Tropical Forestry Change in a Changing World

Volume 5:
Dry Forest Ecology and Conservation

FORTROP II International Conference
Kasetsart University, Bangkok, Thailand
17-20 November 2008

Published by:

Kasetsart University Faculty of Forestry
(KUFF)

Editors:
Sapit Diloksumpun and Ladawan Puangchit

Language editor:
Andrew Warner

Copies are available from:
Faculty of Forestry
Kasetsart University
Bangkok 10900 Thailand
Telephone: 66 2 942 8368
Fax: 66 2 561 4246
Website: http://www.forest.ku.ac.th

ISBN 978-616-7262-27-7

Cover design by:
Nopparat Manavakun
Cover photographs by:
Prateep Duengkae, Dome Pratumtong, and Sapit Diloksumpun

Preface

The FORTROP II International Conference on "*Tropical Forestry Change in a Changing World*" was organized by Kasetsart University Faculty of Forestry. The conference aimed not only to commemorate the 72nd anniversary of forestry education in Thailand but also to motivate exchanges of technology and experience in various aspects of tropical forestry among stakeholders, researchers, technicians and involved professionals. FORTROP II focused on how society can create more sustainable uses of tropical forests, and how the changing global physical and social environment affects the future of tropical forests.

The FORTROP II International Conference was held at Kasetsart University, Bangkok, from 17-20 November 2008. The conference consisted of four major components: technical symposia, poster sessions, an exhibition and in-conference excursions. There were 536 participants representing research, educational and management institutions from 29 countries. There were more than 200 papers and oral and poster presentations presented in 11 technical symposia.

The proceedings of the FORTROP II International Conference consist of 11 volumes:

- Volume 1: Keynote Addresses, Forestry Education and List of Delegates
- Volume 2: Tropical Forests and Climate Change
- Volume 3: GIS/GPS/RS: Applications in Natural Resources and Environmental Management
- Volume 4: International Long-Term Ecological Research
- Volume 5: Dry Forest Ecology and Conservation
- Volume 6: Mangrove and Wetland Ecosystems
- Volume 7: Commercial Plantation Forestry
- Volume 8: Urban Forestry and Urban Greening
- Volume 9: Trends and Issues in Community Forestry
- Volume 10: Protected Areas and Sustainable Tourism
- Volume 11: Wood Products and Bio-Based Materials

The material for this report was prepared by the FORTROP II International Conference Organizing Committee, with financial support from the Kasetsart University Faculty of Forestry (KUFF). Each author was responsible for the text in his/her paper or presentation. I would like to thank them for their excellent contributions.

Damrong Sripraram

Dean
Kasetsart University Faculty of Forestry

Contents

Contents (Cont.)

Fire Management in South Asia's Dry Forests: Colonial Approaches, Current Problems and Perspectives

J. G. Goldammer[1] and K. Wanthongchai[2]

[1]*University of Freiburg / United Nations University, Freiburg, Germany*

[2]*Kasetsart University, Bangkok, Thailand*

Abstract

Tropical dry forest ecosystems are prone to fire and have long been subjected to annual burning by surface fires. Thus, they are well adapted to fire and exhibit many fire-resistant characteristics: a thick bark; an ability to heal fire scars; a capacity to resprout through coppicing or by means of epicormic shoots from dormant buds and lignotubers; and special seed characteristics. Natural fire regimes, however, have been highly modified by human-induced fire and other cultural activities, resulting in either too-frequent or too-infrequent fires in different parts of the landscape. Too-frequent burning impedes and retards natural regeneration and will gradually lead to deterioration, to a change to increasingly dry communities and eventually to grasslands dominated by *Imperata cylindrica*. Conversely, attempts to eliminate fire from this ecosystem may also have undesirable consequences, such as an increased risk of high-intensity, stand-replacing fires and changes to floristic and faunistic biodiversity. Ecosystem health may also decline leading to less vigourous trees and outbreaks of insect pests and diseases.

As elsewhere in the tropical Asia, anthropogenic fires have long been used to clear forest vegetation naturally provided by the forests, or to maintain a certain forest structure to produce a specific range of non-timber forest products. Despite the fact that these forest ecosystems dominate mainland south and Southeast Asia where fire has constituted a long-term evolutionary factor, information on fire history, fire regime and fire effects, as well as fire management history are very scanty. In order to meet all requirements, including local needs, global warming concerns and the significance of fire itself in forest ecosystem, fire management in tropical dry forests is very complicated and a challenge for land managers.

This paper reviews the fire management history during the British colonial period for India and Myanmar, as well as some selected Southeast Asia countries. The current fire problems and management in tropical dry forests in these regions are described. Finally, the review provides perspectives on fire management strategies for the future.

Keywords: fire management, tropical dry forest, South Asia

Introduction

Tropical dry forest ecosystems are prone to fire and have long been subjected to annual burning by surface fires (Stott *et al.*, 1990; Rundel and Boonpragob, 1995). Thus, they are well adapted to fire and exhibit many fire-resistant characteristics, for example, a thick bark, an ability to heal fire scars, a capacity to resprout through coppicing or by means of epicormic shoots from dormant buds and lignotubers, and special seed characteristics (Whelan, 1995). Natural fire regimes, however, have been highly modified by human-induced fire and other cultural activities, resulting in either too-frequent or too-infrequent fires in different parts of the landscape. Too-frequent burning impedes and retards natural regeneration and will gradually lead to deterioration, to a change to increasingly dry communities and eventually to grasslands dominated by *Imperata cylindrica* (Goldammer, 2002). Conversely, attempts to eliminate fire from this ecosystem may also have undesirable consequences, such as an increased risk of high-intensity, stand-replacing fires and changes in floristic and faunistic biodiversity. Ecosystem health may also decline leading to less vigourous trees and outbreaks of insect pests and diseases.

As elsewhere in tropical Asia, anthropogenic fires have long been used to clear forest vegetation naturally provided by the forests, or to maintain a certain forest structure to produce a specific range of non-timber forest products (NTFPs). (Stott *et al.*, 1990; Goldammer, 1993b). However, in most countries of the region, it is now illegal to set forests on fire for any reason. There are conflicts between national fire prevention policies and the need of local smallholders to use fire to maintain their land-use systems. In addition, the pyrogenic release of greenhouse gases and particulates into the atmosphere is affecting the composition and functioning of the atmosphere. Thus, forest degradation, as a consequence of excessive burning practices or wildfires, is contributing to global warming and climate change. The reverse is also true, with extreme climate variability resulting from climate change, notably extreme droughts, impacting forest ecosystems and hence resulting in an increased risk of high-intensity and severity wildfires. Despite the fact that these forest ecosystems dominate mainland South and Southeast Asia, where fire has constituted a long-term, evolutionary factor, information on fire history, fire regimes and fire effects, as well as fire management history is very scanty. In order to meet all requirements, including local needs, global warming concerns and the significance of fire itself in the forest ecosystem, fire management in tropical dry forests is very complicated and challenging for land managers.

This paper reviews the fire management history during the British colonial period in India and Myanmar, as well as in some selected Southeast Asia countries. Thereafter, it tries to review current fire problems and management in the tropical dry forests for these regions. Finally, these reviews provide recommendations for fire management strategies for the next decade.

Fire Management History

Significance of Historical Fire Regimes in Tropical Asia

Prehistoric occurrence of natural vegetation fires has been documented since the evolution of land plants some 350 to 400 million years ago. The first evidence of a wildfire in the world dates back to the early Carboniferous era (Clark and Robinson, 1993). Archaeological and paleoenvironmental research in mainland Southeast Asia has provided insights into the use of fire around early settlements. Early charcoal records show high fire activity during the late Pleistocene, through the period 38 000-12 000 years before present (Penny, 2001). Fire regimes, (frequency, intensity, seasonality, affected area) have exerted influence on the development of vegetation structure and function through evolutionary periods. However, in the paleoecological records from insular Southeast Asia and New Guinea, it is extremely difficult to distinguish between climatic and anthropogenic factors that influence vegetation changes (Goldammer and Seibert, 1989; Maxwell, 2004).

Historical information on fire management in tropical dry forests in South Asia is available for former British India and Burma, where teak was a key species managed under sustainable forestry regimes during the colonial period (Goldammer, 2007). Debate on the contribution of fire to the regeneration of teak was widely discussed among foresters during the 1990s and early 2000s. By contrast, comparatively little is known empirically about the historical fire regimes for other Southeast Asian countries. This is despite the importance of fire as an agent of regional land cover change and in modifying atmospheric chemistry. Fire is widely applied in land cultivation all over insular and mainland South/Southeast Asia. It also has a high incidence within forests in tropical Asia where it is mainly associated with shifting cultivation and the systematic use of fire in land-use change. In addition, mainland Southeast Asia is the focus for regional fires, since it is more strongly seasonal and less humid than many parts of insular Southeast Asia, and both these factors favor the use of fire as a land management tool and support more fire-prone ecosystems (Roy, 2007).

Myanmar

By 1896, the basic concepts of forest fire prevention had been initiated and were concentrated in mixed deciduous forest, where teak occurred naturally. Since the late 1880s, colonial decrees regulated that the Forest Department was obliged to liaise with the local administrative bodies to coordinate the issuance by forest officers of forest fire prevention instructions for compliance. The teak forest area under fire protection increased from 4805 to 21 107 km^2 between 1897 and 1907.

In May 1896 an article entitled 'Too much fire protection in Burma' was published in the journal 'Indian Forester' (Slade, 1896), which considered that there was no doubt of the benefit of fire protection for plantations in their early years. However, he argued against the trend to advocate an enlargement of fire-protected areas and fire protection of all age classes of teak forests. Further, the cost of protection could be reduced, as the cost of subsequent weeding would be reduced. He concluded that fire protection in teak forests should be concentrated in areas of young teak seedlings. Fire protection should be stopped when seedlings reached the sapling stage when individual trees could tolerate a fire. Subsequent research and recommendations similar to those of Mr. Slade were generally confirmed by the Chief Conservator of Forests, Mr. Beadon-Bryant, in 1906 and by

Sir George Hart, the Inspector-General of Forests, in 1911. However, their articles triggered controversial discussions among forest officers in Burma, since they traditionally had given a high priority to fire prevention. Reduction of fire protection was still slow in spite of the opinion of a vast majority of forest officers in favor of burning.

As a result of the global economic depression, and the development of ideas regarding fire management mentioned above, fire protection in the teak forests of Myanmar had fallen to only 368 km^2 by 1923 and came to an end in 1930; fire protection was carried out only in plantations. However, fire prevention was Cont. in the young regeneration areas and measures were undertaken in the reserved forests and adjacent forest areas. Under the new policy, the use of a prescribed fire in teak forests was applied, under the supervision and control of the forest officers, who were able to use or to exclude fire as the condition of teak reproduction demanded.

India

The first ever forest fire in India occurred about 200 million years ago, coinciding with the evolution of early mammals on the earth (Narendran, 2001). Saha (2002) reported that anthropogenic fire in India could be dated back to 50 000 years ago when hunter-gatherers colonized India. Fire was mostly needed for agricultural purposes. In addition, people burned the hills 'with almost religious fervour', in the hope that the ash would wash down to waiting fields (Mukhopadhyay, 2007).

The policy on fires in Indian forests during colonization was historically one of strict suppression. This was first officially articulated in the Indian Forest Act of 1927, which considered the setting of a fire as a punishable offence. In addition, it made it mandatory for all forest-dependent people to provide assistance in preventing and controlling fires (Hiremath, 2007). However, many arguments on whether complete fire suppression suited the forest ecosystems of India and the culture of local people were critically debated among land managers, foresters and the local people. The indigenous people argued that they understood how fire supported agricultural activities. Further, fire kept tigers and cobras away from villages. Some people in India believed that forest ecosystem conservation and development required fires as one of the fundamental elements, and trusted in the spiritual belief and rational knowledge of the local people in the use of fire (Mukhopadhyay, 2007). In addition, fire helped the regeneration of some valued timber species, in particular teak, since the thickness and hardness of the seed coat of this species mean it needs high temperature for cracking to allow germination. By 1914, it was generally recognized that the natural regeneration of Sal (*Shorea robusta*) had ceased throughout the fire-protected forests of Assam and Bengal. Since then, controlled burning, ideally in intervals of four to five years, was applied to all Sal forests in Assam. As a result, rather than abolish fire, as was intended, the Europeans had adopted and adjusted the national fire policy from one of complete fire prevention to prescribed burning in many Indian dry forest ecosystems (Pyne, 2001).

Other Countries (Thailand, Lao, Cambodia and Vietnam)

Fire history information for Thailand before 1970 is not available, because forest fire was not considered a serious matter from the viewpoint of both government officials and the public. However, after a short visit to Thailand, Mr. J.C. Macleod, delegated by the Government of Canada in 1971, proposed that forest fire control in Thailand using all means must be seriously implemented. Consequently, the Forest Fire Control Section was established in 1976 to tackle forest fire problems. Even though many forest fire prevention campaigns had been launched for some decades throughout the country to protect the forests from fire, some cases have been proven that these fire exclusion campaigns did not meet the concept of integrated forest fire management. Moreover, fires in some forest types, such as in the dry deciduous forest (DDF) are unavoidable due to regular fire use both inside and around the forest, and the fact that the forest litter constitutes abundant flammable fuels.

An in-depth study on fire regimes in the monsoonal forests of north-eastern Cambodia demonstrated that the Cambodian people started to use fire over 8000 years ago. Fire frequency, however, has been increasing, maybe due to human control over fire becoming more important than 2500 years ago and continuing up to the present (Maxwell, 2004). There is a suggestion that anthropogenic fire is an adaptation to the monsoonal environment and may be conserving forest cover in open forest formations in Cambodia.

The impact of forest fires caused by war is a key element in Lao PDR's fire history. During the Indochina War, much of the forest along the legendary Ho Chi Minh Trail, on the Lao PDR-Vietnam border, was bombed by United

States Forces. It was not known how much forest was permanently damaged by fire from bombs and by defoliants used during the war (London, 2003).

The main fire regimes of Vietnam include: (1) regularly occurring fires in seasonally flammable deciduous forests; (2) wildfires in pine forest ecosystems; (3) wildfires in other natural and degraded vegetation; (4) targeted land-use fires (shifting agriculture, forest conversion); and (5) use of fire in intensively treated agricultural lands (Goldammer, 1992). The peak of burning activities in Vietnam is during the mid-to-late dry season (January to April). In many of the deciduous dipterocarp forests, wildfires occur almost annually, e.g. in the Central Plateau areas near the border with Cambodia. The dominating dipterocarps, e.g. *Dipterocarpus intricatus*, resprout after fires. As in the neighbouring countries of Cambodia, Lao PDR, Thailand, Myanmar and India, these seasonal forests (or 'monsoon' forests) are quite adapted to the regular occurrence of fire. Much of the lowlands and the high plateau of Vietnam, formerly covered by seasonal or evergreen broadleaved forests, is now a degraded shrub-tree-grass savanna. This vegetation is utilized extensively. Wildfires occur on a frequent basis. The fires are not set for specific purposes, but occur largely as a result of carelessness or intentional setting without any land-treatment purpose. Shulman (2002) recommended a deliberate strategy of fire use, in combination with an effective community fire prevention program, based on economic incentives extraneous to park resources, that would result in a decrease in unplanned ignitions. Improving the capacity of fire fighting forces to suppress unwanted fires would be the final step in enhancing the overall fire management program. Recently the concept of prescribed burning has been introduced to the forest management of pine plantations in Vietnam (Van Huong, 2007).

During the Vietnam war, large tracts of forests were destroyed by herbicides, called 'Agent Orange', and some of these forests were purposely ignited. The Military Assistance Command-Vietnam (MACV) ordered the Sherwood Forest and Pink Rose operations, which involved chemically defoliating the jungle to create dry fuel and then dropping incendiary weapons to start a firestorm (Lewis, 2006). These operations were not successful in terms of destroying the vegetation cover for military ground forces.

Current Fire Problems and Management

Current Fire Status

Forest fire occurrence in mainland South and Southeast Asia varies spatially and temporally, depending on forest types, local weather conditions and cultural practices.

The fire season in mainland Southeast Asia is usually between December and April. In southern Asia, however, various regions of India have different normal and peak fire seasons, which usually vary from January to June. In the Himalayan region, fires are common in May and June (Roy, 2007). All fires in the dry forest ecosystems in the southern and southeastern regions of Asia are of anthropogenic origin. The rural population uses fire as a traditional tool for clearing forest understory and managing pasture lands. Fire is also used to facilitate the gathering of NTFPs, and in hunting and herding. In many cases, fires that were set for clearing agricultural debris spread out of control into adjacent forests. Fortunately, many dry forests are located on less fertile sites, in particular in DDFs in mainland Southeast Asia where slash-and-burn is not practiced. In these forests, people are setting fires only for gathering NTFPs and for hunting. In mixed deciduous forests (MDF), however, where sites are more fertile, people set fires for shifting cultivation, which often escape and affect the forest beyond the intended area to be cleared.

In Thailand, extended forest areas are regularly affected by human-caused surface fires. Both in the DDF and in the MDF, surface fires occur once every year (Akaakara, 2000), (Figure 1). The peak fire period occurs between February and March (Figure 2), following leaf fall, when the availability of surface fuels is high. It has been estimated that by 1984, the annual forest area burned was about 18 772 000 ha. Since 1986, fire surveys have been conducted continuously, based on reports made by ground staff. Burned area assessments based on the interpretation of satellite images have been in place since 1992. The majority of the burned area is concentrated in the northern and western regions, where most of the forests occur (Forest Fire Control Office, 2002). In 2000 and 2002, fires occurring in these deciduous forests accounted for 91 and 72% of the total forest area burned, respectively (Ongsomwang *et al.*, 2000; Ongsomwang *et al.*, 2002). DDFs located in protected areas such as national parks and wildlife sanctuaries, by contrast, have not been burned for a long time due to fire suppression policies. Owing to general environmental concerns, many fire prevention programmes have been launched throughout all the forested areas in Thailand, including DDFs and MDFs, where fire may play an important role in ecosystem processes. As a consequence, traditional, quite-sustainable fire regimes in these forests have been highly modified by human intervention, possibly leading to either too-frequent or too-infrequent fires in different parts of the landscape. During extended periods of drought related to the El Niño Southern Oscillation (ENSO), fires were more widespread, extending to a certain extent into the dry evergreen forests, hill evergreen forests and even into some parts of the moist evergreen rain forests (Goldammer, 2002). In recent years, a notable number of crown fires have taken place in pine plantations in the northern part of the country, and there have also been ground fires in the swamp forests in southern Thailand (Akaakara, 2000).

Recently, there is a perception that DDFs in Cambodia are lacking substantial areas of younger regeneration, since this forest is burned regularly. In fact, where an annual burning regime is applied to this forest type, the fire-supported forest structure may collapse through a lack of regeneration and transit to a fire-tolerant shrub or grassland as mature trees senesce and disappear (Shields *et al.*, 2006). The Forest Fire Control Unit in Cambodia has been established since 2000. Although its priorities include fire management prevention and suppression, and the development of a research capability to examine fire behaviour and a fire danger rating system, to date there has been no published information about fire-related topics.

Forest Survey of India data indicates that 50% of the country's forest areas are fire prone. In absolute terms, out of the 63 million ha of forests, an area of around 3.73 million ha can be presumed to be affected by fire annually. At this level, the annual losses from forest fires in India can be moderately estimated at USD 107 million (Roy, 2007). Forest fires in this country are today almost entirely attributed to burning by people. People burn forests for a variety of reasons: to encourage a fresh flush of fodder for grazing livestock; to facilitate the collection of fuelwood and certain non-timber forest products; to clear the forest understory to improve access; and because of religious beliefs or cultural practices (Goldammer, 1993a). Fires are also used as a management practice to maintain wildlife habitat. In addition, fires are sometimes set as a form of protest against restrictive forest policies, while many fires also spread accidentally from agricultural burning-and-clearing

(Hiremath, 2007). India witnessed the most severe fires in recent times during the summer of 1995 in the hills of Uttar Pradesh and Himachal Pradesh in the Himalayas that form part of northern India. Approximately 677 700 ha of forest land were affected by fires, resulting in losses of approximately US$45 million in quantifiable timber. A lack of adequate manpower, communication and water availability in the hills allowed this fire to spread rapidly.

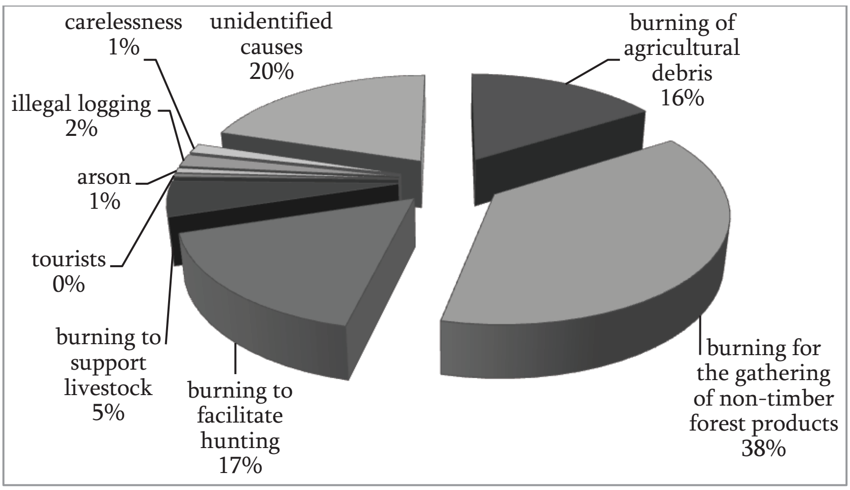

Figure 1 Causes of forest fire in Thailand.
Source: Forest Fire Control Office (2005)

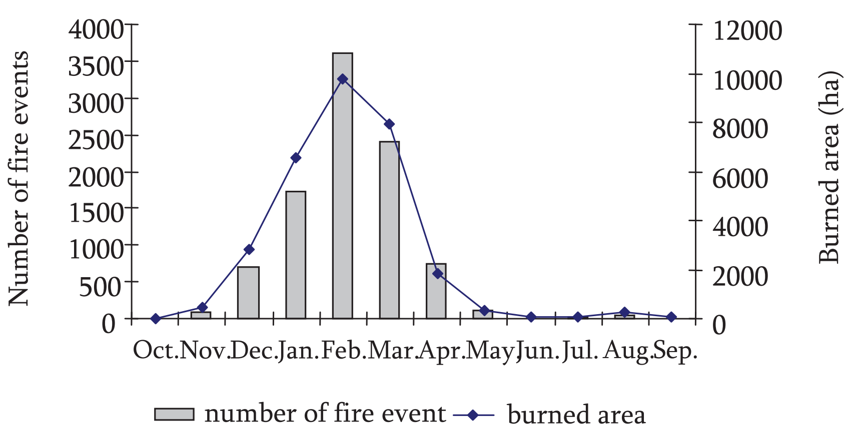

Figure 2 Frequency of fire and damaged area during 2005 in Thailand.
Source: Forest Fire Control Office (2005).

Influences of Human-Caused Fires on Burning Regimes

The dry forest ecosystems of South and Southeast Asia are characterized by diverse climate patterns, land-use systems, socio-economic and cultural settings resulting in diverse fire regimes and vulnerabilities. Due to the increase in human population and land-use pressure, the character of fire regimes in some ecosystems has been altered fundamentally in recent decades, resulting in much shorter fire-return intervals and larger damaged areas. Outside the protected areas, the fire-return intervals in natural forests in general are shorter than inside protected areas. This is due to the fact that unprotected forests have much higher human population densities, are more intensively used for various cultural activities, are more fragmented and are closer to fire-dependent agriculture. Kodandapani *et al.* (2004) reported that the fire return interval for the Mudumalai Wildlife Sanctuary in the Western Ghats of India over an observation period of 14 years (1989-2002), was only 3.3 years. This represented a threefold increase in fire frequency over the last 80 years. The problem has been compounded by land-cover transformations in the surrounding landscape. Large tracts of forests have been lost to agricultural areas (Ramesh, 2001; Subramanyam and Nayay, 2001), resulting in fragmented forest remnants. It is hypothesized that fragmentation of the forests makes them more vulnerable to escaped agricultural fires along their extensive edges and that the reduced patch size makes it more likely that entire fragments will burn during a single fire event.

Generally, it is accepted that a single fire will not result in the destruction or long-term degradation of most dry forest types. However, recurrent fires may lead to a loss of habitats, forest ecosystem biodiversity and nutrient depletion. This problem can be linked to the concept of ecological rotation for sustainable management, as proposed by Kimmins (1997). The ecological rotation may be represented in terms of ecological succession and site nutrient capital. When a forest is burned, the site reverts to an earlier stage of the successional sequence, and the forest requires a certain time to recover to the pre-burn stage. Unless the burning frequency is appropriate, the ecosystem properties and functions within that forest will gradually decline (Figure 3). The cumulative effects of frequent, particularly annual, fires therefore are very important. As the fire-return intervals decrease, it becomes more unlikely that the majority of tree species will be able to recruit new trees to a size resistant to mortality from the frequent fires. Therefore, apparently overmature dry forests are found in large forest areas of mainland

SE Asia and South Asia, which are completely lacking young trees. Saha and Howe (2003) reported that annual low-intensity burning in the dry deciduous forest of Mendha village, central India, resulted in reduced diversity of tree seedlings. The authors concluded that >80% of tree diversity could be lost within a period of 100-200 years, if this process continued. Hence, burning frequency is crucial to the maintenance of forest composition and the ecological functions of dry forest ecosystems. The effects of the short fire-return intervals have led to some mono-dominant and even-aged stands of *Shorea roxhburghii* in India (Kodandapani, 2001). Marod *et al.* (1999) suggested that if fires occurred less frequently, e.g. with intervals of 3-4 years, seedlings in MDF in western Thailand could become large enough to tolerate fire. In addition, there are some reports that too-frequent burning could contribute to the rapid invasion by exotic fire-adapted species. In India, *Lantana camara* and *Chromoleana odorata* have colonized regions subjected to repeated forest fires (Kodandapani, 2001). Besides competing with native species for resources and space, these and other exotic invasive species may also alter the fire behaviour in these forests by changing the fuel structure and hence potentially creating more intense fires that could further accelerate the loss of native species and nutrients.

Recently, Wanthongchai (2008) reported a disparity in the proportions of the most dominant species in DDF, i.e. *Shorea siamensis* and *S. obtusa,* at annually burned sites in the Huai Kha Khaeng Wildlife Sanctuary, Thailand. The number of saplings of these species increased with the length of fire-free interval, which suggested that they may require 4-7 years free from fire for a seedling to reach the sapling stage (Figure 4). Furthermore, Wanthongchai (2008) also reported that the soil fertility at frequently burned sites was generally lower than for less frequently burned sites. In addition, the relative nutrient losses from aboveground biomass burning were significantly higher for sites that had been frequently burned in the past, compared to other less frequently burned sites (Table 1). Therefore, DDF in this sanctuary should be subjected to prescribed fire every 6-7 years to maintain ecosystem structure and function (Wanthongchai, 2008). Prescribed burning at this frequency could be safely managed as a low-intensity fire according to Cheney (1994) (Table 2).

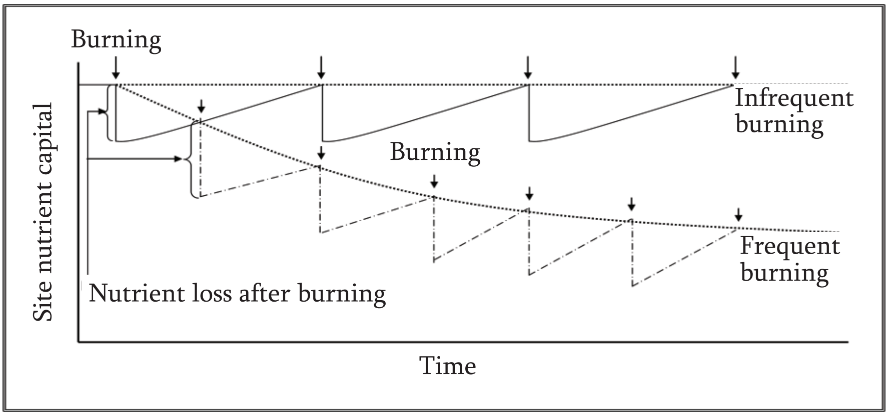

Figure 3 Simple graphic analysis of the relationship between the available nutrient capital of a site and the burning frequency. The dotted lines indicate the expected long-term trends.
Source: redrawn after Kimmins (1997).

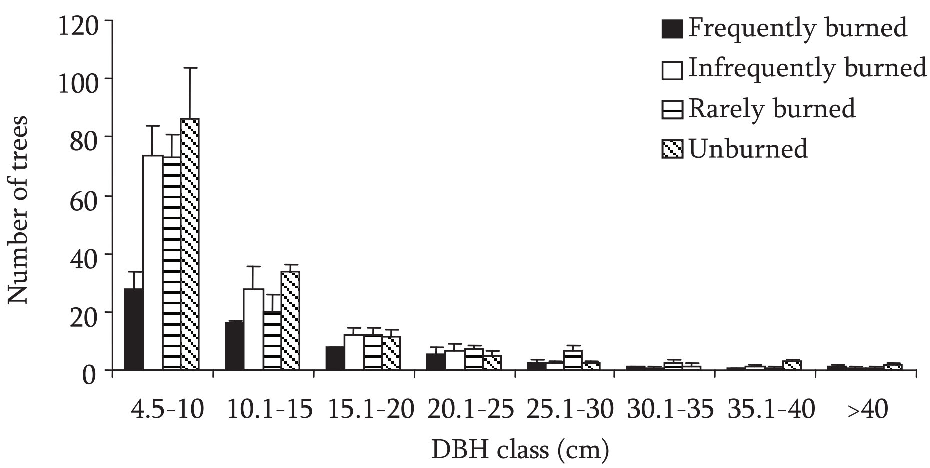

Figure 4 Tree diameter distribution of different burning regimes.
Source: Wanthongchai (2008)

Table 1 Fire-related gross losses of selected elements in a 10-year period of different burning frequencies: frequently burned = 7 out of 10 yrs; infrequently burned = 3 out of 10 yrs; and rarely burned = once in 10 yrs.

Burning regime	Gross losses (kg/ha)			
	N	P	K	Ca
7 out of 10	-179.2	-6.3	-97.3	-132.3
3 out of 10	-99.3	-9.6	-57.3	-71.7
1 out of 10	-52.7	-3.5	-11.3	-19.5

Source: modified from Wanthongchai (2008)

Table 2 Quantitative fire behaviour characteristics recorded for experimental fires applied to sites with different burning regimes.

Fire characteristics	Burning regime[1]		
	FB	IB	RB
Rate of spread (m/min)	2.7 [a]	2.6 [a]	1.3 [b]
	(1.0)	(0.3)	(0.2)
Flame height (m)	1.2 [a]	1.5 [a]	1.2 [a]
	(0.1)	(0.7)	(0.1)
Flame length (m)	1.51 [a]	1.53 [a]	1.27 [a]
	(0.22)	(0.09)	(0.11)
Fireline intensity (kW/m)	361.1 [a]	466.8 [a]	291.2 [a]
	(149.9)	(61.5)	(43.1)
Heat released per unit area (kJ/m^2)	132.8 [a]	190.4 [b]	229.5 [b]
	(3.5)	(20.4)	(20.7)

Note: [1] Different letters (a, b, c) indicate significant differences (ANOVA, $p<0.05$, followed by Duncan's multiple range test or Kruskal-Wallis test followed by Mann-Whitney U test) in the fire characteristics between the burning regimes.
FB = frequently burned; IB = infrequently burned; RB = and rarely burned. Standard errors are in parentheses.
Source: Wanthongchai (2008)

Influences of El Niño on Burning Regime

In the tropical forest biome, the prolonged droughts caused by El Niño-Southern Oscillation (ENSO) events have drastically changed the fuel complex and the flammability of the vegetation, and hence encourage the application of fire in land use and land-use change, resulting in altered burning regimes (Goldammer and Seibert, 1990). El Niño-related droughts tend to occur every 2-7 years and last for a period of 12-18 months at a time. However, analysis of data by the US National Oceanic and Atmospheric Administration (NOAA) from the 10 strongest El Niño events of the past century has shown that they are occurring more frequently, and that they are becoming progressively warmer. Since 1970, ENSO events have occurred in 1972, 1976, 1982/83, 1987, 1991/92, 1994 and 1997/98. It has been suggested that rising temperatures, as a consequence of climate change, will result in more frequent and intense ENSO occurrences. The daunting fact is that the world is facing a positive feedback cycle in which climate change will be exacerbated by forest fires and deforestation, which will increase the frequency of El Niño, which in turn will create conditions of excessive burning activity and wildfires. This will consequently affect ecosystem structure, process and dynamics in the region. The burned area from some selected countries (Table 3), indicates that during the El Niño events, the fire-damaged areas tend to increase significantly, compared to non-ENSO years.

Table 3 Annual burned area from forest fire for some selected countries.

Year	Country				Remark
	Malaysia[1]	Thailand[2]	Sri Lanka[3]	Vietnam[4]	
1992	418	2030 160	259	na	El Niño year
1993	56	1459 617	174	na	
1994	156	763 648	191	na	El Niño year
1995	25	643 799	372	na	
1996	18	490 303	271	na	
1997	26	660 208	610	1360	El Niño year
1998	1646	1145 452	204	15 088	El Niño year
1999	27	293 480	417	2191	
2000	6	93 324	na	na	

Sources: [1] Shields *et al.* (2006), [2] Ganz (2003), [3] Benndorf *et al.* (2006), [4] Goldammer *et al.* (2001)

Current Smoke Pollution Problems

Smoke pollution resulting from fires has affected Southeast Asian countries since at least the late 1800s (Potter, 2001). The pyrogenic emissions constitute a bouquet of pollutants including aerosols, radiatively active trace gases and toxic compounds that are affecting human health in the region and the functioning of the global atmosphere. Peatland and rainforest conversion fires, in Indonesia in particular, are the major source of smoke-haze pollution in this region, whereas the pyrogenic pollution from other ecosystem is relatively less significant. In 2008, however, at the border between northern Thailand and Myanmar, slash-and-burn and forest wildfires in dry forest ecosystems also resulted in significant impacts on human health, the environment and the transportation system of northern Thailand (Figure 5). Recently trans-boundary haze pollution arising from forest fires and slash-and-burn activity has been one of the big issues among Southeast Asia countries. Beginning in 1992, as a consequence of the regional smog problems caused by land-use fires, member states of the Association of South East Asian Nations (ASEAN) created joint activities to encounter problems arising from trans-boundary haze pollution. ASEAN workshops held in Balikpapan (1992) and Kuala Lumpur (1995) summarized the problems and urged appropriate initiatives. Most important in future regional ASEAN-wide cooperation in fire management will be the sharing of resources. Three main sharing targets will be: (1) predicting fire hazard, and fire effects on ecosystems and the atmosphere; (2) detection monitoring and evaluating fires; and (3) sharing fire suppression resources and technologies. The ASEAN region will potentially serve as a pilot region in which resource sharing will be based on the fact that two distinct fire problem seasons exist within the region. (Roy, 2007). Although this agreement has been accepted in principle and cast as a global role model for other regions to follow, it is noted that not all member countries have ratified the agreement and given it their full endorsement (Shields *et al.*, 2006).

Figure 5 Burning at the border between Myanmar and Thailand resulting in a trans-boundary smoke problem.
Source: Global Fire Monitoring Center

Recommendations for Fire Management in the Future

Despite the fact that dry forest ecosystems dominate mainland South and Southeast Asia where fire has constituted a long-term evolutionary factor, information on fire history, fire regimes and fire effects, as well as fire management history is very scanty. Fire management in tropical dry forests is very complicated and a challenge for land managers that must be addressed in order to meet all requirements, including local needs, to address global warming concerns and the significance of fire itself in forest ecosystems. However, the policy of complete fire prevention/exclusion must be revised. Fire-dependent ecosystems must be separately managed from fire-independent or fire-sensitive ecosystems. Further, variation in the burning frequency and burnt-patch size may have beneficial effects for the ecosystem, just as a highly regular fire frequency may also have adverse ecological effects (Tolhurst *et al.*, 1992; Keith and Bradstock, 1994; Morrison, 2002). Therefore, variation in the burning interval, burning intensity and extent may result in both a spatially and temporally variable mosaic of burned areas across the landscape, thereby resulting in greater landscape diversity. In many cases, reforestation by means of fire and fire prevention is required to restore ecosystem goods and services. However, the potential for planned fire must be further investigated from many aspects before prescribed burning can be applied.

Regarding people participation in fire management, the so-called 'Community-Based Fire Management' (CBFiM), is a concept that could be a good solution to address the conflicts of interest in the forest. It is not surprising that local communities are often blamed as 'the igniter'. However, the underlying reason for the local community's failure to control fires is not a lack of awareness or carelessness, but rather a lack of incentives to protect forest resources (FAO, 2003). Therefore, CBFiM has emerged as a new and increasingly adaptive mechanism for working with and managing fire in many regions of the world.[1]

Finally, global climate change is expected to result in changes in the annual rate of burnt areas. However, there is positive feedback that fire contributes significant quantities of greenhouse gases and particulate matter to the atmosphere, which is in turn resulting in global climate changes. If the El Niño phases of ENSO become stronger as global warming continues into the next century (e.g., Jin *et al.*, 2003), then it is assumed that fires in the South and Southeast Asian region will grow even more severe (i.e. more frequent, higher intensity and greater area affected) than they used to be. In addition, the great concern about the global warming crisis will make it difficult for fire management in tropical dry forests. As a result of burning, smoke pollution, greenhouse gases emission (CO_2, CH_4 and NO_x) and soil erosion have been discussed in detail and criticism among scientist is that they are likely to outweigh any potential benefits of fire in maintaining fire-related ecosystems. Therefore, the future uses of prescribed fire in any case will be even more of a challenge to meet both environmental and ecosystem maintenance concerns. The application of fire therefore must be used in a very specific space and time.

[1] http://www.fire.uni-freiburg.de/Manag/CBFiM.htm

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