EFFECTS OF FOREST FIRE PROTECTION ON PLANT DIVERSITY, TREE PHENOLOGY, AND SOIL NUTRIENTS IN A DECIDUOUS DIPTEROCARP-OAK FOREST IN DOI SUTHEP-PUI NATIONAL PARK

SHESH KANTA KAFLE

A THESIS SUBMITTED TO THE GRADUATE SCHOOL IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN ENVIRONMENTAL RISK ASSESSMENT FOR TROPICAL ECOSYSTEMS

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27 MARCH 1997

ACKNOWLEDGMENTS

The idea of this study developed a few years ago when I got some resentful responses about my article on the impacts of forest fire, in which I mentioned some positive aspects of fire on forest ecosystems from the members of an NGO involved in forest fire control in rural Nepal. Earlier, I had published an article focusing on the negative effects of forest fires of which the members were unaware. However, it always encouraged me to find new facts relating to the effects of forest fire. Furthermore, I found a big rift even among researchers on the subject. A two-year GTZ fellowship through the Chiang Mai University for this MS degree enabled me to quench, even a part, of my interest.

Many individuals helped me to accomplish this thesis work. First and foremost was Dr. Stephen D. Elliott, Chairman of my advisory committee, who not only helped shape the problem areas and gave overall guidance for the study, but also the academic discussions which was instrumental in sharpening my crude research experiences in the past. Mr. J. F. Maxwell, my co-advisor and a renowned plant taxonomist in the region, helped in the identification of plant specimens. Without his active help, at least the ground flora component would not have completed. Also, the "*Mekhongs*" with him once a month helped relieve tensions incurred far away from home. Dr. Vilaiwan Anusarnsunthorn, my other co-advisor, gave invaluable comments and help.

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Needless to say, no one above is responsible for any mistakes that might occur in this thesis.

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Thesis Effects of Forest Fire Protection on Plant Diversity, Tree Phenology, and Soil Nutrients in a Deciduous Dipterocarp-Oak Forest in Doi Suthep-Pui

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M.S. Environmental Risk Assessment for Tropical Ecosystems

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ABSTRACT

A two-hectare plot of a deciduous dipterocarp-oak forest of Doi Suthep-Pui National Park protected against fire for 28 years was compared with a similar, but frequently burnt forest nearby with respect to changes in the plant community, phenological variation and alteration of soil properties. To survey the tree communities, six meter wide transects with a total length of 650 m in each site were laid out across the slope of the mountain following a bearing of 60^0. To survey the ground flora, quadrats of 2×2 m^2 area were positioned every 30 m, along the transects on alternate sides. Twenty one quadrats were placed in each site covering 2.3 % of the total transect area. The importance value percentage (IP) of trees > 10 cm DBH (diameter at breast height), species composition and diversity and evenness indices, for both tree and ground flora communities, were calculated. The seasonal variation in leafing, flowering and fruiting of trees was monitored over the period of eight months from May to December 1996, using crown density method. Twenty one 1 kg soil samples were collected from just outside each quadrat and were analyzed at the Central Soil Research Laboratory, Chiang Mai University.

Fire protection increased the density of trees and consequently basal area. It slightly changed the species composition and eliminated *Dipterocarpus tuberculatus* var. *tuberculatus* (Dipterocarpaceae). The species richness of both the ground flora and tree species were higher in the protected area, but diversity indices were not significantly different. The occurrence of evergreen or tropophylous trees was greater in the protected area than in the burnt area. Phosphorus and soil temperatures were significantly higher ($p > 0.05$) in the burnt area, but there were no significant different in other soil paramiters between the two sites. Average soil moisture content was significantly higher ($p > 0.05$) in the protected area throughout the study period except in September. The mean community scores for senescent leaves in November and December were significantly higher in the burnt area than in the protected area. *Shorea siamensis* var. *siamensis* (Dipterocarpaceae) and *Craibiodendron stellatum* (Ericaceae) retained their leaves longer in the dry season or early rainy season in the protected area than in the burnt area. Trees in the burnt area had less fruit in May than in the protected area, even if their flowering scores were comparatively higher.

Overall, this study shows that fire protection is a useful conservation management tool in deciduous dipterocarp forest for increasing tree density, increasing plant species richness and changing tree phenologies towards more favorable conditions for wild animals.

ชื่อเรื่องวิทยานิพนธ์ ผลของการป้องกันไฟป่าต่อความหลากหลายของพืช ฟีโนโลยีของไม้ยืนต้นและแร่ธาตุในดินในป่าเต็งรัง-ก่อ ภายในอุทยานแห่งชาติดอยสุเทพ-ปุย

ชื่อผู้เขียน นาย ซีส กันตา กัฟเล

วิทยาศาสตรมหาบัณฑิต สาขาวิชาการประเมินความเสี่ยงทางสิ่งแวดล้อมในระบบนิเวศเขตร้อน

คณะกรรมการสอบวิทยานิพนธ์

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รศ.ดร. วิไลวรรณ อนุสารสุนทร	กรรมการ

บทคัดย่อ

การศึกษาเปรียบเทียบ พื้นที่ 2 บริเวณ ในป่าเต็งรัง-ก่อ ภายในอุทยานแห่งชาติ ดอยสุเทพ-ปุย บริเวณหนึ่งที่มีการป้องกันไฟป่าเป็นเวลา 28 ปี กับบริเวณใกล้เคียงที่มีไฟไหม้อยู่เสมอ เนื้อที่แต่ละบริเวณศึกษา 2 เฮคเทอร์ โดยมุ่งศึกษาถึงการเปลี่ยนแปลงของสังคมพืช ชีพลักษณ์วิทยา (phenology) และคุณสมบัติของดินในการสำรวจสังคมพรรณไม้ยืนต้น ทำโดยวางแนวสำรวจกว้าง 6 เมตร ยาว 650 เมตร ไปตามแนวลาดของภูเขาในมุม 60° การสำรวจพืชคลุมดิน ทำโดยวางขอบเขตสำรวจ (quadrat) ภายในเนื้อที่ 2 x 2 ตารางเมตรในทุก ๆ 30 เมตร สลับด้านซ้ายและด้านขวา ตามแนวสำรวจเดิม รวม 21 ขอบเขตในแต่ละบริเวณศึกษา ซึ่งคิดเป็น 2.3% ของพื้นที่แนวสำรวจ จากนั้นคำนวณค่าความสำคัญของต้นไม้ (IP) ที่มีเส้นผ่าศูนย์กลางที่ระดับอก (DBH) หาความหลากหลายของชนิดพืช และคำนวณค่าความสม่ำเสมอ (evenness indices) ของทั้งไม้ยืนต้นและพืชคลุมดิน บันทึกการเปลี่ยนแปลงตามฤดูกาลของการแตกใบ การออกดอกและออกผลโดยวิธีหาความหนาแน่นของเสียบยอด ในช่วงระยะเวลา 8 เดือน ตั้งแต่เดือนพฤษภาคมถึงเดือนธันวาคม 2539 นอกจากนี้ยังเก็บตัวอย่างดินจากจุดใกล้ขอบเขตสำรวจ จำนวน 1 กก. จากแต่ละจุดนำไปวิเคราะห์ที่ห้องปฏิบัติกลางในการวิจัยดิน มหาวิทยาลัยเชียงใหม่

ผลการศึกษาพบว่าการป้องกันไฟป่าเพิ่มความหนาแน่นและขนาดของต้นไม้ องค์ประกอบของพรรณไม้มีการเปลี่ยนแปลงเล็กน้อย ยกเว้นไม่พบไม้เดีย (Dipterocarpus tuberculatus Roxb. var. tuberculatus) และพบว่า ความหลากหลายของพรรณไม้ยืนต้นและไม้คลุมดินจะมีมากกว่าในพื้นที่การป้องกันไฟ แต่ไม่ได้มีความแตกต่างอย่างมีนัยสำคัญในพื้นที่ทั้งสอง การคงสภาพของพรรณไม้ที่ไม่ทิ้งใบหรือการแปรสภาพของพรรณไม้ในป่าที่ไม่มีไฟป่า จะคงที่มากกว่าในบริเวณที่มีไฟป่า ปริมาณของฟอสฟอรัสและอุณหภูมิของดินจะสูงกว่าอย่างมีนัยสำคัญในพื้นที่ที่เคยถูกไฟไหม้ ส่วนคุณสมบัติอื่น ๆ ของดินไม่มีความแตกต่างกันในพื้นที่ทั้งสอง ค่าเฉลี่ยของความพื้นในดินในพื้นที่ที่มีการป้องกันไฟป่าจะสูงกว่าอย่างมีนัยสำคัญ ($p > 0.05$) ตลอดเวลาที่ทำการศึกษายกเว้นในเดือนกันยายน ค่าเฉลี่ยของปริมาณใบไม้ร่วงในสังคมพืชดังกล่าวในเดือนพฤศจิกายนและเดือนธันวาคมสูงกว่าอย่างมีนัยสำคัญในบริเวณที่ถูกไฟไหม้ ไม้รัง (Shorea siamensis Miq. var. siamensis) และไม้ยางที่เคย (Craibiodendron stellatum) รักษาไม้ไว้บนต้นเป็นเวลานานกว่าในฤดูแล้ง และแตกใบอ่อนมากกว่าในช่วงปลายฤดูแล้งหรือก่อนฤดูฝนในพื้นที่ที่มีการป้องกันไฟ ถึงแม้ว่าการออกดอกของต้นไม้ในพื้นที่ถูกไฟไหม้มีมากกว่า แต่การติดผลจะมีน้อยกว่าเมื่อเทียบกับบริเวณที่มีการป้องกันไฟป่า

ผลจากการศึกษานี้ แสดงให้เห็นว่าการป้องกันไฟในป่ามีประโยชน์ในด้านการจัดการอนุรักษ์ในป่าเต็งรัง เป็นการช่วยเพิ่มความหนาแน่นของต้นไม้ เพิ่มความมากมายของชนิดพันธุ์และการเปลี่ยนแปลงชีพลักษณ์ของไม้ยืนต้นที่เอื้ออำนวยแก่สัตว์ป่าต่าง ๆ ยิ่งขึ้น

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INTRODUCTION

Background

Thailand has suffered a rapid decline in forest cover over the past three decades, loosing more than one half of its forested area. With a total forest cover of 60 % in 1953, Thailand has only about 27 % now[1] (Poffenberger and Mc Gean, 1993; TDRI, 1987). This rampant destruction of forest cover in the past was due to logging concessions, encroachment and development of infrastructure such as roads, hydro-power plants and mining. However, the rate of deforestation has slowed in the past few years (Figure 1). This can be attributed to the ban on logging concessions, increasing government control over encroachment, and an increase in conservation movements in recent years. It is also because there is less forest left to cut. Nevertheless, the practices of shifting cultivation and intentional forest fires are still common in northern Thailand, where forests are estimated to cover more than 40 % of the land area.

In Thailand, more than 1.6 million hectares of natural forests are affected, if not destroyed, by fire every year (Bangkok Post, 1995). The conflagrations that occur in the lowland seasonal tropical forest are considered the main cause of the forest degradation. Of the total forest cover in Thailand, 46 % is tropical seasonal forest (Stott, 1983), where fire has been a major factor determining the composition, extent, and functioning of ecosystems. Moreover, all northern Thailand's forests belong to this category (TDRI, 1987). In many places, the primary forest has disappeared and a fire climax vegetation such as dipterocarp-oak forest has developed, which is maintained by fire (FAO, 1981). In an effort to gather more facts relating to the impacts of forest fire on natural ecosystems, this study attempted to determine the effects of protecting a forest from fire on plant diversity, tree phenology and soil nutrients in an area protected from fire for 28 years, compared with a similar area frequently burnt in deciduous dipterocarp-oak forest in Doi Suthep-Pui National Park in northern Thailand.

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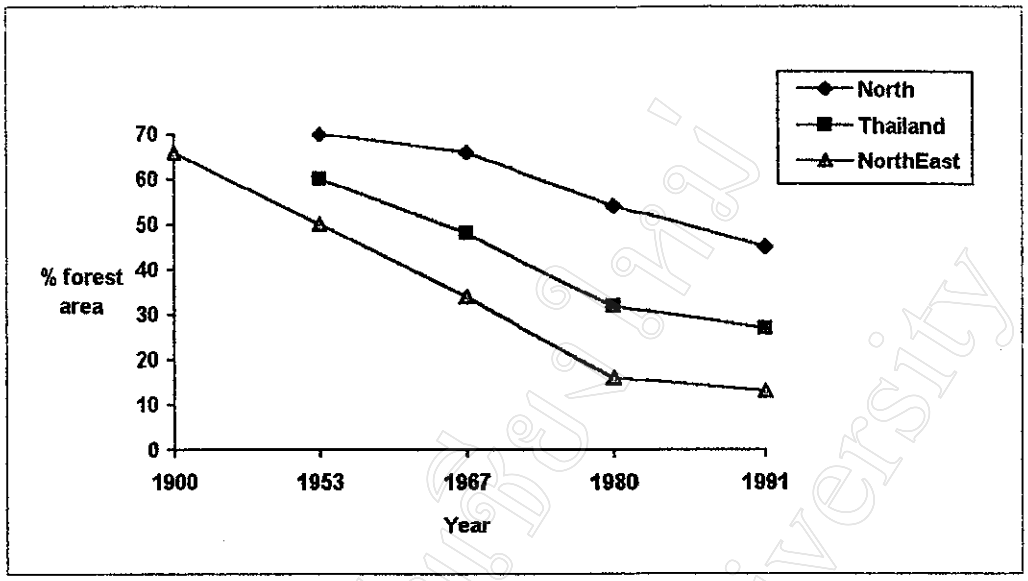
[1] Recent satellite images indicate much less than this.



(Poffenberger and Mc Gean, 1993)

Figure 1. Patterns of deforestation in Thailand

Rationale

Forest fire has increasingly become a frequent and problematic phenomenon in Thailand. Fires have a major impact on National Parks in particular, where protection of the flora and fauna and their habitats is the primary aim. Since plant variety and abundance, flowering, fruiting, and leafing phenologies of trees, and also soil nutrients status are essential features for ecological niches of wild animals, studies on the impacts of forest fire on these factors are essential to properly manage the biodiversity in such areas.

Millions of baht are spent preventing and extinguishing fires in national parks and wildlife sanctuaries in Thailand in the belief that this will "improve" the forest in terms of biodiversity or ecosystem functioning (e.g. nutrient cycling). There has been little research to determine whether fire protection actually causes such "improvements" to occur and to quantify them. Particularly in dciduous dipterocarp-oak forest (DOF), no study has been made on the effects of fire and little is known about its general effects (UNESCO, 1978; Sonthichai, 1995). Therefore, this study attempted to examine some aspects of plant diversity (shrub and herbaceous ground flora and trees) and ecosystem functioning (soil nutrients and phenology) in a tropical seasonal dipterocarp-oak forest.

Hypotheses

Fequent forest fires reduce leaf litter and organic matter content in the soil. This will result in low organic matter in the soil, decreased field capacity, and changes in soil depth. Low soil moisture content should promote drought-resistant species of a deciduous nature to grow. Remezov and Pogrehnyak (1969) mentioned that burning of the herbaceous-mossy cover, forest litter, soil humus in high and low fires, causes considerable changes in the biological cycle of elements under forest, and the following changes take place simultaneously: ash elements are liberated from organic substances, while C, N, some of the S, P, K contained in the organic matter are dissipated into the atmoshphere.

As leaf abscission in tropical deciduous trees occurs in response to declining soil moisture content, trees in a fire protected area theoretically should retain their leaves for longer during the dry season. If fires are very hot, litter, leaf mold, and at least the upper layers of humus are destroyed. This interrupts nutrient cycles and eventually impoverishes the soil (Doubenmire, 1965). Compounds of Ca, P, and K are changed to soluble forms which, though more readily available, are subject to rapid leaching while N is volatized and lost. However, prolonged protection of forests from fire reverses the processes. The hypothesized mechanism is shown in Figure 2.

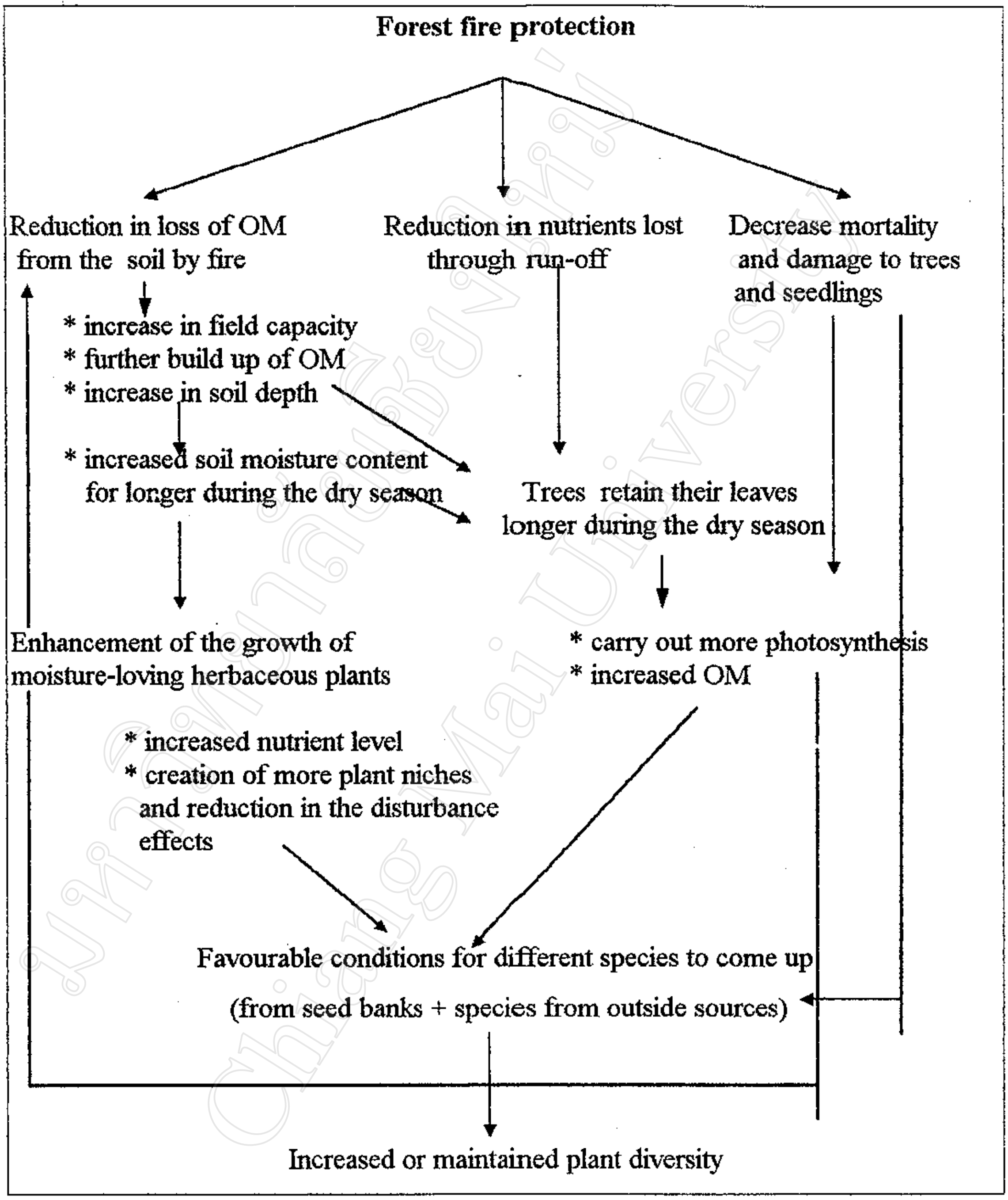


Figure 2. A hypothesised mechanism of the effects of forest fire protection in a deciduous dipterocarp-oak forest.

With this conceptual background, this study examined the following hypotheses:

1. Prolonged protection of a forest from fire changes the species composition of the ground flora to be more characteristic of a mixed deciduous forest,
2. There will be less disturbance effects after protection from fire, therefore, there will be higher plant diversity in a protected area, and
3. The protected area will have more soil moisture and therefore, phenological characters of the vegetation will be altered.

Statement of the problem

This study examined and analyzed the effects of forest protection from fire on a tropical deciduous-oak forest, to find out whether forest fire protection is worthwhile in terms of biodiversity, tree phenology and soil nutrients. In order to analyze the problem in detail, the following questions were identified:

1. What is the level of variation of tree and ground flora diversity between protected and burnt sites ?,
2. What seasonal changes occur in leafing, flowering, and fruiting patterns of trees after prolonged protection of forest from fires ?, and
3. Are there differences in soil nutrient levels between burnt and protected areas ?

Objectives

The objectives of this study were:

1. To compare and analyze the plant composition and diversity of burnt and protected forests from fire.
2. To investigate and compare the phenological characteristics of tree species between protected and burnt forests, and
3. To assess the nutrient status of burnt and protected areas.

Future implications of the study

The results of this study will be helpful in obtaining some more facts about the impacts of forest fire on a deciduous dipterocarp-oak forest (DDF or DOF) with particular reference to plant diversity, composition, tree phenologies, and soil nutrients. As DOF is regarded to have emerged as secondary succession after fire, any changes observed from the protected site would give an indepth knowledge about the natural succession which can be employed in rehabilitating fire disturbed areas. The study could also be helpful in planning future fire protection strategies for better forest resource management.

Limitations of the study

A major assumption of the study was that the species composition, soil properties, and other microenvironments of the protected and the burnt areas were similar before the fire protection activities were initiated 28 years before. Although the two areas consist of similar forest types and physiographic conditions, more accurate estimations could be done if baseline data were available. Also, due to the lack of replications in wider areas, the chance factor could not be avoided.

LITERATURE REVIEW

General review on the effects of forest fire

Forest fire has played a significant role in the shaping of terrestrial ecosystems. Next to climate and soil, fire is the most important factor affecting the extent, composition, and character of forest and other vegetation cover on natural areas (Davis, 1959). However, the role it plays in ecosystem maintenance is under debate among ecologists, geographers and forestry practitioners. In fire studies, two views are prevalent. One regards fire as an effective tool of forest management and considers it a "good servant, but bad master". The other regards it as the real destroyer of forest ecosystems. Past studies have been focused on situational and site specific investigations as these influence the government policies of a country.

The effects of fire on natural ecosystems have largely been studied on the North American prairies and in temperate forests. Very few studies have been conducted in tropical forests. Deciduous tropical forests and tropical savannas have been the focus of fire studies as these are thought to be post-fire successions. Nevertheless, the term 'savanna' has been a cause of much dispute and confusion, the literature being reviewed by Kanjanavanit (1992). Taking a broader perspective, dry deciduous forest / deciduous dipterocarp-oak forest has been included under savanna forest (Schimper, 1903; Stamp, 1925; Richards, 1952; Sewandono, 1956; Ogawa *et al.*, 1961; Stott, 1984).

Schimper (1903) divided tropical woodlands into four categories, viz. rain forest, monsoon forest, savanna forest, and thorn forest and described savanna forest as a formation which is "more or less leafless during the dry season, rarely evergreen, is xerophilous in character; usually, often much, less than 20 meters high, park-like, very poor in underwood, lianes, and epiphytes, rich in terrestrial herbs especially grasses." Stott (1984) added that "...however, epiphytes of genera like *Dendrobium*

(Orchidaceae), *Vanda (*Orchidaceae), and *Dischidia* (Asclepiadaceae) tend to be abundant in savanna forest...and in some associations top canopy trees can attain heights of over 30 meters."

In a description of the Klong Hoi Khong forest of southern Thailand, Maxwell (1986) put forward similar views for savanna forest and true savanna (thorn forest) to that of Schimper's (1903) and Stott's (1976, 1984). However, he used the terms **savanna** and **thickets** to mean the **savanna forest** and **true savanna** (grasslands) respectively. The term DDF, commonly used by various authors including Stott (1976; 1984) and the Royal Forest Department, to mean dry deciduous dipterocarp forest, dry deciduous forest, dry dipterocarp forest or savanna forest does not encompass oak (Fagaceae) species usually present along with the dipterocarps. Especially at lower altitudes in Doi Suthep-Pui National Park, such a dipterocarp-oak association is widely present, however, their percentage composition is low. Maxwell (1988) and Maxwell *et al.* (1995) rightly call this a deciduous dipterocarp-oak association. In this thesis, however, the term DOF and DDF are used interchangeably to mean deciduous dipterocarp-oak association or savanna forest, and savanna to mean the thickets or grasslands or true savanna.

Deciduous dipterocarp forest is the most widespread forest type in Thailand comprising 47 % of the whole forest area in the country (Stott, 1988). Fires are common in these forests, as DDF in South East Asia normally experiences a 5-7 month dry season, with a total annual precipitation of 1000-1500 mm (Smitinand, 1962; Stott, 1988a). This kind of forest, in general, is associated with poor, dry, and acidic lithosols or soils of the red-yellow podzolic group, which often occupy steep rocky slopes (Kanjanavanit, 1992). The occurrence of seasonally dry periods in the tropics increases with distance from the humid equatorial zone, leading to more open, semi-deciduous and deciduous forest formations. Such forests are often subject to frequent fires (often annual, but sometimes two or three times a year) and fire-tolerant species tend to dominate (Goldammer and Manan, 1996).

Some studies recommend "prescribed burning" as a tool of forest management on the premise that it helps reduce potential fire hazards by reducing fuel, helps in seedbed preparation, and enhances plant growth and the flowering, fruiting, and seed ripening patterns of tree species. It also helps create appropriate conditions for herbaceous legumes and possibly food plants which become established after burning and are valuable for wild animals (Stoddard, 1935). This is the reason why the practice has been a regular feature of forest management in America (Moore, 1987) and is being recommended for the deciduous dipterocarp forest (DDF/DOF) of Thailand (Stott, 1986).

The seasonal dipterocarp forests of mainland South East Asia are frequently regarded as fire climaxes, spread and developed from edaphic cores by the constant pressures of burning and cutting (Stott, 1976; 1984, 1986; Barrington, 1931). As Mather (1978) has noted, if forest fires did not occur, savanna forest would not have existed in much of its present area and would have been confined to edaphic cores. Furthermore, Kanjanavanit (1992) mentioned that a change in fire regime, whether to a greater or lower intensity of fires, will allow other vegetation types to take over. From this opinion, the use of fire for forest management is not only practicable, but also inevitable.

However, it would be unwise to minimize the effects of fire on forest destruction, soil erosion, and changes in phenological patterns. Studies suggest that fires affect the microclimate and vegetation, change ecosystems, and reduce species diversity. Studies in tropical savannas in India have shown that short plants are badly affected by fires (Naidu and Sribasuki 1994). However, the severity of damage varies with the intensity of fire, species, age and, size of trees, climate, and topographic conditions. Tropical rainforests are more fire-sensitive than dry eucalypt forest (Gill *et al.*, 1989) the latter is comparable to savanna forest (Gillison, 1983). In tropical rainforests the rate of soil erosion in burned areas is higher than that of unburned areas (Shimokawa, 1988).

Blasco (1983) expressed the opinion that the more disturbed the community is, the more open and the simpler floristic structure it will have. Fire protection, on the other hand, reverses the process and allows the establishment of a greater density of woody species. However, in Myanmar, the stability of DOF became apparent after 30-40 years of general fire protection from 1874 to 1914. Protection had no appreciable effect on seasonal dipterocarp forest soils (Champion, 1936). Sukwong and Dhamanitayakul (1977) found overall nutrients to be less in repeatedly burned areas in northern Thailand. Repeated burning also increases erosion 3-32 times the "normal" rate, particularly on steep slopes (Komkris *et al.*, 1969).

Drought creates a long period of moisture stress which is one of the factors that inhibits vegetation growth, giving DDF its open character and overall low stature and comparatively lower biomass than most of the other formations in mainland South East Asia (Ogawa *et al*, 1965; Sabhasri and Wood, 1967). In his controlled experiment on seedlings of *Pentacme suavis* (Miq.) Kurz. (Syn. *Shorea siamensis* Miq. var. *siamensis* Miq.), *Dipterocarpus intricatus* Dyer (both Dipterocarpaceae) and *Pterocarpus parvifolius* Pierre (Syn. *P. macrocarpus* kurz.) (Leguminosae, Papilionoidae) Sangtongpraow (1982) found that reduced soil moisture had no appreciable effects on the height of the first two species, which are characteristic of deciduous dipterocarp forest.

In temperate countries, fire reduces organic matter and releases biologically essential nutrients to the soil as a natural fertilizer (Stark and Steel, 1977). Once the nutrients are released they reach shrub and herb root zones before reaching the tree root zone. From a nutrient cycling standpoint, it is better to have the elements taken up by shrub or herb roots than to have massive losses below the tree root zone. The roots of herb and shrubs are vulnerable to temperature effects. If they are killed by fire, nutrient losses from erosion and leaching can be significant (Stark, 1977). So, by comparing nutrient leves in protected and annually burned areas, the impacts of fires on plants can be assessed. Repeated forest fires affect the temperature, soil moisture and nutrients as well as the physical and chemical properties of soil. These factors will have direct influence on the phenology of plants. After prolonged protection of forest from fire, changes in phenological patterns of tree species are expected.

Effects of fire on tree phenology

Kreb (1994) simply defined phenology as the study of seasonal changes in plants. To Le Floch (1969) phenology is "the study of the relations between the periodicity of morphological and physiological phenomena of plants and that of ecologically active, particularly climatic variables". Lieth (1974) elaborated on this definition by stating that phenology studies: 1, the rhythm of repetitive biological events; 2, the biotic and abiotic causes for these rhythms; and 3, the relations between phenophases of different species or of a single species.

Very few phenological studies have been done for tropical trees. A preliminary, but comprehensive study of more than 90 tree species in Doi Suthep-Pui National Park in northern Thailand has been started by the Chiang Mai University herbarium since 1987 and more recently by the Forest Research Unit of Chiang Mai University (Elliott *et al.*, 1996). More studies must be done to draw general laws which govern vegetation patterns (Seghieri *et al.*, 1995). Sympatric species that show similar phenological rhythms in the vegetative phase often differ in the timing of their reproductive phases. This allows a categorization of phenological patterns or strategies at different levels of similarity (Monasterio and Sarmiento, 1976).

Phenological characteristics vary among sites depending on moisture, temperature, soil, and other physiographic conditions. Even in the same locality, timing of leaf shedding may vary. A number of studies on phenology of DOF trees at Sakaerat Research Station in Korat Province, eastern Thailand have shown that *Shorea obtusa* Wall.ex Bl. tends to be slower in shedding its leaves than *Shorea siamensis* var. *siamensis*. The time of leaf shedding has a direct influence on the time of the main period of fires (Nalamphun *et al.* 1969; Wongpaibul, 1974; and Sukwong *et al.* 1975).

Sukwong *et al.* (1975) identified at least two phenological patterns in fruiting, both with obvious adaptive importance. The fruits of the dominant dipterocarps are " winged" and wind dispersed, tend to fall after the peak period of forest fires, and germinate on the burned soils at the start of rainy season. On the other hand, a range of tree taxa which produce fruits with hard, thick seed coats tend to drop their fruits before the fires, in November and December, and it appears that the fires may actually have a role in their successful germination. From all this, it is certain that the dominant species are resistant physiognomically, physiologically and phenologically to most types of dry season fire, although the severest fires and intensely localized burns may lead to ' torching' and death of individuals, especially in species which are only transgressives in the savanna forests (Stott, 1988).

In a comparative study of tree phenology in tropical wet and dry forest in the lowlands of Costa Rica, Frankie *et al.* (1974) showed that striking leaf changes take place in a greater proportion of species (75%) in dry forest than in the wet forest (17%). The length of the leafless period for individual species and for the ecosystem as a whole was also significantly longer in the dry forest. There was also a marked different in the time of leaf flushing in the two sites. Wet forest species produced most of their leaves during early dry season (February-April), while dry forest species flushed predominantly during the beginning of the wet season (May-June). Most fruiting occurred during the second shorter dry season (April-October) at the wet site, while at the dry forest site a pronounced peak in fruiting activity occurred in April during the long dry season.

A three year study of the phenology of flowering and seed production of DOF trees on Doi Suthep by Elliott *et al.*, (1989) noted a sharp peak in flowering in March, the least from July to September, with the peak flowering during May-June. There was fire in one year during this study. Similarly, Sukwong *et al.* (1975) observed at Sakaerat Research Station that DDF tree species began to loose their leaves in January and mostly from late February to March. The most intense leaf flushing occurred in late

March. A large number of species still produced a few new leaves until May. A high percentage of species bloomed during the hot dry season (March- April).

Effects of fire on soil nutrients

When fire occurs it releases heat energy which is transmitted by conduction to the soil layers, thereby affecting the chemical, physical, and biological properties there. (Bahuguna and Lal, 1989). Transmission of heat to soil during burning has been studied by various researchers. Hensel (1923) and Aldous (1934) reported that heat of combustion from burning was confined to immediate ground surface and soil temperature up to 18 cm depth was significantly higher during two months after burning. Beadle (1940) found that soil temperatures at various depths were significantly different in dry and wet soil, the later being 'cooler'.

In a study conducted in the savanna of northern Guinea, Brookman-Amissah *et al.* (1980) concluded that prolonged protection of clear-felled areas give higher tree density and diversity than the early and late burnt areas. Basal area, biomass, and diversity of grasses were significantly higher in burnt areas than in protected areas. The greatest differences were found in soil organic matter and total nitrogen, both of which were highest without burning, lower with early burning, and least after later burning than in the other situations. Available phosphorus showed a marginally significant difference only between early burnt and protected plots. Exchangeable potassium was lowest in the late burnt plots.

Several researchers have studied the effects of burning on moisture content. Banerjee *et al.* (1981) explained that water holding and available water capacities were considerably reduced after burning in Indian tropical forests. While Quirk and Sykes (1971) in interior Alaska found soil moisture contents 10-15 per cent higher in unburnt spruce forests than on a previously burned south slope, but they implied this factor to be casual in preventing fire rather than an effect.

Effects of burning on soil structure has been studied in India. Experiments on black cotton soil showed that heating by fire resulted in a marked improvement in the physical texture and degree of aggregation of the soil colloids. Breaking of small soil particles into lumps is an effect of high temperatures during fires. These lumps could not be broken up by the usual methods of mechanical analysis, indicating that the soil texture has changed. Oven-heated soil was somewhat improved in structure, but not in the texturre (Bahuguna and Lal, 1989).

When organic matter is burnt the mineral substances in it are released in the form of oxides or carbonates that usually have an alkaline reaction (Bahuguna and Lal, 1989). Decrease in soil pH due to burning has been noted by several researchers (Barnette, 1934; Barnette and Hester, 1930; Heyward, 1936). Griffith (1943), Gupta (1946), Ehrenreich and Aikaman (1963) found that the pH of the surface soil increased by burning, the extent varying with quantity of organic matter burned. Austin and Baisinger (1955) observed that pH was changed from 4.5 to 7.5, but on samples taken two years after the initial burn, pH was reduced to 5.7. Sonthichai (1995) in DOF in Doi Suthep-Pui National Park, Thailand observed that the pH of soil in both a burnt area and a non-burnt area was slightly less acidic than neutral, except immediately after burning when the soil in the burnt area was alkaline. Beadle (1940) reported that there was no change in the pH value of very poor soils such as in Sydney in New South Wales, and in the Jzrrah forests. Hatch (1959) showed no change in pH value after light fires.

After burning, large amounts of nutrients are available in the surface soils and losses by leaching are then possible, owing to absence of vegetation (Bahuguna and Lal, 1989). Some effects of burning forest soils of western Oregon and Washington (Austin and Baisinger, 1955) documented large increases in exchangeable Ca, Mg, and K in the surface soil soon after burning. Benerjee *et al.*, (1981) found drastic reduction in organic carbon (33% to 50%), total N, CEC, exchangeable Ca and Mg, available P_2O_5 and K_2 in fire affected forest soils of West Bengal.

Austin and Baisinger (1955) observed that two years after the initial burn, available nutrients such as K, P and Mg had dropped back down to about normal. Similarly, Letspeich *et al.* (1970) found no significant trends in soil nutrients one year after a fire in black spruce stands in eastern Alaska, but noted a slight increase in K. Fire stimulates nitrification in the upper humus layers by reducing the acidity of soil. Burning greatly increaes available nitrogen in mineral rich soils (Bahuguna and Lal, 1989).

Effects of fire on ground flora

In tropical forests, the ground flora has not been studied as widely as tree communities. This is mainly due to lack of taxonomists while tree communities get high priority as these are directly beneficial to the government from the commerial point of view. Most of the field techniques to study the ground flora have also been developed in temperate countries where species richness is very low compared to tropical areas.

Morphological tolerance to fire is present in many herbaceous ground flora. *Phoenix humilis* Roy. var. *humilis* (Palmae) is a typical example of fire resistent species found in DOF. During large fires, all the parts including leaves and epidermis of this species are burnt except the meristematic tissues.

In the savanna of northern Guinea, Brookman-Amissah *et al.* (1980) found significantly higher grass diversity in burnt areas than in the protected areas. In a comprehensive survey of herbaceous ground flora in the DOF of a small portion of Doi Suthep-Pui National Park, Phuakam (1994) studied a number of fire resistant and shade tolerant ground flora. They are discussed in detail in the discussion.

Field methods and diversity indices

Structural or physiognomic methods do not demand species identification and are often considered more meaningful for small-scale (large area) studies, and for habitat description for scientists of other disciplines. Methods based on species composition or floristics are more useful for large-scale (small area) studies of a more detailed e.g. botanical nature (Goldsmith *et al.*,1986). In this study, both the physiognomic (periodicity) and floristic measures (frequency, cover, basal area, density) have been used to study the changes in ground flora and tree communities after burning.

In some types of vegetation, the use of plots may be impractical and prohibitively time consuming. Also, the point-quarter method is often difficult to apply due to nonrandom distribution of the sampled individuals. Transects are useful in these instances and are especially advantageous and efficient in studies of contiguous stages in ecological succession or of communities studies at transitional zones (Brower and Zar, 1977). This holds added significance when tree communities are being studied in a short period. However, permanent quadrats have been the backbone of long-term studies of vegetation change, i.e. studies of patterns (Goldsmith *et al.*, 1986).

The quadrat is the most widely used sample unit to survey the ground flora community (Goldsmith *et al.*, 1986; Ludwig and Reynolds, 1988; Southwood, 1992). The shape of the sample plots first used in North American vegetation studies by F. E. Clements and co-workers was square, and the term quadrat was appropriately coined for the unit. Later circular, triangular, oblong, linear, and dimensionless observational units were used by other workers. These can not be properly called quadrats (Doubremere, 1977). However, Greig-Smith (1983), Clapham (1932) and Bormann (1953) advocate the use of rectangular quadrats. Clapham (1932) showed for one particular case that the variance between rectangular strips was markedly less than between squares, and that the variance was least, i.e. the efficiency was greatest.

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The size of quadrats to be used depends on the morphologies of the species in the vegetation to be sampled and the homogeneity of the vegetation (Goldsmith *et al.*, 1986). In general, a quadrat size upto 0.25 m^2 is suitable for herbaceous vegetation, while sizes larger than than 1 m^2 are required for work with woody species (Causton, 1988). However, the quadrat size should not be too large. As quadrat size increases and approaches the size of the patches, variance relative to the mean will rise sharply (Greig-Smith, 1983).

Cover is the convenient measure for working with many types of herbaceous vegetation especially those for which density is not appropriate (Myers and Shelton, 1980). It is defined as the proportion of ground occupied by perpendicular projection on to it of the aerial parts of individuals of the species under consideration (Greig-Smith, 1983). The Domin scale method of cover estimation is widely used in ground flora studies. This is more useful than the Braun-Blanquet scale as it can be converted into Braun-Blanquet, but not the other way around. However, both of these measures may be criticized on the grounds that they are 'pseudoquantitative' and give little information than frequency symbols (Transley and Adamson, 1913), but they are easily and quickly used in the field (Goldsmith *et al.*, 1986).

arbitrary height 1.3 m (breast height) is used to measure diameter or girth. In some countries 1.37 m from ground level is considered as breast height.

Frequency is the chance of finding a species in a particular area in a particular trial sample (Goldsmith *et al.,* 1986). It is extremely quick and easy to record and has consequently always been popular amongst ecologists (Goldsmith, 1986). The frequency is dependent upon quadrat size and it is for this reason that the measure is considered 'non-absolute' (Greig-Smith, 1983). The frequency value obtained reflects the pattern of distribution of the individuals as well as their diversity. However, the flaw of this measure is that two aeas having equal density may have different frequency values.

Importance value is an index of the vegetational importance of a tree species within a stand. It is calculated by summing the percentage of basal area, density, and frequency, where each is weighted equally for a species relative to a stand as a whole (Holdridge *et al.* 1971). The Importance Value (IV) gives an overall estimate of the influence or importance of a plant species in a community. This estimate has the advantage of using more than one measure of influence, however, it has the disadvantage of giving similar values for different combinations of the three relative values (Greig-Smith, 1983; Brower and Zar, 1977).

Diversities indices are the most widely used measures in plant and animal community studies. Simply speaking, species diversity is the total number of species present in the forest communities to be studied. However, this definition does not take into account the number of individuals of each species present. It becomes clear that it is more desirable for any measure of diversity to take account of both species number and species abundance (Wratten and Fry, 1980). A number of diversity, evenness, and similarity and difference indices have been proposed (e.g. Simpson, 1949; Margalef, 1958; McIntosh, 1967; Moore and Chapman, 1986). Among them, Shannon-Wiener function, Hill's diversity numbers, modified Hill's ratio, Sorensen's index, and Chord

Distance are widely used. A summary of the characteristics of some of the statistics are given in Table 1.

Table 1. Summary of the performance and characteristics of a range of diversity statistics (see: Magurran, 1988 for a detailed discussion).

Statistics	Discriminant ability	Sensitivity to sample size	richnes or evenness dominance	calculation	Widely used ?
X (logseries)	good	low	richness	simple	yes
y(lognormal)	good	medium	richness	complex	no
Q statistic	good	low	richness	complex	no
S (sp. rich.)	good	high	richness	simple	yes
Margalef	good	high	richness	simple	no
Shanon	medium	medium	richness	intermed.	yes
Brillouin	medium	medium	richness	complex	no
McIntosh U	good	medium	richness	intermed.	no
Simpson	medium	low	dominance	intermed.	yes
Berger-Park.	poor	low	dominance	simple	no
Shannon-ev.	poor	medium	evenness	simple	no
Brillouin ev.	poor	medium	evenness	complex	no
McIntosh DI	poor	medium	dominance	simple	no

Evenness indices measure the distribution of the number of individuals in each species. E1, E2, E3 are very sensitive to species richness, whereas E4 and E5 are relatively unaffected by species richness. In addition, E4 and E5 remain relatively constant with sampling variations. As E5 (Hill's modified ratio) approaches zero a single species becomes more and more dominant in a community. In Hill's another ratio, E4, as the diversity of a comunity decreases, that is , as one species tends to dominate both the N1 and N2 will tend toward the value of one (Peet, 1974). That is why E5 is preferable.

Sorensen's similarity index is the simplest similarity coefficient. This index is designed to equal 1 in cases of complete similarity and 0 if the set is dissimilar and has no species in common. One of the great advantage of this measure is its simplicity. However, this virtue is also a disadvantage in that the coefficient takes no account of the abundances of species (Magurran 1988). This index is fully based on the common species occurrences in two communities. However, its significance is on the relative proportions of the species in sampling units. It does not take into account the evenness measure as well.

Chord distance is widely used measure among distance indices. This measure puts greater importance on the relative proportions of species in the standard sampling units. Correspondingly less importance on their absolute quantities (Ludwig and Reynold 1988). Distance and similarity of two comunities can be reflected in a square diagram prepared manually.

Based on a review of these previous studies, the field of fire study in particular to tropical forests, is still at an early stage. Detailed studies with regard to the effects of fire on plant diversity, soil nutrients, and phenological characteristics of trees in tropical deciduous dipterocarp-oak forest are still lacking. Moreover, since the effects of fires are not uniform even within the same forest type and climatic zone (FAO, 1953), site specific studies are required. This study is an attempt to fill up a part of such information gap.

STUDY SITE DESCRIPTION

Introduction

This study was carried out in a deciduous dipterocarp-oak forest in Doi Suthep-Pui National Park in northern Thailand (Figure 3). The area lies a few kilometers west of Chiang Mai city at approximately 18°50' N latitude and 98°50' E longitude. The forest was designated as a National Park in 1981 and covers an area of 261 km^2. The DOF is situated from the eastern base at 350 m to 950 m elevation whereas the highest point of the park, Doi Pui, is at an elevation of 1685 m.

There is a marked variation in rainfall and temperature from the base to the top of the mountain. Temperatures are relatively high and rainfall is low in the lower parts of the national park resulting in little moisture content holding in the soil. The highest average monthly temperature is recorded in March and April (Figure 4). Annual rainfall varies from 1000 mm/yr near the lower slopes to approx. 2000 mm/yr near the summit. In 1996 the peak rainfall occurred in September, whereas it was in August in 1995. The dry season occurs from November to May with little or no rainfall. Usually, the rainy season starts from May and remains until October. The cool-dry season starts in November and ends in March.

The vegetation of Doi Suthep-Pui National Park is composed of a monsoonal (seasonal) forest, including a deciduous dipterocarp-oak association and a mixed evergreen + deciduous hardwood association in c. 800-1000m and primary evergreen forest with pines in some areas above 1000 m (Elliott and Maxwell, 1993). The dipterocarp-oak association is dominated mainly by two dipterocarp genera namely *Dipterocarpus* with *Dipterocarpus obtusifolius* Teijsm. ex Miq. var. *obtusifolius* and *Dipterocarpus tuberculatus* Roxb. var. *tuberculatus* and *Shorea* having *Shorea obtusa* Wall. ex Bl. and *Shorea siamensis* Miq. var. *siamensis*. The dominant species from Fagaceae include: *Lithocarpus elegans* (Bl.) Hatus. ex Soep., *Lithocarpus sootepensis* (Craib) A. Camus, and *Quercus kerrii* Craib var. *kerrii*.

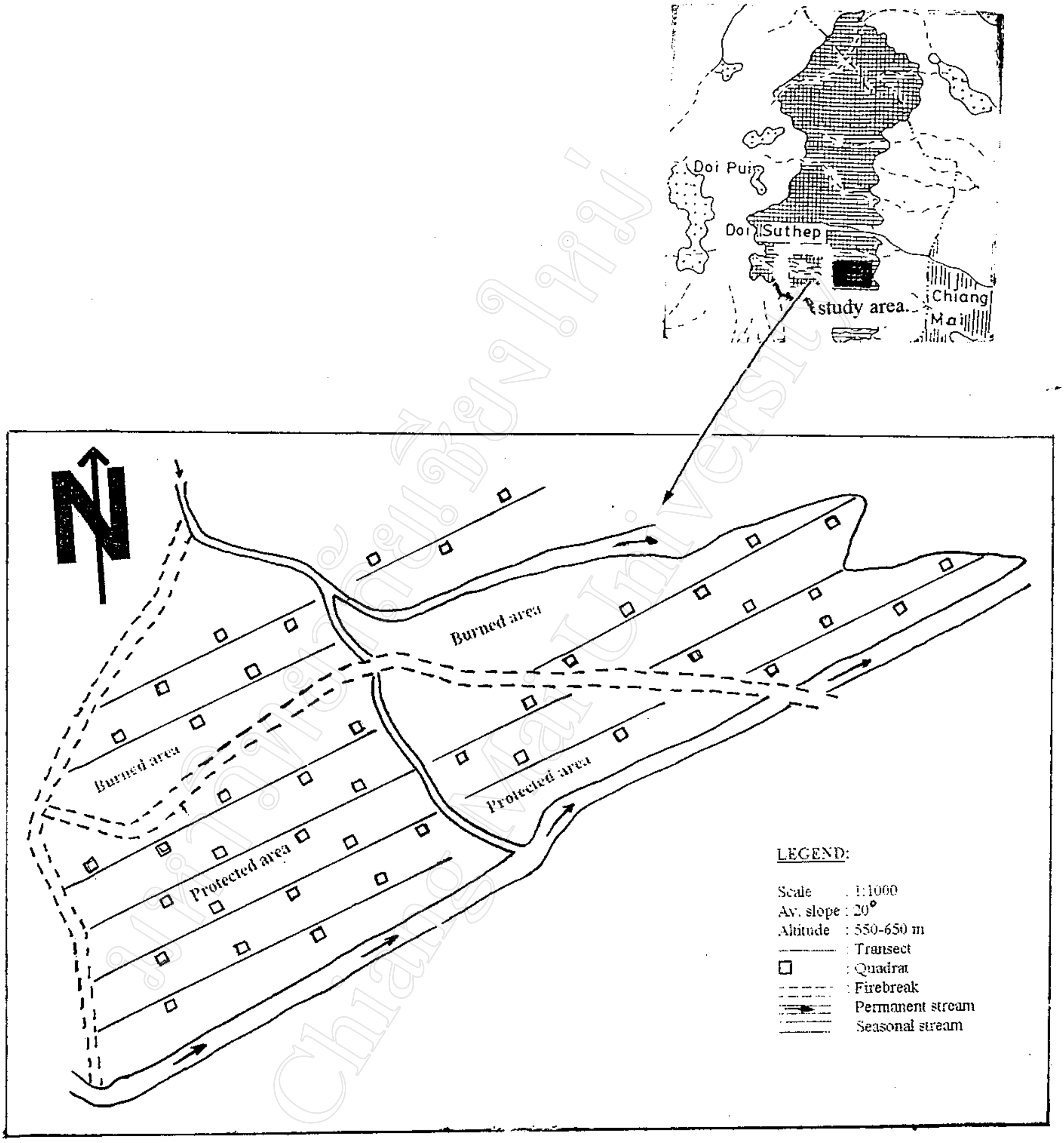


Figure 3. Map of Doi Suthep-Pui National Park showing the study area.

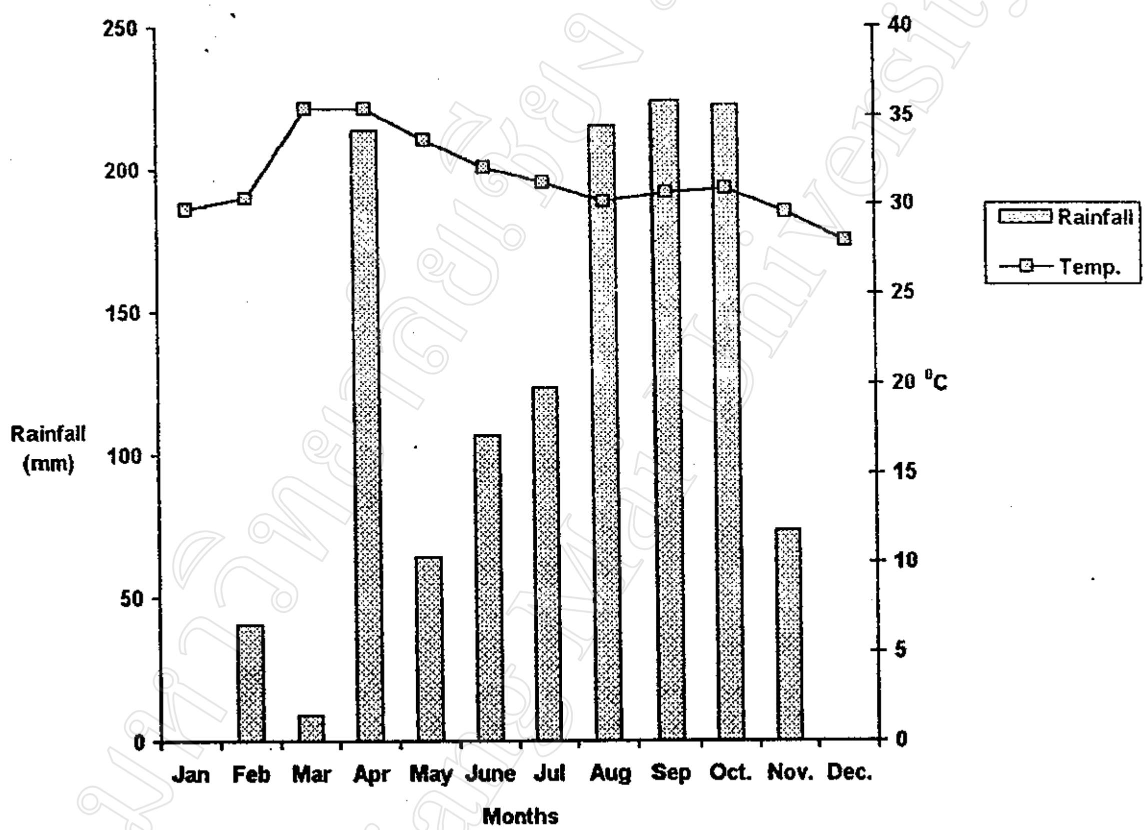


Figure 4. Total monthly rainfall and temperature in Chiang Mai in 1996 (source: Chiang Mai Meteorological Department, Chiang Mai)

Two sites were selected, one protected against fire for 28 years and the other left unprotected. When selecting the burnt area, besides similar vegetation composition and soil type, much attention was given to other site factors such as aspect, distance from water sources, rocks, and elevation. Prior to the final selection, possible sites nearby were reconnoitered and site factors closely examined. A survey by compass was done to locate the exact position of the sites. In the protected area three meter wide fire breaks had been maintained to prevent fire spreading into the area. The elevations of both sites ranged from 500 to 650 m. The bedrock was granite (Maxwell, 1988). In most of the places, soils are shallow, highly weathered, and exposed to soil erosion.

Site 1: Protected Area (PA)

This site was located 500 m south west of Wat Pahlaht ("Palad" Temple). Pahlaht Stream passed by its south-western flank which acted as a natural firebreak. Most of the area in this site faced a north west direction and has an average slope of 20 °. This site consisted of secondary forest dominated by species in the Dipterocarpaceae and Fagaceae families (Figure 5). It had been protected from fires for 28 years with the active initiation of a former abbot of Wat Pahlaht. However, the area was heavily logged before the 1960's (Svasti, pers. comm., 1996). This is the reason that even dominant trees in the area had not attained their potential height. A few stumps of *Dipterocarpus tuberculatus* var. *tuberculatus* were found in the area. However, no single living tree of this species was found.

The major tree species found in this forest include: *Dipterocarpus obtusifolius* var. *obtusifolius*, *Dipterocarpus tuberculatus* var. *tuberculatus*, *Shorea siamensis* var. *siamensis*, *Shorea obtusa*, *Buchanania lanzan* Spreng., *Lithocarpus elegans*, *Lithocarpus sootepensis* (Craib) A. Camus, *Quercus kerrii* var. *kerrii*, and *Tristaniopsis burmanica* (Griff.) Wils. and Wat. var. *rufescens (Myrtaceae)*. Some common herbaceous ground flora species in this site were: *Curcuma zedoaria* (Berg.) Rosc. (Zingiberaceae), *Globba schomburgkii* Hk.f (Zingiberaceae), *Boesenbergia rotunda* (L.) Mansf.(Zingiberaceae), *Scleria levis* Retz. (Cyperaceae), *Inula cappa* (L.)

Sw. *forma cappa* (Compositeae) and *Desmodium motorium* (Hout.) Merr. (Leguminosae, papilionoideae). The ground flora in this site was abundant outside of the boundary and the area exposed to sun light. In some of the patches which have tree species with dense crowns, the ground flora was absent (Figure 6). Instead, woody climbers and vines were more prevalent in this site compared to the BA.

Figure 5. Protected area with many Dipterocarpaceae and Fagaceae trees (Aug.1996)

Figure 6. Protected area with its mostly deciduous ground flora (Sept.1996).

Site 2. Burnt Area (BA)

This site was situated adjacent to the protected area, about 800 m north-east from Wat Pahaht. (Figure 7). It was separated from the PA by a fire break. Unlike the PA, this site had been frequently burnt in the recent past. Most of the area had a NE aspect with an average slope of 20°. It had a relatively open tree canopy, and is very exposed. As a consequence, this area had dense ground cover, compared with the PA. The dominant tree species of this site were: *Dipterocarpus obtusifolius* var. *obtusifolius*, *Dipterocarpus tuberculatus* var. *tuberculatus*, *Shorea obtusa*, *Shorea siamensis* var. *siamensis*, *Tristaniopsis burmanica* var. *rufescens*, *Buchanania lanzan*, *Lithocarpus elegans*, and *Craibiodendron stellatum* (Pierre) W.W.Sm. (Ericaceae). Ground flora species commonly found in the area included: *Curcuma zedoaria* (Zingiberaceae), *Scleria lithosperma* (L.) Sw. var. *lithosperma* (Cyperaceae), *Boesenbergia rotunda* (Zingiberaceae), *Amorphophallus longituberosus* (Engl.) Engl. & Gehrm. and, *Amorphophallus yunnanensis* Engl. (Araceae), *Globba reflexa Craib* (Zingiberaceae), *Desmodium motorium*, and *Dunbaria longeracemosa* Craib (Leguminosae, Papilionoideae).

Figure 7. Open canopy and dense ground flora in the burnt area (Sept.1996)

MATERIALS AND METHODS

Study of tree phenology

Sampling

Six meter wide transects were laid out across the slope of the mountain, following a bearing of 60^0. The distance between any two parallel transects was kept to 20 m, but varied from 15 to 25 m because of differences in aspect, slope, and the terrain encountered. In some places, due to the same reasons, the direction of the transects was oblique rather than the perpendicular to the slope. There were 4 transects in the protected area (PA) and 5 in the burnt area (BA) laid out with varying lengths. However, the total length of transects in each area was 650 m covering 5 % of the total area. The number of transects in each site was fixed to cover the existing diverse habitat after observation of site factors, whereas the total length was fixed deliberately to make the length in both areas equal.

Data collection

All trees greater than 10 cm diameter at breast height (dbh) were labelled and identified. The reason for ignoring trees less than 10 cm dbh was that most are not mature enough to produce flowers and fruits. Labelled trees were scored for flowers, fruits, and leaves during the last week of every month using the crown density method (Koelmeyer, 1959; Marsh, 1981; Newton, 1988; Elliott *et al.*, 1994). According to this method, the density of flowers, fruits, and leaves is scored using a linear scale of 0-4, with 4 representing the maximum intensity. Values of 3, 2, 1, and 0.5 represent three quarters, half, one quarter and less than one quarter of the maximum density respectively. In leafing phenology, the maximum value of 4 was divided amongst bare canopy, young leaves, mature leaves, and senescent leaves. In addition, tree density and basal area of two sites were calculated and compared.

canopy, young leaves, mature leaves, and senescent leaves. In addition, tree density and basal area of two sites were calculated and compared.

Study of ground flora community

In this study, the term ground flora is used to mean all the herbaceous plants including herbs, shrubs, vines, and climbers. It excludes tree seedlings.

Sampling

An intensive quantitative survey of the ground flora was done by partial random sampling. As quadrat positins were determined by a compass bearing regardless of any physical or biological features of the forest, the sample may be regarded as effectively random (Causton 1988, Elliott *et al.* 1989). Quadrats of 2×2 m area were positioned every 30 m, along the transects on alternate sides. Altogether 21 quadrats were placed in each site covering 2.3 % of the total transect area of the sites. The number of sample units (quadrats) was found to be sufficient by using running mean and area-curve methods. Quadrats were delineated using string to avoid trampling the vegetation within them.

Data collection

The percent cover of each species was recorded using the Domin scale (Table 2). The area overshadowed by tree seedlings and saplings was also recorded. The ground flora community was surveyed at the beginning of the rainy season (June), during the rainy season (September), and at the end of rainy season (November). Moreover, some specimens were collected and taken to the Chiang Mai University Herbarium for identification and curation (Figure 8).

Table 2. Domin scale

Category	Score
+	single individual
1	1-2 individuals
2	<1 % cover
3	1-4 % cover
4	5-10 % cover
5	11-25 % cover
6	26-33 % cover
7	34-50 % cover
8	51-75 % cover
9	>75 % <100%
10	100 % complete cover

Figure 8. *Desmodium oblongum* Wall. ex Bth. (Leguminosae, Papilionoideae), One of several ground flora species collected during the study and kept at the CMU Herbarium.

Study of soil properties

Sampling

Soil sampling units were fixed just outside each ground flora quadrat to investigate possible relationships between ground flora and soil factors. Therefore, there were also 21 soil sampling units. Since soil samples for moisture content were collected every month, the sampling points were moved a few centimeters away from the previous points, but were placed within the boundaries of 6 meter wide transects and fixed as close as possible the corresponding quadrats.

Data collection

Twenty-one one kg soil samples from each site were collected at 0-15 cm depth using an auger. Stones and undecomposed plant parts were removed from the collected soil. The samples were then packed in polythene bags. Before analyzing, the soil was sieved. For moisture content analysis, about 150 gm of soil was collected from each sampling unit in air tight polythene bags.

Data analysis

Most of the vegetation and soil data were analysed statistically using ECOSTAT and SPSS computer programs. Phenological data were analysed with Microsoft Excel -5. Further details are given below.

Hill's diversity numbers

Hill's diversity numbers, N1 and N2, were used to describe the species dversity in the communities. They are expressed as: $N1 = e^{H'}$ where H' is Shannon's species diversity index.

$H' = -\sum (ni/N) \ln (ni/N)$

Where,

n_i = no. of individuals of ith species in the sample area.

N= Total no. of individuals in the area.

$N2 = 1/\lambda$; $\lambda = \sum p_i^2$ where, $p_i = n_i / N$ proportional abundance.

T-test was used to test whether the species diversity indices were significantly different. For this, the following formullas were used (Batten, 1976, Pielou, 1977 Magurran, 1988).

$t = H'_1 - H'_2 / \sqrt{(Var\ H'_1 + var\ H'_2)}$

$var\ H' = [\sum pi (\ln pi)^2 - \sum p_i \ln pi^2] / N = (S-1) / 2N^2$

$df = (var\ H'_1 + var\ H'_2)^2 / (Var\ H'_1)^2/N_1 + (var\ H'_2)^2/N_2$

Where,

H'_1, and H'_2 are Shannon's diversity indices of the PA and BA.

var H' = variance of Shannon's index

p_i = Proportion of individuals = ni/N

N = Total number of individuals in the site

Evenness

Hill's modified index (E5) was used to calculate the evenness. This is expressed as:

$E5 = (1/\lambda-1) / (e^{H'}-1) = (N2-1)/N1-1$

Where

E5= Hill's modified index

y= Simpson's index = Ep_i^2

H' = Shannon's index

N1 and N2 are Hill's diversity numbers where N1 indicates the number of very abundant species in the sample, and N2 the number of abundant species in the sample.

Similarity and difference

The following indices were used to compare the similarity differences of the two communities:

a. Sorensen's Index (SI)

$SI = 2C/A+B$

Where,

C= number of species common to both sites

A = total number of species in community A

B = total number of species in community B.

b. Euclean Distance

$ED_{jk} = \sqrt{\Sigma(X_{ij} - X_{ik})^2}$

Where,

EDjk = distance between community j and k.

X_{ij} = number of species in community j.

X_{ik} = number of species in community k

c. Chord Distance

Chord distance was calculated using CRD measure which:

$CRDjk = \sqrt{2(1-ccos_{jk})}$

$ccos_{jk} = E (X_{ij} \times X_{jk}) / \sqrt{(EX2_{ij} \times EX2_{jk})}$

d. Overlap method

Overlap figures were drawn manually based on the total number of species observed in each community and their common species. For this, all the values were calculated in square roots and square shaped figures were made. The overlapping portions were coincided. These figures provide the simple sketch for common species in both communities.

Basal Area / Relative Basal Area

Basal Area was calculated using the equation:

$BA = (\Pi d^2/4) \times 1/1000$

where,

BA = basal area (m^2)

Π= 3.14156

d = diameter at breast height (cm)

Relative basal area (RBA) of each species was calculated dividing the total basal area of that particular species by the total basal area of all species.

Community dominance (CD)

Dominance was calculated for both communities using a community dominance index similar in form to one developed by McNaughton (1968) to describe the apportioning of standing crop biomass among the most important species of the community (Tomkins and Grant, 1977).

$CD = (N1 + N2) / N \times 100\ \%$

where,

CD = Community Dominance

N1 and N2 are the number of individuals of the most abundant species

N = total number of individuals.

Tree density / Relative density

Density was measured in terms of numbers of individuals per hectare. The relative density of each species was calculated dividing the total density of that particular species by the total density of all species.

Frequency / Relative frequency

The frequency of each tree species occurred in the transects were counted. Since the length of each transect was varied, frequency was counted taking a 100 m. length in each transect. Similarly, relative frequency was calculated dividing the frequency of the particular species by the total frequency of all species.

Importance value index / Importance percentage

Importance Value Index (IMI) was calculated by adding the three parameters namely, relative basal area, relative density and relative frequency. Importance percentage (IP)was calculated dividing the importance value of each species by the total importance values of all species. Mathematically,

$$IMI = RBA + FD + RF$$

$$IP = (RBA + RD + RF) / Total\ IM \times 100$$

Soil Moisture Content

Twenty one 1 kg soil samples in each month were collected from each site and the soil moisture content was analysed. The formula used in calculating soil moisture content was:

$$\%\ Soil\ moisture\ content = (B\text{-}C/C\text{-}A) \times 100$$

where,

A = wt. of polybag (container)

B = wt. of polybag + wt. of wet soil

C = wt. of polybag + wt. of wet soil

Materials and Equipment (Field)

Compass

Altimeter

Binoculars

Metal labels

Nails

Bamboo pegs

Measuring tapes (5 m and 50 m)

String

Hammer

Paper, Pencils, Scissors, Knife

Plant press

Plastic bags

RESULTS

Species composition and Diversity

Tree and ground flora composition

The protected area supported a richer ground flora community than the burnt area, although the species richness of tree community was very similar in both areas. The PA also contained slightly more 'unique' species, found only there, than the burnt area. *Dipterocarpus obtusifolius* var. *obtusifolius* was the most abundant species followed by *Shorea siamensis* var. *siamensis* in both sites. Two deciduous trees namely *Dipterocarpus tuberculatus* var. *tuberculatus* and *Tristaniopsis burmanica* var. *rufescens* had a greater occurrence in the BA compared to PA, even though their percentage contribution was comparatively low. In the PA, *Lithocarpus elegans, Lithocarpus sootepensis, Buchanania lanzan*, and *Quercus kerrii* var. *kerrii* were more abundant.

A total of 130 plant species, with 29 trees and 101 ground flora species, was recorded from the sampled areas (Table 3). In both areas, 14 tree families and 36 ground flora families were identified. The majority of the ground flora in the PA was composed of herbs (70.3 %) followed by shrubs (13.5 %) and vines (12.2 %). Whereas the percentage composition of herbs, shrubs and vines in the burnt area was 70.1, 16.4 and 11.9 respectively. Moreover, 44 % of all species of protected area and 39 % of burnt area were specific to those sites. Moreover, the PA was more diverse than the BA in terms of genetic diversity as it contained 31 families compared to 27 in the BA (Appendix 3). Leguminosae, Cyperaceae (Cuperaceae) and Convolvulaceae families were dominant in the BA whereas Zingiberaceae, and Commelinaceae in the PA. The number of species belonging to Leguminosae and Cyperaceae families were much higher in the BA whereas it was replaced by Zingiberaceae, Commelinaceae, and Rubiaceae families in the PA.

Table 3. Species composition in the sampled area[1]

Composition	Number of species[2]				
	Total	PA	BA	% (PA)	% (BA)
Tree spp. (>10 cm dbh)	29	22 (8)	21 (7)	76	72
woody climbers	3	3 (2)	1 (0)	100	33.3
Shrubs	14	10 (3)	11(4)	71	79
Vines	10	9 (2)	8 (1)	90	80
Herbs	74	52 (27)	47 (22)	70	64
Total	131	96 (42)	88 (34)	74	68

[1] The number of tree species is based on the transect survey whereas ground flora is based on the quadrats made along the transects.

[2]. Figures in parentheses indicate the number of species only found in that site.

Dipterocarpaceae was the dominant family of trees (Table 4). The percentage composition of individuals of this family was higher in the burnt area (63.58 %) than in protected area (56.8 %). *Dipterocarpus obtusifolius* var. *obtusifolius* was the most abundant tree species in both the PA and BA, accounting for 37 % and 36 % tree individuals respectively. Composition of species of Fagaceae ana Anacardiaceae were higher in PA. Another marked difference noticed between the PA and BA was that *Dipterocarpus tuberculatus* var. *tuberculatus* was completely absent in the *PA*. The relative abundance of *Tristaniopsis burmanica* var. *rufescens*, *Shorea siamensis* var. *siamensis* and *Shorea obtusa* was higher in BA, whereas that of *Dipterocarpus obtusifolius var. obtusifolius*, *Buchanania lanzan*, *Quercus kerrii* var. *kerrii*, *Lithocarpus sootepensis*, and *Lithocarpus elegans* was higher in the PA.

Table 4. Composition of major tree species ≥10 cm dbh in the burnt and protected areas

Species	Number of individuals[1]	
	Protected site	Burnt site
Dipterocarpus obtusifolius var. *obtusifolius*	100 (37.45 %)	58 (35.80 %)
Shorea siamensis	30 (11.24 %)	22 (13.58 %)
Buchanania lanzan	27 (10.11 %)	9 (5.56 %)
Shorea obtusa	22 (8.24 %)	15 (9.26 %)
Quercus kerrii var. *kerrii*	26 (9.74 %)	15 (9.26 %)
Lithocarpus sootepensis	15 (5.62 %)	4 (2.47 %)
Lithocarpus elegans	10 (3.75 %)	3 (1.85%)
Craibiodendron stellatum	9 (3.37 %)	5 (3.09 %)
Tristaniopsis burmanica var. *rufescens*	2 (0.75 %)	8 (4.94 %)
Dipterocarpus tuberculatus var. *tuberculatus*	0 (0.0 %)	8 (4.94 %)
Miscellaneous	26 (9.74 %)	15 (9.26 %)
Total	267 (100.0 %)	162 (100.0 %)

[1]Percentage figures in parentheses indicate relative dominance of the species.

Basal Area, Tree Density and Community Dominance

Basal area, and tree density (p >10 cm DBH) were both higher in the PA than in the BA. (Table 5). However, average basal area of trees in aggregate was similar in both sites. McNaughton's community dominance index (CD) was practically the same in both sites. This indicates the higher relative dominance values of two most dominant species.

Table 5. Percentage and total basal area, tree density and community dominance of protected and burnt sites

Community statistic	Unit	Sites	
		PA	BA
Basal Area Ha^{-1}	m^2	22.67	13.95
Tree Density (>10 cm dbh)	no./ha.	685	415
Community Dominance	%	48.7	49.4

Importance value of major tree species

More than 50 % of the importance percentage, calculated from relative basal area (RBA), relative frequency (RF) and relative density (RD), was contributed by Dipterocarpaceae in both sites (Table 6). Importance percentage is a measure of influence of each species on the forest community. Importance values of *Tristaniopsis burmanica, Dipterocarpus tuberculatus* and *Shorea siamensis* were higher in BA. The influence of *Dipterocarpus obtusifolius* was found to be exactly the same in both sites. Both the relative basal area and relative density of *Dipterocarpus obtusifolius* were slightly higher in the PA. Almost all the tree species were evenly distributed in the PA whereas this was not the case in BA. In the protected area, *Shorea siamensis* accounted for 11 % by the density and 19 % by basal area compared to 14 % and 16 % respectively in the BA.

Table 6. Importance value (IV) of major tree species in the PA and BA

Species	Protected Area					Burnt Area				
	RBA	RF	RD	IV	IP (%)	RBA	RF	RD	IV	IP
Diptrocarpus obtusifolius	0.48	0.07	0.37	0.92	30.7	0.47	.09	.36	.92	30.7
Shorea siamensis	0.19	0.07	0.11	0.37	12.3	0.16	.09	.14	.39	13
Buchanania lanzan	0.06	0.07	0.10	0.23	7.7	0.03	0.7	.06	.16	5.3
Quercus kerrii	0.08	0.07	0.10	0.25	8.3	0.08	.07	.09	.24	8.0
Shorea obtusa	0.08	0.07	0.08	0.23	7.7	0.07	.07	.09	.23	7.7
Lithocarpus sootepensis	0.03	0.07	0.05	0.16	5.3	0.01	.07	.03	.11	3.7
Lithocarpus elegans	0.02	0.07	0.04	0.13	4.3	0.04	.06	.02	.12	4.0
Craibiodendron stellatum	0.002	0.07	0.03	0.12	4.0	0.01	.07	.03	.11	3.7
Tristaniopsis burmanica	0.034	0.04	0.01	0.05	1.7	0.02	.06	.05	.13	4.3
Dipterocarpus tuberculatus	0	0	0	0	0	0.04	.06	.05	.15	5.0

(RBA = relative basal area; RF = relative frequency; RD = relative density;
IV = importance value; IP = importance percentage).

Species Richness, Diversity, and Evenness

Computed values of different community statistics are given in Tables 7 and 8. The results failed to show a clear distinction between the protected and burnt sites. In PA, irrespective of high species abundance and richness, the diversity index (H') was slightly lower than in the BA. However, the values were not statistically different. Also, individuals were more evenly distributed in the burnt area.

Table 7. Species richness, species diversity and evenness indices of trees in the burnt and protected areas

Community statistic		**Protected Area**	**Burnt Area**
Species richness	N0	22	21
Diversity	λ	0.18	0.17
	H'	2.18 a	2.24 a
	N1	8.81	9.43
	N2	5.46	5.90
Evenness	E5	0.57	0.58

a Values of diversity indices of two sites are not statistically different (using t-test).

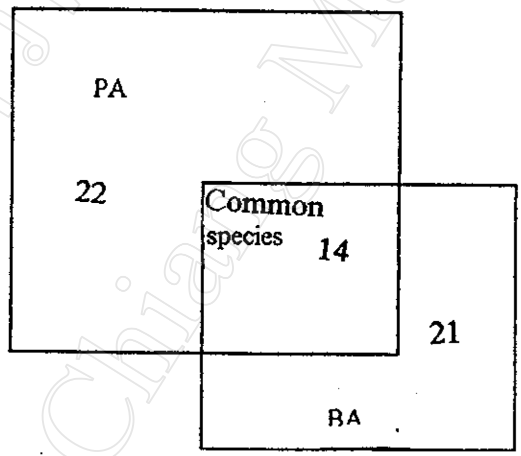
Similarity and Difference

Similarity and difference indices (Table 8) and the overlap sketch prepared manually (Figure 9) show a quite similar vegetative composition in the two sites. However, with the assumption of completely similar sites before the fire protection activities were initiated 28 years ago, the values indicate a trend towards dissimilarity developing between two sites.

Table 8. Computed values of different similarity and difference indices of trees between burnt and protected areas

Statistic	Computed values
Similarity	
Sorensen measure (qualitative)	0.65
Difference	
CRD	0.24
ED	51.49

Figure 9. Tree species overlap between two sites.



Size class Distribution

Figure 10 shows a larger amount of regeneration in the PA than in the BA. Around 73 % of the tree individuals found in the PA were 10-20 cm DBH. It further reveals that very young trees were quite abundant in this site. In the BA, however, only 64 % of individuals were in this category. There was no marked difference in the distribution of tree individuals in other categories.

Size class distribution of the major tree species are shown in Figures 11, 12, 13, 14, and 15. Results reveal that the majority of tree individuals in PA were under 10-20 cm DBH, whereas the percentage distribution of individuals over DBH classes in BA was found to be slightly even.

Ground flora diversity

Regardless of the significantly lower percentage cover, based on the total Domin score (t-test, $p > 0.05$), the protected area supported a greater number of ground flora species (Table 9). However, the burnt area contained higher species diversity and evenness indices than the protected area. Nevertheless, the species diversity index was not significantly different (t-test, $p > 0.05$).

Table 9. Ground flora diversity, richness and Evenness in the protected and burnt areas

Community statistic		**Protected area**	**Burnt area**
Species richness	N0	74	67
	R1	12.49	10.298
	R2	3.98	2.91
Diversity	λ	0.812	0.553
	H'	3.401a	3.477a
	N1	30.207	32.37
	N2	12.316	18.080
Evenness	E5	0.387	0.544
Total Domin Score	TDS	349.5	505.0

T-test ($P>0.05$).

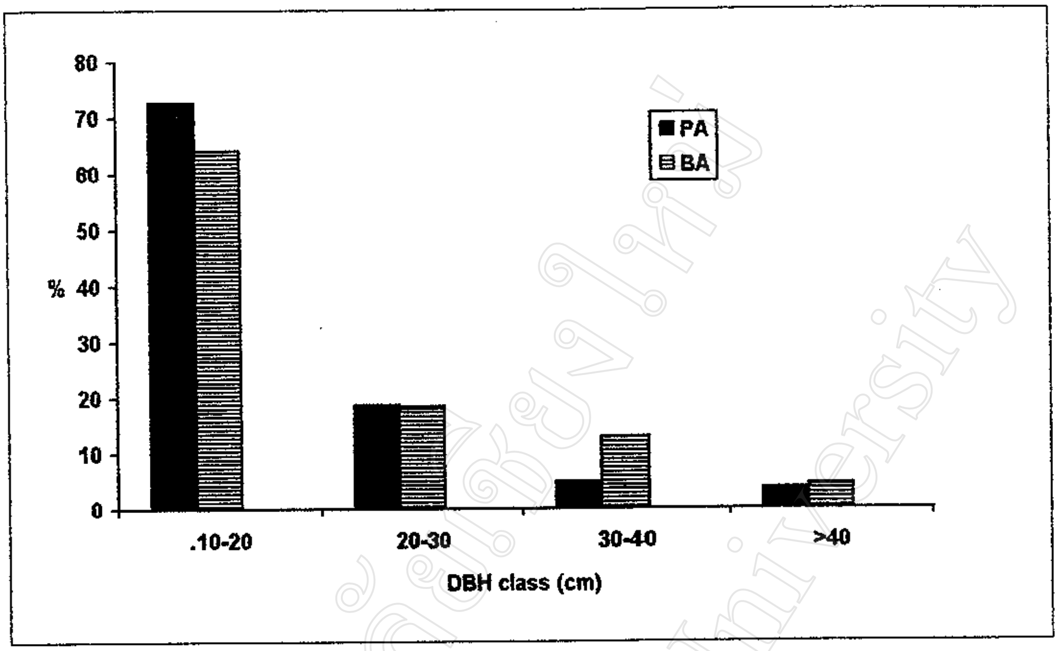


Figure 10. Size class distribution of trees >10 cm DBH in the study area.

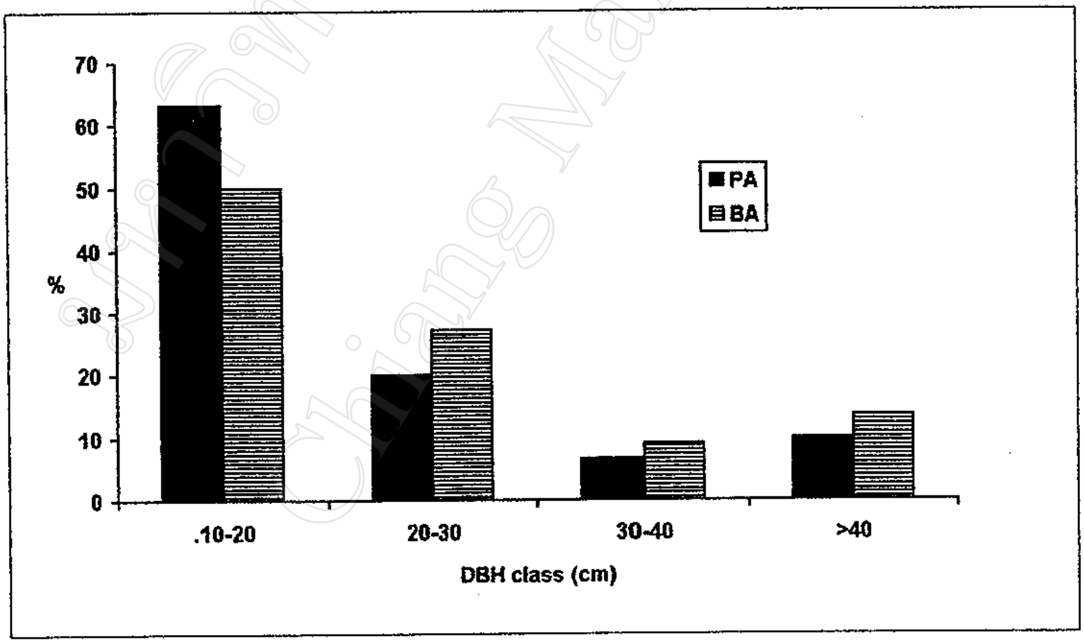


Figure 11. Size class distribution of *Dipterocarpus obtusifolius* Teijsm.

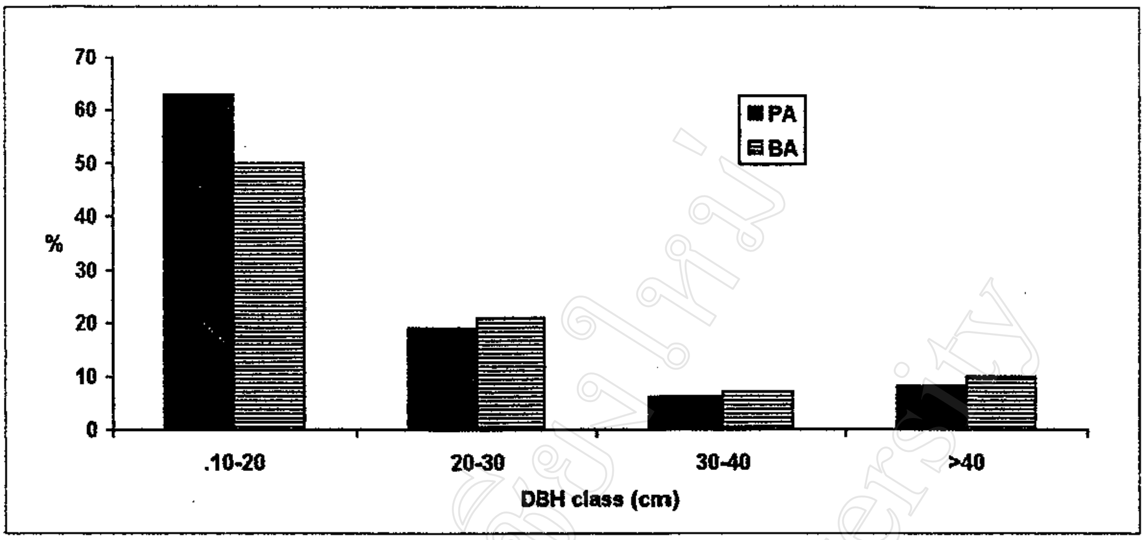


Figure 12. Size class distribution of *Shorea siamensis* in the study area.

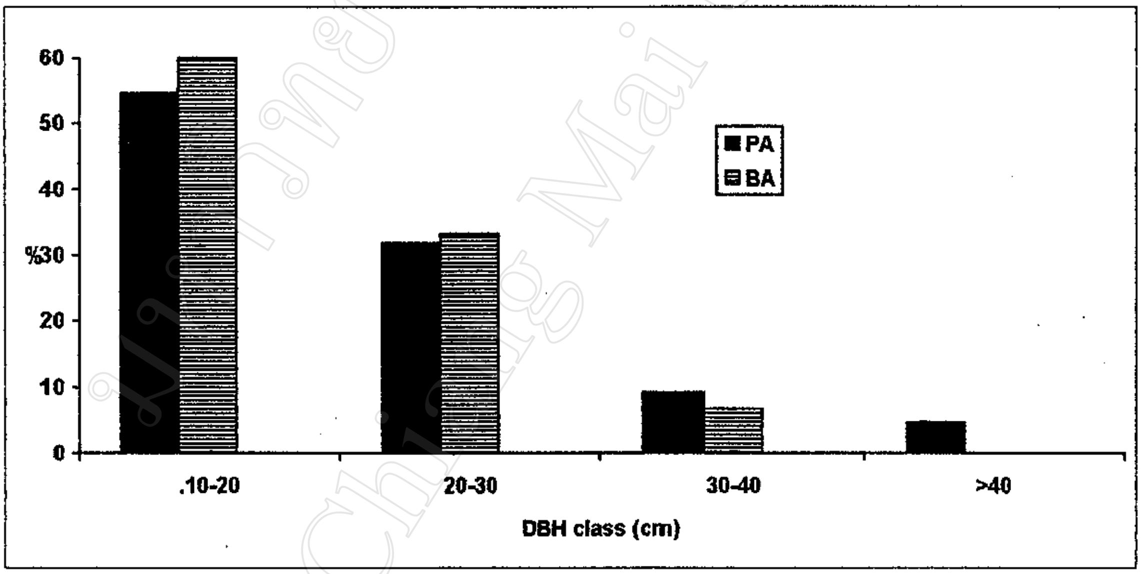


Figure 13. Size class distribution of *Shorea obtusa* in the study area.

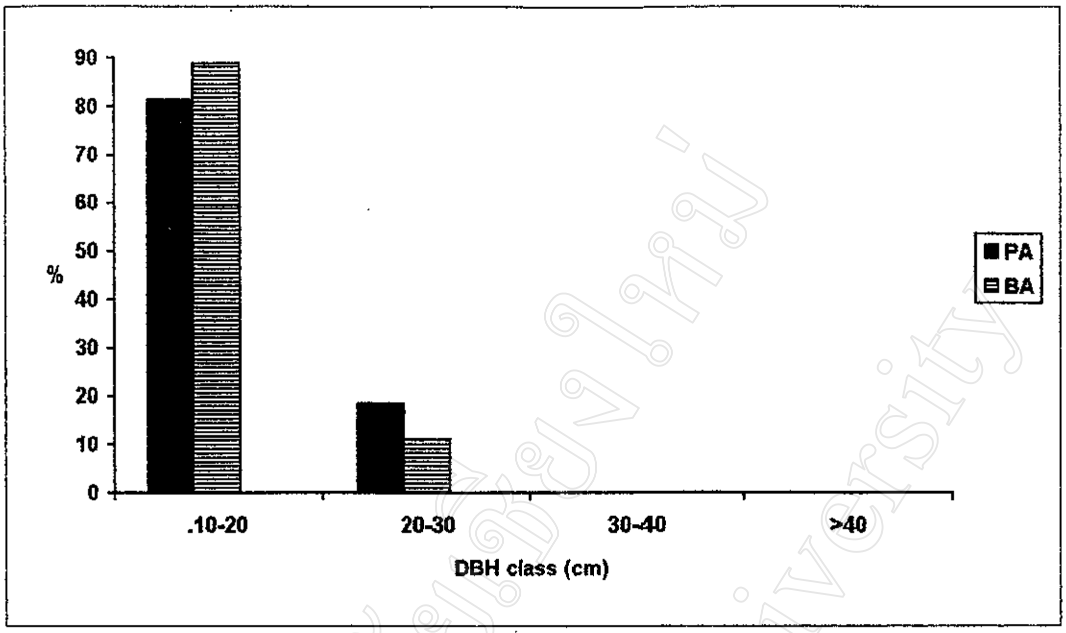


Figure 14. Size class distribution of *Buchanania lanzan* in the study areas.

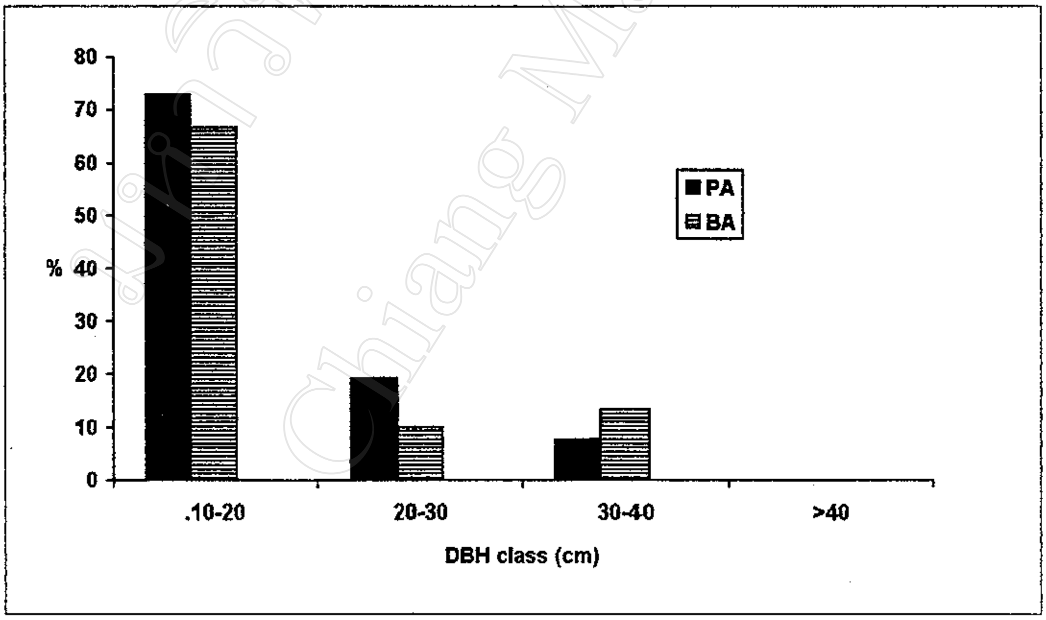
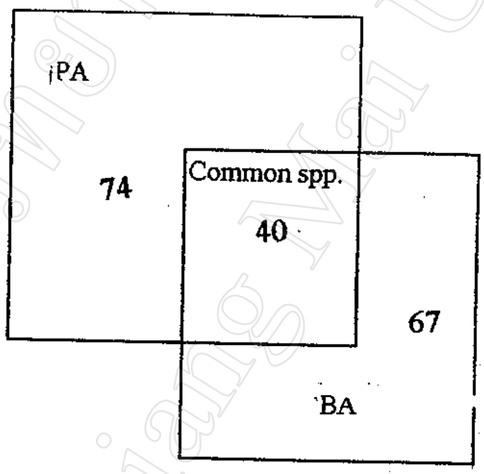


Figure 15. Size class distribution of *Quercus kerrii* var. *kerrii* in the study areas.

Similarity and Difference

The ground flora community composition were more dissimilar between two sites than that of trees. Figure 16 shows the simmilarity and dissimilarity of species between the two communities. The overlapping portion of the figure indicates the number of species present in both communities. Sorensen's similarity index was 0.53 compared with 0.65 in the tree community.

Figure 16. Common ground flora species between PA and the BA.



Frequency and Abundance score

In both sites, very few species were dominant in terms of their frequency and abundance scores. *Themeda triandra* Forssk. (Gramineae) was the most frequent and highly abundant in both sites followed by *Globba schomburgkii* Hk.f. (Zingiberaceae) in the BA and *Scleria lithosperma* var. *lithosperma* (Cyperaceae) in the PA. The most frequent and highly abundant species in both sites are given in Table 10.

Table 10. Ground flora species with high abundance and frequency scores in the study areas.

Species	Av. Domin Score[1]		% Frequency	
	PA	BA	PA	BA
Themeda triandra	83	72	81	86
Uraria lacei	-	15	-	20
Scleria lithosperma var. lithosperma	14	18	33	48
Scleria levis	-	19	-	43
Abrus precatorius	10	10	52	43
Globba schomburgkii	-	32	-	52
Globba reflexa	8	12	24	33
Dunbaria longeracemosa	-	22	-	57
Aristolochia kerrii	7	-	33	-
Curcuma zedoaria	-	18	-	52
Lygodium flexuosum	9	-	29	-
Scutellaria glanduolosa	10	-	48	-
Murdania loureirii	8	-	24	-
Desmodium laxiflorum ssp. *laxiflorum*	8	-	29	-

1. Average of Total Domin Score of July, September and November. The blank (-) does not mean that the species is absent in the site. It indicates the species does not fall within the nine maximum abundant species.

Visual Observations

Denser vegetation in the upper canopy was observed in the proteced area compared to sparse vegetation in the burnt area through out the study period. Also, more saplings were comming up in the protected area. Three distinct canopy covers, saplings, middle aged and mature/overmature trees, could be seen in the protected area compared to two canopy covers, middle aged trees and overmature trees in the burnt area.

Soil properties

Protection of forest from fire had no significant effects on all the physical and chemical properties of soil, except available phosphorus and soil temperature (Table 11) which were higher in the BA. Field capacity greatly varied among plots within both sites. The degree of variation, standard error of the mean, in the PA was slightly higher than in the BA. In the PA, sampling plots of higher field capacity were in the upper part of the study site (i.e. at the higher altitude) with medium slopes, however this was not the case in the BA

Table 11. Chemical and Physical Properties of the Soil in the Protected and Burnt Sites

Soil Characters	Unit	Mean [a]	
		Protected Area (PA)	Burnt Area (BA)
pH	-	5.85 ± 0.13	5.72 ± 0.04
Field capacity	%	17.08± 0.72	17.31 ± 0.67
Organic matter	%	3.08± 0.20	2.83 ± 0.26
Total nitrogen	%	0.14 ± 0.01	0.13 ± 0.01
Available phosphorus	ppm	13.03[b]± 0.32	16.90[b] ± 1.33
Available potassium	ppm	144.38± 13.76	131.75 ± 9.47
Temperature	^0C	26.14[b]± 0.15	27.19[b] ± 0.26
Texture			
Sand	%	64.02± 1.43	59.26 ± 2.20
Silt	%	16.16± 0.66	17.73 ± 0.85
Clay	%	19.81± 1.03	22.53 ± 1.97

[a] Average of twenty-one samples ± standard error of the mean
[b] Significant difference between protected and burnt sites (t-test, $p < 0.05$)

In the PA, phosphorus was relatively stable over the areas, whereas soil emperatures were higher in the lower part of the study area, and relatively constant in the upper parts. Average moisture content was significantly higher in the PA in all the months, from June to December except in September (Figure 17).

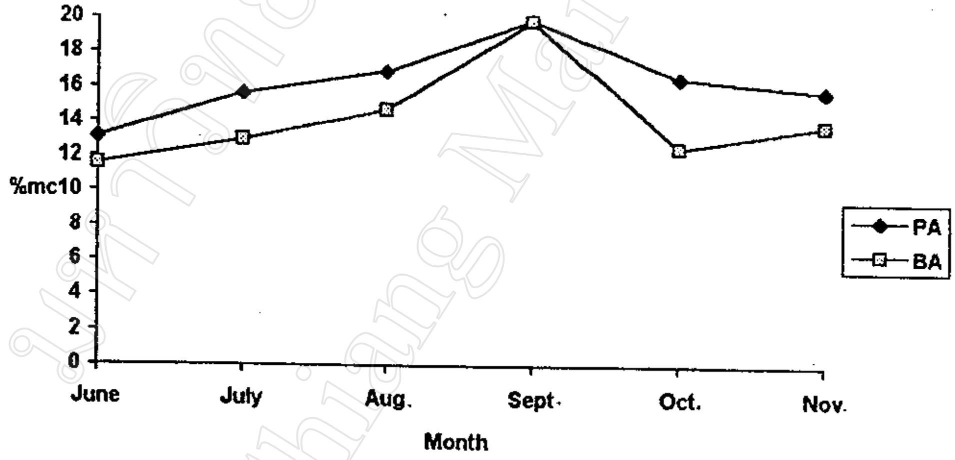


Figure 17. Average soil moisture content over the study period in the BA and the PA.

Tree phenology

Leaf abscission and leaf flushing

The majority of species (75 %) observed in both sites were deciduous and dropped their leaves during the drier part of the study period. Some of the species were tropophyllous, species which have very short duration between leaf shedding and leaf flushing. They included *Quercus kerrii* var. *kerrii*, *Tristaniopsis burmanica* (Griff.) Wils. & Wat., var. *rufescens*, *Rothmania sootepensis* (Craib) Brem. (Rubiaceae) and *Castanopsis diversifolia* King (Fagaceae).

The mean community scores for senescent leaves in November and December were significantly higher in the burnt area than in the protected area (Mann Whitney U-test, $p > 0.05$). Moreover, the protected area also retained more young leaves until the early rainy season (Figure 18). Bare canopy scores were highest in May in both sites. At the community level, both the highest bare canopy and young leaves scores were in May in both sites. Leaves appeared senescent after October. The lowest scores for bare canopy were recorded in September in PA, and in July in BA. Leaf flushing and bare canopy scores after the end of the rainy season, however, were quite similar in both sites.

The leafing periodicity of 8 of the commonest species is illustrated in the figures 19-26. These figures show a trend of highest scores of bare canopy and young leaves at the end of dry season, and lowest at the peak of the rainy season. These figures also show that fire protection increased the retention of leaves longer into the dry season and resulted in a higher proportion of leaf flushing during the late dry season or early rainy season in the case of *Shorea siamensis* var. *siamensis*. and *Craibiodendron stellatum*. However, this was not the case with the other species.

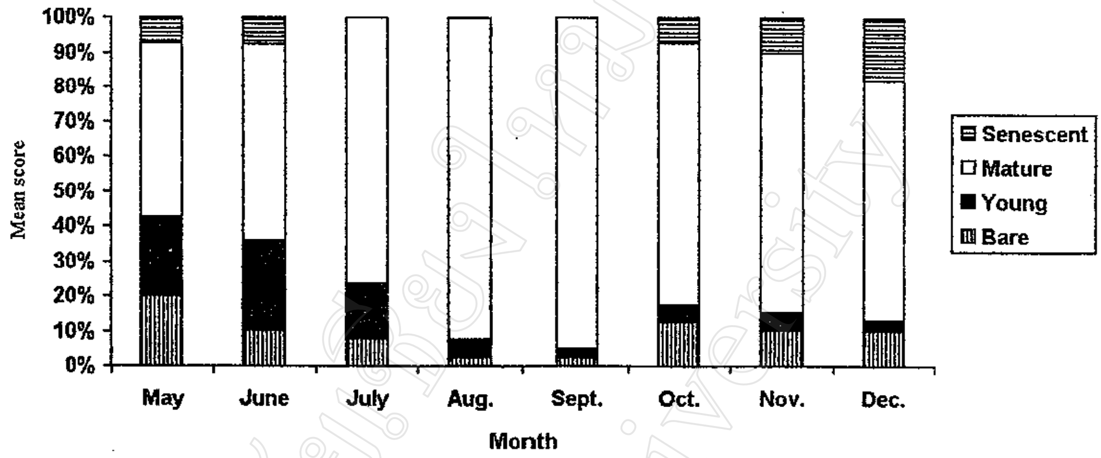
A striking difference between PA and BA was noticed in the timing of leaf abscission of *Shorea siamensis* (Figure 22). It was roughly estimated that two thirds of the *Shorea siamensis* canopies in the burnt area were bearing senescent leaves, compared to half of the total canopy cover in the protected area in the first week of February. Young leaves of *Lithocarpus elegans* in the PA had higher community scores than the scores in BA throughout the study period, except in October (Figure 26).

Flowering and fruiting

No distinct differences in the timing of flowering and fruiting patterns of species between the PA and BA were found. However, a difference in the intensity of these patterns was clearly observed (Figure 27). The BA had a higher community scores for flowering in May with the lower scores of fruiting in that month compared to the PA. However, this was reversed in December. Similar patterns of flowering and fruiting were observed in both sites during the rainy season. Peak levels of flowering occurred in May in both sites. The BA had more species in flower during the eight months of study period. Ten of the 15 species flowered in May. The lowest number of species flowering was observed during the peak rainy season (Table12).

Two peak seasons of flowering and fruiting were observed (Figure 27), i.e. *pre* and *post* rainy season. Highest scores for flowering were in May and in November, whereas the highest scores for fruiting were in June and December. No significant differnces between the community scores were observed (Mann Whitney, U-test $p > 0.05$). Flowering and fruiting behaviour of *Dipterocarpus obtusifolius var. obtusifolius*, *Quercus kerrii* var. *kerrii*, *Craibiodendron stellatum, Lithocarpus sootepensis,* and *Lithocarpus elegans* were highly synchronous. It was clearly observed in *Dipterocarpus obtusifolius* var. *obtusifolius* (Figure 28*)*. Two peaks of fruiting were observed in *Buchanania lanzan*, *Craibiodendron stellatum*, *Lithocarpus sootepensis* in both sites. Flowering peaks were followed by fruiting peaks in all the cases. Maximum number of trees bearing fruits was in June (Table 13).

A. Protected area



B. Burnt area

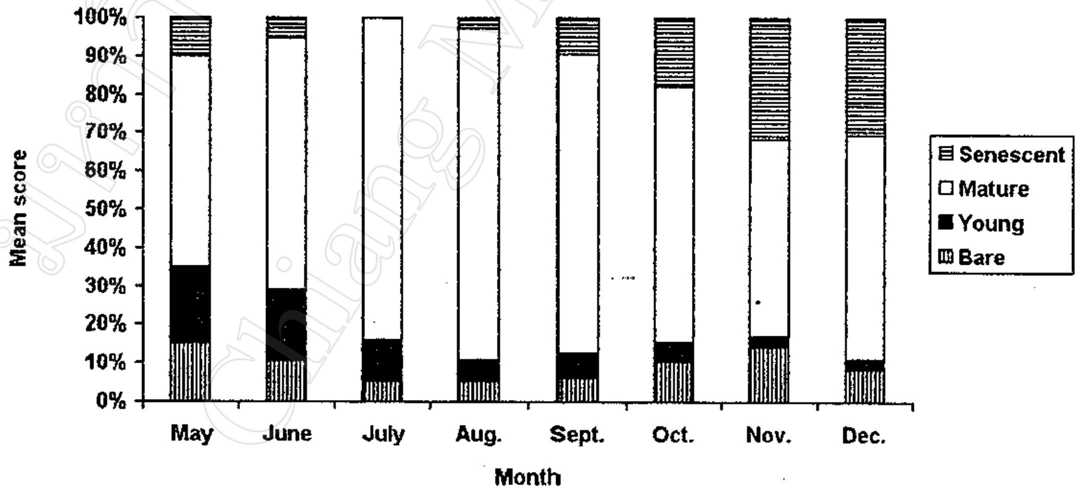
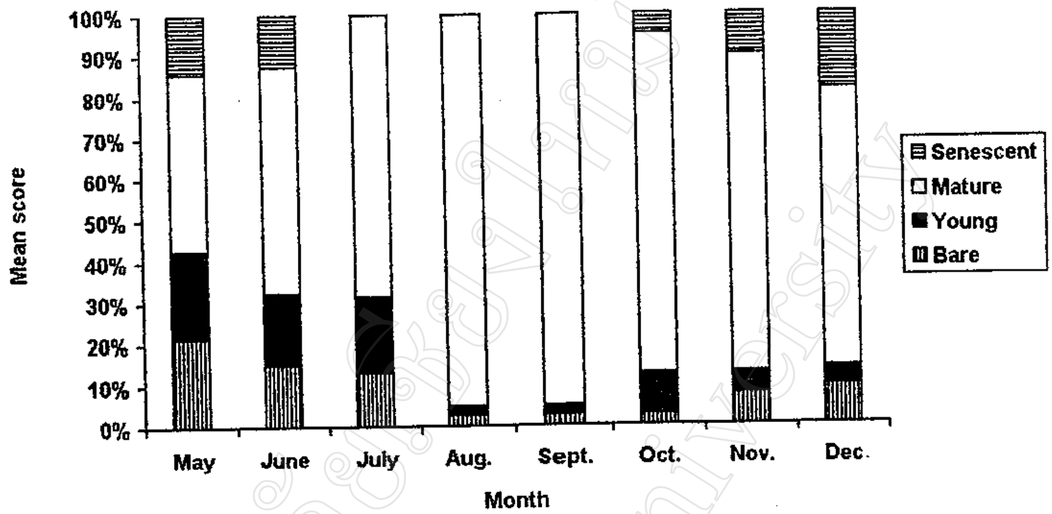


Figure 18. Leafing phenology of trees at community level in the study areas.

A. ***Dipterocarpus obtusifolius*** **var. o*btusifolius*** **in the PA.**



B. ***Dipterocarpus obtusifolius*** **var. o*btusifolius*** **in the BA.**

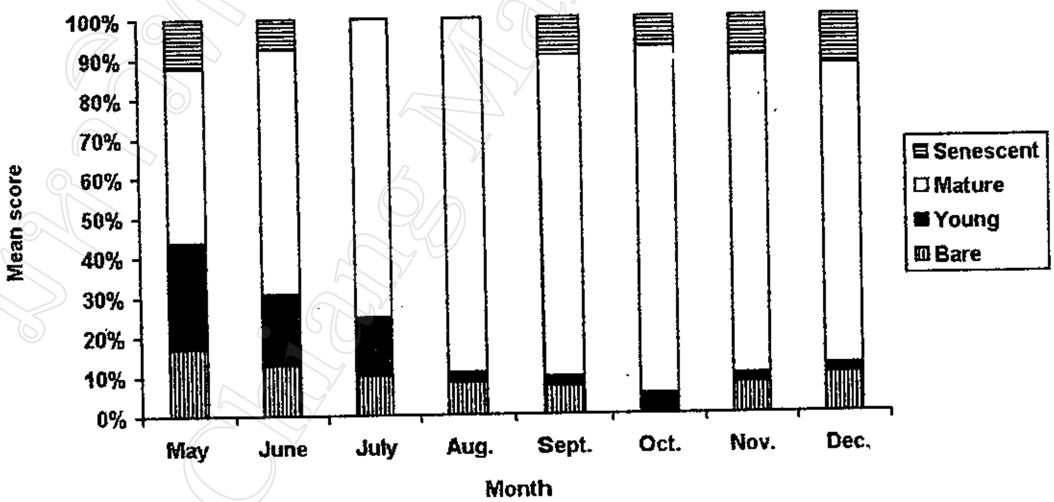
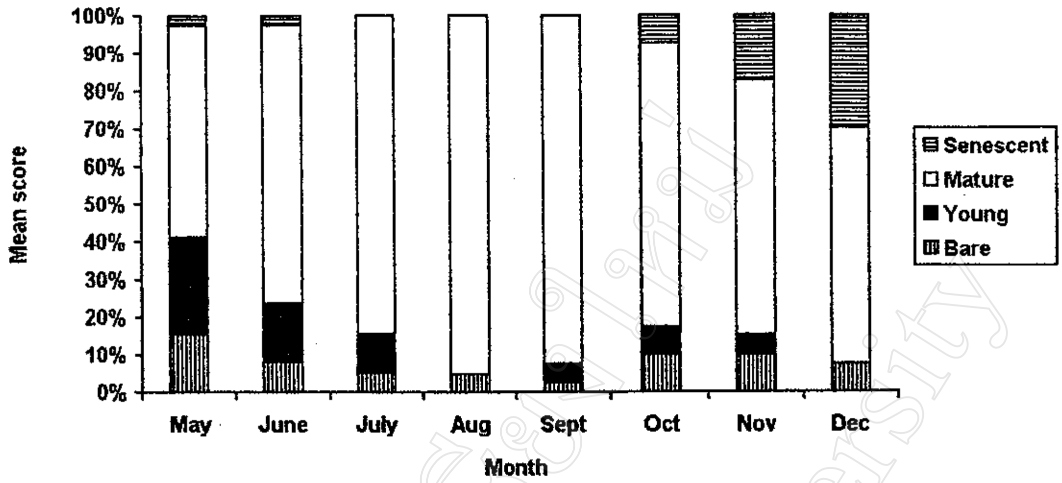


Figure 19. Leafing phenology of *Dipterocarpus obtusifolius* var. *obtusifolius* in the study areas.

A. *Buchanania lanzan* × PA



B. *Buchanania lanzan* × BA.

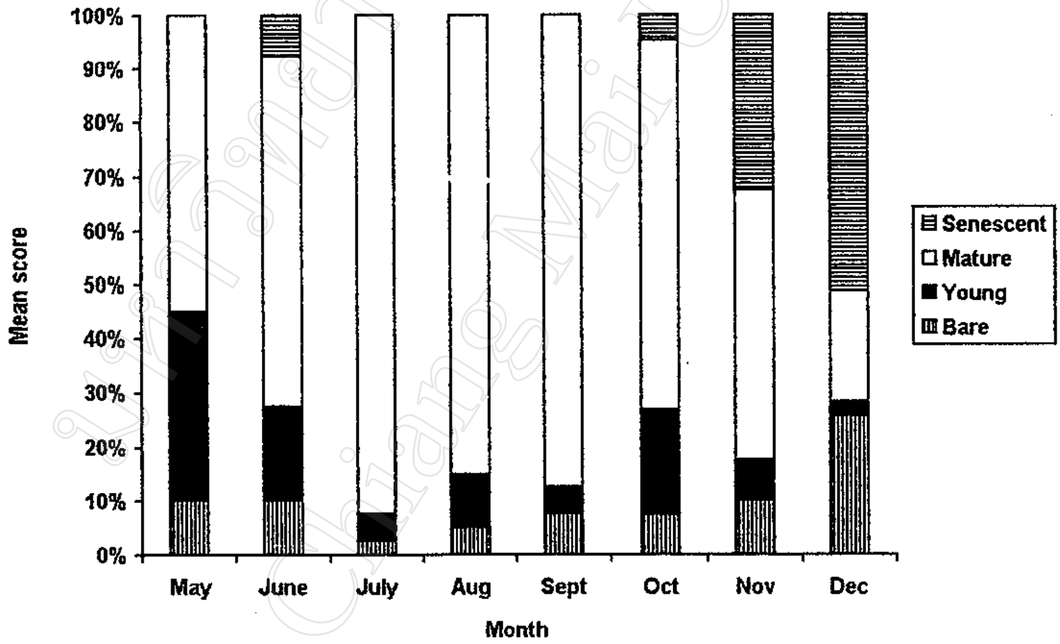
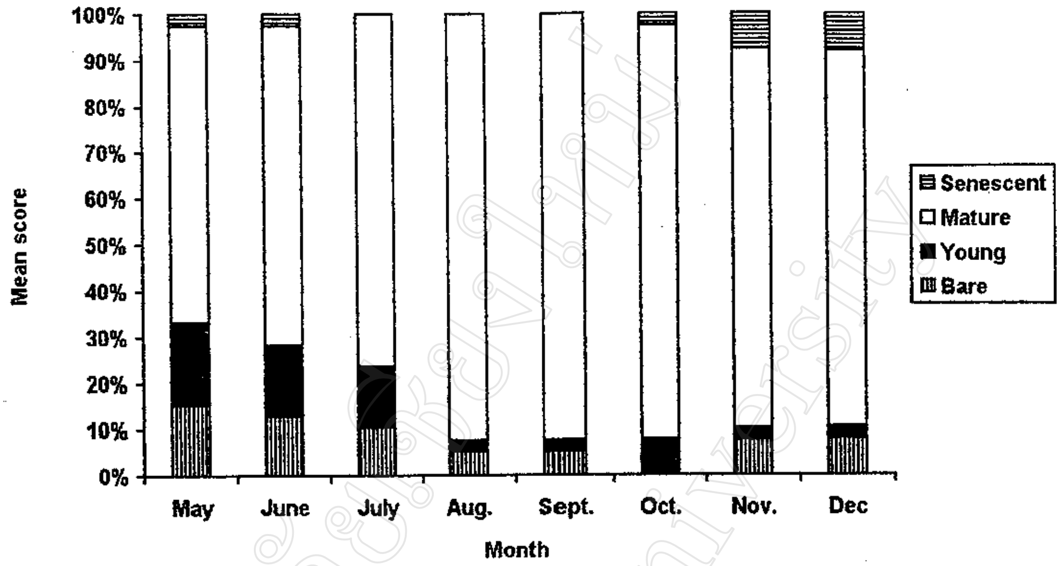


Figure 20. Leafing phenology of *Buchanania lanzan* in the PA and the BA.

A. *Shorea obtusa* in the PA



B. *Shorea obtusa in the* BA.

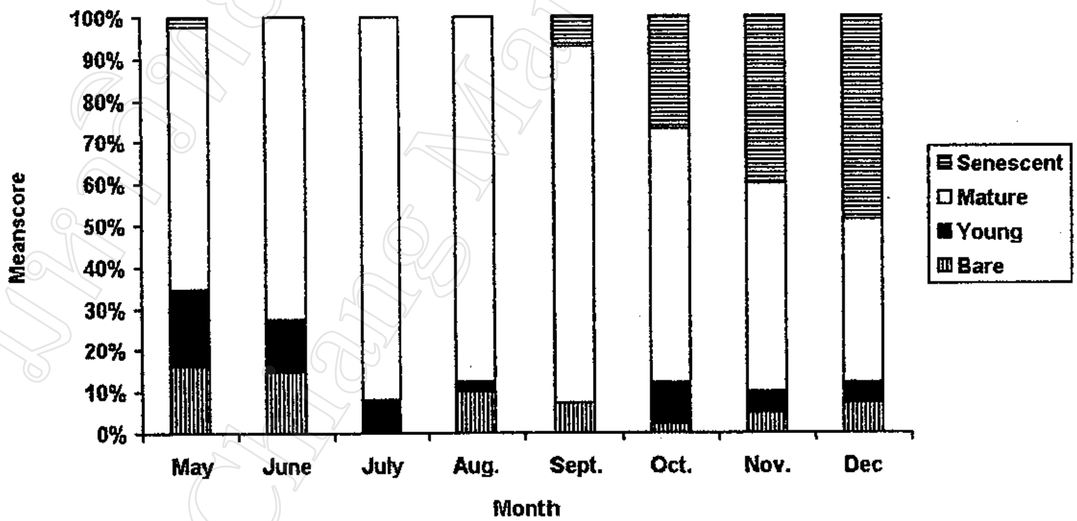
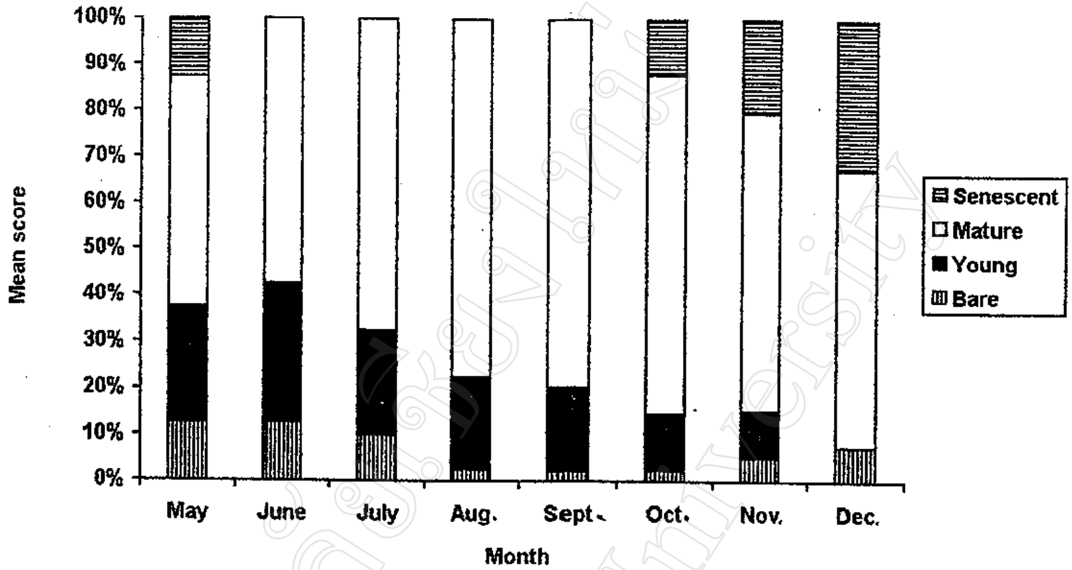


Figure 21. Leafing phenology of *Shorea obtusa* in the study areas.

A. *Shorea siamensis* var. *siamensis* in the PA.



B. *Shorea siamensis* var. *siamensis* in the BA.

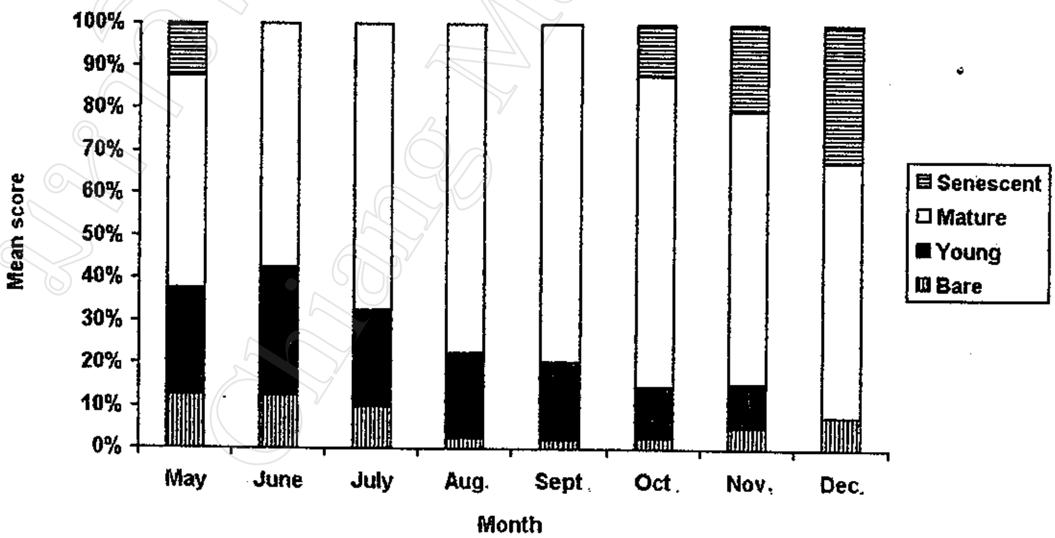
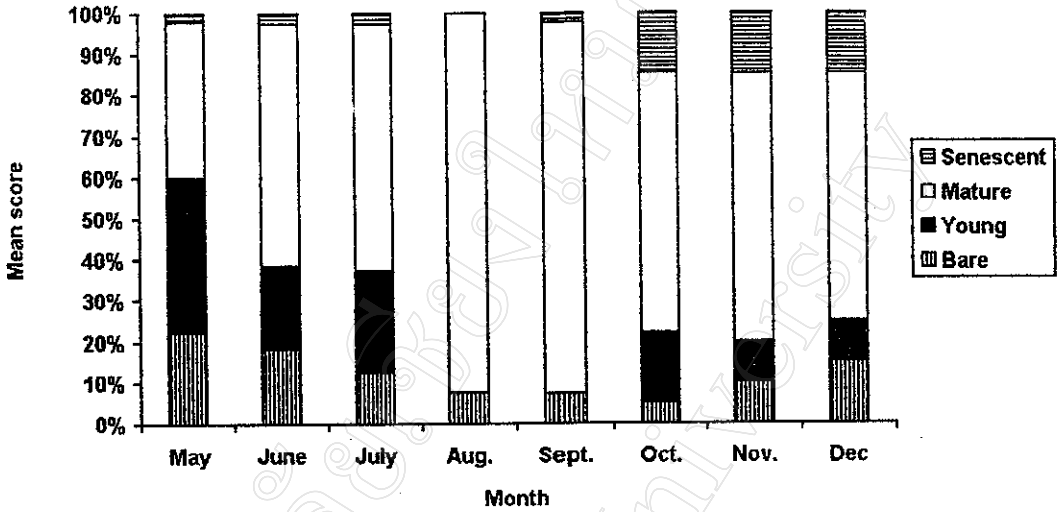


Figure 22. Leafing phenology of *Shorea siamensis* var. *siamensis* in the study areas.

A. *Craibiodendron srtellatum* in the PA.



B. *Craibiodendron stellatum* in the BA.

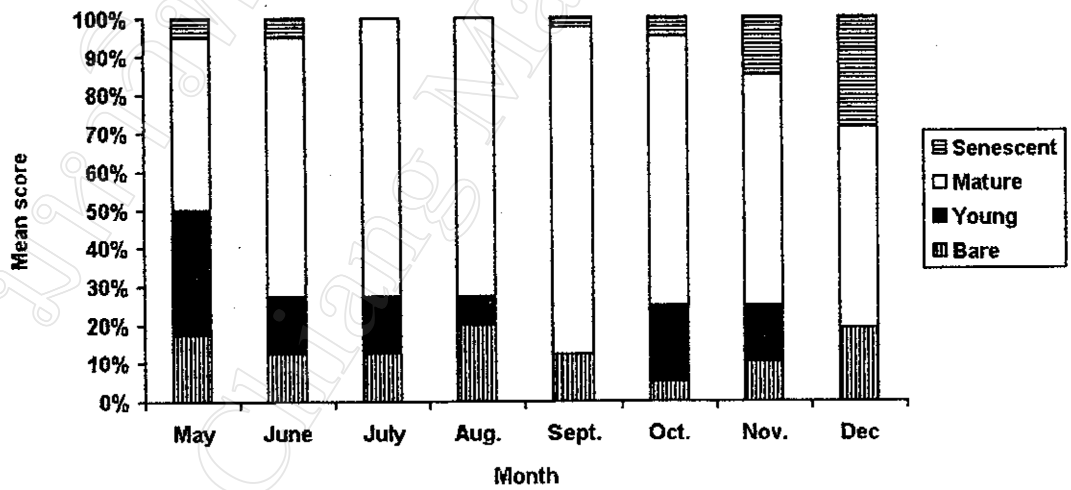
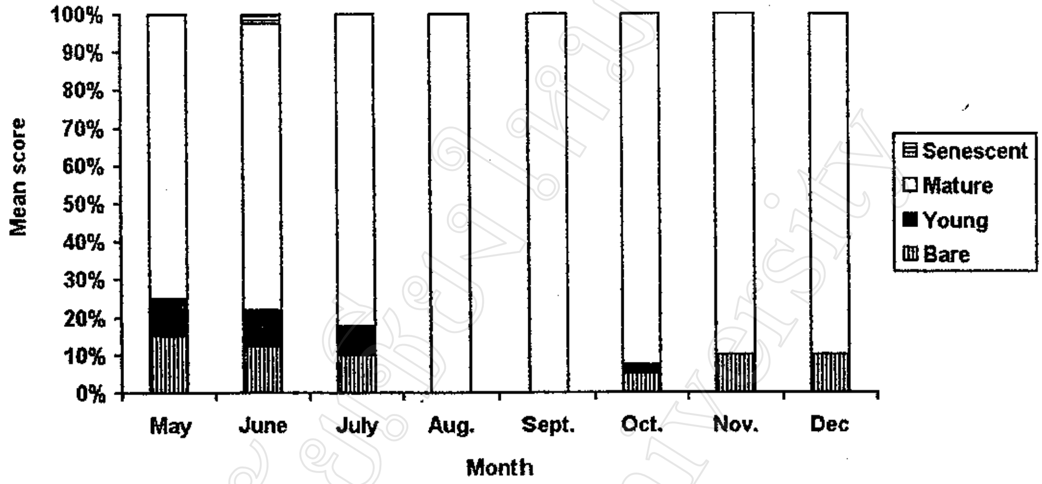


Figure 23. Leafing phenology of *Craibiodendron stellatum* in the study areas.

A. *Quercus kerrii* var. *kerrii* in the PA.



B. *Quercus kerrii* var. *kerrii* in the BA.

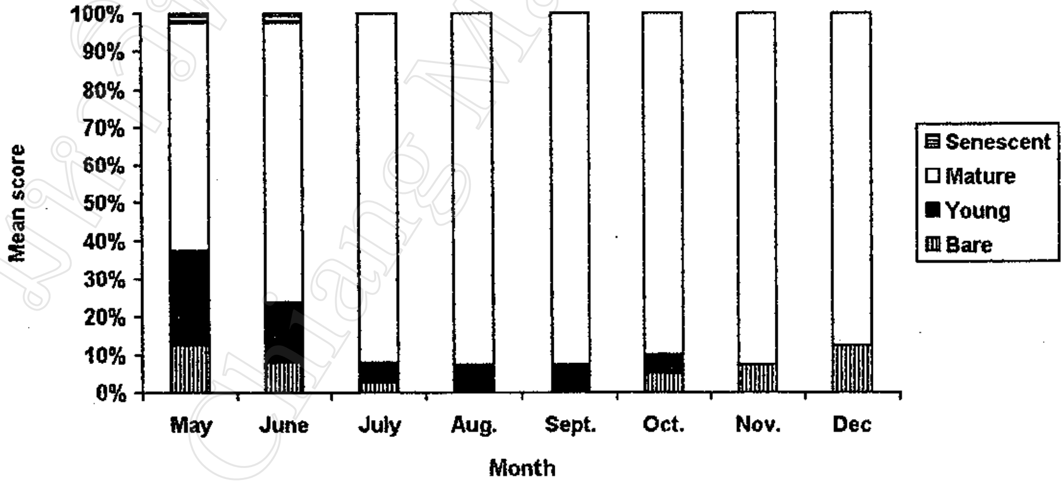
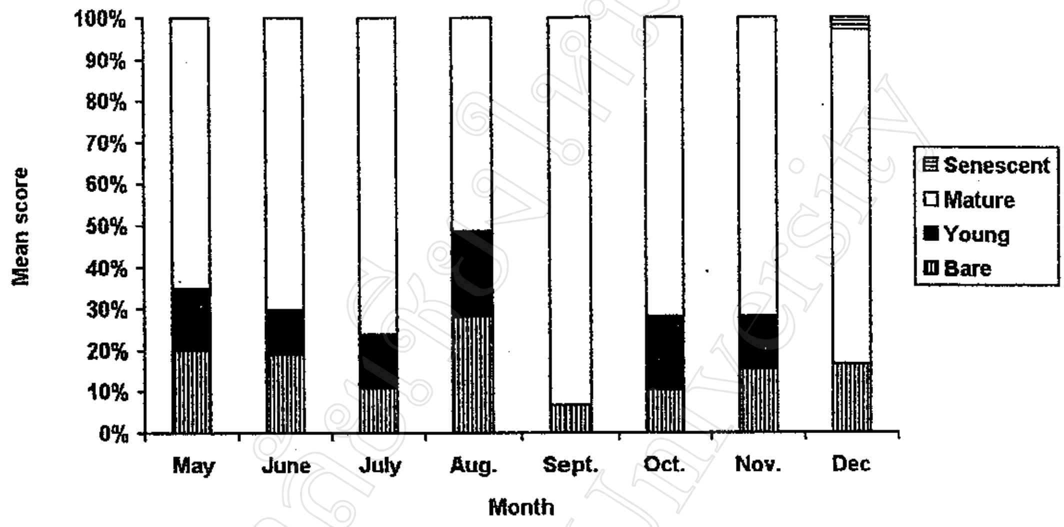


Figure 24. Leafing phenology of *Quercus kerrii* var. *kerrii* in the study areas.

A. ***Lithocarpus sootepensis*** **in the PA.**



B. ***Lithocarpus sootepensis*** **in the BA**

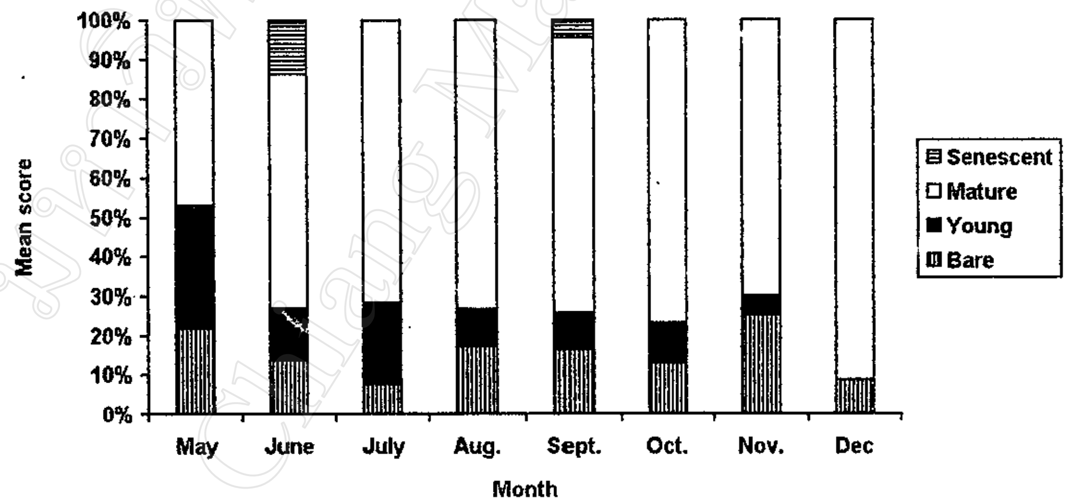
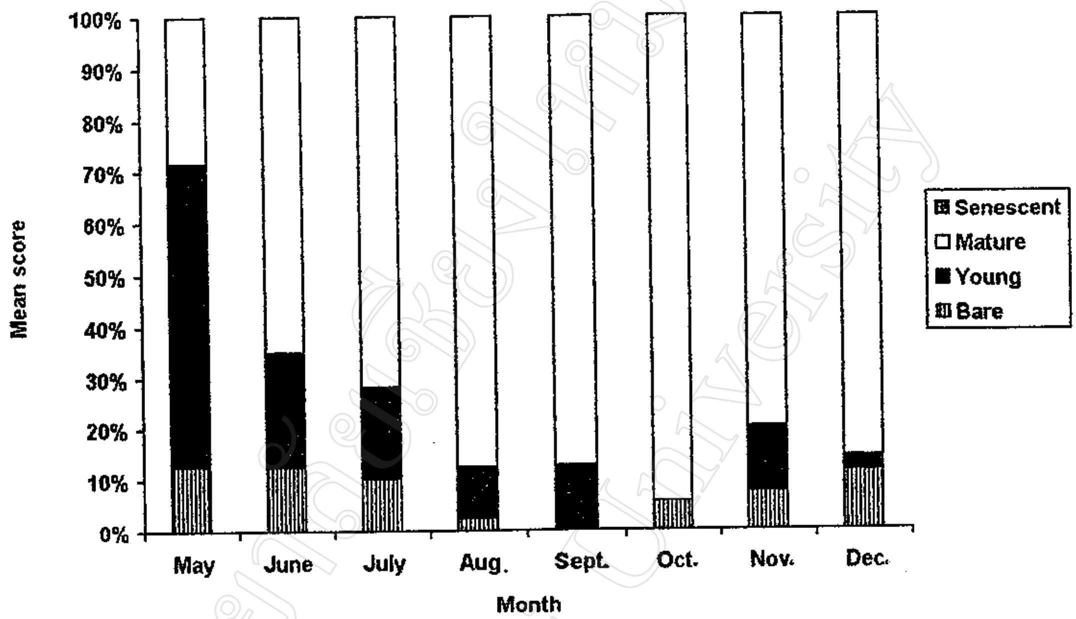


Figure 25. Leafing phenology of *Lithocarpus sootepensis* in the study areas.

A. *Lithocarpus elegans* in the PA.



B. *Lithocapus elegans* in the BA.

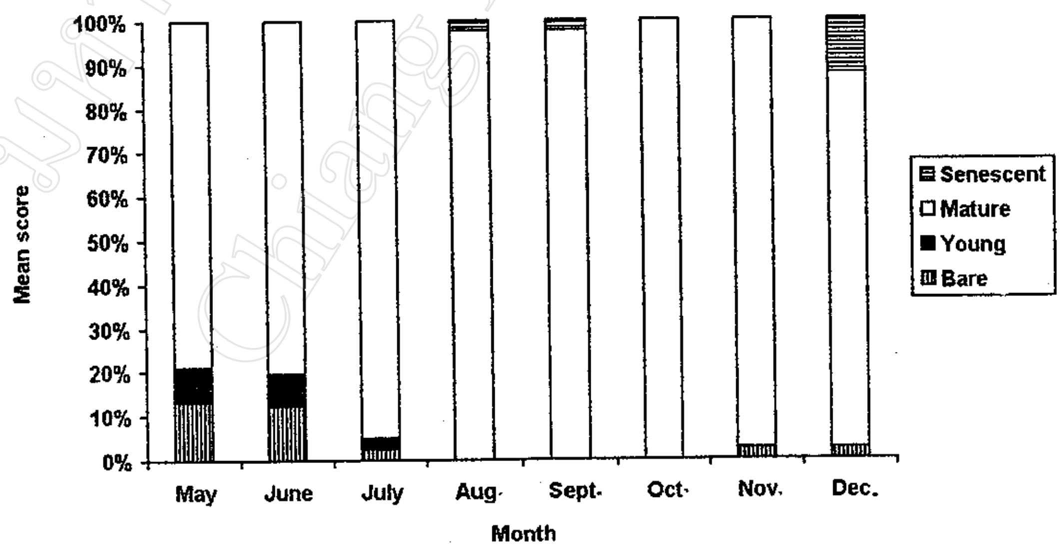
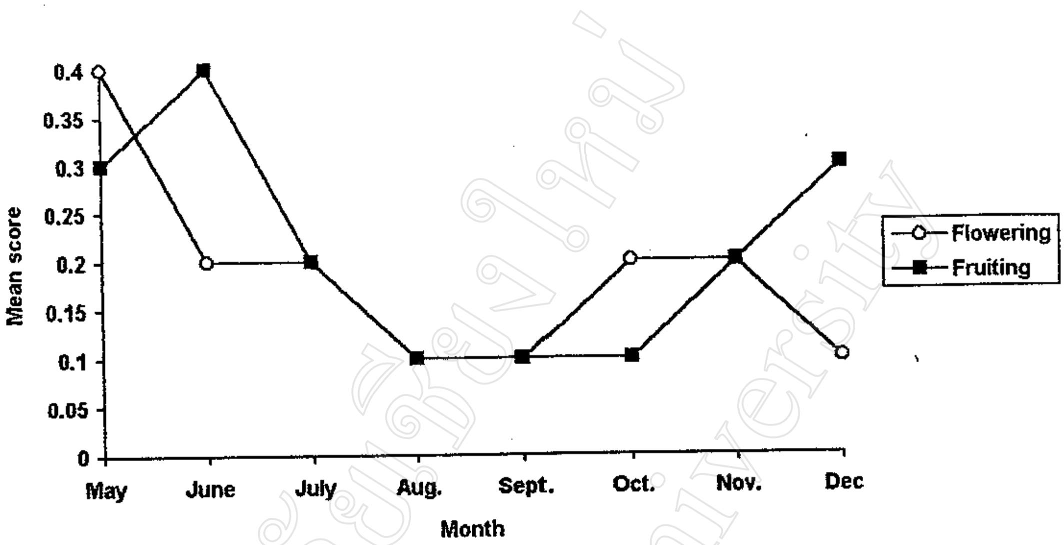


Figure 26. Leafing phenology of *Lithocarpus elegans* in the study areas.

A. Protected area.



B. Burnt area

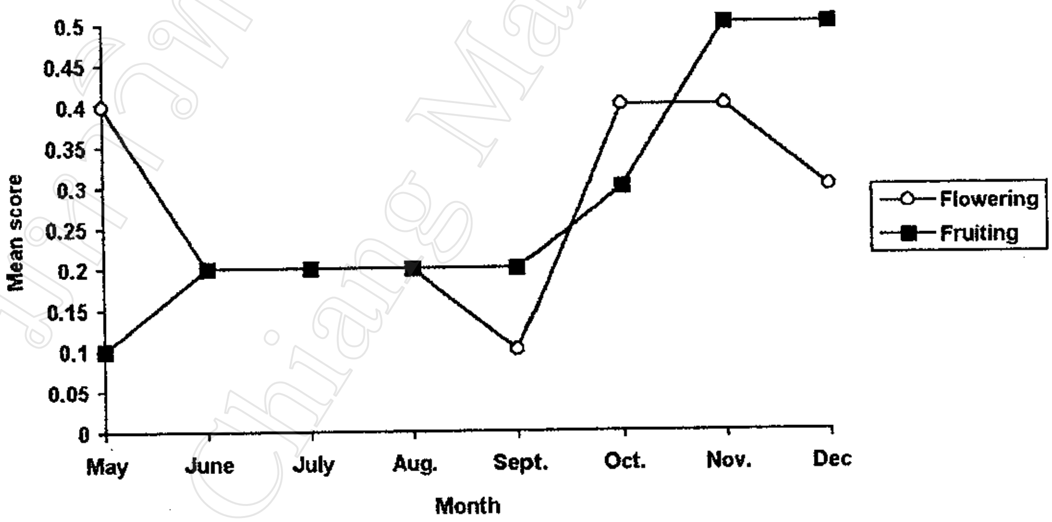
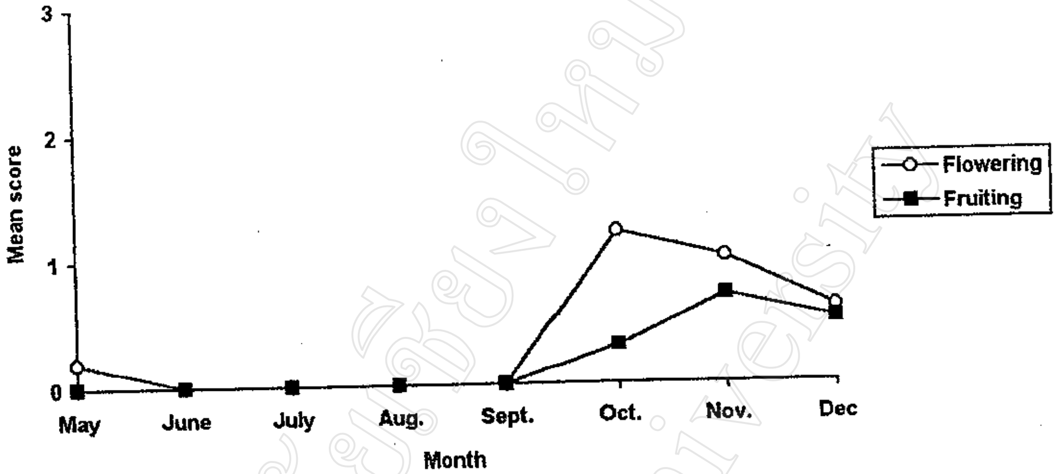


Figure 27. Flowering and fruiting periodicity of trees at community level.

A. ***Dipterocarpus obtusifolius*** var. ***obtusifolius*** in the PA.



B. ***Dipterocarpus obtusifolius*** var. ***obtusifolius*** in the BA.

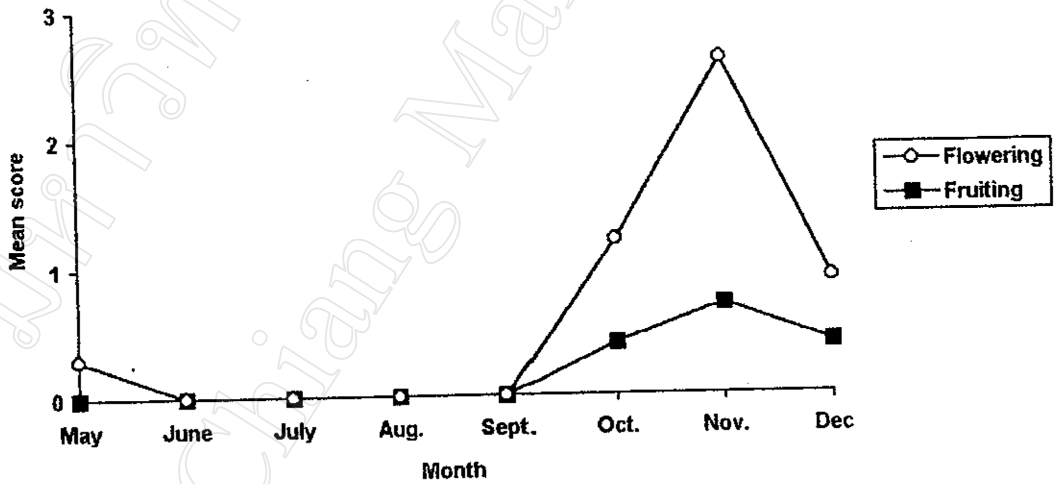


Figure 28. Flowering and fruiting phenology of *Dipterocarpus obtusifolius* var. *obtusifolius* in the study areas.

Flowering phenology of trees

Table 12. Flowering phenology of tree species in the study area.

Tree Species	No. of trees observed		Months during which flowers were observed							
	PA	BA	M	J	J	A	S	O	N	D
Dipterocarpus obtusifolius Teijsm. ex Miq.	100	58	*				*	*	*	*
Shorea obtusa Wall. ex Bl.	22	15	*							
Buchanania lanzan Spreng.	27	9	*							
Quercus kerrii Craib.	26	15	*	*						
Craibiodendron stellatum (Pierre) W.W. Sm.	9	5	*	*	*	*	*	*		
Dalbergia dongaiensis Pierre	0	2						*	*	*
Gardenia sootepensis Huthch.	1	3	*							
Gluta usitata (Wall.) Hau	4	2							*	*
Ochna integerrima (Lour.) Merr.	0	1	*							
Tristaniopsis burmanica (Griff.) Wils. & Wat.	2	8	*							
Canarium subulatum Guill.	2	0	*							
Wendlandia tinctoria DC.	0	1							*	*
Garcinia cowa Roxb.	1	0	*	*	*					
Anneslea fragrans Wall.	3	1							*	*
Vitex limonifolia Wall. ex Kurz.	0	1				*	*		*	
Total species flowered each month	11	13	10	3	2	2	3	3	6	5

Table 13. Fruiting phenology of tree species in the study area.

Tree Species	No. of trees observed		Months during which fruits were observed							
	PA	BA	M	J	J	A	S	O	N	D
Dipterocarpus obtusifolius Teijsm. ex Miq.	100	58						*	*	*
Shorea obtusa Wall. ex Bl.	22	15	*	*						
Quercus kerrii Craib.	26	15			*	*				
Craibiodendron stellatum (Pierre) W.W. Sm.	9	5	*	*	*		*	*	*	
Dalbergia dongaiensis Pierre.	0	2		*					*	*
Gluta usitata (Wall.) Hau.	1	3			*	*	*			
Ochna integerrima (Lour.) Merr.	0	1	*							
Tristaniopsis burmanica (Griff.) Wils. & Wat.	2	8	*							
Canarium subulatum Guill.	2	0		*	*					
Anneslea fragrans Wall.	3	1	*							
Vitex limonifolia Wall. ex Kruz	0	1		*						*
Dipteocarpus tuberculatus Roxb.	0	8								*
Antidesma acidum Retz.	1	0						*	*	*
Terminalia mucronata Craib & Hutch.	2	0		*	*	*				
Dalbergia fusca Pierre	2	2	*	*			*	*		
Aporusa villosa (Lindl.) Baill.	3	1	*							
Lithocarpus elegans (Bl.) Hatus.	10	3			*	*		*		
Lithocarpus sootepensis (Craib) A. Camus	15	4					*	*	*	
Xylia xylocarpa (Roxb.) Taub. var. kerrii	0	1							*	*
Gardenia sootepensis Hutch.	1	3		*	*	*	*			
Total no. of species bearing fruits	15	17	7	8	7	5	5	6	6	6

DISCUSSION

Species Composition and diversity

The greater tree population density in the protected area was a direct consequence of fire protection. The protected area contained 25 % more individual trees than the burnt area. Also, it has more young trees of DBH 10-20 cm category than in the burnt area. 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. This result also supports the findings made by Naidu and Sribasuki (1994) that young plants are more badly affected by fires than mature ones.

Despite a significantly higher tree population density in the PA, the percentage of tree species in both areas was quite similar. However, both areas contained significant percentages of 'unique' species which accounted for 36.4 % in the PA and 33.3 % in the BA. Among the common species found in both areas, evergreen or tropophyllus trees were more common in the PA, and deciduous trees in the BA, with the exception of *Dipterocarpus obtusifolius* var. *obtusifolius* which dominated both areas. Trees of Dipterocarpaceae family were more abundant in the BA whereas Fagaceae and Anacardiaceae were more abundant in the PA. The Dipterocarpaceae family accounted for 64.6 % of trees in the BA but only 57 % in the PA. *Buchanania lanzan, Quercus kerrii* var. *kerrii, Lithocarpus sootepensis*, and *Lithocarpus elegans* had higher relative dominance in the PA. Similarly, *Tristaniopsis burmanica* var. *rufescens* and *Shorea obtusa* had higher dominance in the BA. This suggests that conditions in the protected area favored evergreen or tropophyllous trees. This statement is also supported by the 'importance values'. Meng (1997) also observed more tree seedlings of Fagaceae family in the PA.

Another striking feature noticed during the study was that no individuals of *Dipterocarpus tuberculatus* var. *tuberculatus* greater than 10 cm DBH were found in the PA. However, a few emerging coppicing shoots were seen. This observation agrees with a statement made by Barrington (1931) in a study of forest in Burma that "... protection encourages an evergreen undergrowth which prevents the reproduction of *Dipterocarpus tuberculatus* var. *tuberculatus* and would obviously change the consociation to a moister type".

Fire protection seemed to have more impact on the herbaceous community than trees. Almost half of the ground flora species recorded were specific to each site. The majority of herbaceous species in the PA were typical of moist conditions and some species found in the burnt area are fire resistant. *Phoenix humilis* Roy. var. *humilis* (Palmae) and *Pennisetum pedicellatum* Trin. (Gramineae) are typical examples. Although the total Domin score in the BA is much higher than in the PA, there was no significant difference in the species diversity index. This was probably due to the dominance of a few species rather than the even distribution of species. *Themeda triandra* Forssk. (Gramineae), and *Globba schomburgkii* (Zingiberaceae), *Scleria lithosperma* (L.)Sw. ssp. *lithosperma* (Cyperaceae) were among the dominant ground flora species in both areas.

The presence of certain species in only one site gives an indication of possible fire protection effects. For example, the presence of some of the ground flora species such as *Hedyotis tenelliflora* Bl. var. *tenelliflora (Rubiaceae)*, *Pouzolzia hirta Hassk. (Urticaceae)*, *Centotheca lappacea (L.) Desv. (Gramineae)*, *Kaempferia rotunda* L. (Zingiberaceae), *Globba nuda* K. Lar. (Zingiberaceae), *Barleria strigosa Willd. (Acanthaceae)*, *Cyrtococcum oxyphyllum* (steud.) Stapf (Gramineae), *Cymbidium aloifolium* (L.) Sw.(Orchidaceae), and *Dioscorea bulbifera* L. (Dioscoreaceae) only in the PA and complete absence in the BA indicates the PA to be more favoured by certain species. Previous studies (CMU, Herbarium Data Base, 1996; Phuakam, 1995) stated that these species are typical species of shady and moist areas of mixed deciduous+evergreen forest. Similarly, the presence of *Phoenix humilis* var. *humilis*, *Argyreia capitiforrmis* (Poir.) Oost. (Convolvulaceae), *Blumea lacera* (Burm. f.) DC. *(Compositae)*, *Capillipedium parviflorum* (R. Br.) Stapf (Graminae), *Pennisetum pedicellatum* Trin. (Graminae), and *Polytoca digitata* (L.f.) Druce (Graminae) in the BA and completely absence in the PA implies a difference in species composition between the two sites. Moreover, the CMU Herbarium Data Base and Phuakam (1995) mentioned these species to be characteristic species of DOF. Particularly, *Phoenix humilis* var. *humilis* (Palmae) is well known for its typical fire-resistant character.

Species diversity indices for both trees and ground flora failed to show a clear distinction between the two forested areas. This was because of the dominance of only a few species in both areas. However, the number of individuals of trees in the PA and percent cover (Domin score) in the BA were distinctly higher. Also, this is a typical example of the failure of species diversity indices. The protected area was richer in both tree and ground flora species which indicated that the PA was more diverse than the BA. Furthermore, the PA was richer in ground flora compared to tree species. This suggests that protection had a more pronounced effect on the ground flora community, particularly with herbs. This is the reason why Sorensen's similarity index was lower for the ground flora communities than for the tree communities.

The lower diversity index in the PA despite higher species richness was due to the less ground cover. This condition indicates more species, but more rare cases. This was probably due to less area exposed to sunlight in the PA. This follows the ecological principle that diversity enhances stability. Hutchinson (1959) explained that when species are added to a community it involves taking over part of the niche of a species already present. That reduces fluctuations in the population of the later and keeps it from "being underrepresented to a dangerous degree". Therefore, despite a high Domin score, the BA was less stable and was at high risk of species loss.

The reason behind the higher number of Leguminosae and Convolvulaceae species may be due to heat generated by fire which works as a stimulus for seed

The reason behind the higher number of Leguminosae and Convolvulaceae species may be due to heat generated by fire which works as a stimulus for seed germination. Bewley and Black (1982) and Mirov (1936) reported that seeds of many species in several families (e.g. Leguminosae, Malvaceae, Sterculiaceae, Cannaceae, and Convolvulaceae) have a form of dormancy enforced by an impermeable seed coat. The hard seed coat must be broached somehow, if germination is to occur. Similarly, the higher influence of fire on herbs and vines than on shrubs and woody climbing species implies a possible relationship between fire and growth and development of plants. Wheelan (1995) reported that dormant plant tissues that are in a dehydrated state can tolerate much more severe heat than can tissues that are metabolically active and fully hydrated. As compared to shrubs, herbs are more sensitive to heat disturbance. Herbs are less rigid and have more water per unit area in their parts. This is the reason that they are more easily affected by fire. Furthermore, shrubs and tree species have bark, so that the time taken for cambial cells to reach a lethal temperature during the burn is longer than in the epidermis of herbaceous plants (Wheelan, 1995). However, some ground flora species (e.g. *Phoenix humilis* var. *humilis) are* fire resistant due to their resprouting capacity. Elliott (1991) argued that artificial watering might favour perennials more than annuals, which does not coincide with my results.

Soil Properties

The Average soil temperature and phosphorus were both higher in the burnt area than in the PA. Higher phosphorus was probably due to the release of phosphorus from plant materials after burning. This result coincides with those of Ramakrishnan and Toky (1981). Lambert and Arnason (1989) also reported that available phosphorus and exchangeable potassium were significantly lower in an unburned plot than in a burned one. In my study, the lower value of phosphorus could also be associated with the greater density of trees which absorbed more phosphorus from the soil.

After burning, the forest ecosystem loses its ability to hold nutrients. Large losses occur through volatilization of carbon and nitrogen during burning leading to reduction in the quantity of these elements in the surface soil (Ramakrishnan, 1989). In my study, however, no significant changes in nitrogen and organic matter content were recorded. This might be due to recovery of these soil properties during the unburned period, as the frequency of fire in the present study area was once every three years. The recovery in soils in BA occurs partly from the addition of organic matter through plant biomass (leaves, twigs, etc.) and rapid nitrogen fixation by soil microbes. No significant differences in nitrogen level might be due to the recovery of the available nitrogen originally lost during the burn. This is because accelerated microbial activity follows a rise in soil temperature of the surface soil, which enhances nitrogen recovery (Ahlgren and Ahlgren, 1965).

It seems that 28 years is still not enough time to produce significant changes in soil properties. Ramakrishnan (1984) mentioned that a 10 year cycle for slash and burn agriculture is the shortest possible time to recover the soil nutrients. More deciduous trees with a fast turnover of leaves is an added advantage to recover nutrient losses in the BA. However, species composition, leaching, run-off, soil moisture, and other physiographic conditions have a major role in determining the period of recovery. Temperature has a pronounced effect on the mineralization of organic matter (Wild, 1989).

The higher soil temperature in the BA is due to the more exposed conditions compared to the PA. The average soil moisture content was slightly higher throughout the study period in the PA mainly due to the closed canopy, high organic matter, and consequently low evapo-transpiration rate. Soil temperatures following a burn are influenced by an alteration in the insulating capacity of the litter layer and heat absorption pattern of the soil surface layer as a result of a dark ash deposit (Prichett 1979). The effects of forest fires on the physical, chemical, and biological properties of soils are directly related to the intensity and duration of the burn. Prichett (1979) reported that fire drastically speeds up the process of oxidation and some of the mineral nutrients released are dissolved after rain and rapidly leached into the soil. Thus, the ash deposit from a fire increases available phosphorus, potassium, calcium, and magnesium.

Phenological patterns

A marked difference in leafing periodicity between the PA and the BA was observed in October, November, and December at community levels. In both sites, an increasing trend of senescent leaves was observed. The mean community scores for senescent leaves in these three months were much higher in BA than in the same period in the PA. It shows that fire protection increases the retention of leaves longer in the dry season and results in a higher proportion of leaf flushing during the late dry season or early rainy season. *Shorea siamensis* var. *siamensis* has followed this trend. However, this result contrasts with Paonsapanh (1994) who reported that irrigation had no effect on leafing phenology of *Shorea siamensis* in DOF at Huai Hong Khrai, north of Chiang Mai. Nevertheless, Beard (1994) found that at a dry forest site, trees lost their leaves in the dry season at a faster rate than those in a moist deciduous community. Young leaves of *Lithocarpus elegans* in the PA have higher community scores than the scores in the BA throughout the study period, except in October.

No distinct differences in the flowering and fruiting patterns of species between PA and BA were observed. However, differences in intensity of phenophases were clearly noticed. In May, flowering scores in the BA were much higher than the fruiting scores, compared to these patterns the PA. It shows that either burning decreased the vigour of fruiting of trees or trees in BA bore fruits earlier during the dry season. However, the gap of flowering and fruiting scores is slight in December, during the early dry season. The cause of early and intense flowering in the BA may be closely related to increased productivity after fire.

The peak level of tree flowering was in May and fruiting in December in both sites. This result coincides with Elliott *et al.* (1994). Two peaks of flowering and fruiting were observed in both areas. This might be due, in part, to differences in the natural timing of fruiting between wind dispersed and animal dispersed species (Elliott *et al.* 1994).

Tree density, soil moisture and phenology

In this study, the average soil moisture content, organic matter and tree density were higher in the PA. Greater density of deciduous trees in the PA adds more leaf litter and organic matter to the soil. Neal *et al.* (1965) suggested that the fire reduces the content of organic matter and, therefore, decreases its moisture-holding capacity. Mallik (1986) found that water content in the top 2 cm of soil generally decreased in response to burning. The higher soil moisture content, lower soil temperature and greater tree density in the PA helped trees retain their leaves longer during the dry season. In such conditions, the ground surface is less exposed to sunlight and there will be less evaporation. Trees in the PA will get water longer during the dry season than the trees in the BA. Also, trees in the BA get more heat from fire during burning. All these factors contribute to the phenological differences between the two sites. The distinct phenological changes observed mainly in May and December (which indicates greater effect in the dry season) were due to higher effect of these factors in the dry season than in the wet season.

CONCLUSIONS AND RECOMMENDATIONS

Based on the results and discussion, the following conclusions are made:

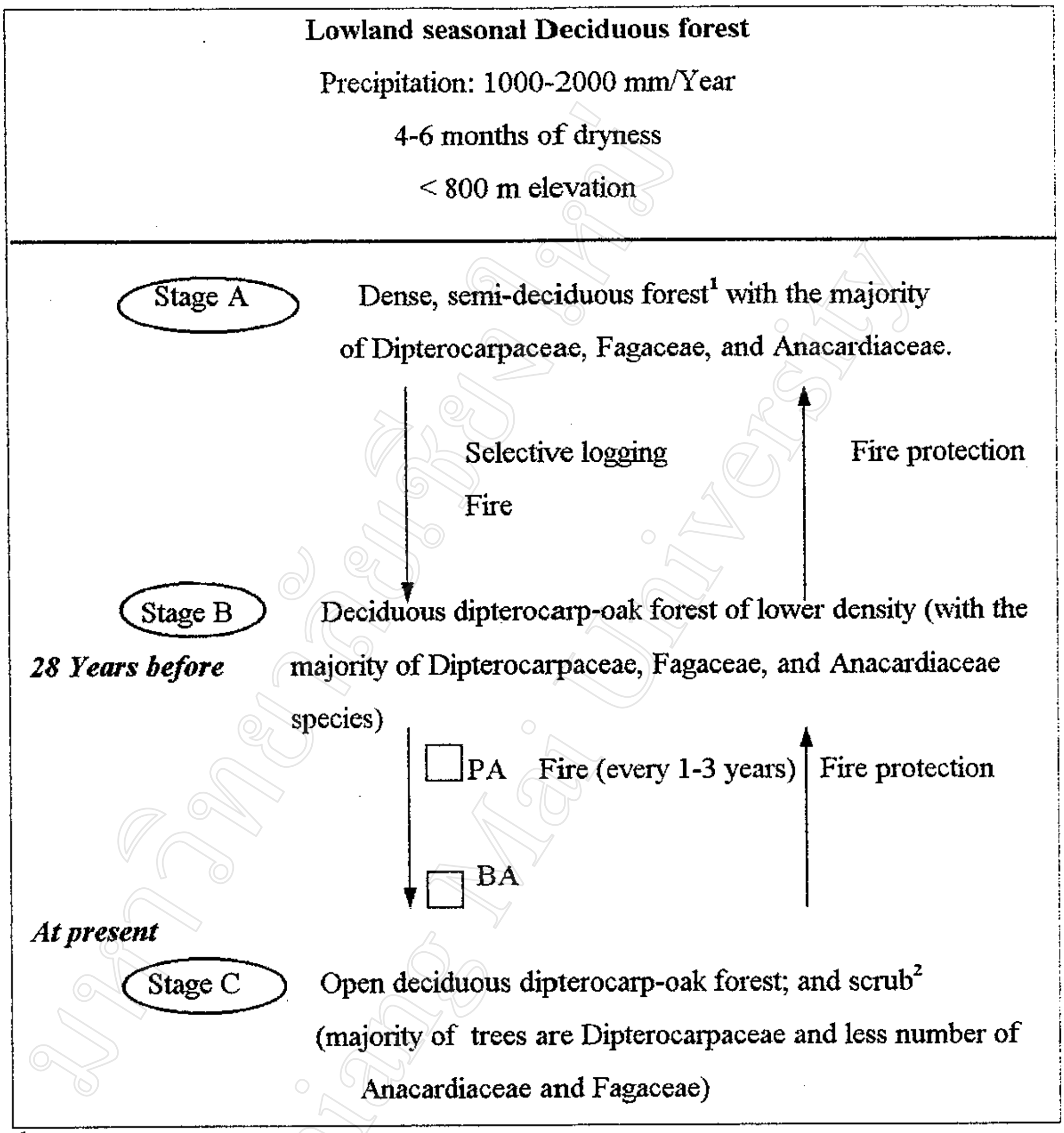
1. The greater influence of evergreen or tropophyllous trees and the presence of some shade-loving herbaceous flora in the protected area suggest that the forest environment in the protected area was favored by plants associated with a mixed evergreen + deciduous forest. However, no distinct differentiation was observed. Hence, the hypothesis that prolonged protection of forest from fire changes the species composition of the plant community to be more characteristic of a mixed evergreen + deciduous forest was only partially proved. In order to know whether the presence of certain shade demanders was due to changes in the local environment or chance, detailed studies in different physiographic conditions are needed..

2. The higher tree density and more young trees of 10-20 cm DBH category in the protected area adds supports to the idea that the fire protection decreased mortality and damage to trees which ultimately leads to more favorable conditions for different species to grow. However, species diversity indices failed to show a clear difference between the two sites. A distinct change was apparent with field observations. The protected area was very dense with saplings, had a three layered canopy, and had moister soil compared to the sparse vegetation, mostly two layered canopy and dry soils most of the places in the BA. Thus, the hypothesis that there will be less disturbance effects, and consequently higher plant diversity after the fire protection was supported. However, this statement should be verified with detailed studies with different levels of disturbances and in different areas.

3. Soils in the protected area retained slightly higher soil moisture content, but the study failed to demonstrate any changes in soil nutrients. Leafing phenologies of certain species were greatly altered. In the burnt area, the fruiting scores for May were much lower than the flowering scores, compared to little difference in the protected area. Burning seemed to affect the fruiting capacity of some of the trees. Therefore, the hypothesis that the protected area will have more soil moisture with altered phenological characters seems to be true. However, the changes in leafing, flowering and fruiting periodicity might be due to different species in those sites, and not because of fire protection.

4. Finally, it can be concluded that the existing deciduous dipterocarp-oak forest of lower density could regrow into dense, semi-deciduous forest if fires were eliminated (Figure 29). The hypothesised mechanism proposed for this study can now be modified (Figure 30):

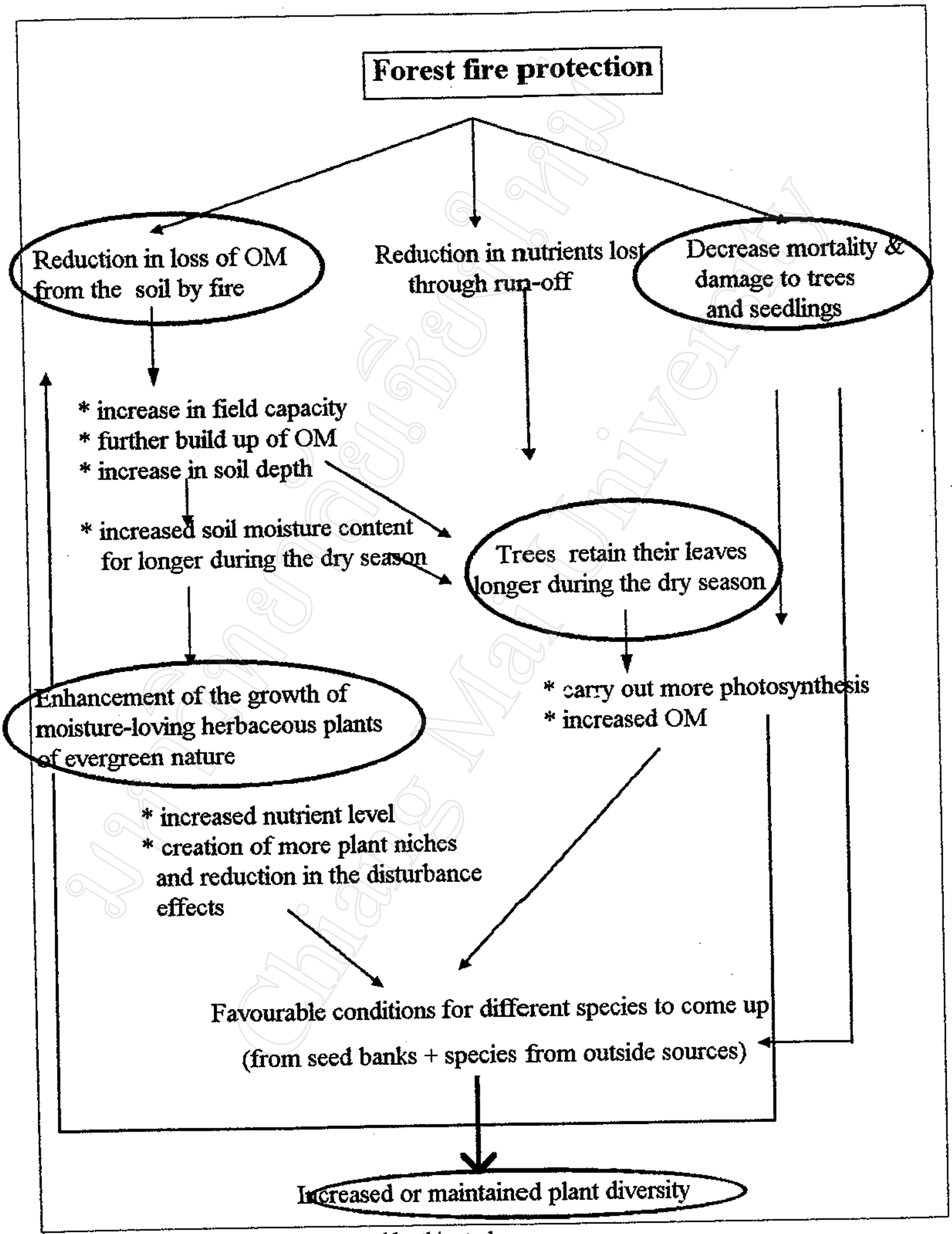
5. Overall, considering all these points, both quantitative as well as qualitative, fire protection in DOF in Doi Suthep-Pui National Park is recommended. In order to understand whether the observed changes are due to chance or purely from the protection effects, further studies focusing on similar parameters in different physiographic conditions with replications are suggested.



[1] Term suggested by Blasco (1983). J. F. Maxwell (Pers. comm., 1997) opines that the original forest was a primary deciduous forest dominated by *Tectona grandis* L. f. (Verbenaceae, Teak). The **stage A** indicates the recent past, upto 30-50 years before the fire protection activity started in the site.

[2] Open DOF leads to scrub, if the burning continues.

Figure 29. Fire maintained forest ecosystems in the lower elevations of Doi Suthep-Pui National Park, northern Thailand.



Note: Circled statements are supported by this study.

Figure 30. A modified mechanism of the effects of forest fire protection from the hypothesised mechanism originally proposed before the study initiated (Ref. Figure 2).

REFERENCES

Abuzinadah, R. A.; R. D Finlay, and D. J. Read. 1986. The Role of Protein in the Nitrogen Nutrition of Ectomycorrryzal Plants. II. *New Physilogist,* **103**, 495-506.

Ahlgren, I. F. and C. E. Ahlgren. 1965. Effects of Prescribed Burning on Soil Microorganisms in a Minnesota Jackpine Forest. *Ecology* **46**, 304-310.

Aldous, A. E. 1934. Effect of Burning on Kansas Blue Stem Pastures. *Kansas Agr. Expt. Stn. Bull.*38, 65.

Alexander, I. J. 1983. The Significance of Ectomycorrhyzas in the Nitrogen Cycle. In: Nitrogen as an Ecological Factor, A. Lee, S. McNeil, and I. H. Rorison (Eds.) Blackwell Scientific Publications, 69- 93.

Austin, R. C. and D. H. Baisinger. 1965. Some Effects of Burning on Forest Soils of West Oregon and Washington. *J. Forestry* **53**, 275-280.

Bahuguna, V. K. and P. Lal 1989. The Effects of Fire on the Nature and properties of Forest Soils-A Review of the work done. *My forest* **25** (4) Forest Reasearch Institute, Dehradun.

Banerjee, S. P. and S. Chand. 1981. Physico-Chemical Properties and Moistue Characteristics of Soils as influenced by Forest Fire. *Ind. Forester* **107**, 178-182.

Bangkok Post 1995. Forest Fires. 21 March 1995.

Barnette, R. M. and J. B. Heser. 1930. Effect of Burning upon the accumulation of Organic Matter in Forest Soils. *Soil Sci.* 29.

Barrington, A. H. M. 1931. Forest Soil and Vegetation in the Hlaing Forest Circle Burma. *Burma Forest Bulletin* **25**, Ecology series No.1. Rangoon.

Batten, L. A. 1976. Bird Communities of Some Killarney Woodlands. *Proc. Roy. Irish Acad.* **76**, 285-313.

Beadle, N. C. W. 1940. Soil Temperatures during Forest Fires and their effect on the Survival of Vegetation. *Jour. Ecology*, **28**, 180-192.

Bewley, J. D. and M. Black. 1982. The Release from Dormancy. In: Physiology and Biochemistry of Seeds in Relation to Germination, vol. 2. Springer-Verlag, Berlin; 184-198.

Blasco, F. 1983. The Transition from Open Forest to Savanna in Continental Southeast Asia. In: F. Bourliere (ed.) Tropical Savannas: Ecosystems of the World. Proceedings of the Tall Timber Fire Ecology Conference. 1967; **6** 171-207.

Bormann, F. H. 1953. The Statistical Efficiency of Sample Plot Size and Shape in Forest Ecology. *Ecology* **34**, 474-487.

Bourliere, F. and M. Hadley. 1983. Present-day Savannas: an Overview. In: F.

Bouliere (ed.) Tropical Savannas. Ecosystems of the World, Elsevier Scientific Publishing Co.; 183-243.

Brookman-Amissah, J.B.; M. Hall, D. Swaine, and J. Y. Attakorah. 1980. A Re-assessment of a Fire Protection Experiment in North-Eastern Ghana Savanna. *Journal of Applied Ecology* 17(1), 85-99.

Brower, J. E. and J. H. Zar. 1977. Field and Laboratory Methods for General Ecology. Dubuque, Iowa.

Causton, D. R. 1988. Introduction to Vegetation Analysis. Unwin Hyman, London.

Champion, H. G. 1936. A Preliminary Survey of Forest Types of India and Burma. *Indian Forest Records*, Silviculture, 1(1).New Delhi.

Clapham, A.R. 1932. The Form of Observational Unit in Quantitative Ecology. *J. Ecol.*, **20**, 192-197.

CMU Herbarium Database. 1996. Department of Biology. Chiang Mai University, Thailand.

Daubenmire, R. 1965. Plant Communities. Harper & Row.

Davis, K. P. 1959. Forest Fire:Control and Use. Wiley and Sons.

Doubenmire, R. 1972. Phenology and other Characteristics of Tropical Semi-Deciduous Forest in North-Western Costa Rica. *J. Ecol.* **60**, 147-170.

Ehrenreich, J. A. and J. A. Aikman. 1963. An Ecological Study of the Efffect of Certain Management Practices on Native Prairie in Iowa. *Ecol. Monog.* **33**, 113-130.

Elliott, S., J. F. Maxwell, and O. P. Beaver. 1989. A Transect Survey of Monsoon Forest in Doi Suthep-Pui National Park. *Nat. Hist. Bull. Siam Society,* **37**; 137-171.

-----1991. Effects of Artificial Watering on a Deciduous Dipterocarp Forest. A Preliminary Report Compiled for the Dhamanat Foundation, Department of Biology, Chiang Mai University, Thailand. 14 pp.

-----S. Promkutkaew and J. F. Maxwell, 1994. The Phenology of Flowering and Seed Production of Dry Tropical Forest Trees in Northern Thailand. In: Proceedings of the International Symposium on Genetic Conservatin and production of Tropical Forest Tree Seeds; 52-62.

-----V. Anusarnsunthorn, S. Kopachon, D. Blakesley, and Garwood. N 1996. Research Towards the Restoration of Nortern Thailnds' Degraded Forests. In: Symposium/Workshop on Accelerating Native Forest Regeneration of Degraded Tropical Lands. (Abstracts). IUFRO/WB/USDA-Forest Service.

FAO, 1981. Forestry in the Asia Pacific Region. RAPA, Bangkok.

FAO, 1953. Elements of Forest Fire Control. FAO, Rome.

Frankie, G. W.; H. G. Baker, and P. A. Opler. 1974. Comparative Phenologial Studies of trees in Tropical Wet and Dry Forest in the lowland of Costa Rica. *J. Ecol.* **62**, 881-919.

Gill, A. M., J. R. L. Hoare and N. P. Cheney. 1989. Fires and their Effects in the Wet- Dry Tropics of America. Springer-Verlag, Berlin.

Gillison, A. N. 1983. Tropical Savannas of Australia and the SouthWest Pacific. In: F. Bourliere (ed.) Tropical Savannas, Ecosystems of the World **13**, Elsevier Scientific Publishing, 183-243.

Goldammer, J. and S Manan. 1996. Fire in Tropical Forests. In: ITTP-Tropical Forest Update. 6(1).

Goldsmith, F. B., C. M. Harrson, and A. J. Morton. 1986. Desscription and Analysis of Vegetation In: Methods in Plant Ecology. P. D Moore. and S. B. Chapman (Eds.) Blackwell Scientific Publications.

Greig-Smith, P. 1983. Quantitative Plant Ecology. Blackwell Scientific Publications.

Griffith, A. L. 1943. The Effects of Burning on the Soil as a Preliminary to Artificial Regeneration. *Indian Forest Bulletin* **130**.

Gupta, R. S. 1946. The Effect of Burning and other accessory operation upon the Soil as an effective artificial regeneration. Proceedings of the VII Silvicultural Conference Dehradun. Item no. **12**. Paper no. 2, 497-516.

Hatch, A. B. 1959. The Effect of frequent burning on the Jarrah (*Eucalyptus marginata*) Forest Soils of Western Australia. *J. Roy. Soc.* W. Aust, **42**, 97-100.

Hensel, R. L. 1923. Effect of burning on Vegetation in Kansas Pastures. *Joun. Agric. Res.*, **23**; 631-643.

Heyward, F. 1936. Soil Changes associated with Forest Fire in the Long leaf Pine Region of the South America. Amer. Soil Survey Assoc. (Bulletin. 16, 41-42).

Hogberg, P. 1989. Symbiosies of trees in Savannas In: Mineral Nutrients in Tropical Forest and Savanna Ecosystems. J. Proctor (Ed.) Blackwell Scientific Publications; 121-136.

Holdridge, L. R.; W. C. Grenke, W. H. Hatheway, T. Liang, and J. A. Tosi, Jr. 1971. Forest Environemnts in Tropical Life Zones: A Pilot Study, Oxford. Pergamon Press.

Kanjanavanit, S. 1992. Aspects of the Temporal Pattern of Dry Season Fires in the Dry Dipterocarp Forests of Thailand. Asia. Unpublished PhD Dissertation, Department of Geography, School of Asian and African Studies, University of London.

Koelmeyer, K. O. 1959. The Periodicity of Leaf Change and Flowering in the Principal Forest Communities of Ceylon. *Ceylon Forester* **4**, 301-364.

Komkris, T. V. Naraballobh, K. Chunkao, C. Ngampongsai, and N. Tangtham, 1969. Effect of Fire on Soil and Water Losses at Mae-Huad Forest. Amphur Ngao, Lamphang Province, Forest Research Bulletin, 6, Kasetsart University, Bangkok.

Krebs, C. J. 1994. Ecology: The Experimental Analysis of Distribution and Abundance. Harper Collins College.

Lambert, J.D. H. and J. T. Arnason. 1989. Role of weeds in Nutrient Cycling in the Central America. **In:** Mineral Nutrients in Tropical Forest and Savanna Ecosystems. J. Proctor (ed.) Blackwell Scientific Publications; 301-313.

LeFloch, E. 1969. Charactrisation Morphologique des Stades, et Phases Phenologiques dans les Communautes Vegetales. Thesis of 3 rd Cycle. Universite des Sciences et Tecniques du Languedoc, Montepellier II. CNRS.-CEPE. doc. no. **45**, 132.

Leith, H. 1974. Phenology and Seasonality Modelling. Ecological Studies **8**, Springer-Verlag.,Berlin.

Ludwig, J. A. and J. F. Reynolds. 1988. Statistical Ecology. Wiley and Sons.

Magurran, A. E. 1988. Ecological Divesity and its Measurement. Croomhelm.

Mallik, A. U. 1986. Near-ground Micro-climate of Burned and Unburned Cellas Heathland. *Journal of Environmental Management.* **23**, 157-171.

Marsh, C. W. 1981. Diet choice among Red Colbus (*Colobus baclius refornitratus*). on the Tana River, Kenya, *Folia Primatol.*35, 147-178.

Mather, A. D. 1978. Fire Weather Data Technical Note **15**, Chiang Mai: FAO/RFD. Thailand.

Maxwell, J. F. 1986. An Enumeration of the Vascular Flora of Klong Hoi Khong. Hat Yai District, Songkla Province, Thailand. *Songklanakarin J. Sci. Techno.* **8**, 295-314.

-----1988. The Vegetation of Doi Suthep-Pui National Park, Chiang Mai Province. Thailand. *Tiger Pap*er 15(4), 6-14.

----- S. Elliott, P. Palee and V. Anussarnsunthorn. 1995. The Vegetation of Doi Khuntan National Park. Lamphun-Lamphang Provinces, Thailand. *Nat. Hist. Bull. Siam Soc.* **43**, 185-205.

McIntosh, R. P. 1967. An Index of Diversity and the Relation of Certain Concepts to Diversity. *Ecolog* **48**, 392-404.

McNaughton, S. J. 1968. Structure and Function in California Grasslands. *Ecology* **49**, 962-992.

Meng, Monyrak. 1997. Effects of Forest Fire Protection on Seed dispersal, Seed bank, and Seed rain in a Deciduous Dipterocarp-Oak Forest in Doi Suthep-Pui National Park. Unpublished M.S. thesis, Faculty of Science, Chiang Mai University, Thailand.

Mirov, N. T. 1936. Germination Behaviour of some California Plants. *Ecology* **17**, 667-672.

Monasterio, M. and G. Sarmiento. 1976. Phenological Strategies of Plant Species in the Tropical Savanna and Semi-deciduous Forest of the Venezuelan Llanos. *Journal of Biogeography* **3**, 225-256.

Moore, A. W. and E. O. Jaiyebo. 1963. The Influence of coveron Nitrate and Nitrifiable Nitrogen Content of the Soil in a Tropical Rain Forest Environment, *Empire Journal of Experimental Agriculture* **31**, 189-198.

Moore, P. D. 1987. Burning Issues in Fire Contro. *Nature*, **325**.

Naidu, C. V. and K.P. Srivasuki. 1994. Effect of Forest Fire on Tree Species in Different Areas of Aeshachalam Hills. *Journal of Tropical Forestry* July-Sept. **10** (III).

Nalamphun, A.; T. Santisuk, and T. Smitinand. 1969. The Deforestation of Teng (*Shorea obtusa* Wall.) and Rang (*Shorea siamensis* Miq.) at ASRCT Sakaerat Experimental Station. Report 27/8 ASCRT, Bangkok; 28

Neal, J. L.; E. Wright, and W. B. Bollen. 1965. Burning Douglas-Fir Slash: Physiological, Chemical and Microbial Effects on the Soil. Forest Research Laboratory Research Paper, Corvalis, Oregon State University.

Newton, P. 1988. The Structure and Phenology of a moist deciduous forest in the Central Indian Highlands. *Vegetatio* **75**, 3-16.

Ogawa, H.; K. Yoda,. T Kira,. K. Ogino, T. Shidei, D. Ratanawongse, and C. Apasutaya.1965. Comparative Ecological Study on three main types of Forest Vegetation in Thailand. I Structure and Floristic Composition. In: T. Kira and K. Iwata (Eds.). Nature and Life in Southeast Asia. IV Fauna and Flora Research Society, Kyoto;13-48.

Ogawa, H., K. Yoda, and T. Kira, 1961. A preliminary Survey on the vegetation of Thailand. In: Nature and life in Southeast Asia, T. Kira and T. Umesao (eds). 1; 22-157.

Paonsapanh, B. 1994. Effects of Irrigation on the Phenology and seedling community of a Deciduous Dipterocarp Forest at Huay Hong Khrai, Unpublished M.S. thesis, Faculty of Science, Chiang Mai University, Thailand.

Peet, R. K. 1974. The Measurement of Species Diversity. *Ann. Rev. Ecol.* 5, 285-307.

Phuakam, A. 1994. A Survey of Herbaceous Ground Flora on the Eastern Side of Doi Suthep-Pui National Park. Unpublished M.S. Thesis. Department of BIology, Chiang Mai University.

Pielou, E. C. 1977. Mathematical Ecology. Wiley, New York.

Poffenberger, M. and B. McGean. 1993. Community Allies: Forest Co-management in Thailand, Southeast Asia Sustainable Forest Management Network, Center for Asia Studies, University of California.

Prichett, L. W.1979. Properties and Management of Forest Soils. John Wiley & Sons.

Ramakrishnan, P. S. and O. P. Toky. 1981. Soil nutrient Status of Hill Agro-Ecosystems and Recovery Patterns after Slash and Burn Agriculture (Jhum) in North- Eastern India. *Plant and Soil* 60, 41-65.

Remezov, N. P. and P. S. Pogrebnyak, 1969. Forest Soil Science. Translated from Russian by A. Gourevitch. Edited by Y. Haver. Israel Program for Scientific Publications, Jerusalem.

Richards, P. W. 1952. The Tropical Rainforest: An Ecological Study. Cambridge University

Schimper, A. F. W. 1903. Plant Geography upon a Physiologiccal basis. Translation from 1898 edition by W. R. Fisher, P. Groom and I. B. Bafour, Oxford.

Seghieri, J.; C. Floret, and R. Ponteier. 1995. Plant Phenology in Relation to Water availability: Herbaceous and Woody Species in the Savannas of northern Cameroon. *J.Ecology* **11**; 237-254.

Sewandono, R. 1956. The Southeast Asia **In**: S. Haden-Guest, J. K Wright, and E. F. Teclaff, (Ed.) A World Geography of Forest Resources. The American Geographical Society, The Ronald Press Co. New York; 491-517.

Shimokawa, E. 1988. Effects of a Fire of Tropical Rain Forest on Soil Erosion. **In**: A Research on the Process of Earlier Recovery of Tropical Rain Forest after a large scale Fire in Kalimantan Timur, Indonesia, Kagoshima University, 2-11.

Simpson, E. H. 1949. Measurement of Diversity. *Nature,* **163**, 688

Smitinand, T. 1962. Types of Forests of Thailand. Royal Forest Department. Ministry of Agriculture, Bangkok.

Sonthichai, S. 1995. Seasonal Effects on the Soil Arthropod Community of a Deciduous Tropical Forest. *Nat. Hist. Bull. Siam Soc.* **43**, 207-218.

Southwood, T. R. E. 1978. Ecological Methods. John Wiley, N.Y.

Stamp, L. D. 1925. The Vegetation of Burma. Calcutta.

Stark, N. M. 1977. Fire and Nutrient Cycling in a Douglas-Fir/Larch Forest Ecology. **58**, 16-30.

Stark, N. and R. Steel. 1977. Nutrient Content of Forest Shrubs Following Burning. *Amer. J. Bot.* **64**, 10.

Stoddard, H. L. 1935. Use of Controlled Fire in Southeastern Upland Game Management. *Journal of Forestry* **33**: 346-351.

Sttot, P. 1976. Recent Trends in the classification and mapping of dry deciduous dipterocap forest in Thailand, **In**: M. Ashton (Ed.) The Classification and Mapping of Southeast Asian Ecosystems (Transactions of the Aberdeen-Hull Symposium on Malesian Ecology IV) University of Hull; 22-56.

-----1984. The Savanna Forests of Mainland Southeast Asia : An Ecological Survey. *Progress in Physical Geography* **8** (3), 315-335.

-----1986. The Spatial Pattern of Dry Season Fires in the Savanna Forest of Thailand. *J. Biogeog.* **13**, 345-358.

-----1988. The Forest as Phoenix: Towards Biogeography of Fire in mainland Southeast Asia. *The Geographical Journal* 154 (3), 337-350.

Sukwong, S. and P. Dhamaitayakul, 1977. Fire Ecology Invesigations in Dry Dipterocarp Forest **In**: Proceedings of National Forestry Conference. Royal Forest Department. Bangkok; 41-56.

Sukwong, S.; P. Dhamanitayakul and S. Ponggumphai. 1975. Phenology and Seasonal Growth of Dry Dipterocarp Forest Tree Species. *The Katetsart Journal* 9 (2), 105-113.

Transley, A. G. and R. S. Adamson. 1913. Reconnaissance in the Cotteswolds and the Forest of Dean. *J. Ecol.* **1**, 81-89.

Thailand Development Research Institute (TDRI) 1987. Thailand Natural Resources Profile. TDRI, Bangkok; 310

Tomkins, D. J. and W. F. Grant, 1977. Effects of Herbicides on Species Diversity of two Plant Communications. *Ecology* **58**, 398-406.

UNESCO. 1978. Tropical Forest Ecosystems. UNESCO/UNEP/FAO Paris, XIV.

Wheelan, R. J. 1995. The Ecology of Fire. Cambridge University Press.

Wild, A. 1989. Mineral Nutrients in Tropical Ecosystems: A Soil Scientists' View, **In**: Mineral Nutrients in Tropical Forest and Savanna Ecosystems, J. Proctor. (Ed.), Blackwell Scientific Publications.

Wongpaibul, P. 1974. Quantity of Litter Fall in some Forest Fire Control. Faculty of Forestry, Katetsart University, Bangkok (in Thai).

Wratten, S. D. and G. L. Fry. 1980. Field and Laboratory Exercises in Ecology. Edward Arnold.

APPENDIX 1. **List of tree species found in the study areas.**

S. NO.	SPECIES	FAMILY	STATUS
1	*Albizia odoratissima* (L.f.) Bth.	Leguminosae, Mimosoideae	BA
2	*Anneslea fragrans* Wall.	Theaceae	PA, BA
3	*Antidesma acidum* Retz.	Euphorbiaceae	PA
4	*Aporusa villosa* (Lindl.) Baill.	Euphorbiaceae	PA, BA
5	*Buchanania lanzan* Spreng.	Anacardiaceae	PA, BA
6	*Canarium subulatum* Guill.	Burseraceae	PA
7	*Castanopsis diversifolia* King	Fagaceae	PA
8	*Catunaregum tomentosa* (Bl. ex DC.) Tirv.	Rubiaceae	PA
9	*Craibiodendron stellatum* (Pierre) W. W. Sm.	Ericaceae	PA, BA
10	*Dalbergia dongaiensis* Pierre	Leguminosae, Papilionoideae	PA, BA
11	*Dalbergia fusca* Pierre	Leguminosae, Papilionoideae	PA, BA
12	*Dipterocarpus obtusifolius* Teijsm. ex Miq. var. *obtusifolius*	Dipterocarpaceae	PA, BA
13	*Dipterocarpus tuberculatus* Roxb. var. *tuberculatus*	Dipterocarpaceae	BA
14	*Eugenia albiflora* Duth. ex Kurz	Myrtaceae	BA
15	*Garcinia cowa* Roxb.	Guttiferrae	PA
16	*Gardenia sootepensis* Hutch.	Rubiaceae	PA
17	*Gluta usitata* (Wall.) Hou	Anacardiaceae	PA, BA
18	*Lithocarpus elegans* (Bl.) Hatus. ex Soep.	Fagaceae	PA, BA
19	*Lithocarpus sootepensis* (Craib) A. Camus	Fagaceae	PA, BA

20	*Ochna integerrima* (Lour.) Merr.	Ochnaceae	BA
21	*Quercus kerrii* Craib var. *kerrii*	Fagaceae	PA, BA
22	*Rothmania sootepensis* (Craib) Brem.	Rubiaceae	PA
23	*Shorea obtusa* Wall. ex Bl.	Dipterocarpaceae	PA, BA
24	*Shorea siamensis* Miq. var. *siamensis*	Dipterocarpaceae	PA, BA
25	*Terminalia mucronata* Craib & Hutch.	Combretaceae	PA
26	*Tristaniopsis burmanica* (Griff.) Wils. and Wat. var. *rufescens*	Myrtaceae	PA, BA
27	*Vitex limonifolia* Wall. ex Kurz	Verbenaceae	BA
28	*Wendlandia tinctoria* DC. ssp. *orientalis* Cowan	Rubiaceae	BA
29	*Xylia xylocarpa* (Roxb.) Taub. var. kerrii	Leguminosae, Mimosoideae	BA

[1] PA = Protected area

BA = Burnt area

APPENDIX 2. Ground flora species recorded in the study area 1.			
Species	**Family**	**Status**	**Remarks**
Abrus precatorius L.	Leguminosae, Papilionoidae	BA, PA	
Adiantum zollingeri Mett. ex Kuhn.	Parkeriaceae	BA, PA	
Aganosma marginata (Roxb.) G. Don	Apocynaceae	BA	
Amorphophallus longituberosus (Engl).Engl. & Ge	Araceae	BA	
Amorphophallus yunnanensis Engl.	Araceae	PA	
Andropogon chinensis (Nees.) Merr.	Gramineae	BA	*
Aneilema herbaceum Wall. ex Cl.	Commelinaceae	PA	
Antidesma acidum Retz.	Euphorbiaceae	PA	
Appluda mutica L.	Gramineae	BA,PA	
Ardisia crenata Sims. var. crenata	Myrsinaceae	BA, PA	*
Argyreia capitiformis (Poir.) Oost.	Convolvulaceae	BA	
Aristolochia kerrii Craib	Aristolochiaceae	BA, PA	
Arundinella satosa Trin. var. *satosa*	Gramineae	BA	*
Barleria cristata L.	Acanthaceae	PA	*
Barleria strigosa Willd.	Acanthaceae	PA	
Blumea lacera (Burm. f.) DC	Compositae	BA	
Boesenbergia rotunda (L.) Mansf.	Zingiberaceae	BA, PA	
Breynia fruiticosa (L).Hk. f.	Euphorbiaceae	BA, PA	
Capillipedium parviflorum (R. br.) Stapf.	Gramineae	BA	*
Celastrus paniculatus Willd.	Celastraceae	BA	
Centosteca lappacea (L.) Desv.	Gramineae	PA	*
Cheilanthes tenuifolia (Burm. f.) Sw.	Parkeriaceae	BA, PA	
Chlorophytum intermedium Craib	Liliaceae	BA, PA	
Colocasia esculenta L. Schott.	Araceae	BA	
Commelina diffusa Burm. f.	Commelinaceae	BA, PA	
Crotolaria albida Hey. ex Roth.	Leguminosae	BA	
Crotolaria neriifolia Wall. ex Bth.	Leguminosae	BA	
Curcuma zedoaria (Berg.) Rosc.	Zingiberaceae	BA, PA	
Cyanotis cristata (L.) D. Don.	Gramineaae	BA, PA	*
Cymbidium aloifolium (L.) Sw.	Orchidaceae	PA	
Cyrtococcum oxyphylum (Steud) Stapf.	Gramineae	PA	
Dendrobium crystallinum Rehb. f.	Orchidaceae	PA	
Desmodium flexuosum Wall. ex Beth.	Leguminosae	BA	

Desmodium heterocarpon. (L.) DC ssp. heterc	Leguminosae	BA	. *
Desmodium laxiflorum DC.	Leguminosae	BA, PA	
Desmodium motorium (HoutT.) Merr.	Leguminosae	BA, PA	
Desmodium oblongum Wall. ex Bth.	Leguminosae	BA	*
Desmodum het.erocarpon (L.) DC. *var. angu*	Leguminosae	BA, PA	
Dioscorea bulbifera L.	Dioscoreaceae	PA	
Disporum calcaratum Wall ex. Don	Liliaceae	BA	
Dunbaria longeracemosa Craib	Leguminosae	BA, PA	
Ellipea cherrevensis Pierre ex Fin. & Gagnep.	Annonaceae	PA	
Erythroxylum cuneatum Miq. Kurz.	Leguminosae	BA, PA	
Eulalia quadrinervis	Gramineae	PA	
Eulaliopsis binata (Retz.) CE Hubb.	Gramineae	BA	
Eupatorium odoratum L.	Compositae	BA, PA	
Fimbristyllis dichotoma (L.)Vahl.	Cyperaceae	BA	
Flemingia sootepensis Carib	Leguminosae	BA	
Globba nuda K. Lar.	Zingiberaceae	PA	
Globba reflexa Craib	Zingiberaceae	BA, PA	
Globba schomburgkii HK.f.	Zingiberaceae	BA, PA	
Grewia lacei Drum. & Craib	Tiliaceaae	BA, PA	
Hedyotis tenelliflora Bl. var. *tenellifolia*	Rubiaceae	PA	
Heteropogon triticeus (ABS(number)R. Br.)	Gramineae	PA	
Heteropogon triticeus (R. Br.)	Gramineae	PA	
Hibiscus glanduliferus Craib	Convolvulaceae	BA	
Hypoxis aurea Lour.	Hypoxydaceae	PA	
Inula cappa (Ham.ex. D.Don) DC. *forma cap*	Compositae	PA	
Inula indica (L.)	Compositae	PA,BA	
Ixora cibdela Craib	Rubiaceae	PA	
Kaempferia rotunda L.	Zingibearaceae	PA	
Leea indica (Burm. F.) Merr.	Leeaceae	PA	
Linostoma persimile Craib	Thymelaceae	BA, PA	
Lygodium flexuosum (L.) Sw.	Schizaeaceae	PA, BA	
Micromelum minutum (Forst. f.) Weight & Ar	Rutaceae	PA	
Millettia extensa (Bth.)ex Baker	Leguminosae	PA	
Murdannia loureirii (Hans.) Rao & Kam.	Commelinaceae	PA, BA	
Murdannia scapiflora (Roxb.) Roy.	Commelinaceae	PA, BA	

Myxopyrum smilacifoliu (Wall.) Bl. var. smilacifoli	Commelinaceae	PA	
Ophiopogon brevipes Craib	Liliaceae	PA	
Osbeckia chinensis L. var. *chinensis*	Melastomataceae	PA	
Paederia wallichii Hk. f.	Rubiaceae	PA, BA	
Panicum notatum Retz.	Gramineae	PA	
Pavetta petiolaris Wall. ex Craib	Rubiaceae	PA, BA	
Pennisetum pedicellatum Trin.	Gramineae	BA	*
Phoenix humilis Roy. var. *humilis*	Palmae	BA	
Plectranthus glabratus Bth. Alst.	Commelinaceae	PA	
Polygala longifolia Poir.	Polygolaceae	BA	
Polytoca digitata (L.f.) Druce	Gramineae	BA	*
Pouzolzia hirta Hassk.	Urticaceae	PA	
Premna herbaceae Roxb.	Verbenaceae	PA	
Premna nana Coll. & Hemsl.	Verbenaceae	PA	
*Pseudopogonatherum contortum (*Brongn.) A. Can	Gramineae	PA	*
Rhyncospora rubra (Lour). Mak.	Cyperaceae	BA	
Sauropus bicolor Craib. var. *bicolor*	Euphorbiaceae	BA, PA	
Schizachyrium sanguineum (Retz.) Alst.	Gramineae	BA	*
Scleria kerrii Turr.	Cyperaceae	BA	
Scleria levis Retz.	Cyperaceae	PA, BA	
Scleria lithosperma (L.) SW.	Cuperaceae/Cyperaceae	PA, BA	
Scutellaria glandulosa Hk.f.	Labiatae	BA, PA	
Selaginella ostenfeldii Hier.	Selaginellaceae	BA, PA	
Sericocalyx glaucescens (Nees) Brem.	Acanthaceae	BA	
Smilax verticalis Gagnep.	Smilacaceae	BA, PA	
Sopubia festigiata Bon.	Scrophulariaceae	PA, BA	*
Sorghum nitidum (Vahl.) Pers.	Gramineae	PA	
Spatholobus floribundus Craib	Leguminosae	BA, PA	
Stemona burkilii Prain.	Stemonaceae	BA, PA	
Streptocaulon juventas (Lour.) Merr.	Asclepiadaceae	PA	
Tetrastigma laoticum Gagnep.	Vitaceae	PA, BA	
Themeda triandra Forssk.	Gramineae	BA, PA	
Uraria crinita (L.) Desv.ex DC.	Leguminosae, Papilionoidae	BA	
Uraria lacei Craib	Leguminosae, Papilionoidae	BA	
Urena lobata L. ssp. *lobata* var. *lobata*	Malvaceae	PA, BA	*

Vernonia sootepensis Kerr.	Compositae	PA, BA	
* Specimens are collected and kept at CMU Herbarium.			
1. Species found outside the quadrats during specimen collection are also listed here.			

APPENDIX 3. **Number of species by family in the study area**

Family	**Number of species**	
	PA	**BA**
Acanthaceae	2	1
Annonaceae	0	1
Araceae	1	2
Aristolochiaceae	1	1
Asclepiadaceae	1	0
Commelinaceae	7	4
Compositae	4	3
Convolvulaceae	0	2
Cuperaceae (Cyperaceae)	2	5
Dioscoreaceae	1	0
Euphorbiaceae	3	2
Gramineae	11	11
Hypoxidaceae (Amaryllidaceae)	1	0
Labiatae	1	1
Leguminosae	8	14
Liliaceae	2	2
Malvaceae	1	1
Melastomataceae	1	0
Myrsinaceae	1	1
Orchidaceae	2	0
Palmae	0	1
Parkeriaceae	2	2
Polygalaceae	0	1
Polypodiaceae	1	0
Rubiaceae	4	2
Rutaceae	1	0
Schizaeceae	1	1
Scrophulariaceae	0	1
Selaginellaceae	1	1
Smilacaceae	1	1
Stemonaceae	1	1
Thymeleaceae	1	1
Tiliaceae	1	1
Urticaceae	1	0
Verbenaceae	2	0
Zingiberaceae	7	4
Total number of species	**74**	**67**
Total number of families	**31**	**27**

CURRICULUM VITAE

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