretaceae	0.012	3.238	3.490	NE	9.313	T
Terminalia chebula Retz. var. *chebula*	Combretaceae	0.000	0.013	0.014	-	0.494	T
Combretum punctatum Blume	Combretaceae	0.002	0.170	0.183	NE	1.821	WC
Dillenia parviflora Griff.	Dilleniaceae	0.000	0.121	0.131	-	0.738	T
Dillenia obovata (Blume) Hoogland	Dilleniaceae	0.000	0.028	0.030	-	0.398	T
Shorea obtuse Wall.ex Blume	Dipterocarpaceae	0.036	11.953	12.886	PO	26.120	T
Dipterocarpus tuberculatus Roxb.	Dipterocarpaceae	0.004	2.202	2.374	PO	5.874	T
Pentacme siamensis (Miq.) Kurz	Dipterocarpaceae	0.041	44.309	47.766	PO	62.534	T
Diospyros castanea (Craib) H. R. Fletcher	Ebenaceae	0.012	0.523	0.564		6.433	T
Diospyros chretioides Wall. Ex G.Don	Ebenaceae	0.000	0.048	0.052	-	0.788	T
Diospyros montana Roxb.	Ebenaceae	0.000	0.018	0.019	-	0.808	T
Bridelia retusa (L.) A.Juss.	Euphorbiaceae	0.001	0.224	0.242	PO	2.316	T
Phyllanthus emblica L.	Euphorbiaceae	0.000	0.016	0.018	-	1.256	T
Aporosa villosa (Lindl.) Baill.	Euphorbiaceae	0.007	0.716	0.772	NE	5.067	T
Dendrolobium lanceolatum (Dunn) Schindl.	Fabaceae	0.000	0.000	0.000	-	0.120	T
Albizia odoratissima (L.f.) Benth.	Fabaceae	0.000	0.001	0.001	-	0.121	T
Dalbergia assamica Benth.	Fabaceae	0.000	0.046	0.050	-	0.417	T
Dalbergia cultrata Graham ex Benth.	Fabaceae	0.000	0.032	0.034	-	1.017	T
Dalbergia oliveri Gamble	Fabaceae	0.001	0.052	0.056	-	1.236	T
Xylia xylocarpa (Roxb.) W. Theob. var. *kerrii* (Craib & Hutch.) I. C. Nielsen	Fabaceae	0.066	7.255	7.821	NE	30.415	T
Pterocarpus macrocarpus Kurz	Fabaceae	0.003	1.389	1.498	PO	4.512	T
Albizia lebbeck (L.) Benth.)	Fabaceae	0.000	0.012	0.013	-	0.373	T
Phanera bracteata Benth	Fabaceae	0.003	0.524	0.565	NE	3.649	WC
Bauhinia saccocalyx Pierre	Fabaceae	0.001	0.153	0.164	NE	1.638	ST/T
Senna garrettiana (Craib) H. S. Irwin & Barneby	Fabaceae	0.001	0.201	0.217	-	2.094	T
Peltophorum dasyrachis (Miq.) Kurz	Fabaceae	0.002	0.489	0.527	NE	2.824	T
Quercus kerrii Craib	Fagaceae	0.000	0.044	0.047	-	0.783	T
Casearia grewiifolia Vent.	Flacourtiaceae	0.001	0.132	0.143		2.309	T
Flacourtia indica (Burm.f.) Merr.	Flacourtiaceae	0.000	0.015	0.016	-	0.504	ST/T
Cratoxylum cochinchinense (Lour.) Blume	Hypericaceae	0.000	0.009	0.010	-	0.265	T
Cratoxylum formosum (Jack) Benth. & Hook. f. ex Dyer subsp. *pruniflorum* (Kurz) Gogelein	Hypericaceae	0.035	2.317	2.498	PO	15.456	T
Irvingia malayana Oliv.ex A.W.Benn.	Irvingiaceae	0.000	0.082	0.088	-	0.688	T
Vitex peduncularis Wall. Ex Schauer	Lamiaceae	0.000	0.141	0.152	-	1.534	T
Gmelina arborea Roxb.	Lamiaceae	0.000	0.135	0.146	-	0.762	T
Litsea glutinosa (Lour.) C.B.Rob.	Lauraceae	0.000	0.003	0.003	-	0.364	T
Careya arborea Roxb.	Lecythidaceae	0.000	0.119	0.128	-	0.616	T
Strychnos nux-vomica L.	Loganiaceae	0.001	0.347	0.374		2.463	T
Lagerstroemia cochinchinensis Pierre ex Laness.	Lythraceae	0.002	0.231	0.249	NE	2.842	T
Lagerstroemia calyculata Kurz	Lythraceae	0.000	0.174	0.188	-	1.186	T
Lagerstroemia venusta Wall. ex C.B.Clarke	Lythraceae	0.000	0.015	0.016	-	0.384	T
Lagerstroemia macrocarpa Wall. ex Kurz	Lythraceae	0.000	0.019	0.020	-	0.388	T
Abutilon hirtum (Lam.)	Malvaceae	0.000	0.004	0.004	-	0.844	T
Berrya cordifolia (Willd.)	Malvaceae	0.000	0.019	0.021	-	0.141	T
Walsura pinnata Hassk.	Meliaceae	0.001	0.266	0.286	NE	2.723	T
Walsura robusta Roxb.	Meliaceae	0.000	0.026	0.029	-	1.410	T
Ficus sp.	Moraceae	0.000	0.066	0.071	-	0.431	T

Ficus rumphii Blume	Moraceae	0.000	0.047	0.050	-	0.186	T
Artocarpus lacucha Roxb. ex Buch.Ham.	Moraceae	0.000	0.055	0.060	-	0.361	T
Ochna integerrima (Lour.) Merr.	Ochnaceae	0.001	0.068	0.074	NE	2.531	T
Anacolosa ilicoides Mast.	Olacaceae	0.001	0.071	0.076	NE	1.213	T
Olax psittacorum (Lam.) Vahl	Olacaceae	0.001	0.067	0.072	NE	1.658	T
Champereia manillana (Blume) Merr.	Opiliaceae	0.000	0.005	0.005	-	0.741	T
Aporosa penangensis (Ridl.) Airy Shaw.	Phyllanthaceae	0.000	0.001	0.001	-	0.121	ST/T
Antidesma ghaesembilla Gaertn.	Phyllanthaceae	0.001	0.165	0.178	NE	2.630	T
Antidesma acidum Retz.	Phyllanthaceae	0.003	0.062	0.067	NE	2.864	T
Ziziphus cambodiana Pierre	Rhamnaceae	0.000	0.003	0.003	-	0.251	T
Mitragyna hirsuta Havil.	Rubiaceae	0.028	1.850	1.995	NE	12.743	T
Neonauclea sessilifolia (Roxb.) Merr.	Rubiaceae	0.001	0.075	0.080	-	1.470	T
Adina cordifolia (Roxb.) Brandis	Rubiaceae	0.022	5.179	5.583	NE	14.482	T
Pavetta tomentosa Roxb. ex Sm. var. *glabrescens* (Kurz) Bremek.	Rubiaceae	0.001	0.028	0.030	-	1.810	T
Pavetta indica L.	Rubiaceae	0.001	0.021	0.022		1.767	T
Gardenia obtusifolia Roxb. ex Kurz	Rubiaceae	0.000	0.003	0.003	-	0.259	T
Catunaregam nutans (DC.) Tirveng.	Rubiaceae	0.000	0.006	0.007	-	0.727	T
Dioecrescis erythroclada (Kurz) Tirveng.	Rubiaceae	0.000	0.044	0.048	-	0.918	T
Catunaregam spathulifolia Tirveng	Rubiaceae	0.000	0.046	0.049	-	1.265	T
Morinda elliptica Ridl.	Rubiaceae	0.000	0.012	0.013	-	0.771	T
Morinda tomentosa B. Heyne ex Roth	Rubiaceae	0.005	0.822	0.886	NE	4.698	T
Hymenodictyon orixense (Roxb.) Mabb.	Rubiaceae	0.004	0.478	0.516	NE	4.044	T
Catunaregam longispina (Roxb. ex Link) Tirveng.	Rubiaceae	0.000	0.001	0.001	-	0.129	ST/T
Canthium parvifolium Roxb.	Rubiaceae	0.000	0.002	0.002	-	0.482	T
Syzygium cumini (L.) Skeels.	Rutaceae	0.000	0.001	0.001	-	0.241	T
Micromelum minutum (G.Forst.) Wight & Arn	Rutaceae	0.000	0.003	0.003	-	0.498	T
Schleichera oleosa (Lour.) Oken	Sapindaceae	0.001	0.203	0.218	-	1.736	T
Grewia eriocarpa Juss.	Tiliaceae	0.000	0.017	0.018	-	1.025	T
		0.326	92.762	100		300	

Note: T: Tree; ST: Shrubby Tree; WC: Woody Climber. D: Density (Stem ha^{-1}); BA: basal area (m^2 ha^{-1}); RBA: relative basal area (%); DF: DBH class form; IVI: important value index (%)

MDF species such as *X. xylocarpa* var. *kerrii* and *Canarium subulatum* Guillaumin (Figures 3.A-3.B), *Huberantha cerasoides* (Roxb.) Chaowasku (Table 3), and DEF species, such as *Walsura pinnata* Hassk. and *Hymenodictyon orixense* (Figures 4.A-4.B) had the NE form, in which a higher population was found in the lower size class and was reduced in larger size classes. After fire protection and water drainage, the MDF and DEF species appeared more stable in maintaining their population than the DDF-dominant species. Because their establishment may cause a lack of successful regeneration of DDF climax species, seedlings and saplings of the DDF species are often weaker, as they are adapted to drought and do not tolerate extremely humid conditions (Marod et al. 2004). Late pioneer species, such as *C. formosum* subsp. *pruniflorum*, *P. dasyrhachis*, and *A. cordifolia* also followed the PO distribution form (Figures 5.A-5.C), and their distribution mainly occupied the canopy gaps, indicating that strong light conditions were important factors for their successful establishment (Swinfield et al. 2016; Sangsupan et al. 2021; Marod et al. 2022). The latter two species were pioneer species in DEF, which required high moisture content after water was drained into the study areas.

Forest dynamics

The forest dynamics after fire protection from 2004 to 2022 (18 years) showed drastic changes in species diversity (from 37 to 73 species), among other forest characteristics. The average BA (DBH≥4.5 cm) was 17.18±7.27 m^2 ha^{-1} and trended to increase. However, it varied among periods; the most increased BA was found between 2004 and 2017 and was almost 2.5 times higher and slightly increased in the latter monitoring (Table 4). A similar trend was observed for tree density dynamics. It increased by approximately 4.6 times (from 347 to 1,750 stem ha^{-1}), which was related to the high recruitment rate, particularly between 2004 and 2017 (Table 4).

Table 4. Summary of the DDF characteristics after fire protection between 2004 to 2022

	2004		2017		2022	Mean±SD
Number of Species	37	-	70	-	73	-
BA ($m^2 \cdot ha^{-1}$)	8.82	-	20.70	-	22.01	17.18±7.27
Loss (m^2 ha^{-1})	-	0.41	-	1.73	-	0.91±0.01
Gain (m^2 ha^{-1})	-	12.29	-	3.04	-	14.10±0.03
Tree density (stem ha^{-1})	347	-	1749	-	1740	1279±807
Recruitment rate (% y^{-1})	-	12.67	-	2.74	-	9.48±7.02
Mortality rate (% y^{-1})	-	0.21	-	2.84	-	0.51±1.86

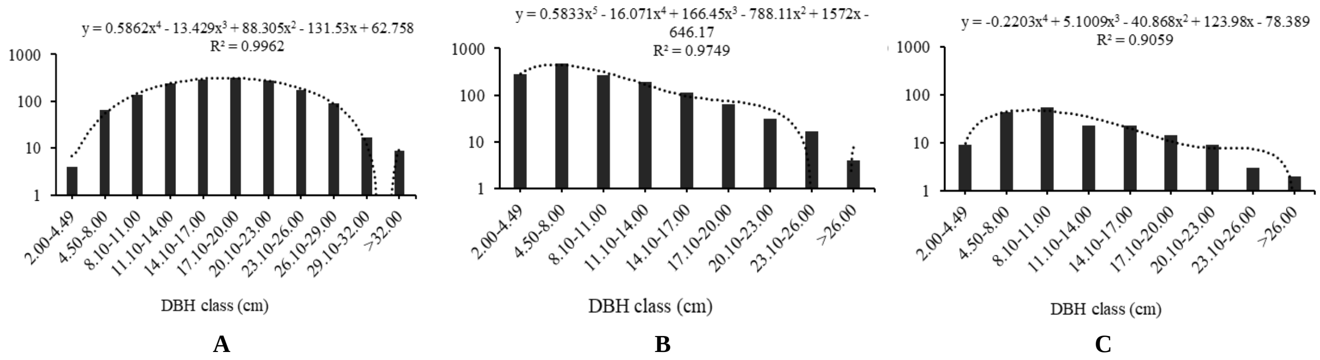

Figure 2. Diameter class distributions plotted on a logarithmic scale for deciduous Dipterocarpaceae species: A. *Pentacme siamensis*; B. *Shorea obtusa*; and C. *Dipterocarpus tuberculatus*. DBH: Diameter at Breast Height

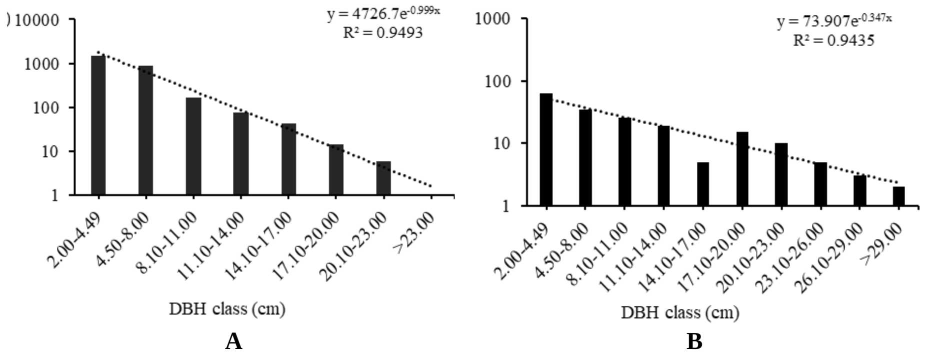

Figure 3. Diameter class distributions plotted on a logarithmic scale for some tree species of MDF: A. *Xylia xylocarpa* var. *kerrii* and; B. *Canarium subulatum*. DBH: Diameter at Breast Height, MDF: Mixed Deciduous Forest

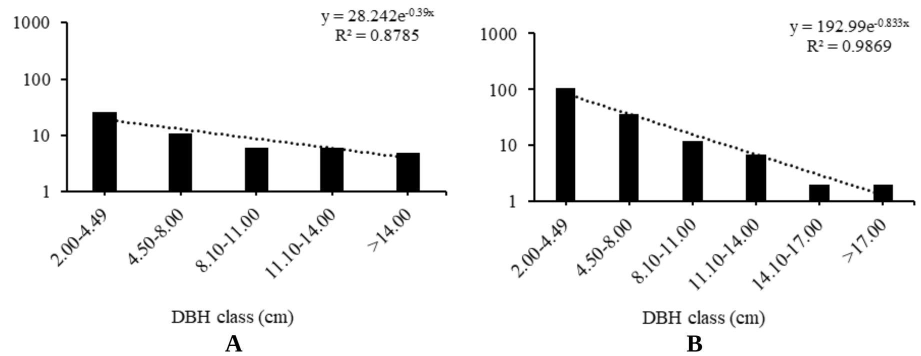

Figure 4. Diameter class distributions plotted on a logarithmic scale for some tree species of DEF: A. *Walsura pinnata*; and B. *Hymenodictyon orixense*. DBH: Diameter at Breast Height, DEF: Dry Evergreen Forests

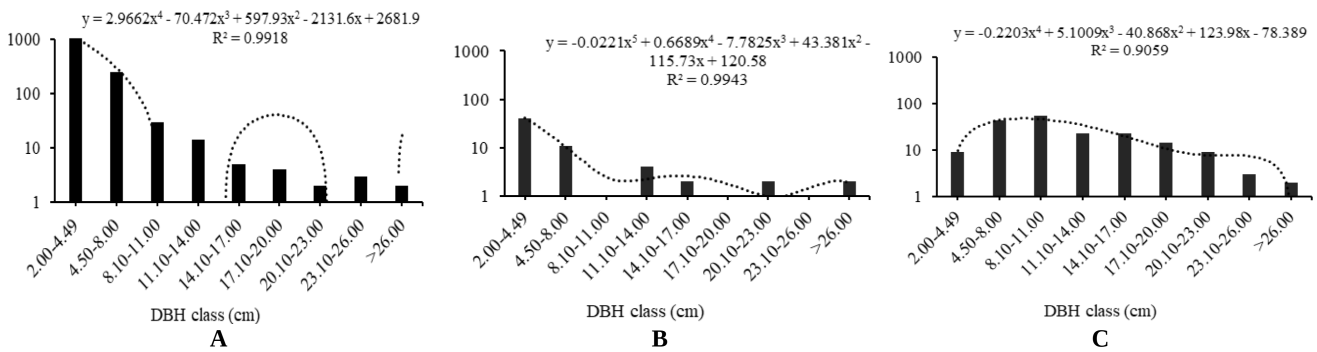

Figure 5. Diameter class distributions plotted on a logarithmic scale for pioneer species: A. *Cratoxylum formosum* subsp. *pruniflorum*; B. *Peltophorum dasyrhachis*; and C. *Adina cordifolia*. DBH: Diameter at Breast Height

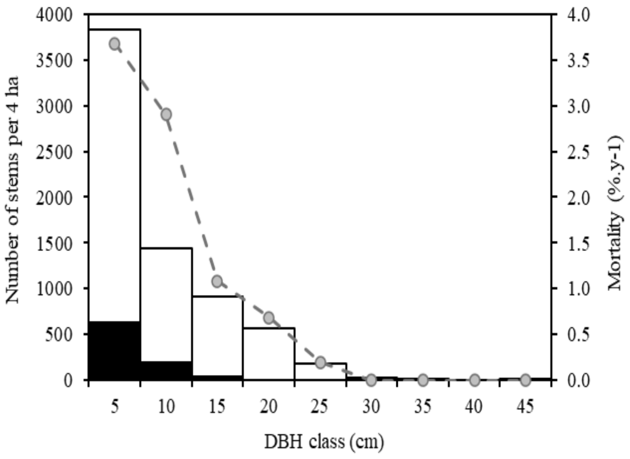

Figure 6. DBH-distribution and size-specific mortality from 2017-2022. The dots and broken lines show the mortality rate in each class. White and black columns show DBH distribution and mortality, respectively. DBH: Diameter at Breast Height

The mortality rate rapidly increased almost 14 times between 2017 and 2022, even though the mortality and recruitment rates were almost balanced, 2.84 and 2.74%.y^{-1}. Size-dependent mortality was detected, in particular small size classes (χ^2 = 1,466.44; df = 2; p<0.001, Figure 6). Indicating long fire protection times in the DDF activated high recruitment rates. A similar result was found in almost a 7-fold higher mortality rate after 4 years of fire protection and subsequent long-wet conditions at Sakaerat Man and Biosphere Reserve, northeastern Thailand (Yatar et al. 2024). However, high tree density is associated with high mortality owing to conspecific negative density dependence (LaManna et al. 2021; Jevon et al. 2022). This study was also similar to the study reported by Comita et al. (2014), Inman-Narahari et al. (2016), and Kellner and Hubbell (2018), who found that recruitment is less in areas of high conspecific density or in regions of high conspecific adults. Plants are unable to survive in the area surrounding adults of their same species, a pattern mediated by density-dependent mortality.

During the 18 years, the relationship between the mortality and recruitment rate of some selected tree species with more than 10 stems showed that all species had a higher average recruitment rate than mortality rate (above 20% y^{-1}), such as *M. hirsuta* (Mh), *H. orixense* (Ho), *Diospyros castanea* (Dc), *X. xylocarpa* var. *kerrii* (Xx), *B. retusa* (Br), *Morinda tomentosa* (Mt), *Terminalia elliptica* (Te), *C. formosum* subsp. *pruniflorum* (Cf), *Miliusa velutina* (Dunal) Hook. f. & Thomson (Mv), and *A. villosa* (Av), whereas that of the remaining species ranged from 5-20% y^{-1})Figure 7.A(. Only species of *Quercus kerrii* Craib (Qk) showed a higher mortality than recruitment rate. However, large variations among species and monitoring periods were also detected (Figures 7.B and Figure 7.C). For instance, in the first period (2004-2017), all selected species had higher recruitment rates than mortality rates, and three species groups could be identified (Figure 7.B). First, the highest recruitment group (above 20% y^{-1}) included the species of *M. hirsuta* (Mh), *H. orixense* (Ho), *D. castanea* (Dc), *X. xylocarpa* var. *kerrii* (Xx), *B. retusa* (Br), *M. tomentosa* (Mt), *T. elliptica* (Te), *C. formosum* subsp. *pruniflorum* (Cf), *M. velutina* (Mv), and *A. villosa* (Av). Second, the intermediate recruitment group (10-20% y^{-1}) included species of *S. obtusa* (So), *A. cordifolia* (Ac), *B. lanzan* (Bl), *Neonauclea sessilifolia* (Roxb.) Merr. (Ns) and *Schleichera oleosa* (Lour.) Oken (Sol), *P. dasyrhachis* (Pd), *Senna garrettiana* (Craib) H. S. Irwin & Barneby (Sg), *D. tuberculatus* (Dt), *Strychnos nux-vomica* L. (Snu), and *Stereospermum neuranthum* Kurz (Sne). Third, the lowest recruitment group (<10% y^{-1}) comprised *C. subulatum* (Cs), *P. macrocarpus* (Pm), *Bombax insigne* Wall. (Bi), *G. usitata* (Gu), and *P. siamensis* (Ps). In the second period (2017-2022), high variation between species was detected (Figure 7.C). The species *Phanera bracteata* Benth. (Pb) still had the highest recruitment rate (22% y^{-1}), whereas that of the remaining species was lower than 10% y^{-1}. Some species showed increased mortality rates, particularly the climax species in the DDF, such as *S. obtusa* (So), *P. siamensis* (Ps), and *D. tuberculatus* (Dt) (Figure 7.C). This indicated that various species adapted to new environments after a long period of fire protection and water being drained into the DDF. High mortality of native and dominant species such as *D. tuberculatus*, *S. obtusa*, and *P. siamensis* occurred after prolonged fire protection, resulting in high soil moisture from the accumulation of litter on the forest floor, preventing water evaporation from the soil. In contrast, high tree densities, which preferred high soil moisture conditions, increased 5-fold from the initial stage after 13-year fire protection (347 to 1,749 stem ha^{-1}), resulting in low light quantity and quality by dense shading (Zhang et al. 2017). These environments are unsuitable for the establishment of the native deciduous Dipterocarpaceae, which prefer high-light-intensity (Phumsathan et al. 2022), and fire protection increases the density of undergrowth on the forest floor, which prevents seed germination (Marod et al. 2002; Chong et al. 2016; Zhang et al. 2023). The new environment supports not only pioneer species that prefer wet conditions but also native species from MDF and DEF, for instance, *P. dasyrhachis*, *H. orixense*, and *C. formosum* subsp. *pruniflorum*, *X. xylocarpa* var. *kerrii*, *W. pinnata*, and *Lagerstroemia calyculata* Kurz, resulting in rapid plant succession in other communities under continuous fire protection (Chazdon and Guariguata 2016; Abbas et al. 2023).

Effects of climbers on tree regeneration

After 18 years of fire protection, many climbers grew rapidly and mostly leaned on tree trunks, with a total of 50 climber species (Table 5).

The most abundant climber species such as *Amphineurion marginatum* (Roxb.) D. J. Middleton, *Dioscorea bulbifera* L., Apocynaceae 1, *Dioscorea glabra* Roxb. and Apocynaceae 2 (4,198, 850, 600, 111, and 104 stems, respectively) were distributed over the entire 4-ha FDP. There were 6,620 climbers found on various tree species, with a total of 83 species. The *X. xylocarpa* var. *kerrii* was the most abundant at 1,432 stems, followed by *S. obtusa*, *C. formosum* subsp. *pruniflorum*, *M. hirsuta*, *P.*

siamensis, and *A. cordifolia* (814, 709, 701, 611, and 411 stems, respectively), and other species range from 1-200 stems. The climbers found on trunks were divided into 2 groups based on DBH-class: small size (0.54±0.37 cm) and large size climbers (3.27±1.54 cm). In addition, small climbers had a higher coverage of trunks than large climbers (5,348 and 1,273 stems, respectively). The total tree mortality between 2017 and 2022 (DBH≥1 cm) was 10.79% (dead trees of the 1,844 stems). However, these dead trees were caused by climbers of about 348 stems (18.87% of total mortality), and small climbers had a larger effect than large climbers, 13.18 and 5.69%, respectively. Mature DDF climax species, such as *S. obtusa*, *P. siamensis*, *D. tuberculatus*, and *M. hirsuta*, were toppled due to climbing climbers and mostly died due to dense covering (Figure 8).

Table 5. List of climber species in 2022, existed in 4-ha plot in the DDF at Kasetsart University Chalermphrakiat, Sakon Nakhon Province Campus, Sakon Nakhon Province, Thailand

Scientific name	Family	D	DBH±SD	Growth form
Thunbergia fragrans Roxb.	Acanthaceae	97	0.49±0.74	Herbaceous climber
Amphineurion marginatum (Roxb.) D. J. Middleton	Apocynaceae	4,189	1.34±1.42	Woody climber
Apocynaceae 1	Apocynaceae	600	0.49±0.67	Herbaceous climber
Apocynaceae 2	Apocynaceae	104	0.49±0.56	Herbaceous climber
Apocynaceae 3	Apocynaceae	54	0.54±0.91	Herbaceous climber
Apocynaceae 4	Apocynaceae	7	0.38±0.35	Herbaceous climber
Apocynaceae 5	Apocynaceae	1	2.23	Herbaceous climber
Apocynaceae 6	Apocynaceae	1	0.27	Herbaceous climber
Ceropegia sp.1	Apocynaceae	1	0.59	Herbaceous climber
Gymnema griffithii Craib	Apocynaceae	1	0.18	Herbaceous climber
Hoya kerrii Craib	Apocynaceae	1	2.39	Herbaceous climber
Streptocaulon juventas (Lour.) Merr.	Apocynaceae	20	0.63±0.93	Herbaceous climber
Araceae 1	Araceae	5	0.80±0.93	Herbaceous climber
Getonia floribunda Roxb.	Combretaceae	1	2.72	Woody climber
Convolvulaceae 1	Convolvulaceae	28	4.23±2.66	Woody climber
Cucurbitaceae 1	Cucurbitaceae	7	0.53±0.28	Herbaceous climber
Neoalsomitra angustipetala (Craib) Hutch.	Cucurbitaceae	1	0.5	Herbaceous climber
Dioscorea alata L.	Dioscoreaceae	92	0.53±0.45	Herbaceous climber
Dioscorea brevipetiolata Prain & Burkill	Dioscoreaceae	99	0.62±0.92	Herbaceous climber
Dioscorea bulbifera L.	Dioscoreaceae	850	0.41±0.41	Herbaceous climber
Dioscorea glabra Roxb.	Dioscoreaceae	111	0.49±0.54	Herbaceous climber
Dioscorea hispida Dennst.	Dioscoreaceae	62	0.58±0.58	Herbaceous climber
Dioscorea sp.1	Dioscoreaceae	87	0.61±0.81	Herbaceous climber
Dioscorea sp.2	Dioscoreaceae	32	0.74±0.93	Herbaceous climber
Diospyros sp.1	Ebenaceae	3	0.74±0.28	Scandent shrub
Abrus melanospermus Hassk.	Fabaceae	11	0.49±0.61	Herbaceous climber
Bauhinia glauca (Wall. ex Benth.)	Fabaceae	5	3.11±1.69	Woody climber
Dunbaria bella Prain	Fabaceae	1	0.24	Herbaceous climber
Indigofera sp.1	Fabaceae (Papilionoideae)	4	0.29±0.02	Herbaceous climber
Indeterminate 1	Indeterminate	11	5.02±1.97	Woody climber
Indeterminate 2	Indeterminate	9	0.68±0.0.62	Scandent shrub
Indeterminate 3	Indeterminate	5	0.32±0.22	Herbaceous climber
Indeterminate 4	Indeterminate	4	0.35±0.18	Herbaceous climber
Indeterminate 5	Indeterminate	4	1.03±0.89	Woody climber
Indeterminate 6	Indeterminate	3	2.07±0.58	Woody climber
Indeterminate 7	Indeterminate	2	0.18±0.06	Herbaceous climber
Indeterminate 8	Indeterminate	2	1.64±1.65	Woody climber
Indeterminate 9	Indeterminate	2	2.45±0.59	Woody climber
Indeterminate 10	Indeterminate	2	1.92±0.17	Woody climber
Indeterminate 11	Indeterminate	1	3.18	Woody climber
Indeterminate 12	Indeterminate	1	0.53	Woody climber
Indeterminate 13	Indeterminate	1	2.3	Woody climber
Indeterminate 14	Indeterminate	1	4.28	Woody climber
Olax psittacorum (Lam.) Vahl	Olacaceae	15	2.97±2.65	Scandent shrub
Jasminum simplicifolium G.Forst.	Oleaceae	1	5.82	Woody climber
Naravelia sp.1	Ranunculaceae	4	2.22±2.19	Herbaceous climber
Smilax bracteata C.Presl	Smilacaceae	4	0.42±0.30	Herbaceous climber
Vitaceae 1	Vitaceae	43	0.99±0.95	Herbaceous climber
Vitaceae 2	Vitaceae	16	1.03±1.44	Herbaceous climber
Vitaceae 3	Vitaceae	14	0.44±0.31	Herbaceous climber
		6,620		

Note: D: Density (stem), DBH±SD: Diameter at Breast Height (cm)

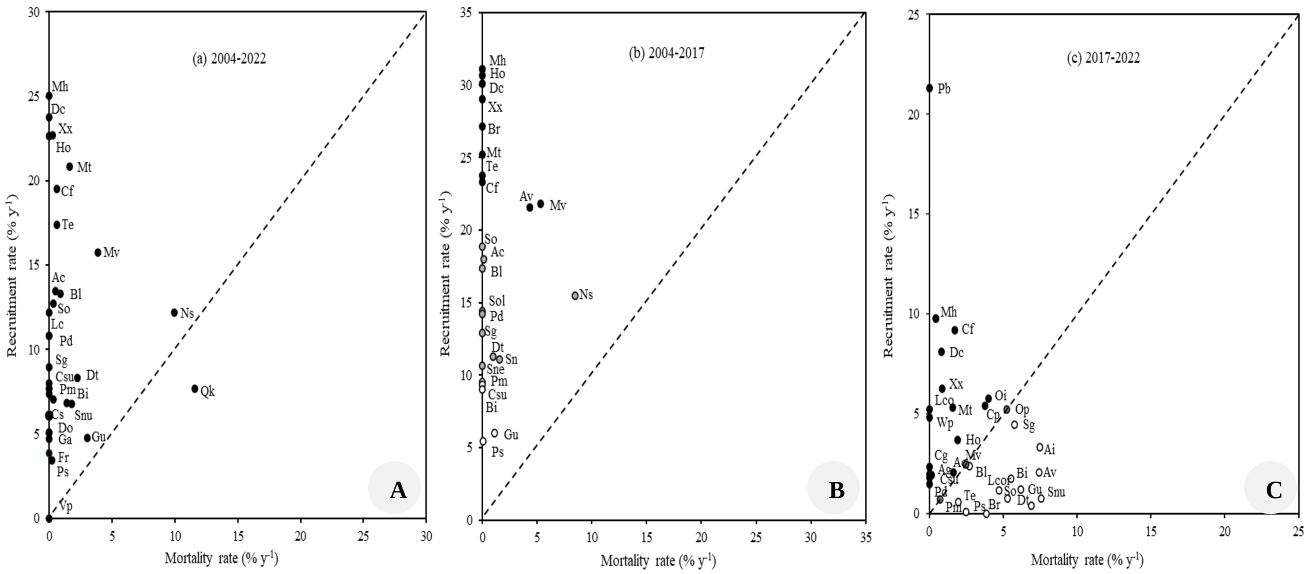

Figure 7. Relationships between recruitment and mortality rates during the 18 years: A., B., and C. represent the first and second periods, respectively, while the broken line indicates the balance between recruitment and mortality rate in each period

Figure 8. Trees were toppled due to the climbing of climbers and died due to dense covering in the DDF after fire protection at Kasetsart University Chalermphrakiat, Sakon Nakhon Province Campus, Thailand. DDF: Deciduous Dipterocarp Forest

This indicates that fire protection allows more climbers to establish and regenerate in the area, similar to the report by Addo-Fordjour et al. (2020), who found that climber species diversity and abundance were highest in areas without fire. In contrast, climber mortality doubles after fire burning (Balch et al. 2015), indicating that fire is a crucial factor that prohibits their regeneration (Phumsathan et al. 2022). In addition, regenerating climbers can alter gap-phase dynamics since the vast majority of climber species have a high demand for light, similar to native species in DDF, and impact tree seedling regeneration (Álvarez-Cansino et al. 2015; Khiewbanyang et al. 2017; Comini et al. 2023; Song et al. 2023). Climbers intensely compete with trees both above and belowground, decreasing tree recruitment, growth, and survival (Martínez-Izquierdo et al. 2016; De Deurwaerder et al. 2018; Ngute et al. 2024) and can cause considerable physical damage to their hosts (Meunier et al. 2021). In addition, high climber abundance caused elevated tree mortality and reduced tree growth due to an increase in competition for light, nutrients, and water (Van Der Heijden et al. 2015).

In conclusion, this study examined forest dynamics, with an emphasis on the effects of fire protection and climbers on the DDF. Our findings reveal that the 18-year fire protection program strongly affected forest dynamics, in which higher recruitment was found, and increased the density of pioneer and dominant species in other forest types. The invasive species showed a DBH class distribution, mostly in the NE form, indicating that they had a robust capacity to maintain a stable population structure in the future. In contrast to the climax species in the DDF, discontinuous DBH class distributions were detected. This was caused by a long period of fire protection, resulting in excessive moisture accumulation, which is unsuitable for their regeneration. In addition, after fire protection, many climbers grew rapidly, mostly leaning on tree trunks. Climbers increase tree mortality, especially in the climax species of the DDF, and climbers toppled these trees. Thus, forest fire management planning should be considered, for example, an appropriate fire frequency that can reduce the establishment of undergrowth and climber species and maintain the climax species in fire-prone communities, such as DDF.

ACKNOWLEDGEMENTS

This research is funded by Kasetsart University, Thailand through the Graduate School Fellowship Program. We would like to thank the Director of Research Management and Academic Services Division, Kasetsart University Chalermphakiat Campus, Sakon Nakhon Province, Thailand, and Research Station, and students from the Thai Forest Ecological Research Network (T-FERN) for all the facilities provided during the study and their help in collecting field data.

REFERENCES

Abbas S, Nichol JE, Irteza SM, Usman M. 2023. Impact of fire on secondary forest succession in a sub-tropical landscape. Forests 14 (5): 865. DOI: 10.3390/f14050865.

Addo-Fordjour P, Kadan F, Rahmad ZB, Fosu D, Ofosu-Bamfo B. 2020. Wildfires cause shifts in liana community structure and liana-soil relationships in a moist semi-deciduous forest in Ghana. Folia Geobot 55: 273-287. DOI: 10.1007/s12224-020-09380-6.

Akaike H. 1998. Information theory and an extension of the maximum likelihood principle. In: Parzen E, Tanabe K, Kitagawa G (eds). Selected Papers of Hirotugu Akaike. Springer, New York. DOI: 10.1007/978-1-4612-1694-0_15.

Allaby M. 2006. A Dictionary of Plant Sciences (Revised eds). Oxford University Press, Oxford.

Allen K, Dupuy JM, Gei MG, Hulshof C, Medvigy D, Pizano C, Salgado-Negret B, Smith CM, Trierweiler A, Van Bloem SJ, Waring BG, Xu X, Powers JS. 2017. Will seasonally dry tropical forests be sensitive or resistant to future changes in rainfall regimes? Environ Res Lett 12: 023001. DOI: 10.1088/1748-9326/aa5968.

Álvarez-Cansino L, Schnitzer SA, Reid JP, Powers JS. 2015. Liana competition with tropical trees varies seasonally but not with tree species identity. Ecology 96 (1): 39-45. DOI: 10.1890/14-1002.1.

Anderson TW, Darling DA. 1952. Asymptotic theory of certain "Goodness of Fit" criteria based on stochastic processes. Ann Math Stat 23 (2): 193-212. DOI: 10.1214/aoms/1177729437.

Aramrak S, Duengkae P, Kullawong A. 2017. Soil. In Study on Development Potential 72nd Years HM. Queen Sirikit Chalemphrakiat Dry Dipterocarp Park at Kasetsart University Chalemphrakiat Sakon Nakhon Province Campus 2nd 2017. Kasetsart University, Chalermphrakiat Sakon Nakhon Province Campus, Sakon Nakhon, Thailand.

Artaxo P, Hansson HC, Machado LAT, Rizzo LV. 2022. Tropical forests are crucial in regulating the climate on Earth. PLoS Clim 1 (8): e0000054. DOI: 10.1371/journal.pclm.0000054.

Balch JK, Brando PM, Nepstad DC, Coe MT, Silvério D, Massad TJ, Davidson EA, Lefebvre P, Oliveira-Santos C, Rocha W, Cury RTS, Parsons A, Carvalho KS. 2015. The susceptibility of Southeastern Amazon forests to fire: Insights from a large-scale burn experiment. BioScience 65 (9): 893-905. DOI: 10.1093/biosci/biv106.

Barlow J, Lennox GD, Ferreira J et al. 2016. Anthropogenic disturbance in tropical forests can double biodiversity loss from deforestation. Nature 535 (7610): 144-147. DOI: 10.1038/nature18326.

Bunyavejchewin S. 1979. Phytosociological Structure and Soil Properties in Nam Pong Basin [in Northeast of Thailand]. Kasetsart University, Thailand.

Chambers J, Cleveland W, Kleiner B, Tukey P. 2017. Graphical Methods for Data Analysis. Chapman and Hall/CRC. New York, USA. DOI: 10.1201/9781351072304.

Chazdon RL, Guariguata MR. 2016. Natural regeneration as a tool for large-scale forest restoration in the tropics: Prospects and challenges. Biotropica 48 (6): 716-730. DOI: 10.1111/btp.12381.

Chernkhunthod C, Hioki Y. 2020. Floristic composition and forest structure in different fire frequency of mixed deciduous forest, Doi Suthep-Pui National Park, Northern Thailand. J Jpn Soc Reveg Technol 46 (2): 202-217. DOI: 10.7211/jjsrt.46.202.

Chong KY, Chong R, Tan LWA, Yee ATK, Chua MAH, Wong KM, Tan HTW. 2016. Seed production and survival of four dipterocarp species in degraded forests in Singapore. Plant Ecol Divers 9 (5-6): 483-490. DOI: 10.1080/17550874.2016.1266404.

Comini IB, Lima GS, Torres CMME, Torres FTP, De Figueiredo LTM, De Camargos VL, Verly OM, Urgal TV, Oliveira LP, Da Rocha SJSS. 2023. Does forest fire modify the diametric distribution of lianas? A study case in a semideciduous seasonal forest with *Araucaria angustifolia* (Bertol.) Kuntze in Brazil. S Afr J Bot 160: 201-208. DOI: 10.1016/j.sajb.2023.06.058.

Comita LS, Queenborough SA, Murphy SJ, Eck JL, Xu K, Krishnadas M, Beckman N, Zhu Y, Gómez-Aparicio L. 2014. Testing predictions of the J anzen- C onnell hypothesis: A meta-analysis of experimental evidence for distance- and density-dependent seed and seedling survival. J Ecol 102 (4): 845-856. DOI: 10.1111/1365-2745.12232.

Condé T, Higuchi N, Lima AJN. 2019. Illegal selective logging and forest fires in the Northern Brazilian Amazon. Forests 10 (1): 61. DOI: 10.3390/f10010061.

De Andrade DFC, Ruschel AR, Schwartz G, De Carvalho JOP, Humphries S, Gama JRV. 2020. Forest resilience to fire in eastern Amazon depends on the intensity of pre-fire disturbance. For Ecol Manag 472: 118258. DOI: 10.1016/j.foreco.2020.118258.

De Deurwaerder H, Hervé-Fernández P, Stahl C, Burban B, Petronelli P, Hoffman B, Bonal D, Boeckx P, Verbeeck H. 2018. Liana and tree below-ground water competition-Evidence for water resource partitioning during the dry season. Tree Physiol 38 (7): 1071-1083. DOI: 10.1093/treephys/tpy002.

De Oliveira AP, Schiavini I, do Vale VS, de Fario Lopes S, de Silvério Arantes C, Gusson AE, Júnior JAP, Dias-Neto OC. 2014. Mortality, recruitment and growth of the tree communities in three forest formations at the Panga Ecological Station over ten years (1997-2007). Acta Bot Bras 28 (2): 234-248. DOI: 10.1590/S0102-33062014000200010.

Dinerstein E, Olson D, Joshi A et al. 2017. An ecoregion-Based approach to protecting half the terrestrial realm. Bioscience 67 (6): 534-545. DOI: 10.1093/biosci/bix014.

Djoudi H, Vergles E, Blackie RR, Koame CK, Gautier D. 2015. Dry forests, livelihoods and poverty alleviation: Understanding current trends. Intl For Rev 17 (S2): 54-69. DOI: 10.1505/146554815815834868.

He T, Lamont BB, Pausas JG. 2019. Fire as a key driver of Earth's biodiversity. Biol Rev 94 (6): 1983-2010. DOI: 10.1111/brv.12544.

Hermhuk S, Chaiyes A, Thinkampheang S, Danrad N, Marod D. 2020. Land use and above-ground biomass changes in a mountain ecosystem, Northern Thailand. J For Res 31: 1733-1742. DOI: 10.1007/s11676-019-00924-x.

Inman-Narahari F, Ostertag R, Hubbell SP, Giardina CP, Cordell S, Sack L. 2016. Density-dependent seedling mortality varies with light availability and species abundance in wet and dry Hawaiian forests. J Ecol 104 (3): 773-780. DOI: 10.1111/1365-2745.12553.

Ito E, Furuya N, Ohnuki Y, Miyamoto K, Araki M, Tamai K, Shimizu T, Iida S, Kanzaki M, Monda Y, Kabeya N, Yaki T, Shimizu A, Toriyama J, Tith B, Keth S, Ly C, Op P, Chann S, Kiyono Y. 2022. Topographical patterns of species composition in a Deciduous Dipterocarp Forest in Kratie Province, Cambodia. Cambodian J Nat Hist 1: 18-37.

Jevon FV, De La Cruz D, LaManna JA, Lang AK, Orwig DA, Record S, Kouba PV, Ayres MP, Matthes JH. 2022. Experimental and observational evidence of negative conspecific density dependence in temperate ectomycorrhizal trees. Ecology 103 (11): e3808. DOI: 10.1002/ecy.3808.

Kaewsong K, Johnson DJ, Bunyavejchewin S, Baker PJ. 2022. Fire Impacts on recruitment dynamics in a seasonal tropical forest in continental Southeast Asia. Forests 13 (1): 166. DOI: 10.3390/f13010116.

Kantasrtla R, Muenrew J, Panyadee P. 2023. Species composition and dynamics of a Deciduous Dipterocarp Forest in Queen Sirikit Botanic Garden, Chiang Mai province. Thai J Bot 15 (1): 1-15.

Kellner JR, Hubbell SP. 2018. Density-dependent adult recruitment in a low-density tropical tree. Proc Natl Acad Sci USA 115 (44): 11268-11273. DOI: 10.1073/pnas.1800353115.

Kent M. 2012. Vegetation Description and Data Analysis: A Practical Approach. 2nd Edition, John Wiley and Sons, Chichester.

Khiewbanyang N, Khudamrongsawat J, Saralamba C, Nathalang A. 2017. The relationships between host tree characteristics and liana climbing success at Mo Singto Forest Dynamics Plot, Khao Yai National Park, Thailand. Trop Nat Hist 17 (1): 1-10.

Kreier F. 2022. Tropical forests have big climate benefits beyond carbon storage. Nature 2022. DOI: 10.1038/d41586-022-00934-6.

LaManna JA, Mangan SA, Myers JA. 2021. Conspecific negative density dependence and why its study should not be abandoned. Ecosphere 12 (1): e03322. DOI: 10.1002/ecs2.3322.

Lara-Reséndiz RA, Álvarez-Yepiz JC, Miles DB, Joos J, Pérez-Delgadillo AG, Méndez-de La Cruz FR. 2024. Climate change and reduced shading restrict the activity period of a threatened tortoise in tropical dry forest. Glob Ecol Conserv 50: e02841. DOI: 10.1016/j.gecco.2024.e02841.

Larpkerna P, Eriksen M, Waiboonya P. 2017. Diversity and uses of tree species in the Deciduous Dipterocarp Forest, Mae Chaem District, Chiang Mai Province, Northern Thailand. Naresuan Univ J Sci Technol 25 (3): 43-55.

Lewis SL, Edwards DP, Galbraith D. 2015. Increasing human dominance of tropical forests. Science 349 (6250): 827-832. DOI: 10.1126/science.aaa9932.

Liebscher E. 2016. Approximation of distributions by using the Anderson Darling statistic. Commun Stat - Theory Methods 45 (22): 6732-6745. DOI: 10.1080/03610926.2014.966844.

Malasiya D, Ray T, Verma S, Rajpoot R, Maurya D, Kumar T, Khare PK, Khan ML. 2022. Effect of forest fire on tree species diversity in the tropical Dry Deciduous Forest of Nauradehi Wildlife Sanctuary, Madhya Pradesh, Central India. Intl J Ecol Environ Sci 48 (3): 381-388. DOI: 10.55863/ijees.2022.0120.

Marod D, Andriyas T, Leksungnoen N, Kjelgren R, Thinkamphaeng S, Chansri P, Asanok L, Hermhuk S, Kachina P, Thongsawi J, Phumphuang W, Uthairatsamee S, Racharak P, Kaewgrajang T. 2023. Potential variables forcing litterfall in a lower montane evergreen forest using Granger and superposed epoch analyses. Ecosphere 14 (6): e4572. DOI: 10.1002/ecs2.4572.

Marod D, Duangkae P, Thongsahwee J, Phumphuang W, Thinkampheang S, Hermhuk S. 2017. Tree stands clustering and carbon stock assessment of Deciduous Dipterocarp Forest at Kasetsart University Chalermphrakiat Sakonnakhon Province Campus, Sakonnakhon Province. Thai For Ecol Res J 1 (1): 1-9. [Thailand]

Marod D, Duengkae P, Sangkaew S, Racharak P, Suksavate W, Uthairatsamee S, Asanok L, Kamyo T, Thinkampheang S, Heumhuk S, Kachina P, Thongsawi J, Phumpuang W, Paansri P, Nuipakdee W, Nakmuenwai P, Pattanakiat S. 2022. Population structure and spatial distribution of tree species in Lower Montane Forest, Doi Suthep-Pui National Park, Northern Thailand. Environ Nat Resour J 20 (6): 1-20. DOI: 10.32526/ennrj/20/202200139.

Marod D, Kutintara U, Tanaka H, Nakashizuka T. 2002. The effects of drought and fire on seed and seedling dynamics in a tropical seasonal forest in Thailand. Plant Ecol 161 (1): 41-57. DOI: 10.1023/A:1020372401313.

Marod D, Kutintara U, Tanaka H, Nakashizuka T. 2004. Effects of drought and fire on seedling survival and growth under contrasting light conditions in a seasonal tropical forest. J Veg Sci 15 (5): 691-700. DOI: 10.1111/j.1654-1103.2004.tb02311.x.

Marod D, Kutintara U, Yarwudhi C, Tanaka H, Nakashisuka T. 1999. Structural dynamics of a natural mixed deciduous forest in western Thailand. J Veg Sci 10 (6): 777-786. DOI: 10.2307/3237302.

Martínez-Izquierdo L, García MM, Powers JS, Schnitzer SA. 2016. Lianas suppress seedling growth and survival of 14 tree species in a Panamanian tropical forest. Ecology 97 (1): 215-224. DOI: 10.1890/14-2261.1.

Martínez-Vilalta J, Lloret F. 2016. Drought-induced vegetation shifts in terrestrial ecosystems: The key role of regeneration dynamics. Glob Planet Change 144: 94-108. DOI: 10.1016/j.gloplacha.2016.07.009.

Meunier F, Verbeeck H, Cowdery B, Schnitzer SA, Smith-Martin CM, Powers JS, Xu X, Slot M, De Deurwaerder HPT, Detto M, Bonal D, Longo M, Santiago LS, Dietze M. 2021. Unraveling the relative role of light and water competition between lianas and trees in tropical forests: A vegetation model analysis. J Ecol 109 (1): 519-540. DOI: 10.1111/1365-2745.13540.

Miller RG, Tangney R, Enright NJ, Fontaine JB, Merritt DJ, Ooi MKJ, Ruthrof KX, Miller BP. 2019. Mechanisms of fire seasonality effects on plant populations. Trends Ecol Evol 34 (12): 1104-1117. DOI: 10.1016/j.tree.2019.07.009.

Muthupandiyan S, Gireesan K, Warrier KCS. 2019. *Haldina cordifolia* (Roxb.) Ridsdale-A promising tree for domestication. Intl J Agric Environ Biotechnol 12 (3): 225-228. DOI: 10.30954/0974-1712.08.2019.6.

Neeraja UV, Rajendrakumar S, Saneesh CS, Dyda V, Knight TM. 2021. Fire alters diversity, composition, and structure of dry tropical forests in the Eastern Ghats. Ecol Evol 11 (11): 6593-6603. DOI: 10.1002/ece3.7514.

Ngute ASK, Schoeman DS, Pfeifer M et al. 2024. Global dominance of lianas over trees is driven by forest disturbance, climate and topography. Glob Change Biol 30 (1): e17140. DOI: 10.1111/gcb.17140.

Nguyen TT, Baker PJ. 2016. Structure and composition of Deciduous Dipterocarp Forest in Central Vietnam: Patterns of species dominance and regeneration failure. Plant Ecol Divers 9 (5-6): 589-601. DOI: 10.1080/17550874.2016.1210261.

Nieman WA, van Wilgen BW, Radloff FGT, Tambling CJ, Leslie AJ. 2022. The effects of fire frequency on vegetation structure and mammal assemblages in a savannah-woodland system. Afr J Ecol 60 (3): 407-422. DOI: 10.1111/aje.12971.

Pati PK, Kaushik P, Malasiya D, Ray T, Khan ML, Khare PK. 2024. Impacts of forest fire frequency on structure and composition of tropical moist deciduous forest communities of Bandhavgarh Tiger Reserve, Central India. Trees For People 15: 100489. DOI: 10.1016/j.tfp.2023.100489.

Phumsathan S, Daonurai K, Kraichak E, Sungkaew S, Teerawatananon A, Pongpattananurak N. 2022. Effects of fire on diversity and aboveground biomass of understory communities in seasonally dry tropical forest in Western Thailand. Sustainability 14 (22): 15067. DOI: 10.3390/su142215067.

Pillay R, Venter M, Aragon-Osejo J, González-del-Pliego P, Hansen AJ, Watson JE, Venter O. 2022. Tropical forests are home to over half of the world's vertebrate species. Front Ecol Environ 20 (1): 10-15. DOI: 10.1002/fee.2420.

Powers JS, Feng X, Sanchez-Azofeifa A, Medvigy D. 2018. Focus on tropical dry forest ecosystems and ecosystem services in the face of global change. Environ Res Lett 13: 090201. DOI: 10.1088/1748-9326/aadeec.

Rundel PW, Boonpragob K, Patterson M. 2017. Seasonal water relations and leaf temperature in a Deciduous Dipterocarp Forest in Northeastern Thailand. Forests 8 (10): 368. DOI: 10.3390/f8100368.

Sangsupan HA, Hibbs DE, Withrow-Robinson BA, Elliott S. 2021. Effect of microsite light on survival and growth of understory natural regeneration during restoration of seasonally dry tropical forest in upland Northern Thailand. For Ecol Manag 489: 119061. DOI: 10.1016/j.foreco.2021.119061.

Schnitzer SA. 2015. The contribution of lianas to forest ecology, diversity, and dynamics. In: Parthasarathy N (eds). Biodiversity of Lianas. Sustainable Development and Biodiversity, vol 5. Springer, Cham. DOI: 10.1007/978-3-319-14592-1_9.

Shannon C, Weaver W. 1949. The Mathematical Theory of Communication. University of Illinois Press, Illinois.

Sherman RE, Fahey TJ, Martin PH, Battles JJ. 2012. Patterns of growth, recruitment, mortality and biomass across an altitudinal gradient in a neotropical montane forest, Dominican Republic. J Trop Ecol 28 (5): 483-495. DOI: 10.1017/S0266467412000478.

Singh MP, Nanjappa MT, Satyanatayana SR, Narayanan A, Renagaian G, Ashtamoorthy SK. 2022. Forest vegetation and dynamics studies in India. In: Carmona EC, Ortiz AC, Canas RQ, Musarella CM (eds). Vegetation Index and Dynamics. IntechOpen, London. DOI: 10.5772/intechopen.97724.

Siyum ZG. 2020. Tropical dry forest dynamics in the context of climate change: Syntheses of drivers, gaps, and management perspectives. Ecol Process 9 (1): 25. DOI: 10.1186/s13717-020-00229-6.
Smitinand T. 2014. Thai Plant Names. Department of National Parks, Wildlife and Plant Conservation, Thailand.
Song S, Schnitzer SA, Ding Y, Wang G, Chen L, Liu J, Wen R, Luan F, Fang X, Yang Q, Song Q. 2023. Light-demanding tree species are more susceptible to lianas than shade-tolerant tree species in a subtropical secondary forest. J Ecol 111 (8): 1656-1669. DOI: 10.1111/1365-2745.14134.
Stan K, Sanchez-Azofeifa A. 2019. Tropical dry forest diversity, climatic response, and resilience in a changing climate. Forests 10 (5): 443. DOI: 10.3390/f10050443.
Stan KD, Sanchez-Azofeifa A, Duran SM, Guzman QJA, Hesketh M, Laakso K, Portillo-Quintero C, Rankine C, Doetterl S. 2021. Tropical dry forest resilience and water use efficiency: An analysis of productivity under climate change. Environ Res Lett 16: 054027. DOI: 10.1088/1748-9326/abf6f3.
Sunderland T, Apgaua D, Baldauf C, Blackie R, Colfer C, Cunningham AB, Dexter K, Djoudi H, Gautier D, Gumbo D, Ickowitz A, Kassa H, Parthasarathy N, Pennington RT, Paumgarten F, Pulla S, Sola P, Tng D, Waeber P, Wilmé L. 2015. Global dry forests: A prologue. Intl For Rev 17 (S2): 1-9. DOI: 10.1505/146554815815834813.
Swinfield T, Afriandi R, Antoni F, Harrison RD. 2016. Accelerating tropical forest restoration through the selective removal of pioneer species. For Ecol Manag 381: 209-216. DOI: 10.1016/j.foreco.2016.09.020.
Tangney R, Paroissien R, Le Breton TD, Thomsen A, Doyle CAT, Ondik M, Miller RG, Miller BP, Ooi MKJ. 2022. Success of post-fire plant recovery strategies varies with shifting fire seasonality. Commun Earth Environ 3: 126. DOI: 10.1038/s43247-022-00453-2.
Trouvé R, Bunyavejchewin S, Baker PJ. 2020. Disentangling fire intensity and species" susceptibility to fire in a species-rich seasonal tropical forest. J Ecol 108 (4): 1664-1676. DOI: 10.1111/1365-2745.13343.
Tuan NT, Bao TQ, Rodríguez-Hernández DI, Gliottone I. 2021. Tree diversity and species composition of tropical dry forests in Vietnam's Central Highlands Region. For Stud 75 (1): 80-103. DOI: 10.2478/fsmu-2021-0013.
Van Der Heijden GMF, Powers JS, Schnitzer SA. 2015. Lianas reduce carbon accumulation and storage in tropical forests. Proc Natl Acad Sci USA 112 (43): 13267-13271. DOI: 10.1073/pnas.1504869112.
Verma SK, Akhtar S, Shrivastava S. 2017. Assessment of particles of varied soil by grain size analysis - A case study in Jabalpur MP. Intl J Eng Res Appl 07 (07): 32-37. DOI: 10.9790/9622-0707093237.
Yang S-Z, Fan H, Li K-W, Ko T-Y. 2018. How the diversity, abundance, size and climbing mechanisms of woody lianas are related to biotic and abiotic factors in a subtropical secondary forest, Taiwan. Folia Geobot 53: 77-88. DOI: 10.1007/s12224-017-9306-z.
Yatar C, Thinkampheang S, Sungkaew S, Wachrinrat C, Asanok L, Kamyo T, Hermhuk S, Kachina P, Thongsawi J, Phumphuang W, Yarnvudhi A, Waengsothorn S, Cheysawat S, Marod D. 2024. The dynamics of Deciduous Dipterocarp Forest in relation to climate variability in the Sakaerat Biosphere Reserve, Northeastern Thailand. Biodiversitas 25 (7): 3088-3098. DOI: 10.13057/biodiv/d250730.
Zahed M, Bączek-Kwinta R. 2023. The impact of post-fire smoke on plant communities: A global approach. Plants 12 (22): 3835. DOI: 10.3390/plants12223835.
Zhang J, Busse M, Wang S, Young D, Mattson K. 2023. Wildfire loss of forest soil C and N: Do pre-fire treatments make a difference? Sci Total Environ 854: 158742. DOI: 10.1016/j.scitotenv.2022.158742.
Zhang R, Hu X, Baskin JM, Baskin CC, Wang Y. 2017. Effects of litter on seedling emergence and seed persistence of three common species on the Loess Plateau in Northwestern China. Front Plant Sci 8: 103. DOI: 10.3389/fpls.2017.00103.
Zou L, Cao S, Zhu Z, Sanchez-Azofeifa A. 2021. Assessment of the response of tropical dry forests to El Niño southern oscillation. Ecol Indic 133: 108390. DOI: 10.1016/j.ecolind.2021.108390.