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

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Abstract: Human activities are causing over-burning and leading to the degradation of the mixed deciduous forest ecosystem in Thailand. This study aims to investigate the current floristic compositions and forest structure in mixed deciduous forests with different fire frequency in Doi Suthep-Pui National Park, Northern Thailand. A ten-year fire frequency map was generated based on satellite data and areas with low and high fire frequency were identified. Then, two sample plots of 50 m × 50 m were established in each site. The flora species, floristic characteristics and forest structure were identified and calculated. The results 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 mixed deciduous forest shows clear evidence of degradation from long-term high fire frequency disturbance. For improving and maintaining a good condition to this protected area, a suitable fire-free interval must be introduced. Thus, a further study that includes information on fuel characteristics, fire behavior and the dynamics of the understory vegetation after burning is recommended.

Key words: floristic composition, forest structure, species diversity, fire frequency, Doi Suthep-Pui National Park

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 (Jumpen 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 (DSP) 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 DSP. The information from this research will be useful for fire/area management planning in DSP, which focuses on keeping the MDF ecosystem in a good condition.

2. Materials and Methods

2.1 Study area

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 km². 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. 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 weather trend (temperature and precipitation) in the last 10 years (2008-2017) and 30 years (1981-2010) found similar as showed in Fig. 1 (Thai Meteorological Department, 2019). 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*, *Xyila xylocarpa*, and *Pterocarpus macrocarpus* (Office of National Park, 2017).

The 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 (Posee, 2010). There is no clear evidence on the earliest fire incident in DSP, but forest fires have been recognized in this area for many decades (Akaakara, 1985). 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 (Fire Information for Resource Management System [FIRMS], 2019). Forest fires in MDF are generally classified as surface fires. The average fuel load is 2.5-4.0 ton ha and the main fuels are dry litter and dead grass. Fire behaviors in MDF are defined as low to moderate intensity, with a 2-4 m min fire spread rate in fair conditions, a flame height of 30-100 cm, and a fire line intensity of 109-119 kW m. The effects of fire on vegetation are usually marked in the undergrowth layer and decrease in severity as the vertical height of the vegetation layer increases (Akaakara, 2015).
2.2 Fire mapping

In October 2017, a fire frequency map for DSP was generated using 20 satellite images from Landsat 7 and 8, which were obtained from 2008 to 2017. 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

\[
NIR = \text{Near infrared reflectance value}
\]

\[
SWIR = \text{Shortwave infrared reflectance value}
\]

\[
dNBR = NBR_{\text{prefire}} - NBR_{\text{postfire}}
\]

Whereas dNBR = Difference normalized burn ratio

\[
NBR_{\text{prefire}} = \text{NBR value of pre-fire}
\]

\[
NBR_{\text{postfire}} = \text{NBR value of post-fire}
\]

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.

2.3 Data collection

In December 2017, after surveying and selecting MDF areas with similar vegetation, and geography, two 50 m × 50 m plots were set up in areas with different levels of fire frequency: 1) the low fire frequency area (LFA), and 2) the high fire frequency area (HFA). Both sites were located at latitude 18°46′37″ N and longitude 98°55′54″ E (Fig. 2), with 509 m in elevation and a slope of 25°. The distance between the two sites was 250 m. Each 50 m × 50 m plot was divided into twenty-five 10 m × 10 m quadrants in which all woody trees, with a diameter at breast height (DBH) of ≥ 4.5 cm and a total height (H) of ≥ 1.3 m, were studied 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 × 4 m and 1 m × 1 m quadrats systematic random in sample area. To study the forest structure, two sample plots of 50 m × 10 m were also randomized in both areas. Species identification was confirmed by a taxonomist of the

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**Fig. 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 MFD
Herbarium in the Department of National Parks, Wildlife and Plant Conservation, Bangkok, Thailand.

Moreover, the light conditions at 30 and 130 cm above the ground were measured by using Opto leaf films (R3D), Taisei Fine Chemical Inc. Ltd., Tokyo, Japan installed in each fire frequency areas, at the twelve positions of 1 m × 1 m sample plot, for three days. In order to generate the Opto leaf fading standard chart for the study area, the 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. All Opto leaf films were measured fading color value before and after installed by T-meter.

2.4 Data analysis

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

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

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

\[
\text{Frequency} = \frac{\text{Area of polts in which a species occurs}}{\text{Total area sampled}}
\]

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

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

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)

\[
H' = - \sum_{i=1}^{s} \frac{P_i \ln p_i}{H_{\text{max}}}
\]

Whereas \( H' \) = Diversity index value

\( P_i \) = Proportion of a species

\( \ln p_i \) = Natural logarithm of \( p_i \)

\( s \) = Number of species in community

Pielou’s evenness index (1975)

\[
J' = \frac{H'}{H'_{\text{max}}}
\]

Whereas \( J' \) = Evenness index value

\( H' \) = Shanon and Weaver diversity index

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

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

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:

\[
D0 = - \log_{10} \left( \frac{T0}{100} \right)
\]

Whereas \( D0 \) = Absorbance before exposure

\( T0 \) = Fading value of opto leaf

\[
D = - \log_{10} \left( \frac{T}{100} \right)
\]

Whereas \( D \) = Absorbance after exposure

\( T \) = Fading value of opto leaf

\[
R - 3D = \log_{10} \left( \frac{D}{D0} \times 100 \right)
\]

Whereas \( R - 3D \) = Fading rate

\( D \) = Absorbance after exposure

\( D0 \) = Absorbance before exposure

The light conditions under canopy was calculated from following formula:

\[
\% \text{ Relative solar radiation} = \frac{\text{ASRs}}{\text{ASRo}} \times 100
\]

Whereas \( \text{ASRs} = \text{Accumulate solar radiation in sample area} \)

\( \text{ASRo} = \text{Accumulate solar radiation in open area} \)

3. Results

3.1 Fire history

The result showed in Table 1 demonstrated that the actual fire sites are mostly found in the high fire frequency (63) as classified by the model. In addition, the confusion matrix showed that the map achieved 79.74% classification accuracy.

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 area of DSP. 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 DSP. The remaining 86.02% of DSP had a low fire frequency which fire occurred 1–5 times within a decade (Fig. 2). Moreover, the list of years that fire occurred in the study area was showed in Table 2.

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

\( H \) = high fire frequency, \( L \) = low fire frequency
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 3). 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 HFA 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 3).

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. In tree category, there were a total of 45 woody tree species in the LFA and 33 woody tree species in the HFA. The numbers of species in sapling, seedling and undergrowth of 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. The density of trees, saplings, seedling, and undergrowth in LFA were 666, 888, 10,400, and 14,200 trees/ha while in the HFA were 362, 206, 5,400, and 6,900 trees/ha, respectively. Furthermore, *Dendrocalamus membranaceus* was the only species of bamboo found in both study areas. In the LFA, the number of culms 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.

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 quadrat units between LFA and HFA showed that in tree category (10 m × 10 m quadrat units) almost characters except species evenness were significant difference, while the difference of all characters in saplings category (4 m × 4 m quadrat units) was not significant. For saplings and undergrowth (1 m × 1 m quadrat units), the number of species, number of genera, number of family, and density showed significant difference between LFA and HFA (Table 5).

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 m²/ha. While in HFA were 18.60 ± 10.40 cm, 13.98 ± 4.96 m, and 14.32 ± 2.51 m²/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 6).

3.4 Diameter distribution of trees category

The diameter class distribution of tree category of the LFA and HFA showed a typical reverse J-shaped curve (Fig. 3). The majority of woody trees were in the lower class (4.5-15.5 cm), with the number decreasing as the size of the

### Table 2
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 |

### Table 3
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%) |

### Table 4
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         |
| 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       |

### Table 5
Summary of some quantitative characteristics in quadrat units of MDF in Doi Suthep-Pui National Park

| Characteristics       | Bamboo (Dendrocalamus membranaceus Munro) |
|-----------------------|-------------------------------------------|
|                       | LFA | HFA |
| Number of culms 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 |

### Table 6
Summary of some quantitative characteristics in quadrat units of MDF in Doi Suthep-Pui National Park

| Characteristics       | LFA          | HFA          |
|-----------------------|--------------|--------------|
| Average DBH (cm)      | 36.00        | 42.00        |
| Average basal area (m²) | 10.00       | 12.00       |
| Average clump height (m) | 10.00       | 12.00       |
Table 5  The comparison mean value of plants characters (number of species, genera, family, species diversity, species evenness and density) in the quadrate units (10 m × 10 m quadrate units for tree, 4 m × 4 m quadrate units for sapling and 1 m × 1 m quadrate units for seedling 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      |
|----------|----------------|-------|----|-------|-------|-------|--------|
| Tree     | 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  |       |        |
| Sapling  | 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  |       |        |
| Seedling | 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
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 woody trees, which had a diameter of >65.5 cm, were only found in the HFA.

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 7, 8 and 9).

3.6 Family and species dominance

3.6.1 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 7). This was followed by Burseraceae and Phyllanthaceae. *Canarium subulatum* in Burseraceae had the greatest IV value (70.08) followed by *Lagerstroemia duperreana* 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 7).

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 7). Among the species in the HFA, *Pterocarpus macrocarpus* showed the greatest IV value (56.60) followed by *Canarium subulatum* (47.19) and *Xyli xylocarpa* (25.95). *Pterocarpus macrocarpus* also had the highest RD and RF values, whereas *Canarium subulatum* showed the greatest RDo value (Table 7).

3.6.2 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 8). *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 8). 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.

3.6.3 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 9). *Lagerstroemia duperreana* 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 formsum*, 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 Combretaceae, Malvaceae and Phyllanthaceae families dominated this category. *Gresia hirsuta* had the highest IV value (34.43), while *Bridelia stipularis* had the highest RF value (19.05).

*Lagerstroemia duperreana* had the greatest RD value (19.23) (Table 9). The two pioneer species, *Cratoxylum*
Table 7  Percentage of 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: Magnoliodes         |      |      |      |      |      |      |      |      |
| 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 | 0.96 | 1.52 | 0.76 | 0.08 | 1.64 | —    |      |
| Falconeria insignis Royle | 0.55 | 0.76 | 0.76 | 0.59 | 0.58 | 1.90 | —    |      |
| Mallotus philippensis (Lam.) Mull. Arg. | —    | 0.96 | —    | 0.76 | —    | 0.08 | —    | 1.64 |
| Suregada multiflora (A. Juss.) Baill. | 0.90 | 1.44 | —    | 0.11 | —    | 2.45 | —    |      |
| Order: 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 cuculata Graham ex Bentham | 0.30 | 0.55 | 0.48 | 0.76 | 0.22 | 0.16 | 1.00 | 1.47 |
| Dalbergia lakahonensis 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|
| Xylocarpa xylocarpa (Roxb.) W. Theob. var. kerrii (Crab & 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 |
| Order: 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 macronata 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 cochinchenisis Pierre | 0.30 | —    | 0.48 | —    | 0.41 | —    | 1.18 | —    |
| Lagerstroemia dupesreana Pierre ex Gagnep. var. dupresreana | 11.11 | 4.42 | 11.00 | 4.55 | 10.45 | 2.94 | 32.56 | 11.91|
| Order: Brassicales         |      |      |      |      |      |      |      |      |
| Family: Capparaceae        |      |      |      |      |      |      |      |      |
| Capparis grandis L.f.      | 0.30 | —    | 0.48 | —    | 0.65 | —    | 1.43 | —    |
| Crateva adansonii DC. subsp. trifoliata (Roxb.) Jacobs | 0.30 | —    | 0.48 | —    | 0.24 | —    | 1.01 | —    |
| Order: Malvales            |      |      |      |      |      |      |      |      |
| Family: Malvaceae          |      |      |      |      |      |      |      |      |
| Berrya mollis Wall. ex Kurz | —    | 1.10 | —    | 0.76 | —    | 0.89 | —    | 2.75 |
| Bombax anceps Pierre       | 0.90 | 4.42 | 1.44 | 4.55 | 2.13 | 6.73 | 4.47 | 15.69|
cochinchinense, IV 12.45, and Colona floribunda, IV 8.61 (Marod et al., 1999; Phongoudome et al., 2013) were found in HFA.

| Family               | Species                              | DBH 0.55 | DBH 0.76 | DBH 1.13 | DBH 2.44 | H 0.55 | H 0.76 | H 1.13 | H 2.44 | Total |
|----------------------|--------------------------------------|----------|----------|----------|----------|--------|--------|--------|--------|-------|
| Order: Sapindales    |                                      |          |          |          |          |        |        |        |        | 100   |
| Family: Anacardiacea | Lankea coromandelica (Houtt.) Merr.  | 0.30     | 0.27     | 0.48     | 3.03     | 0.06   | 4.23   | 0.84   | 10.02  |       |
| Family: Burseraceae  | Canarium strictum Roxb.              | 0.30     | 0.48     | 0.02     | 0.80     |        |        |        |        |       |
| Family: Meliaceae    | Naringi crenulata (Roxb.) Nicolson   | 0.90     | 1.16     | 1.44     | 1.52     | 0.59   | 0.94   | 2.92   | 4.11   |       |
| Family: Rutaceae     | Garuga pinnata Roxb.                 | 0.30     | 0.48     | 1.78     | 2.56     |        |        |        |        |       |
| Family: Simaroubaceae| Harrisonia perforata (Blanco) Merr.  | 0.30     | 0.48     | 0.07     | 0.85     |        |        |        |        |       |
| Clade: Asterids      |                                      |          |          |          |          |        |        |        |        | 100   |
| Order: Cornales      | Alangium indochinense W.J. de Wilde & Duyfjes | 3.00 | 1.91 | 4.78 | 9.70 | |
| Order: Ericales      | Diospyros ehr vietoides Wall. ex G. Don |          |          |          |          |        |        |        |        |       |
| Order: Lamiales      |                                      |          |          |          |          |        |        |        |        | 100   |
| Family: Bignoniaceae | Markhamia stipulata (Wall.) Seem. var. kerrii Sprague | 0.90 | 1.16 | 1.52 | 2.02 | 2.90 |
| Family: Lamiaceae    | Vitex peduncularis Wall. ex Schauer | 1.80     | 3.31     | 2.87     | 1.19     | 1.51   | 5.87   | 7.86   | |

3.6.4 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.
Table 8  Percentage of 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: Magnoliids | % Relative Density (RD) LFA | % Relative Frequency (RF) LFA | % Importance Value (IV) LFA | % Relative Density (RD) HFA | % Relative Frequency (RF) HFA | % Importance Value (IV) HFA |
|-------------------|-----------------------------|-----------------------------|---------------------------|-----------------------------|-----------------------------|---------------------------|
| 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: Santalales |                             |                             |                           |                             |                             |                           |
| 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 |
| 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 lakkonensis Gagnep. | 1.47 | — | 2.33 | — | 3.80 | — |
| Millettia xilocarpa 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 | — |
| Pierispermum 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 | 100 | 200 | 200 | 200 |
Table 9  Percentage of 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) | 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         |     |     |     |     |     |     |
| Cratostigma formosum (Jacc.) | 2.00| —   | 2.56| —   | 4.56| —   |
| Brongniartia sp. 1           | 2.00| —   | 2.56| —   | 4.56| —   |
| Bridelia stipularis (L)      | 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 lachonensis        |     |     |     |     |     |     |
| Millettia xylarca           | 2.00| —   | 2.56| —   | 4.56| —   |
| Phyllanthus macrocarpus      | 4.00| —   | 2.56| —   | 6.56| —   |
| Xyia xylarca (Roxb.) W. Theo var. kerrii (Crab & Hutch.) I.C. Nielsen | — | 3.85| —   | 4.76| —   | 8.61|
| Order: 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     | 10.00| 19.23| 12.82| 9.52| 22.82| 28.75|
| Order: Malvales              |     |     |     |     |     |     |
| Family: Malvaceae            |     |     |     |     |     |     |
| Colola floribunda (Kurz)     | —   | 3.85| —   | 4.76| —   | 8.61|
| Grewia hirsuta Vahl          | —   | 15.38| 5.13| 19.05| 9.13| 34.43|
| Grewia sp.1                  | 4.00| —   | 2.56| —   | 4.56| —   |
| Pterospermum semisagittatum  | 10.00| 7.69| —   | 17.69| —   | 8.61|
| Order: Sapindales            |     |     |     |     |     |     |
| Family: Rutaceae             |     |     |     |     |     |     |
| Naringi crenulata (Roxb.)    | 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: Lamids                |     |     |     |     |     |     |
| Order: Gentianales           |     |     |     |     |     |     |
| Family: Apocynaceae          |     |     |     |     |     |     |
| Wrightia arborea (Dennst.) Mabb. | 6.00| 7.69| —   | 13.69| —   | 8.61|
| Family: Rubiaceae            |     |     |     |     |     |     |
| Meyna grisea (King & Gamble) | 6.00| 7.69| —   | 13.69| —   | 8.61|
| 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 | 100 | 100 | 200 | 200 |
in both the LFA and HFA (Table 10). Moreover, *Opismenus 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 10).

### 3.7 Under canopy light conditions

The light conditions under MDF canopy shown in Table 11. 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.

### 4. 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 Oaksavanna 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 woody 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 plant species in each developmental stage (seedlings, saplings, and trees). In the present study, the density values were decreased in the 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 deterred 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 (Fig. 4). Goldammer (2002) also stated that over the long term, an excessive burning frequency ob-
Table 10 Percentage of 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 |
| *Opismenus 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          | —          | 1.49       | —          | 1.88       | —          | —          |
| Clade: Eudicots            |            |            |            |            |            |            |
| Order: Ranunculaceae       |            |            |            |            |            |            |
| 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            |            |            |            |            |            |            |
| Family: Combretaceae       |            |            |            |            |            |            |
| *Combretum* sp. 1          | 3.60       | —          | 5.97       | —          | 9.57       | —          |
| *Combretum* sp. 2          | 2.83       | —          | 2.99       | —          | 5.82       | —          |
| *Commelina paladausa* Blume | 0.64 | — | 1.49 | — | 2.14 | — |
| Order: Malvaes             |            |            |            |            |            |            |
| 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          |            |            |            |            |            |            |
| *Hedysotis* 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       | —          |
| *Balclera siamensis* Craib | 1.03       | —          | 2.99       | —          | 4.01       | —          |
| *Strobilanthes* sp. 1      | 2.96       | —          | 4.48       | —          | 7.44       | —          |
| Family: Lumaceae           |            |            |            |            |            |            |
| *Gomphostemma strobiinum* 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: Schizaceae          |            |            |            |            |            |            |
| 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        | 100        | 100        | 200        | 200        |
Table 11 Average of relative 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 MDF 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 |

5. Conclusion

This study of the effects of fire frequency on the floristic composition and structure of mixed deciduous forest in DSP, Chiang Mai, Thailand showed that a low fire frequency encouraged greater species diversity in the understory layer than over-burning. Long term disturbance by fire, as was ob-

![Fig. 4](image_url) 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 (Crab) Bremerk, 11) Sterculia guttata Roxb., 12) Terminalia glaucifolia Craib, 13) Terminalia mucronata Craib & Hutch, 14) Xyloxylocarpa (Roxb.) W. Theob. var. kerrii (Crab & 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 Crab, 4) Aporosa wallichii Hook. f., 5) Brucea javanica (L.) Merr., 6) Canarium subulatum Guillaumin, 7) Colona flagcarpa (C.B. Clarke) Crab, 8) Colona floribunda (Kurz) Crab, 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.) Mull. Arg., 14) Markhamia stipulata (Wall.) Seem. var. kerrii Sprague, 15) Millettia xylocarpa Miq., 16) Mitragyna rotundifolia (Roxb.) Kuntze, 17) Naringa crenulata (Roxb.) Nicolson, 18) Schleichera oleosa (Lour.) Merr., 19) Suredaga multiflora (A. Juss.) Baill., 20) Tectona grandis L.f., 21) Vitex canescens Kurz, 22) Xyloxylocarpa (Roxb.) W. Theob. var. kerrii (Crab & Hutch.) I.C. Nielsen
served 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 DSP showed obvious evidence of degradation from long-term fire disturbance. 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, that includes information on fuel characteristics, fire behavior and the dynamics of the understory vegetation after burning is recommended.

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