Fire effects on structure and species composition of mixed deciduous forest in Doi Suthep-Pui National Park, Chiang Mai, Thailand

タイ、ドイステープ・プイ国立公園の落葉混交樹林の構造と種組成に対する山火事の影響

Chonthida CHERNKHUNTHOD

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チャンクントウ・ションティダ

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Chonthida CHERNKHUNTHOD

Approved by
Professor Dr. Yoshiyuki HIOKI
Faculty of Agriculture, Tottori University

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Chonthida CHERNKHUNTHOD (2020)

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Declaration

The thesis is submitted for the degree of Doctor of Philosophy at the United Graduate School of Agricultural Sciences, Tottori University. This dissertation is the result of my own work and has not been and is not being, in part or wholly, submitted for another degree, diploma, or similar qualification.

Chonthida CHERNKHUNTHOD

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Table of Contents

List of Tables

List of Figures

List of Abbreviation

B.E.	: Buddhist Era
cm	: Centimeter
DBH	: Diameter at Breast Height
DDF	: Deciduous Dipterocarp Forest
dNBR	: Differenced Normalized Burn Ratio
DNP	: Department of National Parks, Wildlife and Plant Conservation
H	: Height
HFA	: High Fire Frequency Area
IV	: Importance Value
LFA	: Low Fire Frequency Area
MDF	: Mixed Deciduous Forest
MODIS	: Moderate Resolution Imaging Spectroradiometer
m	: Meter
mm	: Millimeter
MSL	: Mean Sea Level
NBR	: Normalized Burn Ratio
RD	: Relative Density
RDo	: Relative Dominance
RF	: Relative Frequency

CHAPTER 1
Introduction

1.1 Research Background

The Kingdom of Thailand located at the center of the Southeast Asian Indochinese Peninsular. It shares a boundary from north to west with Myanmar, from north to northeast with Lao PDR, along east side with Cambodia and the far south with Malaysia. The total area of the country is 513,115 km^2 or around 51,000,000 ha and the current population in 2019 is 66.56 million people with 0.93% of birth rate per year (Office of the National Economic and Social Development Council, 2020).

The geography in Thailand is divided into 6 parts (Land Development Department, 2020): (1) Northern Mountains and Valleys, most of the terrain in this region is a mountain range stretching in a north-south direction. The important mountain ranges are Dan Lao, Thanon Thongchai, Phi Pan Nam, and Luang Prabang. There is a narrow valley plain between the mountains, where the river flows through, with rich sediment suitable for cultivation. (2) Central Plains, most topographical features are river plains which can be divided into 2 parts: The upper plain above Nakhon Sawan province, the area comprises with rivers, corrugated plains and a sparse mountain. The lower plain located down from Nakhon Sawan to the Gulf of Thailand is a delta plateau with sedimentary soil. (3) Northeastern Mountain Ranges, most topographical features are plateau, shaped like a supine pan with the western and southern edges sloping to the east. The important mountain ranges including Phetchabun, Dong Phaya Yen, San Kamphaeng, and Phu Phan. The central area of the region is a basin namely Korat basin. (4) Eastern Mountains and Plains, Most topographical features are corrugated plains interspersed with mountains and coastal plains and the short rivers. (5) Western Mountain Ranges, most of the terrain is mountains and valleys that stretch from north to south with a narrow flat area. The important mountain ranges are the Tanaosri and Thanon Thongchai, and (6) Southern peninsula, the peninsula is stretched into the sea, with mountains lay down from north to south, the area comprises with short rivers and coastal plains in both east and west side.

Thai Meteorological Department (2020) stated that Thailand is under the influence of two types of monsoons: the southwest monsoon which blowing over Thailand during the middle of May to Mid-October, begins from high pressure areas in the southern hemisphere Indian Ocean Territory which blew out from the center as Northeasterly winds and change to Southwesterly winds when crossing the equator. This monsoon brings moist air mass from the Indian Ocean come to Thailand causing cloudy with a lot of rain especially along the coastal area. After losing the influence of the southwest monsoon around mid-October, the northeast monsoon prevails over Thailand until mid-February. The monsoon originated from high pressure areas in the northern hemisphere, Mongolia and China. Then swept away the cool and dry air from the source to cover Thailand causing a clear sky, cold and arid weather, especially in the northern and northeastern regions. The southern region will have abundant rainfall, because this monsoon brings moisture from the Gulf of Thailand to cover the southern area. Generally, Thailand can be divided into 3 seasons: (1) summer season begins form mid-February to mid-May, the average temperature is between 28.1 – 29.7°C and the maximum temperature is over 40°C (2) rainy season starts from mid-May to mid-October, the average temperature is between 27.3 – 28.3°C and (3) winter season begins from mid-October to mid-February, the average temperature is between 23.4 – 27.0°C and the minimum temperature can be below 0°C in the mountainous area of the northern part. In general, Almost areas of Thailand have 1,200-1,600 millimeters of rain per year. Average annual rainfall throughout the country is approximately 1,587.7 millimeters.

The recent report of forested area in Thailand is 16.4 million hectare or 31.68% of country area (Royal Forest Department, 2019). Thailand is located in the tropics that causing all forests are broadleaf forest. Forests in Thailand can be classified into 2 major types which are evergreen and deciduous forest which shared a proportion cover 44 and 56% of forested area, respectively. The evergreen forest is the area that looks lush throughout the year because almost all trees in this forest type are evergreen species. This forest type is defined as “fire sensitive ecosystem” which easily damage by fire. The important forest types that define into this category including Moist Evergreen Forest, Dry Evergreen Forest, Hill Evergreen Forest, Coniferous Forest, Peat Swamp Forest, Mangrove Swamp Forest, and Beach Forest. The deciduous forest is a forest where deciduous tree species drop all theirs leaves during the dry season and re-spring in the rainy season. This forest type is defined as “fire dependent ecosystem” which has long been subjected to annual fire all nationwide (Stott et al., 1990; Rundel and Boonpragob, 1995). Whelan (1995) stated that the vegetation in this forest type is well adapted to fire, such as have thick bark, a capability to heal fire scars, an ability to resprout through coppicing from dormant buds and lignotubers, and special seed characteristics. The forest types that content in this category are Mixed Deciduous forest, Deciduous Dipterocarp Forest, and Grassland (Royal Forest Department, 2001).

Fire starts with combustion and requires a mixture of heat, fuel and oxygen in suitable proportions (Cochrane and Ryan 2009). After ignition, three main factors drive the behavior of fire: (1) fuel characteristics, including fuel composition, fuel load and arrangement, fuel moisture, and fuel continuity, are crucial determinants of fire behavior; (2) the microclimate, including temperature, relative humidity, and wind, determines the danger of fire and the potential for flammability and fire spreading; (3) the topography, including the elevation, slope angle, aspect, and physiographic characteristics, influences how a fire behaves, i.e., the rate and direction of spread (Graham et al. 2004). The fire frequency is one of a basic elements in fire regime which the most important factor affecting to ecosystem structure and functions, as it is considered as “the ecological rotation” - the time required to return to the pre-burn state before the next successive fire begins. Both too frequent burns and the complete prevention of fire in fire dependent ecosystem may result in ecosystem improvement or even degradation. The fire season in Thailand usually occurs between December and April, with the peak fire period occurring between February and March. The burnt areas recorded annually since 1998 till 2015 have been between 4,078.3 - 51,830.4 ha. The northern part of the country has the most fire incidents: around 64.16% of the total incidents nationwide (Akaakara 2015). The main conditions and factors affecting the occurrence of fire are related to human activities including (1) gathering of non-timber forest products, this includes all local people who enter the forest during the dry season mainly for collecting forest products such as fuel wood, bamboo, honey, mushrooms, etc. These people mainly set fire to clear out litter, grass, and undergrowth on the surface floor in order to make traveling and collecting such products more convenient, (2) illegal hunting, to pursuing small game, rural people set fire to drive the animals from their hiding places, and (3) agricultural debris burning, to prepare agricultural land after harvesting, farmers traditionally set fires without any control, to eliminate the residue, and the fire escapes into the nearby forest. This cause is very serious in areas where shifting cultivation is still widely practiced (Forest Fire Control Division 2017).

In the past decade, many deciduous forests in protected areas especially in the northern part had been experienced an annual burning particularly when a drought increases, causing smoke haze and air pollution which affect the economy, human health, and environment severely. Doi Suthep-Pui National Park is a well-known protected area in Northern Thailand which remarkable level of species diversity, due to its position on the boundary of the Himalayan and Indo-Malaysian biogeographical domains (Elliot et al. 1989), is also facing severe fire situation and affected the local people considerably (Posee 2010). The data from Fire Information for Resource Management System: FIRMS (2019) showed that for each year from 2008 to 2017, there were 16 fire incidents in Doi Suthep-Pui National Park, which represents an increase from the previous period, in which the average was 12. The majority of fire incidents of Doi Suthep-Pui occurred in deciduous forest, even though the vegetation in this forest has a fire-tolerant characters but the ability of any given plant species to tolerate fire has some limited points. It depends largely on maturity, for example, it is well known that bark thickness increases with stem diameter. Thus small and immature trees are more susceptible than larger trees of the same species (Whelan 1995). The concerning point as stated by Goldammer (2002) that too frequent burning obstructs and slowdowns natural regeneration and changes the forest structure in the long term. Frequent fire will be making forests degrade and change to increasingly dry ecosystem, and finally to grassland. In almost all mixed deciduous forests in protected areas of Thailand, including Doi Suthep-Pui National Park, the recent status of floristic composition and forest structure in fire disturbed areas are unknown, as well as the information about the current fuel characteristics and fire behavior which important for strategic fire management planning, including fuel management, fire protection, and fire extinguishing are still lacking.

1.2 Objectives

(1) Investigate fire history in the past decade by investigated latest 10 years fire history from Landsat 7 and 8 imageries via dNBR index and generated fire frequency map.

(2) Describe the current status of floristics composition and forest structure of mixed deciduous forest in different fire frequency areas, by established sample plots for collected floristic characteristic and forest structure data.

(3) Describe the present fuel characteristic and fire behavior of mixed deciduous forest in different fire frequency areas, by established sample plots for collected fuel characteristic data and applied burning experiment for collected fire behavior data.

CHAPTER 2
Theoretical and Conceptual Framework

2.1 Mixed deciduous forest

Mixed deciduous forest, or usually termed as monsoon forest, forms an intensive forest cover in a very broad belt extending from the Ganges River Basin of India through Burma, Thailand and Lao (Rundel, 2009). In Thailand, mixed deciduous forest occupies around 45% of total forested area of the country (Royal Forest Department, 2001) which can be found in north, northeast, western, and central region (Smitinand, 1977). This is often an area of strong seasonality in climate, with the dry season essentially lasts 5-6 months (less than 100 mm rain per month) and average annual rainfall of less than 1,600 mm (Miles et al., 2006). As a result of this severe seasonality, frequent fire is a natural ecological issue. The canopy of mixed deciduous forest is regularly closed and high, often reaching 30 m or in favorable conditions the canopy can be above 40 m (Ogawa et al., 1961; Bunyavejchewin, 1983; Tani et al., 2007). Below this covering, the understory is comparatively open despite a various gathering of undergrowth, shrubs and bamboos forests. In contrast to the evergreen forest formations, lianas and vascular plant epiphytes are uncommon (Rundel, 1999; Rundel & Boonpragob, 1995; Rundel, 2009).

Mixed deciduous forest is characterised by a canopy dominated by a diversity of deciduous species, a drastic importance of members of the Lamiaceae, Fabaceae, Lythraceae, and Combretaceae, along with a relatively low prevalence or absence of Dipterocarpaceae. Dense native stands of bamboo are usually occur, especially in areas with serious human disturbs. Teak (*Tectona grandis*) was once the dominant tree through abundant of this formation, however this species has been heavily logging over the past century in Burma and Thailand. Other wide distribute and codominant woody species embrace members of the family Combretaceae (*Terminalia* spp.), Fabaceae (*Xylia kerii*, *Afzelia xylocarpa*, *Pterocarpus macrocarpus*, and *Dalbergia* spp.), and Lythraceae (*Lagerstoemia* spp.). It has been argued that these forest types are the most species-rich tropical deciduous forests within the world (Elliot et al., 1989).

For Thailand, this type of forest covers huge areas and exhibits abundant variation in composition and structure. Therefore, it has been further divided into several types, as well as moist upper mixed deciduous forest, dry upper mixed deciduous forest, and lower mixed deciduous forest (Smitinand, 1977). Bunyavejchewin (1983) determined tropical dry deciduous forest or mixed deciduous forest into 2 dominance-types which are the *Tectona grandis* type and the *Lagertroemia calyculata* type. The *Tectona grandis* type was divided into 2 sub-types including *Tectona grandis – Xylia kerii* sub-type and *Tectona grandis – Xylia kerii – Terminalia mucronata* sub-type. Other sub-type for this forest type has been classified by Kutintara (2008) using the prevailing of teak and bamboo. The most common bamboo frequent presence within the understory and in gaps including *Gigantochloa albociliata*, *Bambusa tulda*, and *Bambusa nutans* (Kutintara, 1994). The understory layer conjointly covers by a grass and ginger species (Bunyavejchewin, 1983; Bunyavejchewin, 1985; Santisuk, 1988). Podong et al. (2013) reported characters of secondary mixed deciduous forest in western Thailand had low rich and diversity but high density. Dominant species including *Haldina cordifolia*, *Albizia odoratissima* and *Lagerstoemia duperreana*.

This forest type occupies riparian areas and gentle slopes around 100-800 m above MSL (Kutintara, 1975; Smitinand, 1977). It is dominant on deep-toned red and brown latosols that sometimes have a deep top soil (Ogawa et al. 1961). The soils underneath mixed deciduous forest are usually moderately fertile sandy to clay loams of pH 5–6, varied significantly in depth (Bunyavejchewin, 1983; Bunyavejchewin, 1985). The best forests occur on the deeper and better-drained soils. The soil depth has influent on the abundance of tree species among the mixed deciduous forest (Asanok, 2016). Mixed deciduous forest which *Tectona grandis* dominant type reaches its ecological optimum at high levels of calcium and phosphorus. In distinction, *Lagerstoemia calyculata* dominant type achieves its optimum at low level of calcium, phosphorus and potassium content (Bunyavejchewin, 1985).

The phenology of cover trees indicates a complete dominance by a deciduous growth habit, with species nearly equally split between those losing their leaves for fewer than 1 month and those which extended defoliated period. Once the dry season begins in late November, as in northern Thailand, leaf fall usually starts 1-2 months later and continues until the forest becomes defoliated by the end of March. This defoliated period extends for 4-5 months (Rundel, 2009). Marod et al. (2002) reported that most species in tropical seasonal forest have adapted to fire and/or drought by resprouting, seed bank, and/or seedling bank, although the few species which occur mainly in mesic evergreen forests have less adapted to these environments.

2.2 Forest Fire

Forest fires or wildfire have various definition in differ countries and regions. For example, in Europe, the term of forest fire designated to unwanted fires burning in forests and wildland (Tedim et al. 2015). For USA, wildfire is any non-structure fire, other than prescribed fire that occurs in the wildland (Firewise 1998; Wooten 2015). In Australia, there are many different terminology used to describe the fires that occur in vegetation, which are often different emphasis and meaning. The term bushfire is an Australian term that is used to describe unplanned fires that occur in bushland include fires that occur in grass (grassfires), forest (forest fires), scrubs (plants that consist of shrubs; scrub fire) and other plant categories; that is, any fire that happens outside the city (Ellis et al. 2004; Bryant 2008). Brown and David (1973) stated that forest fire is an unclosed and freely spreading combustion which consumes the natural of a forest (i.e. duff, grass, weeds, bush, and tree).

Fire starts with combustion, which must have the right mixture of heat, fuel and oxygen. In the case of forest fires, most of the fuel is carbohydrates derived from biomass of plants such as leaves, wood, humus etc. The combustion process destruct and reform of the chemical bond of photosynthesis product or the process is photosynthesis run in reverse. The total energy in the rearranged bonds that produces the final product is less than the energy in the original substrate bonds. The net change of energy embodied by the chemical bond arrangements is released into heat and light as the equation below:

$$(C_6H_{12}O_6)_n \rightarrow 6nCO_2 + 6nH_2O + energy$$

If the heat is adequate to oxidize continued fuels, the fire then burns continually. The process of volatilized fuels and produces a mass of hot gas that calling flaming combustion. Or, if the combustion is active only on the fuel surface and no flame, the termed is smoldering combustion (Cochrane and Ryan 2009).

2.2.1 Fuel

Plants store energy from sunlight as biomass, and biomass is actually what fuels forest fires. Fuels include living and dead elements of the ecosystem. Forest fuels comprise with leaves, litter, branches, boles, and roots as well as duff, peat, and other forms of soil carbon. Fuel loading mentions to all fuels weight present in the site per unit area. It is a significant parameter, usually use in prognosticating how an area will burn. It is considerable to understand how the fuels are distributed by type (live or dead), size distribution, orientation (standing or fallen), heat content (volatile vs. non-volatile), condition (sound or rotten) and spatial arrangement (Cochrane and Ryan 2009). Estimation of fresh refueling requires knowledge of site composition and structure and dependency on allometric or other proxies for estimation of average biomass and wood density. Fuel bed depth is used to define how tight or pack of fuel, since this will influence on the oxygen availability and the amount of heat transferred to the surrounding fuels. Fuel moisture is a crucial determinant of the flammability of fuel. If a fire cannot convey enough energy to the surrounding fuels before self-smothering then the fire cannot expand. Available fuels are those fuels which truly burn during a given fire. The concept of fuel availability is a basic logic that high-biomass systems like tropical evergreen forests can exist while rarely burning. Given their productivity, there is plenty of fuel that could potentially burn. High humidity beneath intact forest canopies keeps fuels too moist to burn under all but the most severe drought conditions (Cochrane 2003).

Sompoh (1998) reported that in MDF of western Thailand, a total fuel loads was 11.40 ton/ha. The main fuel component was sapling followed by litter, herb, shrub, seedling, and duff. While in DDF, the fuel loads of dead and live fuel were 4.64 and 0.73 ton/ha. The moisture contents of dead and live fuel were 12.43 and 84.81%, respectively and fuel bed depth was 12.57 cm (Wiriya and Kaitpraneet 2009). Wanthongchai et al. (2013) found that the aboveground fuel load in pine forest and pine-oak forest in northeastern Thailand were 1.29 kg/m^2 and 0.87 kg/m^2. The main fuel components in pine forest were grass and litter, whereas leaf litter was the predominant fuel in pine-oak forest. Pine forest requires more than 1 year of fire-free period to recover back to pre-burn conditions. Junpen et al. (2013) mention that in Northern Thailand, the deciduous forests had the average overall fuel load was 3.88 ton/ha which included 2.36 ton/ha of dead leaves and grass and 1.52 ton/ha of twig and undergrowth. The moisture content of overall fuel ranged from 4.52-17%.

2.2.2 Forest fire type

Fires can spread on surface, below, or above the ground, if the structure of the plants allow. The terms used for these fire types are surface fires, ground fires, and crown fires. Individual forest fires can display any or all of these general fire types. Each of these fire types can be described as follow;

(1) Surface fire is a fire that burns surface litter, other loose debris of the forest floor and small vegetation (Wiriya 2009). These fires can be of either flaming or smoldering combustion. As the spread rate of these fire type is regularly low; less than 10 cm/hour. The wind and fuel moisture are main factor that strongly

affected the spread rates and intensity of flaming surface fires (Rowe 1983; Van Wagner 1983; Frandsen 1991; Hungerford et al. 1995; Cochrane and Ryan 2009).

(2) Ground fire consumes the organic material beneath the surface litter of the forest floor such as duff, muck or peat (Wiriya 2009). These fires are generally smoldering combustion and are not much affected by wind or other weather conditions. Ground fires are often started by passing surface fires and can ignite additional or future surface fires as they continue to spread. Ground fires can be extremely difficult to extinguish and may continue for weeks, months, or years. These fires heat and kill the roots of the overlaying vegetation and give off tremendous amounts of particulate emissions (Cochrane and Ryan 2009).

(3) Crown fire is a fire that advances from top to top of trees or shrubs more or less independently of the surface fire (Wiriya 2009). Cochrane and Ryan (2009) mention that this type of fire requires severe drought conditions including low live fuel moisture and/or strong winds. These fires spread very rapidly but are usually short-lived, dropping back to the surface when conditions do not allow for running crown fires. Crown fires consume the foliage of trees and shrubs, thereby severely damaging or killing them.

2.2.3 Forest fire behavior

Generally, fire behavior is defined as the character in which a fire responds to the influences of fuel, weather, and topography. Significant fire characteristics are flame height, flame length, fireline intensity, spread rate, flame depth, and residence time (Cochrane and Ryan 2009).

(1) Flame height

Flame height is the vertical distance from the top of the flame to the fire base. The flame angle is important as it regulates the distance between the flame and the adjacent fuels in the fire spread direction. Fire spread rates will be increased for acute flame angles and decreased for obtuse angles.

(2) Flame length

Flame length is the distance from the peak of the flame to the middle point of the flame base. It is different from the height of the flames, except the fire is take place on the plane ground and in the wind absence condition. If the flame angles is more than 90^{o}, flame length will be greater than flame height. Flame length assessment may essential to give an indication of extinguishment difficulty (Bradshaw et al. 1983) and flame length may be alternative used to give a guide to fire intensity to determine the effects of the fire on vegetation and wildlife (Alexander 1982).

(3) Fireline intensity

Fireline intensity is an estimation of the rate of energy which is emitted by fire. This includes both radiant and conventional heat. The most common of the fireline intensity known as Byram's fireline intensity or frontal fire intensity is the rate of heat energy released per unit time per unit length of fire front, regardless of the depth of the flame zone (Byram 1959).

(4) Rate of spread

The rate of spread is the horizontal length of the moving flame per time unit. It usually mentions the head fire segment of the fire perimeter. The most commonly expressed unit is meter per minute or kilometer per hour. Rate of spread is the primary fire behavior description and its forecast is crucial to gain success in both fire control and application of prescribed burning (Mendes-Lopes et al. 1998). Because the rate of spread can significantly fluctuate over the area of fire, it is normally taken to be an average value over some given period of time. The head of the fire is along the forward-moving perimeter, and generally the fastest rate of spread. In contrast, the slowest rate of spread will be found on the back side of perimeter. The rates of spread along the flanks will be intermediate between the heading and backing rates of spread (Wiriya 2009)

The study in DDF of northeastern Thailand found that fire behaviors was classified as creeping surface fire with the average flame length of 2.58 m. the average rate of fire spread was 2.0 m/min, and the average fire intensity was

266.03 kW/m. (77.15 Btu/ft/sec). It was shown that the more fire frequencies of low fire intensity, the more improvement of the soil properties (Sunyaarch 1989). While in DDF of western Thailand showed a similar fire behavior that the fire spread rate, fireline intensity, and flame length were 1.89 m/min, 190 kW/m, and 0.86 m, respectively (Wiriya and Kaitpraneet 2009). Sompoh (1998) reported that in MDF of western Thailand, the fire line intensity was 91.37 kW/m, flame length was 64 cm. Wanthongchai et al. (2013) reported that fire intensity defined as low in pine-oak forest (48 kW/m) and medium in pine forest (627 kW/m). Soil surface temperature during burning was over 250°C but fire did not cause temperature change in the deeper soil layer. Junpen et al. (2013) stated that fire spread rate in deciduous forest of northern Thailand was ranging from 0.51-2.55 m/min. The fire spread rate of the head fire and flank fire increased with increasing slope whereas the fire spread rate of the back fire decreased with increasing slope.

2.3 Effect of fire on floristic composition and forest structure

The fire effect depends on the intensity, duration and extent of the fire, including the time of year it occurred and the time since the previous fire. Whether or not the effects of fire are seen as beneficial or dangerous are dependent on the views of society and changes over time since the fire occurred (Cochrane and Ryan 2009). The majority of forest fire type in Thailand is surface fire (Akaakara 1995) and fire regime is understory fire which Brown (2000) describes this fire regime type is generally non-fatal to the dominant vegetation and do not substantially change the structure of the dominant vegetation. Approximately 80 percent or more of the aboveground dominant vegetation survives fires. The forest ecosystems, understory fire regimes have the greatest influence on biodiversity within plant communities because the understory vegetation is more affected by fire than the overstory. Baker and Bunyavejchewin (2009) also mention the similar concept that in the strongly seasonal regions of continental Southeast Asia deciduous forests and savannas may burn at low intensity every few years, but have little impact on the majority of trees. The resulted from their study demonstrate that the fires are mostly low-intensity surface fires that generate a low level of mortality across the landscape including seasonal evergreen forest, mixed deciduous forest and deciduous dipterocarp forest.

Fire effects give both positive and negative to the vegetation characteristic and structure of tropical forest across the world. Sunyaarch (1989) reported that in deciduous dipterocarp forest of Thailand, the mortality of understory herbs, forbs, shrubs and grasses induced by a low-intensity surface fire was 100%, while seedling and sapling mortality was 58%. But, there were no significant effects of fire on tree growth. The similar reported from Suthivanit (1989) stated that, in deciduous dipterocarp forest, seedlings with a diameter at the root collar of less than 1 cm are most certainly killed by fire. Fire also reduced the average diameter increments of trees in deciduous dipterocarp forest from 0.44 cm/year in an unburned forest to only 0.24 cm/year in burned forest. Menon et al. (1999) reported that in moist deciduous forest of southern India, fire is more impact on the small trees with have DBH less than 5 cm. The tree species with thick bark such as *Gmelina arborea* and *Pterocarpus marsupium* are more tolerance to fire. Marod et al. (1999) reported the characteristic of mixed deciduous forest in western Thailand was low stem density and basal area and relatively high species diversity. Bamboo undergrowth and frequent forest fire were dominant factors on prevent continuous regeneration. Tree generation could be successful after dieback of bamboo when repeated forest fire did not occurred in subsequent years. While the similar reported from another seasonal mixed evergreen-deciduous tropical forest in western Thailand that the influence of fire and possibly previous agriculture had reflect the characters was a low tree stem density, abundant stems from deciduous, disturbance-specialist species and abundant bamboo (Webb et al. 2011). Another report from the forest in western Thailand found the impact of large fires in 1997-98 which burned across the area created more large gaps in mixed deciduous forest than other forest types. (Baker et al. 2008). Jhariya et al. (2014) stated that in tropical deciduous forest of India, forest fires are driving factor in shaping forest vegetation, biomass accumulation and carbon storage.

Different fire frequency areas reflect different characters of biomass storage. The forest showed the highest tree and seedling biomass storage in low fire zone where as the highest sapling and shrub biomass storage in non-fire zone and high fire zone, respectively. Kachina et al. (2017) reported that the intensity and frequency of fires primarily determine the dynamics of the bamboo population, having potential to alter the forest succession to either less or more bamboo dominating forest community. Peterson and Reich (2001) found that seedling density declined with increasing fire frequency but differentially in each species. Frequent burning prevented development of a sapling layer and canopy ingrowth. Low-frequency burning produced stands with dense sapling thickets. The similar reported from India mention that high fire frequency impedes woody plant in tropical dry forest ecosystems (Schmerbeck and Fiener 2015). The study on the effect of a single fire in tropical dry deciduous forest of India and found that after 2-5 years of fire tree diversity was decreased but for density of tree seedling showed a high value. The diversity could be recovered near its original after 15 years. Fire was encouraged regeneration but affected diversity. The study showed fire has directly effect on diversity of seedling species and after fire occurred it will take at least 15 years for recovery dry deciduous forest to its original (Verma and Jayakumar 2015; Verma et al. 2017). In moist deciduous forest of Chhattisgarh, India, the distribution of tree species were uneven among fire frequency areas. The density of shrub was highest in high fire frequency area and declined following lower to zero fire frequency areas. Fire impede seedling regeneration consequently low tree density in the areas (Kittur et al. 2014).

In contrast, the study in woodland understory found the area had burned twice in 12 years had significantly more plant species, higher shrub density and greater cover than only once burned. The area burned too frequently may lose obligate seedling regenerators, while an area remaining unburned for too long may lose some vegetative regenerating species, and also short-lived obligate seedling regenerators (Fox 1986).

In tropical forests of eastern Amazon, the forest structure and fire damage recorded were substantial variation made consequent extremely heterogeneous burned forests. Increasing fire intensity or frequency made the canopy cover, living biomass and living adult stem densities decreased. Even light burns removed more than 70 percent of the sapling and vine populations. In severely damaged areas, the pioneer species were dominating the understory (Cochrane and Schulze 1999). The similar report from the southeastern Amazonian forests mention that repeated fire caused more mortality rate and less regeneration, species richness and diversity of understory woody plants. Sprouting was increasing over seedling regeneration (Balch et al. 2013) but it would lead to decrease in species diversity (Saha and Howe 2003). Whereas in tropical sub-humid forest in eastern of Bolivia, 60% of trees were die after a year of fire, small trees have a greater mortality rate than larger trees, and mortality varied upon each species. Fire killed liana stems around 75%, 15% of those resprouted and smaller stem of lianas showed ability of resprout than bigger stems. In this area, fires play a role in damaging lianas and herbaceous vines which interrupt seedlings recruitment and obtain fine fuels to support frequent fire (Pinard et al. 1999). Another report from tropical dry forest in lowland Bolivia stated that both high- and low-intensity burns treatments were reduced woody plant density from 50 to 94%. The abundance of tree seedlings were found in all treatment plots more than sprouts. Sprouts were common in low-intensity burned areas than high-intensity burned areas. Mortality of seedlings were higher than sprouts. Sprouts had taller, stems per individual, and larger basal diameters than seedlings (Kennard et al. 2002). The report from southeastern Brazil showed that in seasonally dry tropical forest fragments which affected by a fire in the latest 14 and 25 years, the high frequent burned site showed a major lower value of species richness and diversity than less frequent burned site. However, there was no differ in density and basal area among two sites (Costa et al. 2017). The report from Madagascar stated that in dry deciduous forest, fires which occurred between 1984 and 2009 had significantly effect on decreased tree density, basal area, species richness and diversity of small trees in middle forest layers. These all flora characters could be able to recover in a short time - 12 years (Ehrensperger et al. 2013).

Kafle (2006) reported the deciduous dipterocarp-oak forest which protected against fire for 28 years showed a higher species richness both ground flora and tree species than frequently burnt forest nearby. The greater influence of evergreen or tropophyllous trees and the presence of some shade-loving herbaceous flora in the protected area suggest that the forest environment in the protected area was favored by plant associated with a mixed evergreen and deciduous forest. The greater tree population density in the protected area was a direct consequence of fire protection. This suggests that forest fire protection decreased the killing or damaging of trees, which ultimately leads to increased productivity and organic matter in soil, thus more favorable conditions for growing. However, Wanthongchai et al. (2014) mention that completely fire exclusion may result in change to ecosystem components and an increased risk of high-intensity wildfire and suggested fire-free of at least 6-7 years should be introduced to facilitate the successful recruitment of young trees. Kodandapani et al. (2009) also recommended 6 years fire return interval for dry deciduous forest and gave the opinion that the short rotation of fire on this ecosystem runs the risk of continued erosion of species composition, structure and regeneration.

2.4 Overall Conceptual Framework of the Research

This research determined to describe the last decade (2008-2017) situation of floristic composition, forest structure, fuel characteristic, and fire behavior in mixed deciduous forest with disturbed by fires. The research was divided into 4 subtopic including (1) fire history (10 years, 2008-2017) which intend to generate fire frequency map from Landsat 7, 8 imageries by using dNBR index. Because of fire frequency is a range of fire return interval in forest ecosystem. The frequency of fire can have a strong effect on life cycle attributes, species composition, and community structure. (2) floristic composition and forest structure that needed to establish the sample plots to collecting data and calculate relevant index before describe the vegetation status of the area (3) fuel characteristic also the crucial information, due to the fuel that presents in the area is the consequence of the recent disturbance history. The behaviors and effects of fire will be dominated by fuel, weather, and terrain of the area, and (4) fire behavior is an important factor that shaping the ecological system. To understand the current fire behavior in the study area, burning experiment also needed. The details of overall conceptual framework research indicated in Figure 2.1.

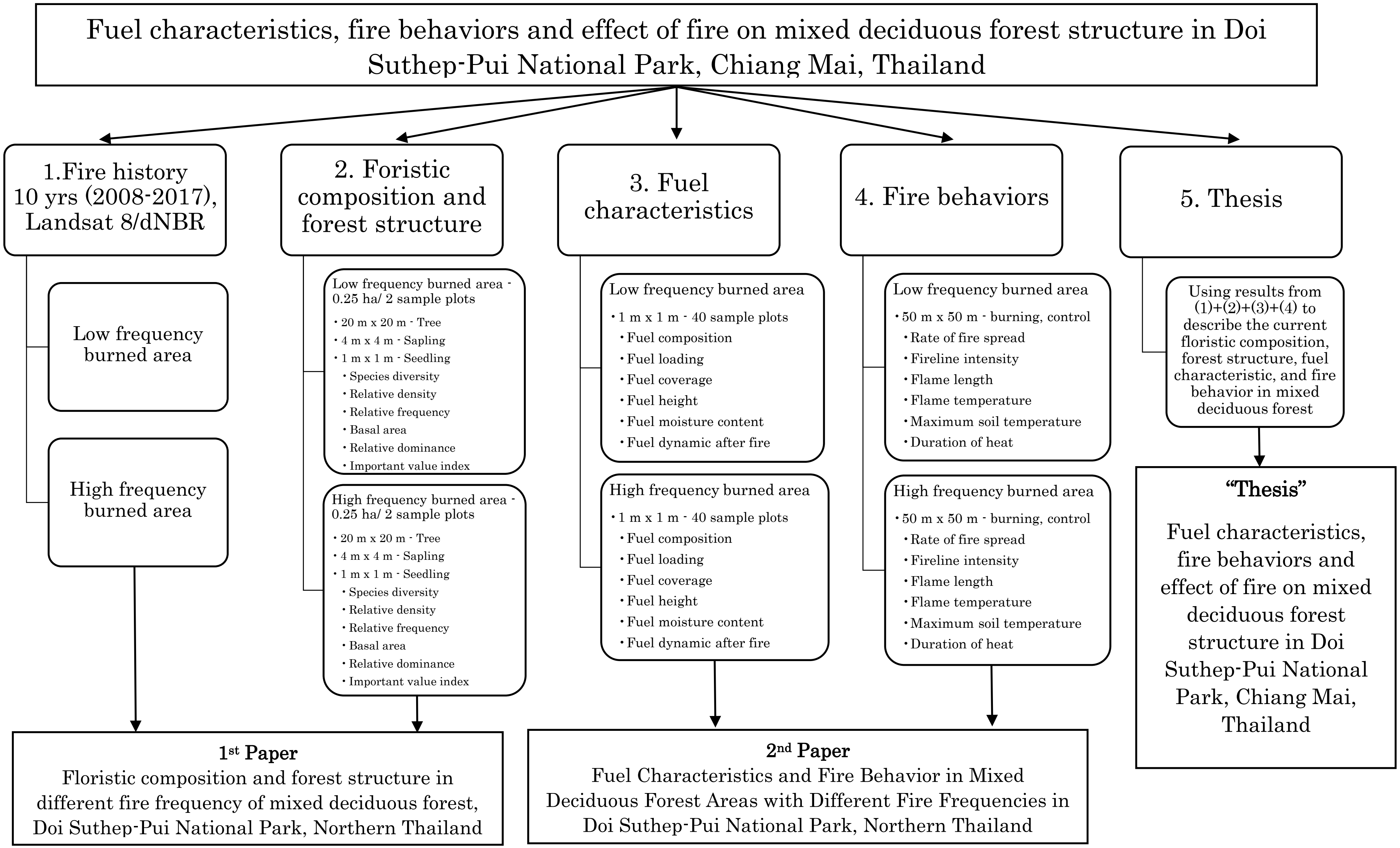

Figure 2.1 Overall conceptual framework of the research

CHAPTER 3

Study Area – Doi Suthep-Pui National Park

3.1 Establishment History

In 1949, there was a Royal Decree determining to be a restricted forest as "Doi Suthep Restricted Forest", which was issued under the Restriction of Land Wasteland Act 1939, which is the public domain of the nation, and announced in the Government Gazette, Book 66, Chapter 28, on May 17, 1949. In 1964, Doi Suthep Restricted Forest is declared a National Forest as "Doi Suthep Forest National Reserved" in accordance with the Ministerial Regulation No. 25 (B.E. 2507) and announced in the Government Gazette, Book 81, Chapter 124, on December 31, 1964. In 1967, it was declared a special national forest reserve as "Doi Suthep Special National Forest" in accordance with the resolution of the Cabinet on January 23, 1967. At the same time, the Royal Forest Department (at that time) was able to establishment of the Northern Experimental Station in this area which to be used as a place to study and research about highland forestry reforestation that replace the encroachment area and experimenting with planting of exotic species such as eucalyptus, pine and many other temperate plants which still remains in many plots in the current national park area. In 1973, the government established a natural richness forest in Doi Suthep area, Chiang Mai Province into a national park. There is a Royal Decree determining Doi Suthep forest areas in Pong Yaeng Subdistrict, Mae Ram Subdistrict, Mae Sa Subdistrict, Don Kaew Subdistrict, Mae Rim Subdistrict, Ban Pong Subdistrict, Hang Dong District and Chang Phueak Subdistrict, Suthep Subdistrict, Mae Hia Subdistrict, Mueang District, Chiang Mai Province to be the Doi Suthep-Pui National Park By announcing in the Government Gazette, Book 98, Section 57, April 14, 1981, covering an area of 16,106 ha or 161.06 square kilometers. And is considered the 24th national park of the country. In 1982, the government was declared in a royal decree, expanded the boundaries of Doi Suthep-Pui National Park covering Mae Sa waterfall, Tad Mok Waterfall - Wang Hang, Mok Fa

Waterfall, and upstream forest areas surrounding all three waterfalls in the area of Sop Poeng Subdistrict, Mae Taeng District and Mae Ram Subdistrict, Pong Yaeng Subdistrict, Mae Rim District, Chiang Mai Province, with an area around 10,000 ha or 100 square kilometers. From the enactment of both recorded in royal decrees, resulting Doi Suthep-Pui National Park has an area covers 26,106 ha or approximately 261.06 square kilometers.

3.2 Physical Condition

3.2.1 Geographic Location

Doi Suthep-Pui National Park is located in the north of Thailand. The national park has cover area of Mueang Chiang Mai District, Mae Rim District, Hang Dong District and Mae Taeng District Chiang Mai Province, between the latitude 18° 43′ to 18° 58′ north and longitude 98° 45′ to 98° 58′ east (Figure 3.1).

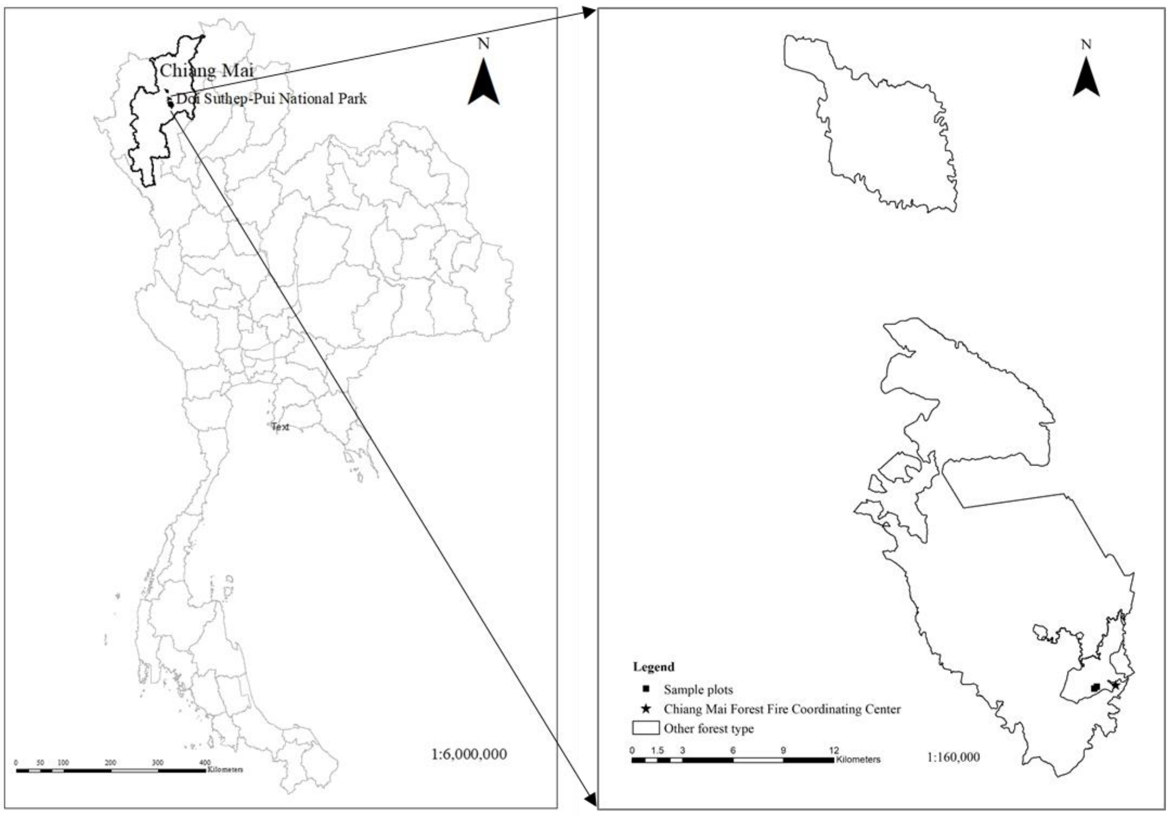

Figure 3.1 Location of Doi Suthep-Pui National Park, Chiang Mai Province, Thailand.

3.2.2 Geological Characteristics

In general, the topography of Doi Suthep-Pui National Park is mountainous, with an elevation of 330 – 1,685 m. The geological structure of the area consists of igneous rock, important types are granite. Granite is a stone that is widely found in the area that occurred in the Triassic era, which contains many minerals such as muscovite, biotite, mica schist, feldspar, etc. There are also sedimentary and metamorphic rock which originated in the pre-Cambrian period. The most important are quartzite and quartz-mica schist which can be found all over the area. The schist, shale and gneiss rocks are abundant in the mixed deciduous forest of Doi Suthep-Pui National Park. Sandstone is found in the upper part of the Park. The limestone is appears in some areas of the park.

3.2.3 Soil Characteristics

Doi Suthep-Pui National Park has richness biodiversity in physical, geomorphic, and climatic characteristics that resulting the soil conditions and properties, both physical and chemical in different areas of the park are varying according to the terrain depending on the type of rock that decay to soil material, moisture of the area, and the type of forest. Generally, in mountainous areas with high moisture condition which suitable for evergreen forest habitat, such as dry evergreen forest and hill evergreen forest. The most common soil is the Doi Pui series are in the Reddish Brown Lateritic - great soil group or in the soil taxonomy - Orthoxic Palehumults which have rocky origins from granite, gneiss and quartzite. The soil in that area is red, well developed, the soil layer quite deep and has a complete layer. The soil texture is loose and has high fertility due to the high amount of organic matter, the soil surface has a humus layer and litter which is quite thick. In addition, this type of soil has a high ability to absorb and drain water. This is because the soil is sandy loam which makes it porous for watering, good draining and ventilation. However, this type of soil is easily erosive, especially when it lacks ground cover plants. Due to the good soil condition, the evergreen forest in the highlands of the park was encroached and converted the area for use in agriculture. In the mixed deciduous forest, most of the soil found in Mae Rim series which belong in the Red Yellow Podzolic-great soil group or in the tax taxonomy of Oxic Paleustults which originate from sediment of the old streams and the shale decay. The soil is a fertile soil with shallow topsoil and well to medium drainage due to loam structure and loamy gravel on the surface. This soil type is erosive, generally found in the area especially in the lowlands of the Mae Sa River Basin. The soil properties in the deciduous dipterocarp forest is mostly gravel or red rays with shallow soil layers and soil surface, low organic matter and lack of fertile. The soil texture is packed causing slowly drainage. The soil surface is quite shallow. In some area, the characteristics of soil is sandy soil which not holding water, making it very dry during the dry season. The soil has acidic condition with a pH 5.5 - 6.0.

3.3 Meteorological Conditions

Due to Doi Suthep-Pui National Park is located in the upper northern region of Thailand. Therefore, it is influenced by the southwest and northeast monsoon which generally, the summer season is March - May, rainy season is June - November and winter season is December – February, alternately. However, due to the physical condition of the park area which has a variety of elevation and the highly complex mountains. Causing different weather characteristics in each area of the park, especially between areas that are higher than 1,000 m at various mountain peaks and in areas that less than 500 m along the edge of the park. For highland areas of the park, such as the Doi Pui peak area, the weather generally cold and moist. Due to cloud covering which cover almost all year round. The lowest average temperature is 10 - 12℃ during the months of December to February. The average maximum and minimum temperature all year round are 32.2 and 20.8°C, respectively. The average annual rainfall is between 1,350 to 2,500 mm. The weather trend (temperature and precipitation) in the last 10 years (2008-2017) and 30 years (1981-2010) found similar as showed in Figure 3.2 (Thai Meteorological Department, 2019).

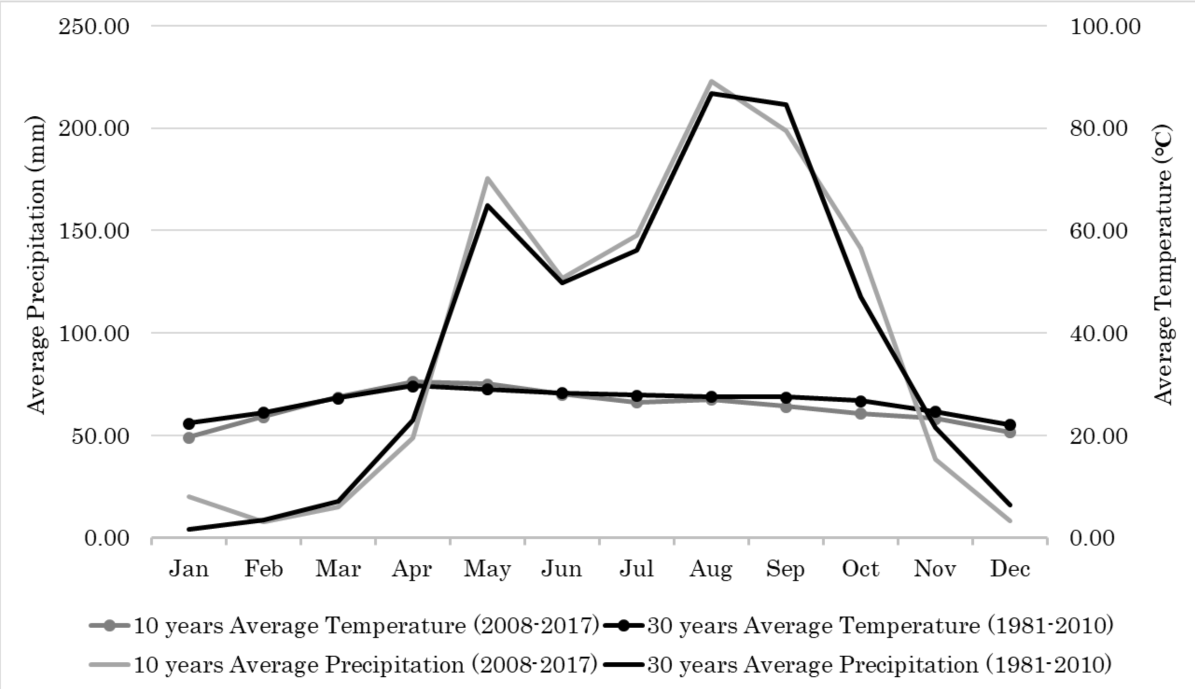

Figure 3.2 Average 30 years (1981-2010) and 10 years (2008-2017) of precipitation (mm) and temperature (°C) in Chiang Mai Province, Thailand.

3.4 Natural Resource

3.4.1 Flora

Because of Doi Suthep-Pui National Park has a high ecologically diverse. There are more than 10 different types of plant community that causing a high species diversity in the park. From the database of plant species in Doi Suthep-Pui National Park reported that there are more than 2,085 of vascular plants in various ecosystems (Maxwell 1989). Mixed deciduous evergreen forest ecosystem is an ecosystem that has the highest species diversity, more than 1,135 species can be found in this forest type and the evergreen forest ecosystems are considered as an ecosystem with a high variety of plant species as well. With a total combination of 1,079 plant species. For unique and rare species that found in Doi Suthep-Pui National Park, the evergreen forest has the most outstanding and rare plant species (850 species). The most prominent and rare species belong in Fagaceae, Magnoliaceae, Theaceae, Lauraceae and Ericaceae Family.

Source: www.qsbg.org

Figure 3.3 Some rare species in MDF of Doi Suthep-Pui National Park.

3.4.2 Fauna

Wildlife in Doi Suthep-Pui National Park is considered to be the most critical resource when compared to other natural resources and the environment that exists in the park. Especially small and medium sized mammals that has a declined number and some large animals disappeared and became extinct from the park. Those animals are threatened to hunting for food, as well as being invasive its habitat for a long time and continuously. Although the wildlife resources in Doi Suthep-Pui National Park are not much left when comparing others resources, but it is considered an important resource because it has a lively part and tourist attraction for a variety of activities, especially for recreation and natural science study which is one of the objectives of the establishment of the Park. Doi Suthep-Pui National Park is a home for over 400 wildlife species, divided into 4 types which are 30 of mammals, 30 of reptiles, 18 of amphibians, and 360 of birds. Some of rare fauna species in DSP shown in Figure 3.4.

Source: https://www.monaconatureencyclopedia.com/ and http://www.dooasia.com/

Figure 3.4 Some rare fauna species in Doi Suthep-Pui National Park.

3.5 Tourism and Recreation

Doi Suthep-Pui National Park is one of the most visited national park in Thailand with at least 1.9 million tourists per year visiting the national park. Due to the location of the park is closest the Chiang Mai metropolitan city make it ease of access. And there are a variety of resources for tourism such as creeks, gorges, streams and waterfalls, as well as forested area, scenic spots which distribute throughout the area (Figure 3.5).

Tourist attraction and recreation areas of Doi Suthep-Pui National Park, which can be divided into 3 main groups as follows

(1) Doi Suthep-Pui area group, the areas including Kruba Srivichai Monument, Huai Kaew Waterfall, Wang Bua Ban, Pha Ngeb, Monta Than Waterfall, Pha Lat Temple, Wat Phra That Doi Suthep Ratchaworawihan, Ruesi Cave, Phuping Niwat Palace, Pha Dam, Doi Pui Peak, San Ku, Ban Hmong Doi Pui, and Ban Hmong Khun Khian, etc.

(2) Mae Sa Waterfall Area and Mae Rim-Samoeng route Group, the area comprises with Mae Sa Waterfall, Tat Mok-Wang Hang Waterfall, Mae Yim Waterfall, Queen Sirikit Botanical Garden, and private tourist attractions such as resorts, elephant camps, butterfly gardens, and orchid gardens etc.

(3) Other parts of Doi Suthep-Pui National Park area, such as Sri Sangwan Waterfall, Mok Fah Waterfall, private resort on Hang Dong-Samoeng route, etc.

Source: https://blog.airpaz.com/ and http://guruchiangmai.com/

Figure 3.5 Some famous attractive point for tourist in Doi Suthep-Pui National Park.

3.6 Environment and Local Socioeconomic

The total number of communities living in the Doi Suthep-Pui National Park area is 16 villages, settlement in 3 districts including 6 villages located in Mueang Chiang Mai District, 9 villages located in Mae Rim District, and 1 village located in Mae Taeng District. Most of the communities are Thai lowland (69%), followed by Hmong hilltribe (25%), and Li su hilltribe (6%).

Even though Doi Suthep-Pui National Park became a protected area since 1981. The land use model in Doi Suthep-Pui National Park is not in compliance with the National Park regulation 1961, the encroachment and expand agricultural area activity of the villagers who both living before and after established the park causing the diverse land use in the area. The analysis of aerial imagery, satellite imagery, and field survey can divide land use patterns in Doi Suthep-Pui National Park as follows;

(1) Natural forest is a forest condition that remains from the encroachment of hill tribes and Thai people in lowland that live in and outside the national park. Most of the forest types are deciduous dipterocarp forest, mixed deciduous forest and hill evergreen forest in the highlands.

(2) Forest plantations are parts of the area covered with forests, planted by government agencies with a purpose to restore the forest and watershed area.

(3) Agricultural area, this type of area is mostly in the form of shifting cultivation, the rice fields along the slopes and the rice terraces of the hill tribes and Thai lowland, as well as the agricultural experiments conducted by government agencies or educational institutions such as Kasetsart University, Chiang Mai University, Highland Agricultural Experiment Station, etc. Most agricultural crops are economic crops such as cabbage, rice, maze, temperate flowers, lychee, longan, mango and beans, etc. Generally, the agricultural methods are simple. There are a few that use soil and water conservation measures. In the area of shifting cultivation, the Hmong hilltribe generally use the land around 3-5 years per cycle. However, due to the strictness of the national park officers and a limited of the available areas. Resulting the current activity of shifting cultivation and expanding agricultural area reduced. The majority of the economic crops are using chemical fertilizer and pesticides to get high productivity. As for the crops used for their own consumption, they do not receive much attention. Among the communities of Doi Suthep-Pui National Park, the Karen are the people who is an agricultural operation for sustenance and consumption in the household rather than to produce for sale. The average size of the Hmong hilltribe agricultural land occupies is 1.6 ha/household, but only uses 0.48-0.80 ha/year, while Karen hilltribe occupies about 0.48-0.64 ha/household and uses the all available area. For local people who live in and around the national park boundary, there will be approximately 0.48-0.64 ha of land occupied and using the same full benefits as Karen.

(4) Abandoned farmland is a natural forest that has been cleared in the past and used for agriculture until the soil lacks nutrients for plants and gave yielding products not worthwhile. Finally, it was abandoned. Most of these areas become grasslands or weeds.

CHAPTER 4

Floristic composition and forest structure in different fire frequency of mixed deciduous forest, Doi Suthep-Pui National Park, Northern Thailand

4.1 Introduction

Thailand has two main forest ecosystems: evergreen forest and deciduous forest, which are classified as fire sensitive ecosystems and fire dependent ecosystems, respectively (Stott et al., 1990; Rundel & Boonpragob 1995; Akaakara, 2015). The deciduous forests, which cover approximately 56% of the forested area in Thailand include deciduous dipterocarp forest (DDF; 21%), mixed deciduous forest (MDF; 34%) and pine forest (1%) (Royal Forest Department, 2001). The majority of deciduous forest is MDF, which has developed throughout the country, especially in the north, northeast, western and central regions (Smitinand, 1977). This forest type has been further divided into 2 dominant types by Bunyavejchewin (1983): the Tectona grandis type and the Lagerstroemia calyculata type.

Forest fires generally occur during the dry season, which begins from December, peaks in March, and ends in May. Deciduous forests, including DDF and MDF, are the most threatened by fire (Akaakara, 2015). In the last decade (2008-2017), MODIS hotspot statistics from the Forest Fire Control Division (2017) have illustrated that in northern Thailand, approximately 77% of annual fire incidents occurred in forested areas and that 99% of fire incidents were caused by human activities, including the gathering of non-timber forest products, illegal hunting, burning of agricultural debris, raising cattle, carelessness, illegal logging, arson, and tourism. From 2007 until now, these forest fire incidents have also been a major cause of the annual haze pollution in the far north of the country, which has serious direct effects on respiratory health of the local population (Junpen et al., 2013) and which also impacts the tourism industry and aerial transportation in this region.

Even though fire frequency is a basic element of the fire regime, which is the most significant factor influencing the structure and function of the ecosystem, if fires occur too frequently in fire-dependent ecosystems, including MDF, ecosystem degradation may occur (Akaakara, 2015). The only previous study in Doi Suthep-Pui National Park to analyze the vegetation structure in burned and unburned areas of MDF was conducted in 1985 by Akaakara. Since then, the impact of fire on the floristic composition and forest structure of MDF in this area has been unknown. It is a concern that the current heavy burns in the last decade have damaged the original structure and plant diversity in MDF, transforming it into another type of dry ecosystem. Thus, the present study aims to investigate the current floristic composition and forest structure in areas of MDF with different fire frequencies within Doi Suthep-Pui. The information from this research will be useful for fire/area management planning in Doi Suthep-Pui National Park, which focuses on keeping the MDF ecosystem in a good condition.

4.2 Materials and Methods

4.2.1 Fire mapping

In October 2017, a fire frequency map for Doi Suthep-Pui National Park was generated using 20 satellite images from Landsat 7 and 8, which were obtained from 2008 to 2017 (Table 4.1). The spatial resolution of the satellite images was 30 m. All satellite images were geo-corrected and burned areas were classified according to the normalized burn ratio (NBR) and difference normalized burn ratio (dNBR) (Key & Benson, 2006). The formula for calculation as followed;

$$NBR = \frac{NIR - SWIR}{NIR + SWIR}$$

Whereas NBR = Normalized burn ratio

NIR = Near infrared reflectance value

SWIR = Shortwave infrared reflectance value

$$dNBR = NBR_{prefire} - NBR_{postfire}$$

Whereas dNBR = Difference normalized burn ratio

$NBR_{prefire}$ = NBR value of pre-fire

$NBR_{postfire}$ = NBR value of post-fire

Table 4.1 Detail of Landsat 7 ETM+ and Landsat 8 OLI/TIR for burned areas analysis in Doi Suthep-Pui National Park

No.	Satellite	Acquisition Date	Fire Development Stage	Data Source
1	Landsat 7 ETM+	7 January 2008	Pre-fire	USGS
2	Landsat 7 ETM+	12 April 2008	Post-fire	USGS
3	Landsat 7 ETM+	9 January 2009	Pre-fire	USGS
4	Landsat 7 ETM+	30 March 2009	Post-fire	USGS
5	Landsat 7 ETM+	13 February 2010	Pre-fire	USGS
6	Landsat 7 ETM+	2 April 2010	Post-fire	USGS
7	Landsat 7 ETM+	15 January 2011	Pre-fire	USGS
8	Landsat 7 ETM+	20 March 2011	Post-fire	USGS
9	Landsat 7 ETM+	2 January 2012	Pre-fire	USGS
10	Landsat 7 ETM+	22 March 2012	Post-fire	USGS
11	Landsat 7 ETM+	20 January 2013	Pre-fire	USGS
12	Landsat 7 ETM+	10 April 2013	Post-fire	USGS
13	Landsat 8 OLI/TIR	31 January 2014	Pre-fire	USGS
14	Landsat 8 OLI/TIR	5 April 2014	Post-fire	USGS
15	Landsat 8 OLI/TIR	2 January 2015	Pre-fire	USGS
16	Landsat 8 OLI/TIR	7 March 2015	Post-fire	USGS
17	Landsat 8 OLI/TIR	5 January 2016	Pre-fire	USGS
18	Landsat 8 OLI/TIR	26 April 2016	Post-fire	USGS
19	Landsat 8 OLI/TIR	8 February 2017	Pre-fire	USGS
20	Landsat 8 OLI/TIR	12 March 2017	Post-fire	USGS

The accuracy fire frequency map was tested against actual fire which was the government's ground fire report from 2008-2017. The confusion matrix of Congalton (1991) which showing the correspondence between predicted and actual classifications, was used to verify the map. The accuracy was calculated from the percentage of correctly classified instances. The schematic workflow of research methodology of fire history study shown in Figure 4.1

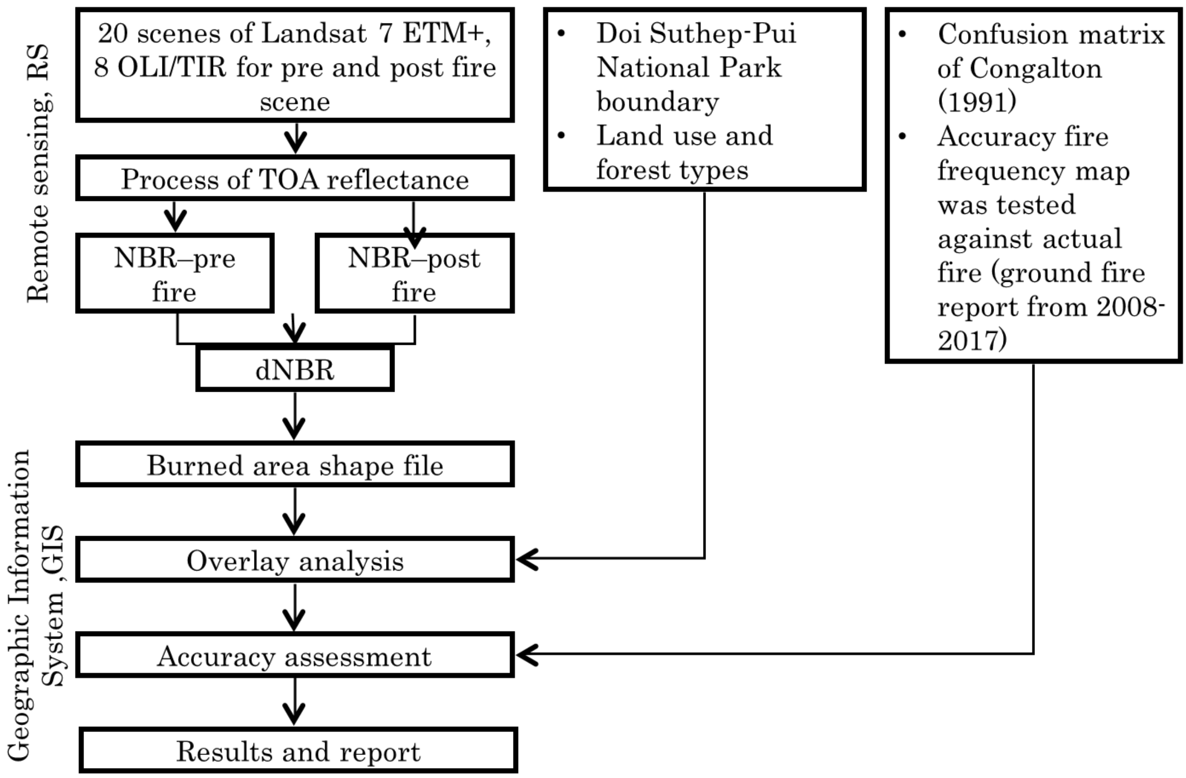

Figure 4.1 Fire history schematic workflow of research methodology in MDF of Doi Suthep-Pui National Park.

4.2.2 Data collection

In December 2017, after surveying and selecting MDF areas with similar vegetation, and geography, two 50 m x 50 m plots were set up in areas with different levels of fire frequency: 1) the low fire frequency area (LFA; two fires occurred in 2010 and 2015); and 2) the high fire frequency area (HFA; 6 fires occurred in 2008, 2009, 2010, 2012, 2013, and 2015). Both sites were located at latitude 18°46′37″N and longitude 98°55′54″E (Figure 4.2 and 4.3), with 509 m in elevation and a slope of 25°. The distance between the two sites was 250 m. Each 50 m x 50 m plot was divided into twenty-five 10 m x 10 m quadrants in which all woody trees and shrubs, with a diameter at breast height (DBH) of ≥ 4.5 cm and a total height (H) of ≥ 1.3 m, were studies by identified species, and measured DBH and H. Saplings (DBH < 4.5 cm but H ≥ 1.3 m) and seedling/undergrowth (DBH < 4.5 cm and H < 1.3 m) were also recorded species by using twelve 4 m x 4 m and 1 m x 1 m quadrats systematic random in sample area (Figure 4.4). To study the forest structure, two sample plots of 50 m x 10 m were also randomized in both areas. Species identification was confirmed by a taxonomist of the Herbarium in the Department of National Parks, Wildlife and Plant Conservation, Bangkok, Thailand.

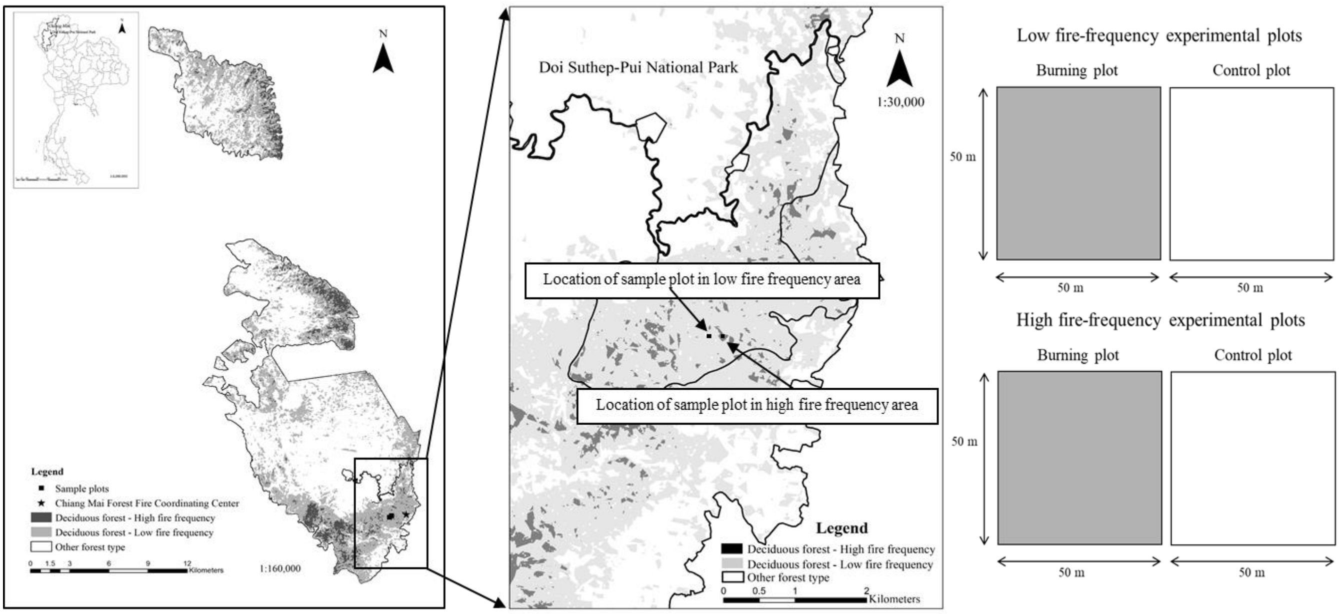

Figure 4.2 The boundary of Chiang Mai Province, Doi Suthep-Pui National Park, fire frequency areas, and the sample plot location in low and high fire frequency areas of mixed deciduous forest.

(A) High frequency burned area

(B) Low frequency burned area

Figure 4.3 General condition of MDF in Doi Suthep-Pui National Park: (A) High frequency area and (B) Low fire frequency area.

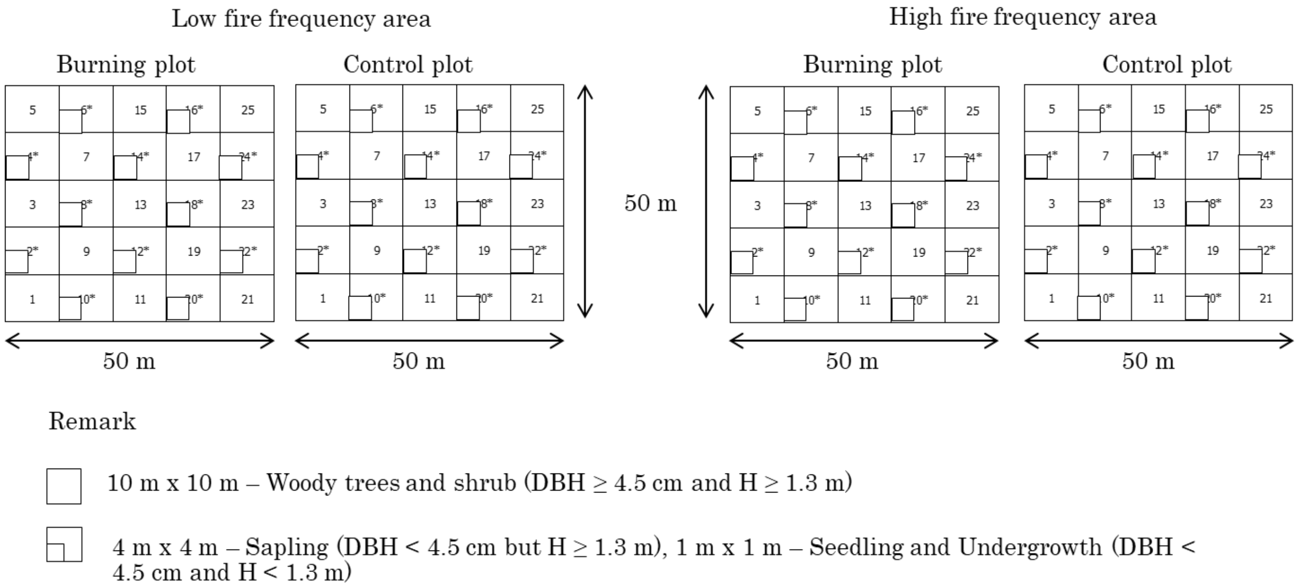

Figure 4.4 Experimental design for collecting data of floristic composition in low and high fire frequency MDF of Doi Suthep-Pui National Park.

Moreover, the light conditions at 30 and 130 cm above the ground were measured by using Opto leaf films (R-3D), Taisei Fine Chemical Inc. Ltd., Tokyo, Japan installed in each fire frequency areas, at the twelve positions of 1 m x 1 m sample plot, for three days. In order to generate the Opto leaf fading standard chart for the study area, Sunshine Sensor Type BF3, Delta-T Device Ltd., Cambridge, U.K. and six Opto leaf films were used to measure the total solar radiation in the open area nearby the sample plot for three days (Figure 4.5). All Opto leaf films were measured fading color value before and after installed by T-meter.

Figure 4.5 Light intensity measurement by opto leaf film and pyranometer in study area and open area.

4.2.3 Data analysis

The density, frequency, basal area, important value (IV), diversity index, evenness index, and diameter class distribution were calculated using the following formulae:

$$\text{Density} = \frac{\text{Number of individuals of a species}}{\text{Total area sampled}}$$

$$\text{Relative density} = \frac{\text{Density of a species}}{\text{Total density of all species}} \times 100$$

$$\text{Frequency} = \frac{\text{Area of plots in which a species occurs}}{\text{Total area sampled}}$$

$$\text{Relative frequency} = \frac{\text{Frequency of a species}}{\text{Total frequency of all species}} \times 100$$

$$\text{Dominance} = \frac{\text{Total basal area of a species}}{\text{Total area sampled}}$$

$$\text{Relative dominance} = \frac{\text{Dominance of a species}}{\text{Total dominance of all species}} \times 100$$

Importance value = Relative density + Relative frequency + Relative dominance

Shanon and Weaver diversity index (1963)

$$H' = -\sum_{i=1}^{s} Pi \ \ln p_i$$

Whereas H' = Diversity index value

P_i = Proportion of a species

lnpi = Natural logarithm of pi

s = Number of species in community

Pielou's evenness index (1975)

$$J' = \frac{H'}{H'_{max}}$$

Whereas J' = Evenness index value

H' = Shanon and Weaver diversity index

H'_{max} = the maximum possible value of H', equal to:

$$H'_{max} = -\sum_{i=1}^{s} \frac{1}{s} \ln \frac{1}{s} = \ln S$$

The average data of number of species, genera, family, species density, species evenness index, density, DBH, height, and basal area were analyzed for statistical differences at the $P < 0.05$ level using the independent sample t-test method in the IBM SPSS Statistics 26 software package.

The color fading rate of Opto leaf was calculated via following formulae:

$$D0 = -log10(\frac{T0}{100})$$

Whereas D0 = Absorbance before exposure

T0 = Fading value of opto leaf

$$D = -log10(\frac{T}{100})$$

Whereas D = Absorbance after exposure

T = Fading value of opto leaf

$$R - 3D = log10(\frac{D}{D0} * 100)$$

Whereas R – 3D = Fading rate

D = Absorbance after exposure

D0 = Absorbance before exposure

The light conditions under canopy was calculated from following formula:

$$\% \text{ Relative solar radiation} = \frac{\text{ASRs}}{\text{ASRo}} \text{ x } 100$$

Whereas ASRs = Accumulate solar radiation in sample area

ASRo = Accumulate solar radiation in open area

4.3 Results

4.3.1 Fire history

The result showed in Table 4.2 demonstrated that the actual fire sites are mostly found in the high fire frequency (63) as classified by the model (Figure 4.6). In addition, the confusion matrix showed that the map achieved 79.74% classification accuracy.

Table 4.2 Accuracy assessment of fire frequency map based on confusion matrix.

Actual fire points		Predicted fire points		% of correctly classified instances
		H	L	
	H	63	0	79.74
	L	16	0	

H = high fire frequency, L = low fire frequency

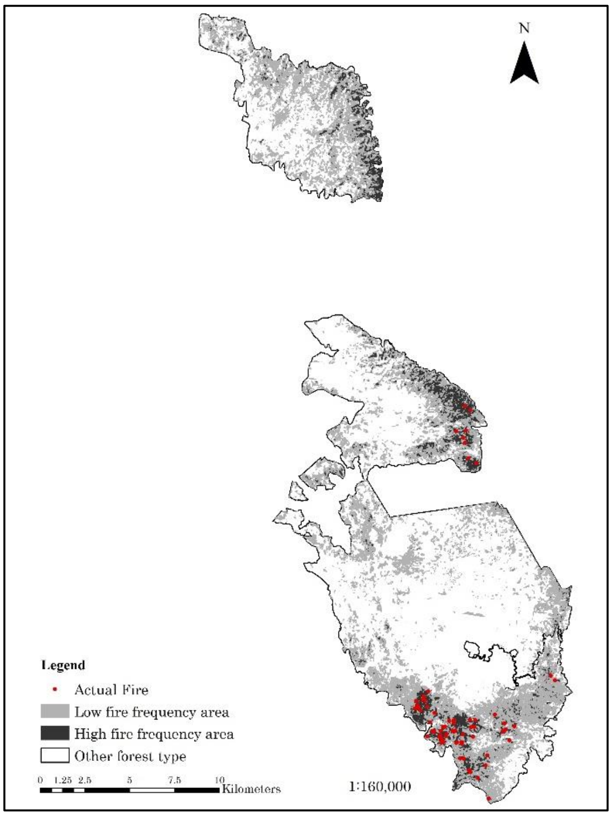

Figure 4.6 Estimated fire frequency compared with actual fire sites.

The results of the ten-year (2008-2017) Landsat imagery analysis showed that all areas of deciduous forest in Doi Suthep-Pui National Park had experienced at least one fire. The total burned area was 10,940 ha, which amounted to 41.9% of the area. The high fire frequency areas which has fire repeated 6-10 times in a decade were located in the northeast and southwest areas, covering approximately 13.92% of Doi Suthep-Pui. The remaining 86.02% of the area had a low fire frequency which fire occurred 1-5 times within a decade (Figure 4.7). Moreover, the list of years that fire occurred in the study area was showed in Table 4.3.

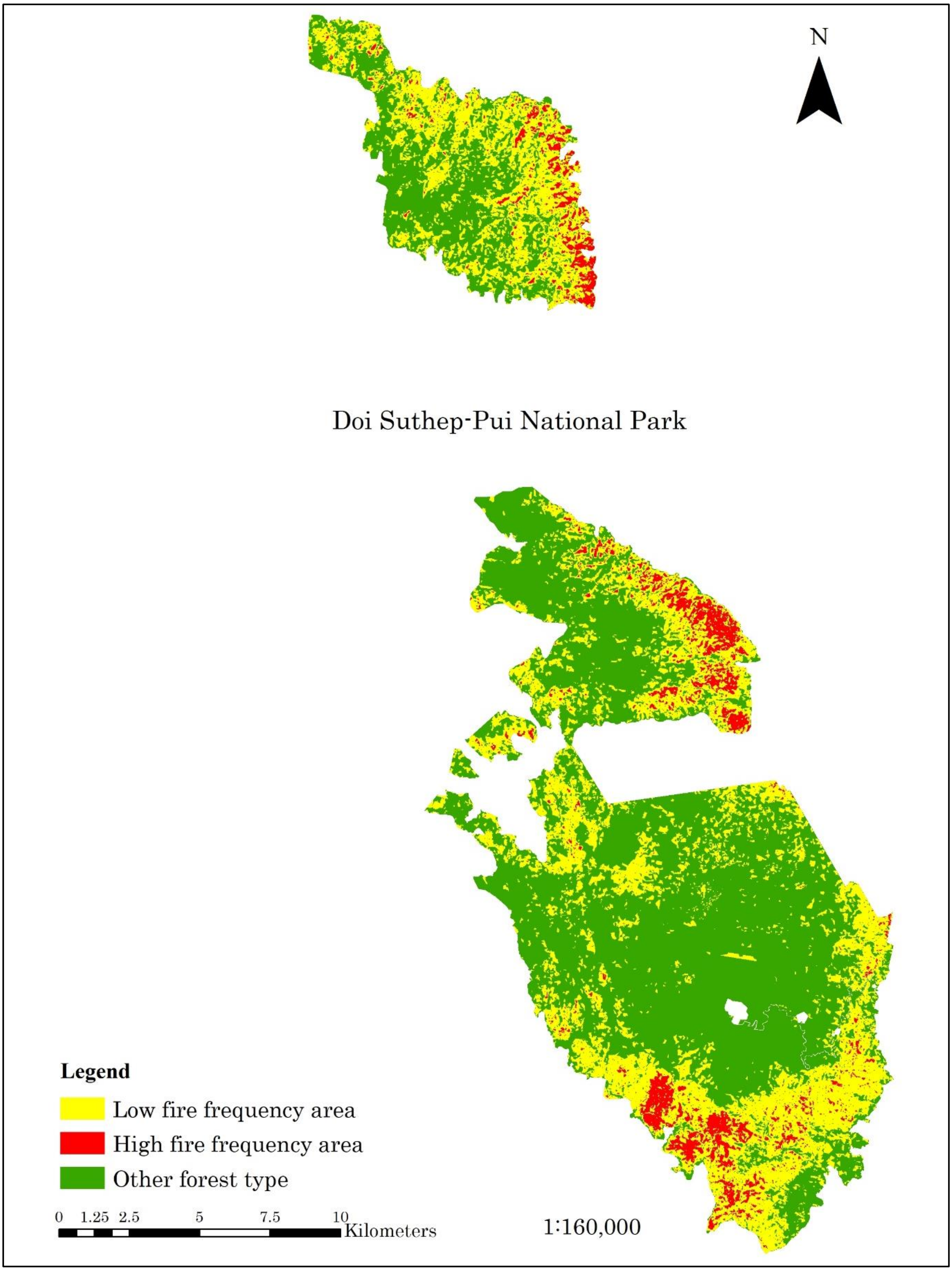

Figure 4.7 Fire frequency map in deciduous forest of Doi Suthep-Pui National Park.

Table 4.3 List of fire occurrence year in study areas during 2008 – 2017 in MDF, Doi Suthep-Pui National Park. LFA indicates low fire frequency area while HFA is high fire frequency area.

Area	**Year**
LFA	2010, 2015
HFA	2009, 2010, 2012, 2013, 2015

4.3.2 Composition of plant life form

A total of 104 plant species, with 58 trees, 20 shrubs and 26 ground flora species (climbers, herbs and grasses) were recorded from the sample areas (Table 4.4). The species richness of the flora in the LFA (89 total individual species [85.58% of overall species]) was richer flora species than that in the HFA (51 total individual species [49.04% of overall species]). Most climber and grass species could be found in the LFA while only 1 climber and 3 grass species were found in the HFA. In the LFA, there were 47 species of tree (81.03% of overall tree species), 18 species of shrub (90.00% of overall shrub species) and 10 species of herb (83.33% of overall herb species). The HFA showed smaller numbers and percentages than the LFA. The tree, shrub, and herb species appeared in HFA were 31, 11, and 5 or 53.45, 55.00, and 41.67% of overall tree, shrub, and herb species, respectively (Table 4.4).

Table 4.4 Number of species and portion (%) of each plant life form in overall, low fire frequency area (LFA), high fire frequency area (HFA), of MDF in Doi Suthep-Pui National Park.

Plant life form composition	Number of species		
	Overall	LFA	HFA
Tree	58	47 (81.03%)	31 (53.45%)
Shrub	20	18 (90.00%)	11 (55.00%)
Climber	10	10 (100.00%)	1 (10.00%)
Herb	12	10 (83.33%)	5 (41.67%)
Grass	4	4 (100.00%)	3 (75.00%)
Total	104	89 (85.58%)	51 (49.04%)

4.3.3 Species number, diversity, evenness, density, diameter at breast height (DBH), basal area and height

The summary of some quantitative characteristics are shown in Table 4.5. There were a total of 45 woody tree species in the LFA and 33 woody tree species in the HFA. The numbers of sapling, seedling and undergrowth species in the LFA were two to nearly three times that in the HFA. The number of genera and families showed a similar trend to the number of species. In the LFA, greater species diversity was observed, in all categories, in comparison to the HFA. However, the HFA showed a higher species evenness value in the tree, sapling, and seedling categories in comparison to the LFA. Furthermore, *Dendrocalamus membranaceus* was the only species of bamboo found in both study areas. In the LFA, the number of clumps per hectare, the average number of culms per clump, average culm DBH and average clump height were 360, 10, 20.80 cm and 11.03 m, respectively, while those in the HFA were 200, 12, 21.30 cm and 13.18 m.

Table 4.5 Summary of some quantitative characteristics in low fire frequency area (LFA) and high fire frequency area (HFA) of MDF in Doi Suthep-Pui National Park.

Characteristics	Tree		Sapling		Seedling		Undergrowth	
	LFA	HFA	LFA	HFA	LFA	HFA	LFA	HFA
1. Number of species	45	33	22	9	23	12	23	9
2. Number of genera	39	28	21	9	20	12	22	9
3. Number of family	22	17	13	7	14	8	15	7
4. Species diversity	2.84	2.66	2.13	1.61	2.48	1.83	1.97	0.75
5. Species evenness	0.80	0.85	0.82	0.96	0.95	0.95	0.74	0.46
6. Density (trees/ha)	666	362	888	206	10,400	5,400	14,200	6,900

Bamboo (*Dendrocalamus membranaceus* Munro)	**LFA**	**HFA**
- Number of clumps per ha	360	200
- Average culms per clump	10	12
- Average culm DBH (cm)	20.80	21.30
- Average clump height (m)	11.03	13.18

The comparison of the average values of the number of species, number of genera, number of family, species diversity, species evenness and density in the quadrate units between LFA and HFA showed that in tree category (10 m x 10 m quadrate units) almost characters except species evenness were significant difference, while the difference of all characters in saplings category (4 m x 4 m quadrate units) was not significant. For saplings and undergrowth (1 m x 1 m quadrate units), the number of species, number of genera, number of family, and density showed significant difference between LFA and HFA (Table 4.6).

The average DBH, height, and basal area in LFA were 15.02±10.10 cm, 13.49±5.79 m, and 17.08±3.34 m^2/ha. While in HFA were 18.60±10.40 cm, 13.98±4.96 m, and 14.32±2.51 m^2/ha, respectively. The compared mean result showed that the average DBH and basal area between LFA and HFA were slightly different, but not significant. However, the difference of average height was significant between LFA and HFA (Table 4.7).

4.3.4 Diameter distribution of trees category

The diameter class distribution of trees in the sites showed a typical reverse J-shaped curve (Figure 4.8). The majority of woody trees were in the lower class (4.5-15.5 cm), with the number decreasing as the size of the woody trees increased. In the LFA, the population of woody trees in the 4.5-15.5 cm class was twice that in the HFA. Moreover, similar results were observed in the 15.5-25.5, 25.5-35.5 and 35.5-45.5 cm classes. However, the largest trees, which had a diameter of >65.5 cm, were only found in the HFA.

Table 4.6 The comparison mean value of plants characters (number of species, genera, family, species diversity, species evenness and density) in the quadrate units (10 m x 10 m quadrate units for trees, 4 m x 4 m quadrate units for saplings and 1 m x 1 m quadrate units for seedlings and undergrowth) between low fire frequency area (LFA) and high fire frequency area (HFA) of MDF in Doi Suthep-Pui National Park.

Category	Characteristic	Area	n	Mean	S.D.	t	p
Trees	1. Number of species	LFA	50	4.35	2.60	-3.780*	0.001
		HFA	50	2.78	1.19		
	2. Number of genera	LFA	50	4.22	2.43	-3.675*	0.001
		HFA	50	2.78	1.19		
	3. Number of family	LFA	50	3.72	2.11	-3.586*	0.001
		HFA	50	2.48	1.12		
	4. Species diversity	LFA	50	1.17	0.38	-2.391*	0.019
		HFA	50	0.89	0.44		
	5. Species evenness	LFA	50	0.79	0.19	0.624	0.534
		HFA	50	0.81	0.20		
	6. Density	LFA	50	6.91	5.03	-3.885*	0.001
		HFA	50	3.85	2.10		
Saplings	1. Number of species	LFA	24	2.26	1.28	-1.235	0.228
		HFA	24	1.62	1.06		
	2. Number of genera	LFA	24	2.21	1.27	-1.141	0.264
		HFA	24	1.62	1.06		
	3. Number of family	LFA	24	2.10	1.24	-1.274	0.215
		HFA	24	1.50	0.75		
	4. Species diversity	LFA	24	0.62	0.52	-1.332	0.195
		HFA	24	0.33	0.51		
	5. Species evenness	LFA	24	0.54	0.51	1.181	0.082
		HFA	24	0.89	0.19		
	6. Density	LFA	24	3.57	2.36	-1.781	0.087
		HFA	24	2.00	1.19		
Seedlings	1. Number of species	LFA	24	2.05	1.07	-2.331*	0.028
		HFA	24	1.40	0.50		
	2. Number of genera	LFA	24	2.05	1.07	-2.331*	0.028
		HFA	24	1.40	0.50		
	3. Number of family	LFA	24	1.89	0.80	-2.178*	0.037
		HFA	24	1.40	0.50		
	4. Species diversity	LFA	24	0.56	0.45	-2.097	0.044
		HFA	24	0.26	0.33		
	5. Species evenness	LFA	24	0.57	0.44	-1.530	0.136
		HFA	24	0.33	0.45		
	6. Density	LFA	24	2.68	2.02	-1.834*	0.078
		HFA	24	1.73	0.88		
Undergrowth	1. Number of species	LFA	24	2.79	1.93	-2.557*	0.015
		HFA	24	1.65	0.93		
	2. Number of genera	LFA	24	2.79	1.93	-2.557*	0.015
		HFA	24	1.65	0.93		
	3. Number of family	LFA	24	2.66	1.73	-2.472*	0.018
		HFA	24	1.65	0.93		
	4. Species diversity	LFA	24	0.79	0.68	-2.294	0.027
		HFA	24	0.38	0.47		
	5. Species evenness	LFA	24	0.66	0.47	-1.422	0.162
		HFA	24	0.45	0.51		
	6. Density	LFA	24	2.83	2.01	-2.566*	0.015
		HFA	24	1.65	0.93		

* Significant different, $P < 0.05$

Table 4.7 The comparison mean value of each woody trees characters (DBH, height, and basal area) in trees category between low fire frequency area (LFA) and high fire frequency area (HFA) of MDF in Doi Suthep-Pui National Park.

Characteristic	Area	n	Mean	S.D.	t	p
1. DBH (cm)	LFA	333	15.02	10.10	3.803	0.001
	HFA	181	18.59	10.40		
2. Height (cm)	LFA	333	13.49	5.79	0.992*	0.322
	HFA	181	13.98	4.96		
3. Basal area (m^2/ha)	LFA	333	17.08	3.34	2.603	0.010
	HFA	181	14.32	2.51		

* Significant different, $P < 0.05$

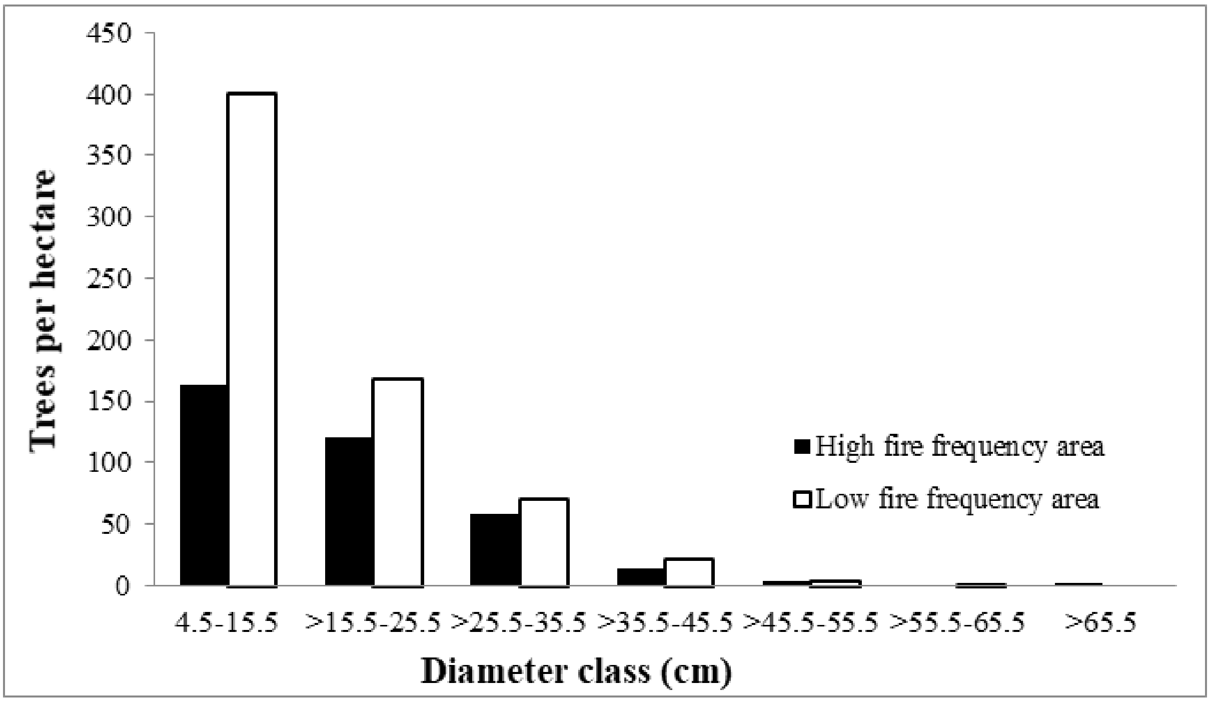

Figure 4.8 DBH distribution of woody trees (DBH $\geq$ 4.5 and H $\geq$ 1.3 m) in low and high fire frequency areas of mixed deciduous forest, Doi Suthep-Pui National Park.

4.3.5 Species overlap between categories (tree, sapling, seedling)

In the LFA, there were 6 species that appeared in all 3 categories (*Wrightia arborea, Millettia xylocarpa, Lagerstroemia duperreana*, *Pterospermum semisagittatum, Antidesma acidum*, and *Antidesma sootepense*). Ten species were found in 2 categories and fifty-two species were only found in one category. In contrast, *Falconeria insignis* was the only species found in all categories in the HFA. Ten species appeared in 2 categories and thirty-one species were only found in 1 category (Table 4.8, 4.9 and 4.10).

4.3.6 Family and species dominance

(1) Woody trees (DBH ≥ 4.5 cm and H ≥ 1.3 m)

Twenty-two families and 45 species of woody trees were found in the LFA. There were 6 species of the Fabaceae family, which was the most of any family (Table 4.8). This was followed by Burseraceae and Phyllanthaceae. *Canarium subulatum* in Burseraceae had the greatest IV value (70.08) followed by *Lagerstroemia duppereana* in Lythraceae (32.56) and *Antidesma sootepense* in Phyllanthaceae (30.76). *Canarium subulatum* also showed the greatest RF and RDo values while *Antidesma sootepense* had the highest RD value (Table 4.8).

Seventeen families and 33 species of woody trees were identified in the HFA. Similarly to the LFA, Fabaceae was the dominant family in the HFA (5 species). This was followed by Combretaceae and Malvaceae (Table 4.8). Among the species in the HFA, *Pterocarpus macrocarpus* showed the greatest IV value (56.60) followed by *Canarium subulatum* (47.19) and *Xylia xylocarpa* (25.95). *Pterocarpus macrocarpus* also had the highest RD and RF values, whereas *Canarium subulatum* showed the greatest RDo value (Table 4.8).

Table 4.8 Relative density, relative frequency, relative dominance and importance value of dominant families of woody trees (DBH ≥ 4.5 cm and H ≥ 1.3 m) in a low fire frequency area (LFA) and high fire frequency area (HFA) of MDF in Doi Suthep-Pui National Park.

Clade/Order/Family/Species	Relative Density (RD)		Relative Frequency (RF)		Relative Dominance (RDo)		Importance Value (IV)	
	LFA	HFA	LFA	HFA	LFA	HFA	LFA	HFA
Clade: Magnoliids								
Order: Laurales								
Family: Lauraceae								
Litsea glutinosa (Lour.) C. B. Rob.	0.30	-	0.48	-	1.49	-	2.27	-
Order: Magnoliales								
Family: Annonaceae								
Hubera cerasoides (Roxb.) Chaowasku	-	1.10	-	1.52	-	0.19	-	2.81
Clade: Fabids								
Order: Malpighiales								
Family: Euphorbiaceae								
Croton acutifolius Esser	-	1.10	-	1.52	-	0.31	-	2.93
Falconeria insignis Royle	-	0.55	-	0.76	-	0.59	-	1.90
Mallotus philippensis (Lam.) Müll. Arg.	0.60	-	0.96	-	0.08	-	1.64	-
Suregada multiflora (A. Juss.) Baill.	0.90	-	1.44	-	0.11	-	2.45	-
Family: Phyllanthaceae								
Antidesma sootepense Craib	18.92	-	10.05	-	1.79	-	30.76	-
Antidesma acidum Retz.	0.60	-	0.96	-	0.05	-	1.60	-
Aporosa wallichii Hook. f.	0.60	8.84	0.96	7.58	0.14	2.94	1.69	19.35
Order: Fabales								
Family: Fabaceae								
Albizia odoratissima (L. f.) Benth.	2.10	4.97	2.39	5.30	3.28	4.86	7.78	15.14
Dalbergia cultrata Graham ex Benth.	0.30	0.55	0.48	0.76	0.22	0.16	1.00	1.47
Dalbergia lakhonensis Gagnep.	1.80	2.76	1.91	3.03	1.45	1.06	5.16	6.85
Millettia xylocarpa Miq.	4.80	-	4.78	-	1.86	-	11.45	-
Pterocarpus macrocarpus Kurz	1.50	20.99	1.91	15.15	1.89	20.46	5.30	56.60
Xylia xylocarpa (Roxb.) W. Theob. var. *kerrii* (Craib & Hutch.) I. C. Nielsen	6.61	8.84	6.22	10.61	7.51	6.50	20.33	25.95
Order: Rosales								
Family: Moraceae								
Artocarpus lacucha Roxb. ex Buch.-Ham.	0.60	1.10	0.96	0.76	0.46	0.96	2.02	2.82
Clade: Malvids								
Order: Myrtales								
Family: Combretaceae								
Anogeissus acuminata (Roxb. ex DC.) Guill. & Perr.	0.30	2.21	0.48	2.27	0.05	1.20	0.82	5.69
Terminalia chebula Retz. var. *chebula*	-	1.66	-	2.27	-	0.26	-	4.19
Terminalia glaucifolia Craib	-	0.55	-	0.76	-	0.60	-	1.91
Terminalia mucronata Craib & Hutch.	0.90	6.63	1.44	6.06	0.68	6.54	3.02	19.23
Terminalia nigrovenulosa Pierre	0.60	-	0.96	-	0.78	-	2.33	-
Family: Lythraceae								
Lagerstroemia cochinchinensis Pierre.	0.30	-	0.48	-	0.41	-	1.18	-
Lagerstroemia duperreana Pierre ex Gagnep. var. *duperreana*	11.11	4.42	11.00	4.55	10.45	2.94	32.56	11.91
Spondias pinnata (L. f.) Kurz	-	1.10	-	1.52	-	0.48	-	3.10

Clade/Order/Family/Species	Relative Density (RD)		Relative Frequency (RF)		Relative Dominance (RDo)		Importance Value (IV)	
	LFA	HFA	LFA	HFA	LFA	HFA	LFA	HFA
Family: Burseraceae								
Canarium strictum Roxb.	0.30	-	0.48	-	0.02	-	0.80	-
Canarium subulatum Guillaumin	16.82	11.05	14.35	12.88	38.91	23.26	70.08	47.19
Garuga pinnata Roxb.	0.30	-	0.48	-	1.78	-	2.56	-
Protium serratum Engl.	2.40	-	3.35	-	1.71	-	7.47	-
Family: Meliaceae								
Heynea trijuga Roxb. ex Sims	0.30	-	0.48	-	0.66	-	1.44	-
Walsura trichostemon Miq.	0.90	1.66	1.44	1.52	0.59	0.94	2.92	4.11
Family: Rutaceae								
Naringi crenulata (Roxb.) Nicolson	0.90	1.66	0.96	0.76	0.59	1.05	2.44	3.47
Family: Sapindaceae								
Schleichera oleosa (Lour.) Merr.	1.80	-	1.44	-	0.32	-	3.55	-
Family: Simaroubaceae								
Harrisonia perforata (Blanco) Merr.	0.30	-	0.48	-	0.07	-	0.85	-
Clade: Asterids								
Order: Cornales								
Family: Cornaceae								
Alangium indochinense W.J.de Wilde & Duyfjes	3.00	-	1.91	-	4.78	-	9.70	-
Order: Ericales								
Family: Ebenaceae								
Diospyros coaetanea H. R. Fletcher	1.50	-	1.44	-	3.84	-	6.78	-
Diospyros ehretioides Wall. ex G. Don	-	0.55	-	0.76	-	0.19	-	1.50
Clade: Lamiids								
Order: Boragianales								
Family: Boraginaceae								
Ehretia laevis Roxb.	0.30	-	0.48	-	0.08	-	0.86	-
Order: Gentianales								
Family: Apocynaceae								
Holarrhena pubescens Wall. ex G. Don	1.20	0.55	1.91	0.76	0.33	0.16	3.45	1.47
Wrightia arborea (Dennst.) Mabb.*	3.90	-	3.35	-	1.68	-	8.93	-
Family: Rubiaceae								
Hymenodictyon orixense (Roxb.) Mabb.	-	0.55	-	0.76	-	0.27	-	1.58
Mitragyna rotundifolia (Roxb.) Kuntze	1.20	-	1.44	-	0.48	-	3.12	-
Order: Lamiales								
Family: Bignoniaceae								
Fernandoa adenophylla (Wall. ex G. Don) Steenis	0.90	0.55	1.44	0.76	0.31	0.12	2.64	1.43
Markhamia stipulata (Wall.) Seem. var. *kerrii* Sprague	0.90	1.10	0.96	1.52	0.16	0.28	2.02	2.90
Stereospermum tetragonum DC.	-	0.55	-	0.76	-	0.24	-	1.55
Family: Lamiaceae								
Tectona grandis L. f.	3.00	-	4.31	-	4.18	-	11.49	-
Vitex canescens Kurz	2.40	0.55	3.83	0.76	1.63	0.26	7.86	1.57
Vitex peduncularis Wall. ex Schauer	1.80	3.31	2.87	3.03	1.19	1.51	5.87	7.86
Total	100	100	100	300	100	100	100	300

(2) Saplings (DBH < 4.5 cm and H ≥ 1.3 m)

Thirteen families and 22 species of saplings were found in the LFA. This category was dominated by the Phyllanthaceae family, which showed the highest abundance in the area (Table 4.9). *Uvaria rufa* had the greatest IV and RF values (46.79 and 23.26, respectively). *Antidesma sootepense* showed the second highest IV value (44.22) and the highest RD value (27.94). Seven families and 9 species of saplings were found in the HFA. The Phyllanthaceae and Rubiaceae families were dominant in this area. *Hubera cerasoides* showed the greatest IV, RD and RF values (45.00, 25.00 and 20.00, respectively). *Aporosa wallichii* had the second highest IV value (38.75) and the highest RF value (20.00) (Table 4.9). Moreover, one pioneer species, *Colona floribunda* (Marod et al., 1999) was found in both LFA and HFA and showed a small proportion in IV value, 3.80 and 19.17 in the LFA and HFA, respectively.

Table 4.9 Relative density, relative frequency, relative dominance and importance value of dominant families of saplings (DBH < 4.5 cm and H ≥ 1.3 m) in a low fire frequency area (LFA) and high fire frequency area (HFA) of MDF in Doi Suthep-Pui National Park.

Clade/Order/Family/Species	Relative Density (RD)		Relative Frequency (RF)		Importance Value (IV)	
	LFA	HFA	LFA	HFA	LFA	HFA
Clade: Magnoliids						
Order: Magnoliales						
Family: Annonaceae						
Hubera cerasoides (Roxb.) Chaowasku	2.94	25.00	4.65	20.00	7.59	45.00
Uvaria rufa Blume	23.53	-	23.26	-	46.79	-
Clade: Superasterids						
Order: Santalales7						
Family: Opiliaceae						
Cansjera rheedei J. F. Gmel.	1.47	-	2.33	-	3.80	-
Clade: Fabids						
Order: Malpighiales						
Family: Euphorbiaceae						
Mallotus philippensis (Lam.) Müll. Arg.	2.94	-	4.65	-	7.59	-
Croton acutifolius Esser	-	6.25	-	6.67	-	12.92
Family: Phyllanthaceae						
Antidesma acidum Retz.	7.35	-	4.65	-	12.00	-
Antidesma sootepense Craib	27.94	6.25	16.28	6.67	44.22	12.92
Aporosa wallichii Hook. f.	1.47	18.75	2.33	20.00	3.80	38.75

Clade/Order/Family/Species	Relative Density (RD)		Relative Frequency (RF)		Importance Value (IV)	
	LFA	HFA	LFA	HFA	LFA	HFA
Bridelia stipularis (L.) Blume	2.94	-	4.65	-	7.59	-
Flueggea virosa (Roxb. ex Willd.) Voigt	1.47	-	2.33	-	3.80	-
Order: Fabales						
Family: Fabaceae						
Adenanthera pavonina L.	1.47	-	2.33	-	3.80	-
Dalbergia lakhonensis Gagnep.	1.47	-	2.33	-	3.80	-
Millettia xylocarpa Miq.	2.94	6.25	4.65	6.67	7.59	12.92
Order: Rosales						
Family: Moraceae						
Streblus asper Lour.	1.47	-	2.33	-	3.80	-
Family: Rhamnaceae						
Ziziphus oenoplia (L.) Mill. var. *oenoplia*	1.47	-	2.33	-	3.80	-
Clade: Malvids						
Order: Myrtales						
Family: Combretaceae						
Terminalia chebula Retz. var. *chebula*	1.47	-	2.33	-	3.80	-
Family: Lythraceae						
Lagerstroemia duperreana Pierre ex Gagnep. var. *duperreana*	5.88	-	4.65	-	10.53	-
Order: Malvales						
Family: Malvaceae						
Colona floribunda (Kurz) Craib	1.47	12.50	2.33	6.67	3.80	19.17
Grewia laevigata Vahl	2.94	-	2.33	-	5.27	-
Pterospermum semisagittatum Buch.-Ham. ex Roxb.	1.47	-	2.33	-	3.80	-
Order: Sapindales						
Family: Sapindaceae						
Schleichera oleosa (Lour.) Merr.	1.47	-	2.33	-	3.80	-
Family: Simaroubaceae						
Brucea javanica (L.) Merr.	2.94	-	2.33	-	5.27	-
Clade: Lamiids						
Order: Gentianales						
Family: Apocynaceae						
Wrightia arborea (Dennst.) Mabb.	1.47	-	2.33	-	3.80	-
Family: Rubiaceae						
Pavetta indica L. var. *tomentosa* (Roxb. ex Sm.) Hook. f.	-	6.25	-	13.33	-	19.58
Rothmannia sootepensis (Craib) Bremek.	-	12.50	-	13.33	-	25.83
Order: Lamiales						
Family: Lamiaceae						
Vitex canescens Kurz	-	6.25	-	6.67	-	12.92
Total	**100**	**100**	**200**	**100**	**100**	**200**

(3) Seedlings (DBH < 4.5 cm and H < 1.3 m)

Fourteen families and 23 flora species of seedlings were found in the LFA. Phyllanthaceae was dominant family in this category, with 6 species (Table 4.10). *Lagerstroemia dupperreana* showed the highest IV value (22.82) it also showed the highest RD and RF values (10.00 and 12.82). This was followed by

Pterospermum semisagittatum, *Wrightia arborea,* and *Antidesma sootepense*, in that order. A *Cratoxylum formosum*, pioneer species (Davies et al., 2003), IV 4.56, was found in the LFA.

Eight families and 12 species of seedlings were found in the HFA. The Combretacea, Malvaceae and Phyllanthaceae families dominated this category. *Grewia hirsuta* had the highest IV value (34.43), while *Bridelia stipularis* had the highest RF value (19.05). *Lagerstroemia dupperreana* had the greatest RD value (19.23) (Table 4.10). The two pioneer species, *Cratoxylum cochinchinense*, IV 12.45, and *Colona floribunda*, IV 8.61 (Marod et al., 1999; Phongoudome et al., 2013) were found in HFA.

Table 4.10 Relative density, relative frequency, relative dominance and importance value of dominant families of seedlings (DBH < 4.5 cm and H < 1.3 m) in a low fire frequency area (LFA) and high fire frequency area (HFA) of MDF in Doi Suthep-Pui National Park.

Clade/Order/Family/Species	Relative Density (RD)		Relative Frequency (RF)		Importance Value (IV)	
	LFA	HFA	LFA	HFA	LFA	HFA
Clade: Superasterids						
Order: Santalales						
Family: Opiliaceae						
Champereia manillana (Blume) Merr.	2.00	-	2.56	-	4.56	-
Clade: Fabids						
Order: Malpighiales						
Family: Euphorbiaceae						
Croton acutifolius Esser	6.00	7.69	2.56	4.76	8.56	12.45
Family: Hypericaceae						
Cratoxylum cochinchinense (Lour.) Blume	-	7.69	-	4.76	-	12.45
Cratoxylum formosum (Jacq.) Benth. & Hook. f. ex Dyer subsp. *formosum*	2.00	-	2.56	-	4.56	-
Cratoxylum formosum (Jacq.) Benth. & Hook. f. ex Dyer subsp. *pruniflorum* (Kurz) Gogelein	10.00	-	2.56	-	12.56	-
Family: Phyllanthaceae						
Antidesma acidum Retz.	4.00	-	5.13	-	9.13	-
Antidesma sootepense Craib	6.00	-	7.69	-	13.69	-
Breynia sp.1	2.00	-	2.56	-	4.56	-
Bridelia stipularis (L.) Blume	4.00	15.38	5.13	19.05	9.13	34.43
Cleistanthus helferi Hook. f.	2.00	7.69	2.56	9.52	4.56	17.22
Phyllanthus columnaris Müll. Arg.	2.00	-	2.56	-	4.56	-
Order: Fabales						
Family: Fabaceae						
Dalbergia lakhonensis Gagnep.	-	3.85	-	4.76	-	8.61
Millettia xylocarpa Miq.	2.00	-	2.56	-	4.56	-
Pterocarpus macrocarpus Kurz	4.00	-	2.56	-	6.56	-
Xylia xylocarpa (Roxb.) W. Theob. var. *kerrii* (Craib & Hutch.) I. C. Nielsen	-	3.85	-	4.76	-	8.61

Clade/Order/Family/Species	Relative Density (RD)		Relative Frequency (RF)		Importance Value (IV)	
	LFA	HFA	LFA	HFA	LFA	HFA
Clade: Malvids						
Order: Myrtales						
Family: Combretaceae						
Anogeissus acuminata (Roxb. ex DC.) Guill. & Perr.	2.00	7.69	2.56	9.52	4.56	17.22
Terminalia chebula Retz. var. *chebula*	-	3.85	-	4.76	-	8.61
Family: Lythraceae						
Lagerstroemia duperreana Pierre ex Gagnep. var. *duperreana*	10.00	19.23	12.82	9.52	22.82	28.75
Order: Malvales						
Family: Malvaceae						
Colona floribunda (Kurz) Craib	-	3.85	-	4.76	-	8.61
Grewia hirsuta Vahl	-	15.38	-	19.05	-	34.43
Grewia sp.1	4.00	-	5.13	-	9.13	-
Pterospermum semisagittatum Buch.-Ham. ex Roxb.	10.00	-	7.69	-	17.69	-
Order: Sapindales						
Family: Rutaceae						
Naringi crenulata (Roxb.) Nicolson	2.00	-	2.56	-	4.56	-
Family: Simaroubaceae						
Brucea javanica (L.) Merr.	6.00	-	2.56	-	8.56	-
Clade: Asterids						
Order: Ericales						
Family: Ebenaceae						
Diospyros coaetanea H. R. Fletcher	2.00	-	2.56	-	4.56	-
Clade: Lamiids						
Order: Gentianales						
Family: Apocynaceae						
Wrightia arborea (Dennst.) Mabb.	6.00	-	7.69	-	13.69	-
Family: Rubiaceae						
Meyna grisea (King & Gamble) Robyns	6.00	-	7.69	-	13.69	-
Order: Lamiales						
Family: Bignoniaceae						
Markhamia stipulata (Wall.) Seem. var. *kerrii* Sprague	-	3.85	-	4.76	-	8.61
Family: Lamiaceae						
Clerodendrum infortunatum L.	4.00	-	5.13	-	9.13	-
Clerodendrum japonicum (Thunb.) Sweet	2.00	-	2.56	-	4.56	-
Total	100	100	200	100	100	200

(4) Undergrowth (herbs, climbers, grasses (DBH < 4.5 cm and H < 1.3 m)

In the undergrowth category, which included herb, climber and grass species, Poaceae was the dominant family in both the LFA and HFA (Table 4.11). Moreover, *Oplismenus compositus* was the dominant undergrowth species in these both areas. However, there was a difference in the number of family and species between the two areas: 15 families and 23 species were found in the LFA, while 7 families and 9 species were found in the HFA. In addition, *Chromolaena odorata*, a pioneer species (Kaewkrom, 2004; Marod et al., 2012; Rosleine and Suzuki, 2012) was found in both LFA and HFA (Table 4.11).

4.3.7 Under canopy light conditions

The light conditions under MDF canopy showed in Table 4.12. The average solar radiation in HFA was 7.81±0.78 % which higher than LFA (5.42±0.53 %). At 30 and 130 cm from the ground, solar radiation were 7.78±0.78 and 7.83±0.76 % in HFA while in LFA were 5.63±0.01 and 5.12±0.75 % respectively.

Table 4.11 Relative density, relative frequency, relative dominance and importance value of dominant families of undergrowth species (herbs, climbers and grass; DBH < 4.5 cm and H < 1.3 m) in a low fire frequency area (LFA) and high fire frequency area (HFA) of MDF in Doi Suthep-Pui National Park.

Clade/Order/Family/Species	Relative Density (RD)		Relative Frequency (RF)		Important Value (IV)	
	LFA	HFA	LFA	HFA	LFA	HFA
Clade: Magnoliids						
Order: Magnoliales						
Family: Annonaceae						
Uvaria rufa Blume	3.47	0.74	5.97	3.03	9.45	3.77
Clade: Monocots						
Order: Asparagales						
Family: Amaryllidaceae						
Crinum sp.1	-	1.03	-	3.03	-	4.06
Order: Poales						
Family: Poaceae						
Dendrocalamus membranaceus Munro	7.72	0.74	1.49	3.03	9.21	3.77
Oplismenus compositus (L.) P. Beauv.	41.57	77.73	28.36	57.58	69.93	135.30
Panicum sp.1	3.86	8.85	2.99	3.03	6.85	11.88
Poaceae 1	1.03	-	2.99	-	4.01	-
Order: Zingiberales						
Family: Zingiberaceae						
Zingiberaceae 1	0.39	-	1.49	-	1.88	-
Clade: Eudicots						
Order: Ranunculales						
Family: Menispermaceae						
Stephania sp.1	5.41	-	4.48	-	9.88	-
Clade: Fabids						
Order: Malpighiales						
Family: Malpighiaceae						
Aspidopterys hirsuta (Wall.) A. Juss.	1.67	-	2.99	-	4.66	-
Order: Fabales						
Family: Fabaceae						
Caesalpinia sp.	0.90	-	1.49	-	2.39	-
Order: Rosales						
Family: Rhamnaceae						
Ventilago denticulata Willd.	2.96	-	4.48	-	7.44	-
Clade: Malvids						
Order: Myrtales						

Clade/Order/Family/Species	Relative Density (RD)		Relative Frequency (RF)		Important Value (IV)	
	LFA	HFA	LFA	HFA	LFA	HFA
Family: Combretaceae						
Combretum sp.1	3.60	-	5.97	-	9.57	-
Combretum sp.2	2.83	-	2.99	-	5.82	-
Commelina paludosa Blume	0.64	-	1.49	-	2.14	-
Order: Malvales						
Family: Malvaceae						
Triumfetta annua L.	-	0.74	-	3.03	-	3.77
Clade: Lamiids						
Order: Gentianales						
Family: Apocynaceae						
Amalocalyx microlobus Pierre ex Spire	0.39	-	1.49	-	1.88	-
Family: Rubiaceae						
Hedyotis sp.1	0.39	-	2.99	-	3.37	-
Order: Lamiales						
Family: Acanthaceae						
Acanthaceae 1	0.39	-	1.49	-	1.88	-
Acanthaceae 2	0.90	-	1.49	-	2.39	-
Barleria siamensis Craib	1.03	-	2.99	-	4.01	-
Strobilanthes sp.1	2.96	-	4.48	-	7.44	-
Family: Lamiaceae						
Gomphostemma strobilinum Wall. ex Benth. var. *acaule* (Kurz ex Hook. f.) Prain	1.67	-	2.99	-	4.66	-
Clade: Campanulids						
Order: Asterales						
Family: Asteraceae						
Chromolaena odorata (L.) R. M. King & H. Rob.	1.67	0.44	2.99	3.03	4.66	3.47
Ferns						
Order: Schizaeales						
Family: Lygodiaceae						
Lygodium sp.1	2.32	8.26	4.48	21.21	6.79	29.47
Family: Tectariaceae						
Tectaria tenerifrons (Hook.) Ching	12.23	1.47	7.46	3.03	19.69	4.51
Total	100	100	200	100	100	200

Table 4.12 Average of solar radiation (%) and standard error at 30 and 130 cm above the ground in a low fire frequency area (LFA) and high fire frequency area (HFA) of mixed deciduous forest in Doi Suthep-Pui National Park.

Level from the ground (cm)	Relative solar radiation (%)	
	LFA	HFA
30	5.63±0.01	7.78±0.78
130	5.21±0.75	7.83±0.76
Average	5.42±0.53	7.81±0.69

CHAPTER 5
Fuel Characteristics and Fire Behavior in Mixed Deciduous Forest Areas with Different Fire Frequencies in Doi Suthep-Pui National Park, Northern Thailand

5.1 Introduction

The fire season in Thailand and Southeast Asian countries usually occurs between December and April (Goldammer and Wanthongchai 2011), with the peak fire period occurring between February and March. The burned areas recorded annually from 1998 to 2015 were between 4,078.3 and 51,830.4 ha. The northern part of the country has the most fire incidents: around 64.16% of the total number nationwide (Akaakara 2015). Fire is commonly associated with human activities in the tropics (Murphy and Lugo 1986), including in Thailand. Population growth and the expansion of agriculture have posed serious problems in forested areas; encroachment and illegal settlement are widespread problems, even in protected areas (Hafner and Apichatvullop 1990). Extensive human-caused fires occur in mixed deciduous forests at frequent intervals (Rundel and Boonpragob 1995). As a result, mixed deciduous forests, which occupy around 45% of the total forested area in Thailand, are becoming degraded ecosystems (Royal Forest Department 2001).

According to the national forest policy, Thailand is required to have forest covering 40% of its total area. This 40% comprises conservation and commercial forest in a ratio of 25:15 (Sharp and Nakagoshi 2006). Doi Suthep-Pui National Park is a well-known protected area in Northern Thailand. It has a remarkable level of species diversity due to its position on the boundary of the Himalayan and Indo-Malaysian biogeographical domains (Elliot et al. 1989). For each year from 2008 to 2017, there were 16 fire incidents in Doi Suthep-Pui National Park, which represents an increase from the previous period, in which the average was 12 (Fire Information for Resource Management System, FIRMS 2019). Posee (2010) reported that the fire situation in Doi Suthep-Pui National Park was severe and affected the local people considerably. The main conditions and factors affecting the occurrence of fire are related to human activities, including the gathering of non-timber forest products, illegal hunting, and agricultural debris burning (Forest Fire Control Division 2017).

Fire requires a mixture of heat, fuel, and oxygen in suitable proportions (Cochrane and Ryan 2009). After ignition, three main factors drive the behavior of fire: (1) fuel characteristics, including fuel composition, fuel load and arrangement, fuel moisture, and fuel continuity, are crucial determinants of fire behavior; (2) the microclimate, including temperature, relative humidity, and wind, determines the danger of fire and the potential for flammability and fire spreading; (3) the topography, including the elevation, slope angle, aspect, and physiographic characteristics, influences how a fire behaves, i.e., the rate and direction of spread (Graham et al. 2004). Information about current fuel characteristics and fire behavior is important for strategic fire management planning, including fuel management, fire protection, and fire extinguishing (Akaakara 2015). In almost all mixed deciduous forests in protected areas of Thailand, including Doi Suthep-Pui National Park, there is a lack of information about the current fuel characteristics and fire behavior. Therefore, the objectives of this research are to describe the current fuel characteristics and to understand the behavior of fire in mixed deciduous forest areas of Doi Suthep-Pui National Park. An experimental trial of artificial burning is needed to obtain the fire behavior parameters, something that only a few previous experiments have carried out in the same type of forest. It is expected that data from this study will help in developing a suitable fire management plan for this area.

5.2 Materials and Methods

5.2.1 Sample Plots

Due to restrictions on burning research in the National Park, it was impossible to either set a large experimental plot or conduct repeat burning trials. Therefore, in the LFA and HFA, one 50 × 50 m sample plot was set aside in each area for burning treatment, and the remaining plot was designated the control plot (unburned). Within the burning plot, the experimental area was a circle 50 m in diameter (Figure 5.1). The center of the experimental plot was at the center of eight 25-m-long radius lines. The first radius line was directly up the slope. Each radius line was placed at 45° from the neighboring line and was divided into sections. Each section was 5 m long and marked by 2-m-high bamboo poles. Firebreaks were established outside each plot, and forest fire control equipment was supplied by firefighters to prevent any accidental spreading of the fires.

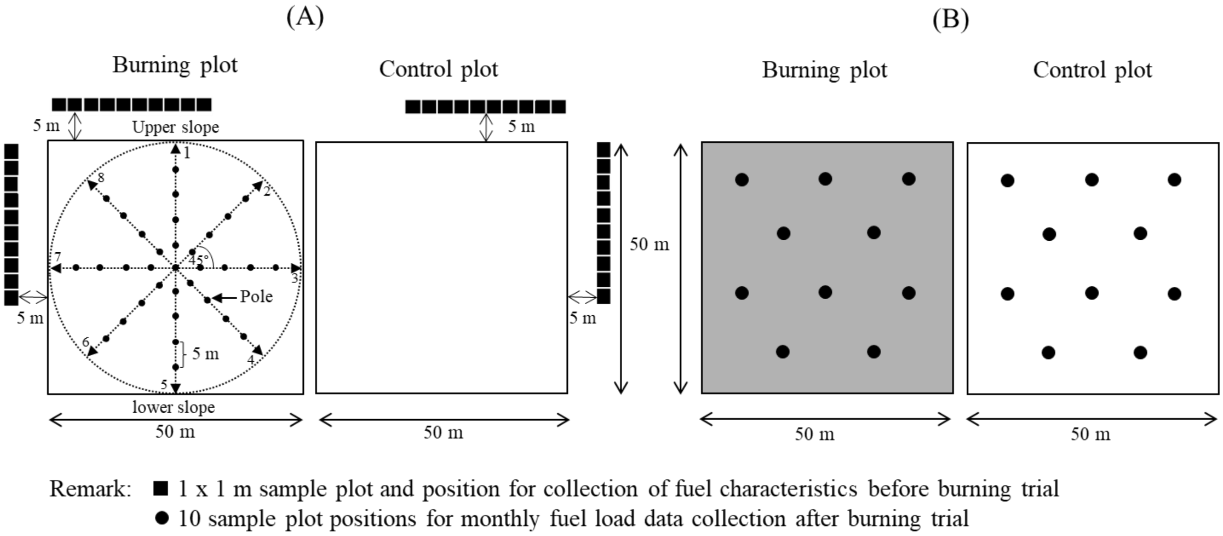

Figure 5.1 Experimental plot design. (A) The plots before the burning trial, showing a burning plot with the experimental design to examine fire behavior and sample plot positions for establishing fuel characteristics (left), and a control plot with sample plot positions (right); (B) the plots after the burning trial, showing ten fuel load sample plot positions in the burning plot (left) and the control plot (right).

5.2.2 Before Burning

Twenty sample plots of 1 × 1 m were established in each area type outside the experimental plots for collecting fuel-load and fuel-height data (Figure 5.1A). Generally, fuel in tropical deciduous forest is defined as all understory vegetation comprising litter (leaves, twigs, and reproductive parts, i.e., flowers, fruits, and other materials) or grass and undergrowth (seedlings, herbs, and climbers) (Wanthongchai et al. 2013). In this study, fuels were divided into two main parts: (1) dead fuel including all litter parts, and (2) living fuel including grass and undergrowth. Coarse, woody fuels, such as dead wood, branches, and bark, were not included, as these were present in only a small number of the study areas. A metal measurement tape was used to measure the height of all fuel parts before collection and measurement of the fresh weight of each part using either a 1 kg or a 7 kg weighing scale (Figure 5.2).

Figure 5.2 Fuel characteristics data collection in study area.

After measuring the fresh weight in the field, parts of each fuel were selected randomly and brought back to the central laboratory of Chiang Mai University for oven drying at 75°C for 48 h. The percentage moisture content was then calculated, and the samples were converted to dry weight using the following equations.

$$\text{Moisture content (\%)} = \frac{\text{fresh weight - dry weight}}{\text{dry weight}} \times 100$$

$$\text{Dry weight} = \frac{\text{fresh weight} \times 100}{100 + \text{\% moisture content}}$$

The data on fuel loads, fuel heights, and fuel coverage were analyzed for mean and standard error in Microsoft Excel 2016.

5.2.3 During Burning

After ignition at the center of the plot, a portable weather recorder (Kestrel 5500 Meter, PA, USA) was used for measuring air temperature, relative humidity, wind speed, and wind direction (Figure 5.3). In addition, details about the behavior of the fire, comprising flame height and fire spreading distance over the eight radius lines, were recorded every two minutes. The experiment was stopped after the fire had spread to the edge of any 25-m-long radius lines (Figure 5.4).

Figure 5.3 Measurement environment weather data during fire experiment by portable weather recorder (Kestrel 5500 Meter).

Figure 5.4 Fire behaviors experiment in study area.

The fire behavior indicators were calculated using the following equations.

$$\text{Fire spread rate (m/min)} = \frac{\text{fire spread distance}}{\text{fire spread time}}$$

Fireline intensity I (kW/m) is given by the equation (Byram 1959)

$$I = H \times W \times R,$$

where H is the heat yield of the fuel consumed (kJ/kg), which is approximately 18 330 kJ/kg for deciduous forest fuel in Thailand (Sompoh 1998), W is the amount of fuel consumed (kg/m2), and R is the rate of spread (m/s). The flame length L (m) is given by (Byram 1959)

$$L = 0.08I^{0.46}$$

The maximum soil temperature and the duration of soil heating were continuously recorded at the soil surface and at 2, 5, and 10 cm beneath the surface using type K thermocouple probes connected to HOBO UX120 (Onset Computer Corporation, MA, USA) four-channel thermocouple data loggers buried 20 cm beneath the mineral soil surface prior to ignition (Figure 5.5A). The surface fire temperatures at 20 and 50 cm above the ground were recorded using a Fluke Ti32 nds infrared thermal imaging camera at every pole passed by the fire on line 1 (heading fire) (Figure 5.5B).

(A) (B)

Figure 5.5 (A) Measurement of maximum soil temperature and the duration of soil heating by HOBO UX120, and (B) Measurement of surface fire temperatures by Fluke Ti32.

5.2.4 After Burning

Immediately after the fire had passed (Figure 5.6), three sample plots of 1 m × 1 m were set up randomly within each burning plot for collection of unburned material. These fractions were brought back to the laboratory for determination of moisture content and dry weight. Furthermore, fuel load data were monitored every month after the burning experiment for a one-year period. The 1 m × 1 m sample plot size was used to collect the fuel load from ten positions in each 50 m

× 50 m burning plot and control plot of the LFA and the HFA (Figure 5.1B). The method of fuel load collection was the same as that described earlier.

Figure 5.6 The study area condition after burning experiment.

5.3 Results

5.3.1 Fuel Moisture Content and Weather Conditions

The fuel moisture content in the LFA and HFA was highest in the undergrowth part, followed by grass, twigs, other material, and leaves (Figure 5.7). The moisture content of the LFA and the HFA in the living part, comprising grass and undergrowth, was 130–190%, whereas in the dead part, including leaves, twigs, and other parts, it was less than 15%.

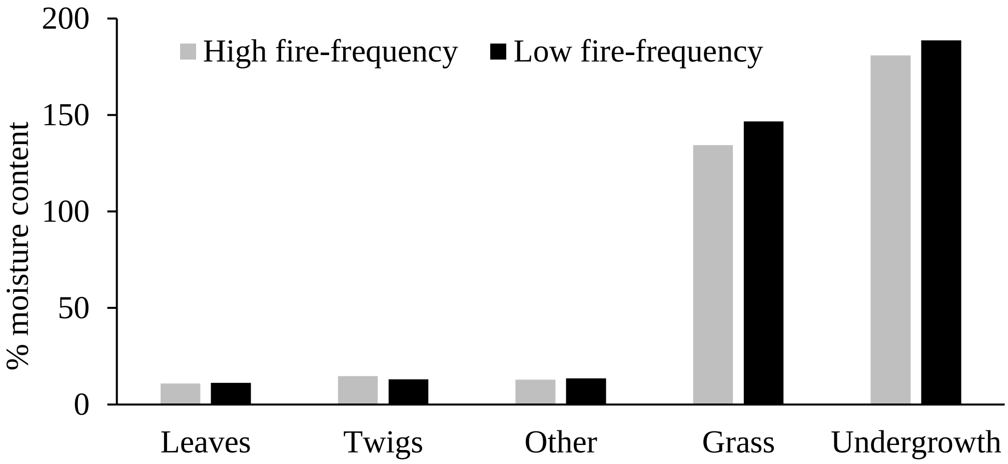

Figure 5.7 Mean fuel moisture content of leaves, twigs, other materials, grass, and undergrowth parts in the low and high fire-frequency areas of mixed deciduous forest.

The weather conditions during the burning experiments were slightly different for the two fire-frequency areas, due to the burning being carried out on different times of the day. The air temperature and relative humidity in the LFA were 33.6°C and 48.6%, while in the HFA they were 35.7°C and 47.3%. The wind speed was low in both areas, at 0.5 and 0.1 m/s in the LFA and HFA, respectively. The wind direction was southwesterly in both the LFA and the HFA (Table 5.1).

Table 5.1 Weather conditions during burning trials in low and high fire-frequency areas (LFA, HFA) of mixed deciduous forest.

Plot	Date	Period	Air temperature (°C)	Relative humidity (%)	Wind speed (m/s)	Wind direction
LFA	27 Feb 18	12:10–12:22	33.6	48.6	0.5	SW
HFA	27 Feb 18	14:10–14:23	35.7	47.3	0.1	SW

5.3.2 Fuel Characteristics Before Burning Trial

(1) Fuel Loads and Composition

Before the burning trial, the above-ground fine-fuel load in the HFA was 3,182.33 ± 1,715 kg/ha, while in the LFA it was 2,948.16 ± 1,467 kg/ha. The majority of the fuel (88–91%) in both areas was dead fuel, comprising leaves (58–66%), twigs (21–31%), and other material (0.8–1.3%). The living fuel part (grass and undergrowth) represented only 8–10% of the total (Table 5.2).

(2) Fuel Height and Fuel Coverage

Table 5.3 shows the fuel heights and coverage in the LFA and HFA. The fuel heights had similar characteristics in the two areas, with the tallest fuel appearing in the living undergrowth part (51.88 ± 37.10 and 50.45 ± 35.91 cm, respectively) followed by the living grass part (8.75 ± 12.12 and 6.42 ± 7.87 cm, respectively). The other dead parts, including leaves, twigs, and other materials were 5.30 ± 3.81, 1.75 ± 1.93, and 0.10 ± 0.91 cm in the LFA and 7.60 ± 4.10, 2.28 ± 1.99, and 0.10 ± 0.89 cm in the HFA, respectively.

Overall fuel coverage in the HFA was 74.00 ± 17.80%, whereas in the LFA it was 70.25 ± 17.01%. The leaf litter made up the highest proportion in both areas, at 43.00 ± 18.00% and 51.00 ± 20.48% in the LFA and HFA, respectively. When arranged by coverage, the order of the fuels was different in the two area types. In the LFA, undergrowth was the second-most abundant fuel in the area, followed by twigs, grass, and other material, while in the HFA, it was twigs, followed by undergrowth, grass, and other material.

Table 5.2 Fuel loads (kg/ha) and portion (%) before burning trial in low and high fire-frequency areas (LFA, HFA) of mixed deciduous forest. Standard error shown in parentheses.

Fuel composition		LFA			HFA		
		kg/ha		%	kg/ha		%
Dead fuel	Leaves	1,968.39	(±1 124.79)	66.77	1,860.53	(±990.07)	58.46
	Twigs	630.08	(±814.68)	21.37	1,009.5	(±295.16)	31.72
	Other Materials	23.70	(±25.42)	0.80	42.04	(±32.48)	1.32
Living fuel	Grass	34.38	(±92.70)	1.17	23.52	(±62.17)	0.74
	Undergrowth	291.61	(±290.98)	9.89	246.74	(±233.37)	7.75
Total		2,948.16	(±1 467)		3,182.33	(±1 715)	

Table 5.3 Fuel height (cm) and fuel coverage (%) with standard error value before burning trial in low and high fire-frequency areas (LFA, HFA) of mixed deciduous forest.

Fuel composition		Fuel height (cm)		Fuel coverage (%)	
		LFA	HFA	LFA	HFA
Dead fuel	Leaves	5.30 ± 3.81	7.60 ± 4.10	43.00 ± 18.00	51.00 ± 20.48
	Twigs	1.75 ± 1.93	2.28 ± 1.99	11.50 ± 8.63	11.25 ± 9.65
	Other Materials	0.10 ± 0.91	0.10 ± 0.89	0.50 ± 0.15	0.30 ± 0.20
Living fuel	Grass	8.75 ± 12.12	6.42 ± 7.87	2.50 ± 4.38	1.50 ± 3.61
	Undergrowth	51.88 ± 37.10	50.45 ± 35.91	14.50 ± 9.32	10.50 ± 6.77
Overall		–	–	70.25 ± 17.01	74.00 ± 17.80

(3) Dynamics of Fuel Loads After Burning Trial

The fuel load dynamics in the burning plots and their control areas over a one-year period after burning are shown in Figure 5.8. Before burning, the fuel loads in the LFA and HFA were 2,948.16 and 3,182.34 kg/ha, respectively. After the burning experiment, 70.00% of the fuel load in the LFA was burned, whereas approximately 62.00% of the initial fuel load in the HFA was consumed by fire. In the burning plots, both areas showed a similar fuel recovery trend, which increased sharply in the first three months after burning, then reduced slightly, followed by a sudden drop in the sixth month. The curve continued to show a slight decrease up to the 12th month (February 2019), when the fuel loads had still not reached full recovery. In the LFA, recovery was around 56.92% of the initial value, whereas in the HFA it was 53.97%. In contrast, the dynamics of the fuel loads in the control plots in the LFA and HFA after 12 months each showed an increase from their initial values, rising by 23.52% and 19.83%, respectively.

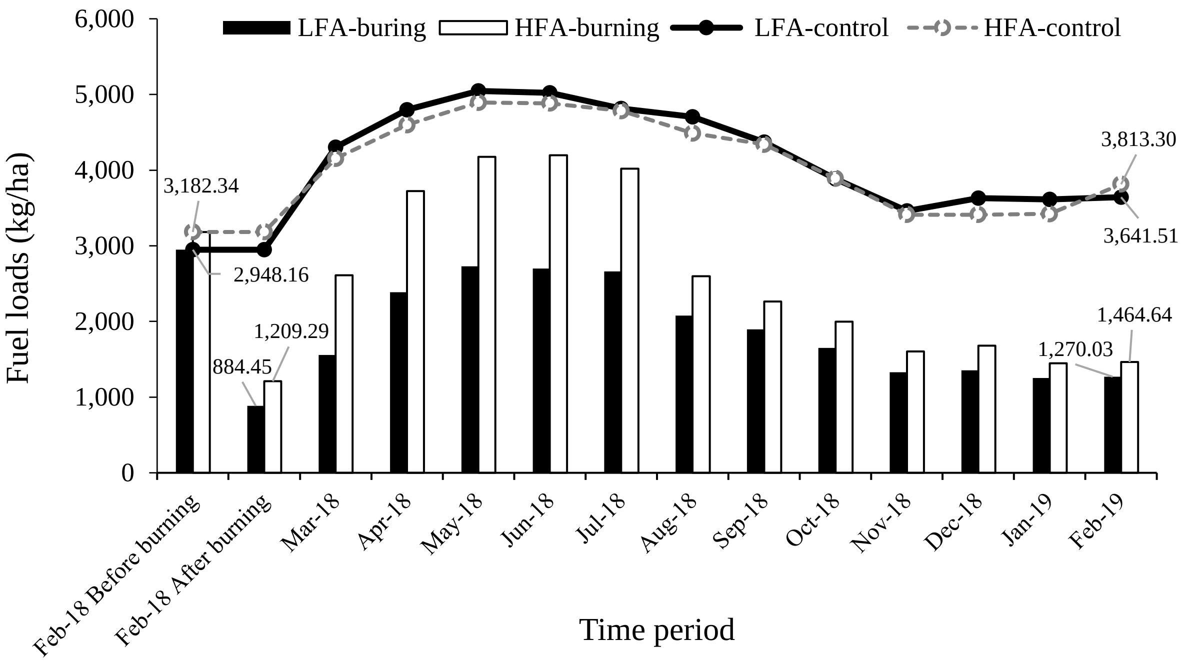

Figure 5.8 Fuel load dynamics of the burning and control plots in the low and high fire-frequency areas (LFA, HFA) in mixed deciduous forest.

5.3.3 Fire Behavior

Descriptors of fire behavior included the rate of spread, flame height, flame length, intensity of the fireline, flame temperature, and soil temperature, and these are shown in Table 5.4. The heading fire in both areas had the fastest fire spreading rate: 1.68 m/min for the LFA and 1.94 m/min for the HFA. The second-fastest rate of spread in both areas was flanking fire (0.76 and 0.50 m/min in the LFA and the HFA, respectively), followed by backing fire (0.56 m/min in the LFA and 0.38 m/min in the HFA). Fire spread direction in LFA and HFA shown in Figure 5.9.

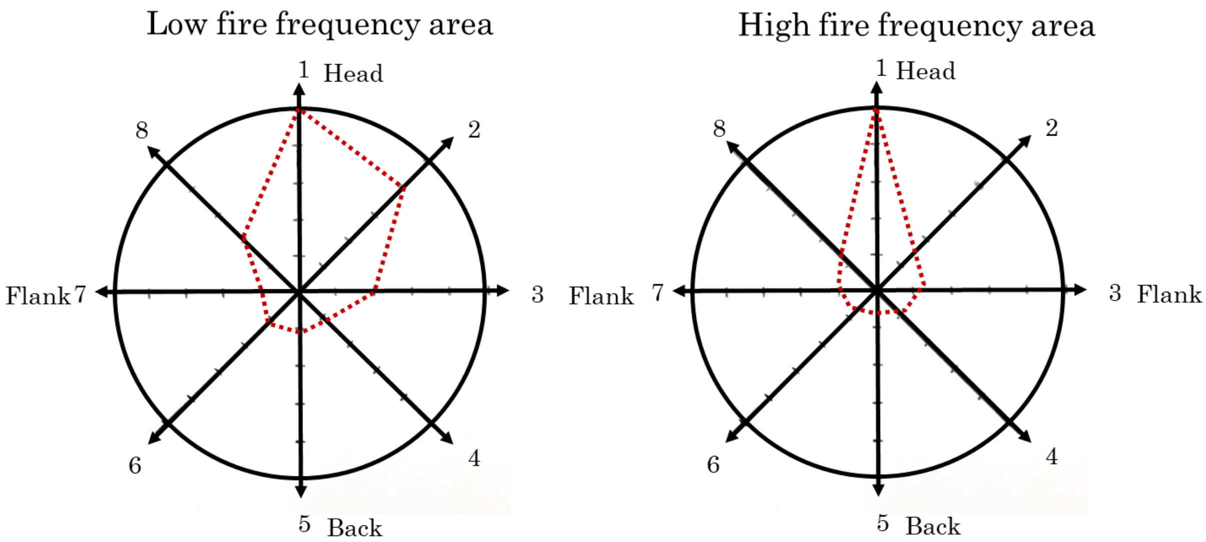

Figure 5.9 Fire spread direction in low and high fire frequency areas

Observations of the fire height in both the LFA and the HFA showed similar results, with the heading fire having the highest flame (90 cm in the LFA and 87 cm in the HFA), followed by the flanking fire and then the backing fire. The flame length, calculated from Byram's formula, was similar for the LFA and HFA (0.69 and 0.72 m, respectively). These results show that the intensity of the fireline was 119 kW/m in the HFA and 109.66 kW/m in the LFA. The average intensity values for the firelines in both areas were defined as low intensity.

During the burning experiment, the maximum surface fire temperature in both the LFA and HFA did not exceed 700°C. The flame temperature varied according to the flame height. A low flame level resulted in a higher temperature than a high flame level. The flame temperature at 20 cm was between 407°C and 482°C, while at 50 cm it was between 301°C and 388°C (Figure 5.10).

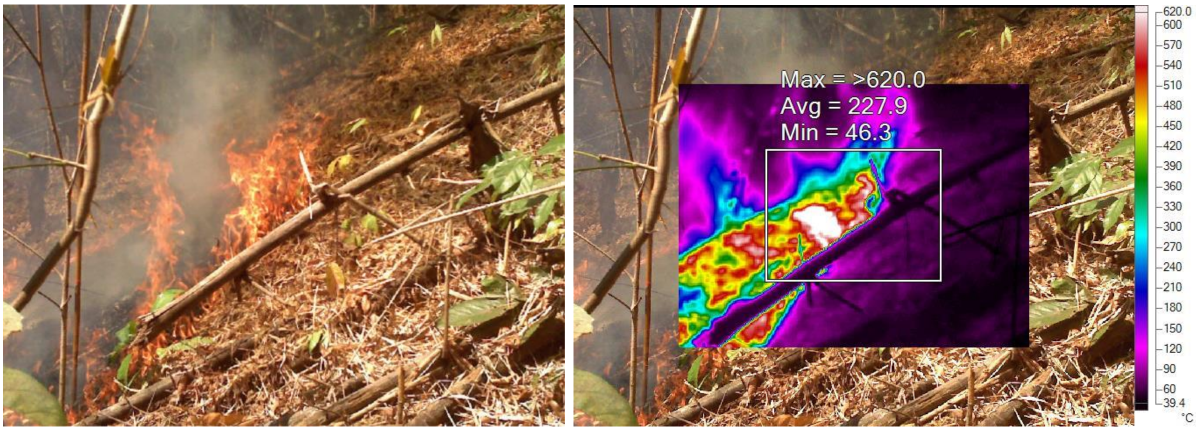

Figure 5.10 Fire temperature image from the thermal infrared camera (Fluke Ti32).

5.3.4 Soil Temperature

The maximum soil temperature during the burning experiments in both the LFA and the HFA was between 550°C and 700°C. The soil surface level showed the highest temperatures, at 375.09°C and 238.79°C in the HFA and LFA, respectively, followed by the levels 2, 5, and 10 cm beneath the soil surface, which reached 29.13°C, 25.77°C, and 25.37°C in the LFA and 30.01°C, 26.15°C, and 25.86°C in the HFA, respectively (Table 5.4).

At ground level, the duration of heating above any of the given critical temperature thresholds, i.e., 60°C, 80°C, and 100°C for biological, chemical, and physical soil properties (DeBano et al. 1998; Wanthongchai et al. 2013), was generally less than 5 min (between 1.52 and 4.54 min) (Table 5.5).

Table 5.4 Quantitative average fire behavior characteristics, flame temperature, and soil temperature in low and high fire-frequency areas (LFA, HFA) of mixed deciduous forest.

Fire characteristic	LFA	HFA
Heading fire rate of spread (m/min)	1.68	1.94
Backing fire rate of spread (m/min)	0.56	0.38
Average flanking fire rate of spread (m/min)	0.76	0.50
Heading fire flame height (m)	0.90	0.87
Backing fire flame height (m)	0.44	0.20
Average flanking flame height (m)	0.52	0.50
Flame length (m)	0.69	0.72
Fireline intensity (kW/m)	109.66	119.00
Flame temperature (°C)		
20 cm above ground	407.22	482.56
50 cm above ground	301.01	388.02
Maximum soil temperature (°C)		
soil surface	238.79	375.09
2 cm beneath the soil surface	29.13	30.01
5 cm beneath the soil surface	25.77	26.51
10 cm beneath the soil surface	25.37	25.86

Table 5.5 Duration of heating at different soil depths for each critical temperature threshold in low and high fire-frequency areas (LFA, HFA) of mixed deciduous forest.

Temperature threshold	Soil depth	Duration of heat (min)	
(°C)	(cm)	LFA	HFA
>60	0	1.52	2.64
	2, 5, 10	0.00	0.00
>80	0	1.98	2.82
	2, 5, 10	0.00	0.00
>100	0	2.36	4.54
	2, 5, 10	0.00	0.00

CHAPTER 6
Discussion and Conclusion

6.1 Discussion

A Low fire frequency encouraged more species diversity in all forest layers whereas a high fire frequency was associated with decreased species diversity in all forest categories. *Dendrocalamus membranaceus* was the only bamboo species (in the two areas, and a low number of clumps was observed in the HFA. The greater numbers of herb and seedling species was found in the LFA. In contrast, in the HFA, showed lower numbers of species in all categories. A low fire frequency encourages more species diversity in the understory layer than zero-burning or over-burning. Because the fires in this area are low-intensity understory fires (Akaakara, 2015), which have the greatest influence on biodiversity within plant communities, the understory vegetation is more affected by fire than the overstory (Brown, 2000). In a tropical dry deciduous forest, the seedling density at 2-5 years after a single fire was increased in comparison to unburned areas (Verma et al., 2017). In a woodland forest, burned twice in 12 years, a significantly greater number of plant species, higher shrub density and greater understory cover was encouraged (Fox, 1986). In sub-tropical evergreen broad-leaved forest, burning after clear-cutting resulted in sprouting regeneration and has a high species diversity similar to non-burned plots (Wu et al., 2006).

Long-term disturbance by high-frequency fires caused the extreme diminishment of species diversity and density, especially in saplings and in the understory of MDF. Similarly, Peterson & Reich (2001) reported that seedling density in Oak-savanna declined with increasing fire frequency but that the decline differed in each species. Related research in tropical forests of the eastern Amazon showed substantial variation in forest structure and fire damage and that burned forests showed extreme heterogeneity. Increased fire intensity or frequency resulted in decreased canopy cover, living biomass and living adult stem densities. Even light burns removed more than 70 percent of the sapling and vine populations. In severely damaged areas, pioneer species dominated the understory (Cochrane & Schulze, 1999). Marod et al. (1999) reported that in MDF of western Thailand, under the gaps of dieback bamboo areas, seedlings can be regenerate and develop to small saplings if repeated fires not occur in the following next 3-4 years. Wanthongchai et al. (2014) similarly suggested for the DDF of western Thailand that 6-7 years without fire is needed to encourage the successful regeneration of young trees.

Zero-burning is a good condition for species diversity in the tree and sapling layer but not in the understory layer. The thick layer of litter that accumulates on the forest floor in an unburned area prevents seeds from contacting the mineral soil, and thereby inhibits their germination (Akaakara, 1985). Another concern related to the absence of fire in this ecosystem is that it will lead to a higher moisture content in both air and soil, which would encourage the expansion of evergreen plant species in the area, and which might ultimately change the type of ecosystem (Goldammer 2002; Wanthongchai et al. 2014). A similar result was reported by Kafle (2006), who found that in a tropical deciduous dipterocarp-oak forest (defined as a fire-dependent ecosystem) that was protected against fire for 28 years, the forest showed a high species richness in both ground flora and tree species. However, evergreen species also shared a great proportion with deciduous species. Wanthongchai et al. (2014) mentioned that complete fire exclusion may result in a change to ecosystem components and an increased risk of high-intensity wildfire.

A natural regeneration trend was indicated by the density of trees in each developmental stage (seedlings, saplings, and trees). In the present study, the density values were decreased in the LFA and HFA, especially in the tree and sapling layers. One possible reason is that annual fire,which also occurred in the burned area, serves as a barrier deterring the development of seedlings; thus, plants could not grow beyond the seedling stage. Even though the present study result indicated that HFA allowed more light intensity reaching the forest floor than the LFA and might encourage the seedlings germinating from seeds or sprouting from an underground root in the rainy season, however, it had been burned back by fire in the following dry season. The establishment of seedlings and the seedlings being burned back by fire is an evident cycle that has occurred in this area for many years (Akaakara, 1985). As a result, the MFD in the current HFA shows clear evidence of degradation from long-term fire disturbance (Figure 6.1). Goldammer (2002) also stated that over the long term, an excessive burning frequency obstructs and slows down natural regeneration and remodels the forest structure. Frequently burned forests will gradually degrade; become to increasingly dry and eventually change to grassland.

The mixed deciduous forests of Doi Suthep-Pui National Park had similar fuel characteristics in both the LFA and the HFA. The study showed that the main fuel component in this forest type was litter (leaves), which fall from the top layer of trees to accumulate on the forest floor. A similar result was also reported by Wiriya and Kaitpraneet (2009), who found that the fuel load of deciduous forest was composed of leaf litter and undergrowth. Wanthongchai et al. (2011) stated that fire in dry dipterocarp forests did not consume the overstory layer, since all fires were surface fires. However, the greater frequency of fires in recent years has had a clear impact on the living understory coverage, including woody seedlings, herbaceous plants, and climbers with a height not exceeding 1.3 m. Saha and Howe (2003) also found a similar result, i.e., that low-intensity ground fires reduced seedling diversity by around 30%. This showed that a high frequency of fires interfered with the succession processes of the plant community. Consequently, the plant structure and diversity were degraded, and the plant community was eventually liable to be permanently degraded (Akaakara 2015). In the case of dry deciduous forests in India, almost all tree diversity is predicted to be lost in 100–200 years if anthropogenic fires continue (Saha and Howe 2003).

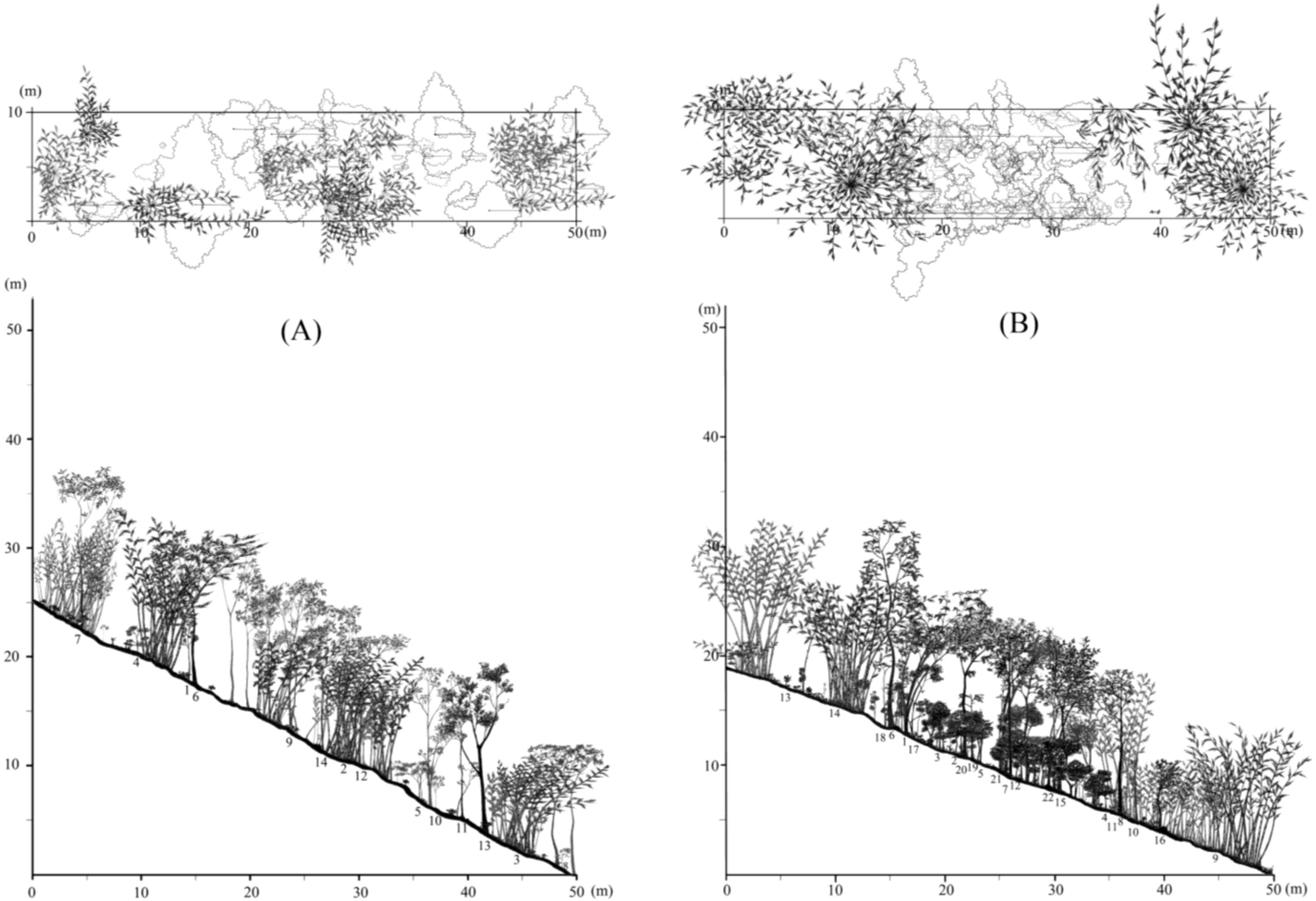

Figure 6.1 Mixed deciduous forest structure in Doi Suthep-Pui National Park; (A) the high fire frequency area included 14 species: 1) *Aporosa wallichii* Hook. f., 2) *Canarium subulatum* Guillaumin, 3) *Dendrocalamus membranaceus* Munro, 4) *Hubera cerasoides* (Roxb.) Chaowasku, 5) *Grewia hirsuta* Vahl, 6) *Lannea coromandelica* (Houtt.) Merr., 7) *Markhamia stipulata* (Wall.) Seem. var. *kerrii* Sprague, 8) *Pavetta indica* L. var. *tomentosa* (Roxb. ex Sm.) Hook. f., 9) *Pterocarpus macrocarpus* Kurz, 10) *Rothmannia sootepensis* (Craib) Bremek, 11) *Sterculia guttata* Roxb., 12) *Terminalia glaucifolia* Craib, 13) *Terminalia mucronata* Craib & Hutch, 14) *Xylia xylocarpa* (Roxb.) W. Theob. var. *kerrii* (Craib & Hutch.) I. C. Nielsen. (B) The low fire frequency area included 22 species: 1) *Alangium indochinense* W.J.de Wilde & Duyfjes, 2) *Antidesma acidum* Retz., 3) *Antidesma sootepense* Craib, 4) *Aporosa wallichii* Hook. f., 5) *Brucea javanica* (L.) Merr., 6) *Canarium subulatum* Guillaumin, 7) *Colona flagrocarpa* (C. B. Clarke) Craib, 8) *Colona floribunda* (Kurz) Craib, 9) *Dendrocalamus membranaceus* Munro, 10) *Grewia hirsuta* Vahl, 11) *Hubera cerasoides* (Roxb.) Chaowasku, 12) *Lagerstroemia duperreana* Pierre ex Gagnep. var. *duperreana*, 13) *Mallotus philippensis* (Lam.) Müll. Arg., 14) *Markhamia stipulata* (Wall.) Seem. var. *kerrii* Sprague, 15) *Millettia xylocarpa* Miq., 16) *Mitragyna rotundifolia* (Roxb.) Kuntze, 17) *Naringi crenulata* (Roxb.) Nicolson, 18) *Schleichera oleosa* (Lour.) Merr., 19) *Suregada multiflora* (A. Juss.) Baill., 20) *Tectona grandis* L. f., 21) *Vitex canescens* Kurz, 22) *Xylia xylocarpa* (Roxb.) W. Theob. var. *kerrii* (Craib & Hutch.) I. C. Nielsen.

Fuel recovery after burning was similar in both the LFA and HFA. The fire reduced the total fuel load by approximately 60–70% and damaged the fuel structure in these areas. Since the majority of fuel was litter, the two main mechanisms involved in fuel recovery were litterfall dynamics and decomposition processes. The results showed that the highest fuel load occurred in May, due to the physiological characteristics of the plant species in mixed deciduous forests, which are defoliated in the dry season (November–April), resulting in the highest amount of litter appearing during the late dry season or early rainy season (May–June). These results were also explained by Richard (1952), who stated that in mixed deciduous forest, leaf fall normally begins in February, well after the onset of the dry season in early December, and continues at varying rates until the forest is leafless by the end of March. The leafless period extends over three to four months.

After the dry season, decomposition activity, which is highest in the rainy season (May–October), plays the main role in shaping the fuel structure and composition, as shown by the fact that the amount of fuel declined from August to November. A similar result was reported by Bargali et al. (2015) in dry deciduous forest, where a higher weight loss occurred during the rainy and summer seasons when compared with the winter season. Pandey and Singh (1982) explained that greater decomposition during the rainy season is due to pronounced microbial activity under favorable temperature and moisture conditions and accentuated leaching due to rainfall. Moreover, after one year, the burning trial showed that around 50% of the initial fuel load was recovered. Therefore, the expected full recovery period would be at least two years. One disadvantage of fire is the damage caused to living plants in the understory. However, fire also has the advantage reported by Ahn et al. (2014) that it accelerates the decomposition of organic matter and nutrient release, consequently improving forest productivity.

All the fire behavior features in the LFA and the HFA showed similar characteristics. Due to the stand structure, the fuel properties, topography, and weather conditions were similar in both areas. Wanthongchai et al. (2014) found similar results, i.e., that in dry dipterocarp forest, the differences in fire behavior between frequently and infrequently burned sites were insignificant. These results also support the proposal by Rothermel (1991) that stand structure and fire behavior are linked. Hence, similar fire environments in both LFA and HFA may logically be expected to produce similar fire behaviors. The fire environment, especially the temperature, relative humidity, and fuel moisture content, significantly influences fire intensity in dry dipterocarp forest (Lertsuchatavanich 1995). Akaakara (2015) mentions that forest fires in Thailand usually develop as surface fires with an intensity of the fireline from low to medium in fire-dependent ecosystems. The fires in this study are also defined as "surface fires," with flame-dominant combustion, actively spreading at a rate of 0.3–8.3 m/min, with a flame length of 0.5–1.5 m, and a line intensity of 58–630 kW/m (Ryan 2002). Moreover, according to the fire severity classes proposed by Chatto and Tolhurst (2004), the fire intensities in both the LFA and HFA were defined as class 1, with intensities of firelines less than 500 kW/m (109.66 and 119 kW/m) and with only surface fuels consumed. Fire-extinguishing practices were suggested for this fire type by Andrews (1980). In cases of low fire severity, firefighters can attack the heading, flanking, and backing fires with hand tools, for example fire beaters combined with water backpacks. Construction of a firebreak at least 4 m wide could stop these fires spreading.

The results for soil temperature and critical duration in both areas were slightly different due to the influence of fuel load, which was greater in the HFA than in the LFA. However, both areas showed that only the surface level of the soil was affected by the fire. Related research has shown a similar result, where the soil surface temperatures during burning in pine–oak forest and pine forest were over 250°C, but the fire did not cause temperature changes in the deeper soil layers (Wanthongchai et al. 2013). Comparing the results of fuel loads and fire behavior in deciduous forests in Thailand, variations are observed depending upon the deciduous forest type, region, and the duration of the fire (Table 6.1). Therefore, more intensive studies of fuel characteristics and fire behavior will help forest/fire managers to make a specific and suitable plan for each forest type and location. In addition, ongoing longitudinal research is suggested to obtain more precise predictions of the impact of fire disturbance on mixed deciduous forest in the long-term future and to find appropriate strategies for maintaining this ecosystem in good condition.

Table 6.1 Fuel load and some fire behavior descriptors in deciduous forest ecosystem of Thailand: DDF is deciduous dipterocarp forest and MDF is mixed deciduous forest.

Ecosystem-Region	Fuel load (ton/ha)	Fire behavior descriptors: Rate of spread (m/min)	Flame length (m)	Fireline intensity (kW/m)	Reference
MDF-North	2.95–3.18	0.38–1.94	0.69–0.72	109.66–119.00	Recently observed (2018)
MDF&DDF-North	2.40–5.17	0.51–2.55	0.39–2.03	39.33–379.79	Junpen et al. (2013)
MDF-Northeast	4.88	0.60–1.00	0.30–1.00	102.09	Sutthichart (1996)
DDF-Central	5.37	1.89	0.86	190.00	Wiriya and Kaitpraneet (2009)
DDF-Central	4.30–8.10	1.30–2.70	1.20–1.50	291.00–467.00	Wanthongchai et al. (2011)
DDF-Northeast	–	2.00	2.58	266.03	Sunyaarch (1989)
DDF-North	4.67	1.26	–	225.33	Lertsuchatavanich (1995)

6.2 Conclusions

This study of the effects of fire frequency on the floristic composition and structure of mixed deciduous forest in Doi Suthep-Pui National Park, Chiang Mai, Thailand showed that a low fire frequency encouraged greater species diversity in the understory layer than zero-burning or over-burning. Long term disturbance by fire, as was observed in the HFA, caused the extreme diminishment of species diversity, especially among saplings and in the understory of MDF. Zero-burning encourages good species diversity in the tree and sapling layers; however, the higher moisture content in the air and soil of the area, may change the ecosystem or cause a high-intensity fire from the accumulation of many tons of litter in the forest area. In the current HFA, the MFD in Doi Suthep-Pui showed obvious evidence of degradation from long-term fire disturbance. While the fuel characteristics and fire behavior in mixed deciduous forest of Doi Suthep-Pui National Park indicated that the LFA and HFA showed similar fuel characteristics in which litter was the main fuel. Consequently, the fire behaviors in the two areas also showed a similar surface fire type and low intensity. Because intensity of the fire was low, it only caused damage to the living understory layer or material near the soil surface and did not affect the structure of the top layer, which produces the main fuel (litter) that falls to the forest floor, or the underlying soil. The one-year fuel dynamics after burning also showed similar trends in both areas, whereby fire consumed approximately 60–70% of the total fuel load and the expected time to full recovery after a fire would be two years.

6.3 Recommendations

To improve and maintain the condition of the MDF in this area, a suitable fire-free interval must be introduced. However, the results of this study are not sufficient to suggest an appropriate fire interval. Thus, a further study of long-period dynamics of the understory vegetation after burning is recommended.

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List of Publications

CHAPTER 4

Author : <u>Chonthida Chernkhunthod</u>, Yoshiyuki Hioki

Title : Floristic composition and forest structure in different fire frequency of mixed deciduous forest, Doi Suthep-Pui National Park, Northern Thailand

Journal : The Japanese Society of Revegetation Technology

CHAPTER 5

Author : <u>Chonthida Chernkhunthod</u>, Yoshiyuki Hioki

Title : Fuel Characteristics and Fire Behavior in Mixed Deciduous Forest Areas with Different Fire Frequencies in Doi Suthep-Pui National Park, Northern Thailand

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Appendix

Appendix 1 General condition of study areas

(a) Low fire frequency area

(b) High fire frequency area

Appendix 2 Establishment of sample plots for collecting data of floristic composition and forest structure

(a) Sample plots setting and equipment

(b) Tree, sapling, and seedling tagging

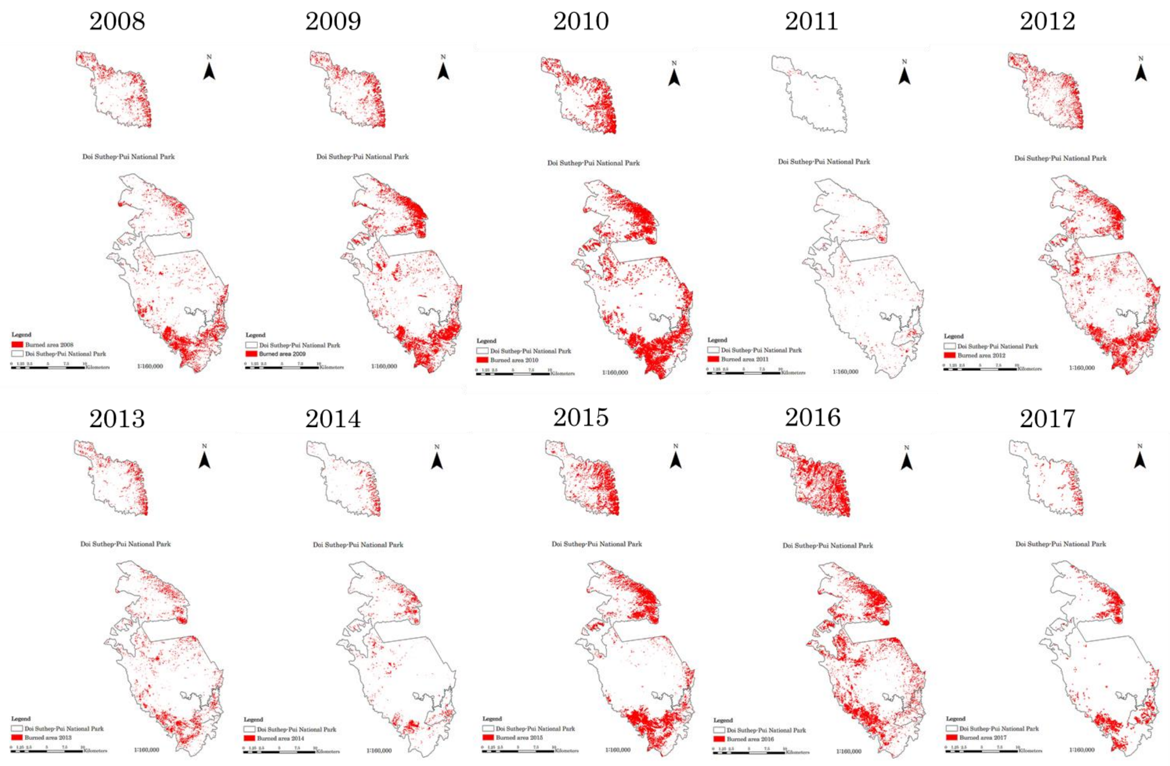
Appendix 2 Continued

(c) DBH and H measurement, species identification, and data record

(d) Fire break construction 3-5 meter width surround sample plots

Appendix 3 Data collection of fuel characteristic

Appendix 4 Burned area map in Doi Suthep-Pui National Park between 2008-2017



Summary

Thailand has two main forest ecosystems: evergreen forest and deciduous forest, which are classified as fire sensitive ecosystems and fire dependent ecosystems, respectively. The deciduous forests, which cover approximately 56% of the forested area in Thailand include deciduous dipterocarp forest (DDF; 21%), mixed deciduous forest (MDF; 34%) and pine forest (1%). The majority of deciduous forest is MDF, which has developed throughout the country, especially in the north, northeast, western and central regions. This forest type has been further divided into 2 dominant types: the *Tectona grandis* type and the *Lagerstroemia calyculata* type. Forest fires generally occur during the dry season, which begins from December, peaks in March, and ends in May. Deciduous forests, including DDF and MDF, are the most threatened by fire. In the last decade (2008-2017), MODIS hotspot statistics have illustrated that in northern Thailand, approximately 77% of annual fire incidents occurred in forested areas and that 99% of fire incidents were caused by human activities, including the gathering of non-timber forest products, illegal hunting, burning of agricultural debris, raising cattle, carelessness, illegal logging, arson, and tourism. From 2007 until now, these forest fire incidents have also been a major cause of the annual haze pollution in the far north of the country, which has serious direct effects on respiratory health of the local population and which also impacts the tourism industry and aerial transportation in this region. Even though fire frequency is a basic element of the fire regime, which is the most significant factor influencing the structure and function of the ecosystem, if fires occur too frequently in fire-dependent ecosystems, including MDF, ecosystem degradation may occur. The only previous study in Doi Suthep-Pui National Park (DSP) to analyze the vegetation structure in burned and unburned areas of MDF was conducted in 1985. Since then, the impact of fire on the floristic composition and forest structure of MDF in this area has been unknown. It is a concern that the current heavy burns in the last decade have damaged the original structure and plant diversity

in MDF, transforming it into another type of dry ecosystem. This study aims to (1) Investigate fire history in the past decade by investigated latest 10 years fire history from Landsat 7 and 8 imageries via dNBR index and generated fire frequency map. (2) Describe the current status of floristics composition and forest structure of MDF in different fire frequency areas, by established sample plots for collected floristic characteristic and forest structure data, and (3) Describe the present fuel characteristic and fire behavior of MFD in different fire frequency areas, by established sample plots for collected fuel characteristic data and applied burning experiment for collected fire behavior data.

The study was carried out in areas of MDF within DSP, Chiang Mai, Northern Thailand. The area lies on the west side of Chiang Mai city at 18°50′N latitude and 98°50′E longitude. The forest received protection as a National Park in 1981 and covers an area 261 km^2. The average annual rainfall of the area is between 1,350 and 2,500 mm, the warm index is 257.7 and the average maximum and minimum temperature are 32.2 and 20.8°C, respectively. The area has 3 seasons: summer (mid of February to mid of May), rainy season (mid of May to mid of October) and winter (mid of October to mid of February). The topography of the area is mountainous, with an elevation of 330 – 1,685 m. This protected area includes 4 forest types: deciduous dipterocarp forest, mixed deciduous forest, dry evergreen forest and hill evergreen forest. The dominant species in the MDF of DSP are *Tectona grandis, Lagerstroemia calyculata, Xylia xylocarpa,* and *Pterocarpus macrocarpus*. DSP is located 5 km at the western side of Chiang Mai Metropolitan Area which has a population of nearly one million people. There are villages, temples, University, Military area, etc. located along the northeast through the east, south and southeast boundary of DSP. There is no clear evidence on the earliest fire incident in DSP, but forest fires have been recognized in this area for many decades. The average MODIS hotspot count of DSP has been 16 times for each year from 2008 to 2017, which represents an increase from the previous period, in which the average was 12 times.

In October 2017, a ten-year fire frequency map was generated based on satellite data and areas with low and high fire frequency were identified. The results of the ten-year (2008-2017) Landsat imagery analysis showed that all areas of deciduous forest in DSP had experienced at least one fire. The total burned area was 10,940 ha, which amounted to 41.9% of the DSP area. The high fire frequency areas which has fire repeated 6-10 times in a decade were located in the northeast and southwest areas, covering approximately 13.92% of the total burned area in DSP. The remaining 86.02% of the burned area had a low fire frequency which fire occurred 1-5 times within a decade. In December 2017, two sample plots of 50 m x 50 m were established in each site. The flora species, floristic characteristics and forest structure were identified and calculated. The results of floristic characteristics showed that a low fire frequency encouraged the abundance of species diversity in all flora layers which in contrast to a high-frequency fires that caused the extreme diminishment of species diversity, especially in the sapling and seedling layers. Even though the light condition under the canopy in high fire frequency area was better than the low fire frequency area and may encourage the seedlings develop in the rainy season, however, it had been burned back by fire in the following dry season. The high frequent fire affects the plants could not grow beyond the seedling stage. The current floristic composition and forest structure of MDF shows clear evidence of degradation from long-term high fire frequency disturbance.

In February 2018, the study of fuel characteristics was conducted by using twenty quadrats, each 1 m × 1 m, were used to collect data regarding fuel characteristics, and 50 m × 50 m quadrats were used to study fire behavior in low and high fire-frequency areas. The fuel load data were collected every month for a period of one year. The results illustrate that the MDF of DSP had similar fuel characteristics in both the low and high fire frequency areas. The main fuel component in the two fire-frequency areas of this forest type was litter (leaves) which fall from the top layer of trees to accumulate on the forest floor. Fire consumed approximately 60–70% of the total fuel loads, and fuel recovery to the

original level was predicted to take around two years. All the fire behavior features in the low and high fire frequency area showed similar characteristics due to the stand structure, the fuel properties, topography, and weather conditions were similar in both areas. The fire type in both areas was defined as surface fire with low intensity, which usually occurs in deciduous forests of Thailand. The results for soil temperature and critical duration in both areas were slightly different due to the influence of fuel load, which was greater in the high fire frequency area than in the low fire frequency area. However, both areas showed that only the surface level of the soil was affected by the fire and did not cause any problems in deeper layers. For improving and maintaining a good condition to this protected area, a suitable fire-free interval must be introduced. Thus, a further study of long-period dynamics of the understory vegetation after burning is recommended.

Key words: Floristic Composition, Forest Structure, Species Diversity, Anthropogenic Fire, Fire Frequency, Fuel Dynamic, Tropical Deciduous Forest, Protected Area

Japanese Summary

タイには、常緑樹林と落葉樹林の 2 つの主要な森林生態系があり、それぞれ山火事に敏感な生態系と山火事依存型生態系に分類されている。タイの森林の約 56%を占める落葉樹林には、落葉樹林(DDF;21%)、落葉樹林(MDF;34%)が含まれる。松林(1%)と落葉樹林の大半は、特にタイの北部、北東部、西部、中央地域で発達した MDF である。この森林タイプは、さらに 2 つの優占種 *Tectona grandis* と *Lagerstroemia calyculata* のタイプに分けることができる。森林火災は一般的に、12 月から始まり、3 月に最盛期を迎え、5 月に終了する乾季に発生する。DDF や MDF を含む落葉樹林は、最も山火事の脅威を受けやすい森林である。過去 10 年間(2008-2017 年)における MODIS ホットスポット統計によると、タイ北部では年間の山火事の約 77%が森林地帯で発生し、山火事の 99%は非木材森林製品の収集、違法狩猟、農業用残骸の燃焼、牛の飼育、不注意、違法伐採、放火、観光など、人間の活動によって引き起こされていた。2007 年から現在まで、これらの森林火災は、タイの最北地で、毎年の煙霧汚染の主な原因となっており、呼吸器疾患に深刻で直接的な影響を及ぼし、この地域の観光産業や航空輸送にも影響を与えている。山火事の頻度は、生態系の構造と機能に影響を与える最も重要な要因であり、山火事が MDF を含む山火事依存型生態系であまりにも頻繁に発生した場合、生態系の劣化を招く恐れがある。ドイステープ・プイ国立公園(DSP)における、山火事による消失／非焼失が植生の構造に与える影響を分析するための唯一の先行研究は、1985 年に行われた。それ以降、この地域における MDF の植物の種組成と森林構造に対する山火事の影響は明らかにされていない。過去 10 年間における重大な山火事が、MDF 元来の構造と植物の種多様性を損ない、別のタイプの乾燥生態系に変換してしまうことが懸念されている。 本研究で著者は、(1) Landsat 7／8 画像から dNBR 指数を通して最近 10 年間の山火事の履歴を明らかにし、山火事頻度図を作成すること、(2)種組成と構造を調査するために設定した標本調査区で得られたデータから異なる山火事頻度域における MDF の植物性

組成と森林構造の現状を説明すること、(3)燃料特性明らかにするために設定した標本調査区における燃焼実験データから異なる山火事頻度域における MFD の現在の燃料特性および火災挙動を説明すること、を目的とした。

本研究は、DSP 内の MDF の領域で行われた。調査地は、タイ北部のチェンマイ市の西側に位置し、緯度 18°50°N、経度 98°50°E°50 である。この森林は、1981 年に国立公園として保護を受け、面積は 261 平方キロメートルである。この地域の年間平均降水量は 1,350~2,500mm、暖かさの指数は 257.7、平均最大気温と最低気温はそれぞれ 32.2 と 20.8°C であり、夏季(2 月中旬~5 月中旬)、雨期(5 月中旬~10 月中旬)、冬期(10 月中旬~2 月中旬)の 3 つの季節がある。この地域は山岳地帯であり、標高は 330~1,685m である。この保護地域には、フタバガキ科の落葉樹林、混交落葉樹林、乾燥常緑樹林、丘陵の常緑樹林の 4 類型の森林がある。DSP の MDF の支配的な種は、*Tectona grandis, Lagerstroemia calyculata, Xylia xylocarpa, and Pterocarpus macrocarpus* である。DSP は、人口約 100 万人のチェンマイ大都市圏の西側 5km に位置し、DSP の東、南、南の境界から北東に沿って、村落、寺院、大学、軍事地域などが存在する。DSP の最も初期における山火事に関する明確な証拠はないが、山火事はこの地域で数十年渡って認識されてきている。DSP における MODIS ホットスポットの平均数は、2008 年から 2017 年の各年で 16 回であり、これは前期間の平均 12 回から増加していた。

2017 年 10 月には、衛星データから 10 年間の山火事頻度地図が作成され、山火事頻度が低・高い地域が識別された。10 年間(2008-2017 年)の Landsat 画像分析の結果、DSP の落葉樹林のすべてが少なくとも 1 回の山火事を経験したことが示された。総焼失面積は 10,940 ヘクタールで、DSP 面積の 41.9%DSP に相当した。山火事が 10 年間に 6~10 回繰り返された高火頻度地域は、北東部と南西部に位置し、DSP の全焼面積の約 13.92%を占めた。焼失地域の残りの 86.02%は山火事発生頻度が低く、10 年以内に山火事が 1~5 回発生していた。2017

年 12 月に、山火事が高頻度及び低頻度の各区域に 50 m 四方の 2 つの標本調査区が設置された。植物種、植物の種特性、森林構造が同定・計測された。植物の種特性は、低頻度山火事区域では、山火事がすべての階層における種の多様性を豊富にしており、これは、特に幼木及び実生について種多様性の極端な減少が引き起こされていた高周頻度山火事区域とは対照的であった。高頻度山火事区域の樹冠下の日照条件は、低頻度山火事区域よりも良好で、雨季に実生の発達を促す可能性があるが、次の乾季には山火事で焼かれていた。 それにより、高頻度の山火事は、実生段階を超えて植物が成長することを妨げていた。落葉混交樹林の植物性組成物と森林構造の現状は、高火頻山火事による攪乱の長期的な劣化を明確に示していた。

2018 年 2 月、燃料特性の研究が、1m×1m の 20 の方形調査区で行われ、また、低頻度及び高頻度山火事区域における火の挙動を研究するために 50m×50m の方形調査区が設けられた。燃料データは、1 年間、毎月収集された。その結果、DSP の MDF における 2 つの山火事頻度区域において燃料は同様な特性を示していた。2 つの山火事頻度区域の主な燃料は、樹幹層から落下して林床に堆積した落葉落枝であった。山火事は燃料の総量の約 60～70%を消費し、燃料が回復するまでの期間は約 2 年と予測された。低頻度山火事区域と高頻度山火事区域の２つの区域で、燃料の特性、地形、気候は同様であった。２つの区域で火炎は同様の特徴を示し、火災タイプは、通常タイの落葉樹林で発生する低強度の地表面火災であった。両区域における土壌温度と高温持続時間は、燃料の量によってやや異なっており高頻度区域の方が低頻度区域に比べてやや高くかつ長かった。しかし、両区域において、山火事の熱は土壌表面にのみ影響を与え、より深い層には影響を及ぼさなかった。この保護区を良好な状態に維持するためには、山火事のない適切な間隔を導入する必要がある。そのため、山火事後の下層植生の長期変動に関するさらなる研究が推奨される。

キーワード:　植物の種組成、森林構造、種の多様性、人為的火災、山火事頻度,

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