

Fire Behavior in Dry Deciduous Dipterocarp Forest at Huai Kha Khaeng Wildlife Sanctuary, Uthai Thani Province

Kraisorn Wiriya^{1*} and San Kaitpraneet²

ABSTRACT

The study of fire behavior in dry deciduous dipterocarp forest at Huai Kha Khaeng Wildlife Sanctuary, Uthai Thani province aimed to determine fire behavior and to find relationships between fire behavior and some environmental factors. The results of the study will be applied to fire control and fire suppression in the area. In total, 21 plots each 200 m × 200 m in size were established at an experimental burning site to collect data on fire behavior. In addition, fuel properties and fire weather data were collected. Byram's model was applied to determine fire intensity and flame length. The results revealed that the average rate of fire spread, fireline intensity and flame length was 1.89 m min⁻¹, 190 kWm⁻¹ and 0.86 m, respectively. The loading of dead and live fuel was 4.64 and 0.73 ton ha⁻¹, respectively. The moisture content of dead and live fuel was 12.43 and 84.81 %, respectively and fuel bed depth was 12.57 cm. The rate of fire spread was correlated positively with wind velocity and fuel bed depth and negatively with the moisture content of the live fuel. Fires with low to moderate fire intensities could generally be attacked at the head fire by firefighters using hand tools. A hand line at least 4 m wide could hold the fire, with readiness at top alert when strong winds were expected. Reducing the fuel bed depth and maintaining high moisture content in the live fuel were recommended for fuel management.

Key words: fire behavior, fire environmental factors, fire control, dry deciduous dipterocarp forest, Uthai Thani province

INTRODUCTION

A forest fire can be described as unclosed and freely spreading combustion, which consumes the natural fuels of a forest that consist of duff, grass, weeds, brush, and trees (Brown and Davis, 1973). Fire behavior is generally defined as the manner in which the fuel ignites, flames develop and the fire spreads and exhibits other related phenomena, such as fire whirls (Countryman, 1964), as determined by the interaction of fuels, weather, and topography (Brown and Davis,

1973). This definition is consistent with that of the National Wildfire Coordinating Group, which considered fire behavior as "the manner in which a fire reacts to the influences of fuel, weather and topography". The popular fire behavior descriptors are rate of fire spread, fire intensity and flame length (Kaitpraneet, 1983). Rate of fire spread is the speed at which the fire moves across the landscape. It is the primary descriptor of fire behavior and its prediction is crucial to achieve effectiveness in both wildfire control and the successful application of prescribed burning

¹ Royal Forest Department, Bangkok 10900, Thailand.

² Department of Silviculture, Faculty of Forestry Kasetsart University, Bangkok 10900, Thailand.

* Corresponding author, e-mail: g4583005@ku.ac.th

(Mendes-Lopes *et al.*, 1998). Fire intensity is the rate of heat energy released during combustion. Flame length is the distance from the average flame tip to the base of the flame in the middle of the flame zone (Teie, 1997).

This study considered fire behavior in dry deciduous dipterocarp forest (DDF) in Doi Suthep-Pui National Park, Chiang Mai province. The rate of fire spread ranged from 0.28 to 6.41 m min⁻¹ and fireline intensity ranged from 33.72 to 883.58 kWm⁻¹, while fire behavior in DDF at Kanchanaburi province during the fire season was described by an average fire spread of the head fire of 2.81 m min⁻¹ and the flank fire and rear fire had rates of spread of 0.59 and 0.40 m min⁻¹, respectively. The most severe fire occurred in early March, when the rate of fire spread reached 6.96 m min⁻¹ on a 45% slope (Akaakara, 2000). In addition, Sunyaarch (1989) studied fire behavior in DDF at Sakaerat, Nakhon Ratchasima province and found that the rate of fire spread, fireline intensity and flame length from burning in February was 2 m min⁻¹, 266.03 kWm⁻¹ and 2.58 m, respectively.

Forest fires in Huai Kha Khaeng Wildlife Sanctuary (HKKWS) and the Buffer Zone Area (BZA) that is located around the eastern border of HKKWS have usually occurred during the dry period. Forest fires always occurred from mid December to late April and the peak fire season is in March. The fires usually started in DDF located in the BZA during the early fire season and spread into mixed deciduous forest later. In addition, in an extreme drought year, the fire would burn in dry evergreen forest at the core area of HKKWS. Daily fires and more severe fires are important problems causing damage and decreasing the richness and diversity of HKKWS and the BZA ecosystems, as shown for example, by decreasing forest health, tree quality, soil fertility and destroyed seedlings. Consequently, surface run off, failed succession and danger to wildlife are evident. Hence, the study of fire behavior and the

relationships between fire behavior and some environmental factors were required in DDF at HKKWS. The results of the study will be applied to fire control and fire suppression, particularly in DDF at HKKWS.

MATERIALS AND METHODS

Study site

HKKWS is located between latitudes 14°56' and 15°48' N and between longitudes 98°58' and 99°28' E. Altitude in the area ranges from 160 to 1,687 m. The climate is divided into three distinct seasons; summer is from February to April, with the temperature ranging from 24 to 38°C. The rainy season is from May to October, with the temperature ranging from 23 to 34°C. Winter is from November to January, with the temperature ranging from 18 to 20°C. The annual rainfall is about 1,500 mm in HKKWS and from, 800 to 1,200 mm in the BZA. The average relative humidity is 55%. The forest types include DDF, mixed deciduous forest, bamboo forest and evergreen forest. In addition, sub-forest types cover the area, including pine forest, stream-sand dune vegetation and scrub forest. HKKWS is home to a large range of wildlife, including 68 species of mammals, 355 species of birds, 77 species of reptiles, 29 species of amphibians and 55 species of fresh water fish (Faculty of Forestry, 2000).

Sample plot and data collection

Twenty-one plots, each 200m × 200m in size, were established at an experimental burning site to collect fire behavior data. A metal post was used to stake the center of the burn plot and other metal posts were staked at the eight cardinal points of the compass, at 10 m intervals. Pre-burning fuel properties (loading and moisture content) were recorded from five sample plots, each 1m x 1m in size, which were located in the north, south, east, west and center of each burn plot. Fuels were classified into two categories of "dead" and "live".

Dead fuel included litter, twigs and dead herbs; live fuel included live herbs and undergrowth. The loading and moisture content were classified into dead and live categories. Fuel bed depths were measured along the eight radius lines of the burn plot. The fuel was ignited at the center of the burning plot. During burning, the distance of fire spread was recorded every five min in eight directions. The wind velocity, weather temperature and relative humidity were also recorded every five minutes at the same time as other fire behavior data. When the fire reached the edge of a burn plot, the burning time was recorded and the distances of fire spread on the eight radius lines of each burning plot were marked. Then, the fire was suppressed immediately.

Data analysis

The rate of fire spread was defined as the distance the flame zone moved per unit of time, expressed in m/min. Fire intensity and flame length were determined using Byram's model (Byram, 1959). Fuel load was determined on a dry weight basis that was expressed in ton ha^{-1} . The moisture content was calculated on a dry weight percentage basis. The average, minimum and maximum values and coefficient of variation were determined for the results of the study. Regression analysis was applied to determine the relationships between fire behavior and some environmental factors.

RESULTS

Fire behavior

Results of the fire behavior study included the rate of fire spread, fireline intensity and flame length (Table 1). The average rate of fire spread was 1.89 m min^{-1} with minimum and maximum values of 0.57 and 3.94 m min^{-1} , respectively. The variation in the values recorded for the rate of fire spread, which are presented in Table 1, were due to environmental factors in each

experimental burning plot during the collection of fire behavior data. Fireline intensity is the rate of heat energy released during combustion per units of time and length, it was derived from Byram's model with the rate of fire spread, amount of available fuel and heat of combustion factors. Table 1 revealed that average fireline intensity was 190 kWm^{-1} , with minimum and maximum values of 36 and 372 kWm^{-1} , respectively. Flame lengths were also derived using Byram's model with fireline intensity. Average flame length was 0.86 m with minimum and maximum values of 0.41 and 1.22 m , respectively.

Chaiwatana (2003) studied fire behavior in DDF at HKKWS and found that the rate of fire spread was 0.95 m min^{-1} , fireline intensity was 227.48 kWm^{-1} and flame length was 1.15 m . Sompoh (1998) also studied fire behavior in DDF at HKKWS and found that fireline intensity was 110.71 kWm^{-1} and flame length was 0.70 m . The results of the present study were close to the results found by Sompoh (1998). Compared with the study of Chaiwatana (2003) the rate of fire spread was higher, but the fireline intensity and flame length were lower, due to the amount of available fuel. The fire behavior in the study was less severe than in Doi Suthep-Pui National Park in Kanchanaburi province, due to the differences in environmental factors, including fuel, weather and topography.

Environmental factors

Fuel factors (loading, moisture content and fuel bed depth) were determined before burning. Table 1 shows the average loading of dead fuel was 4.64 ton ha^{-1} , with minimum and maximum values of 2.88 and 7.70 ton ha^{-1} , respectively. The average loading of live fuel was 0.73 ton ha^{-1} , with minimum and maximum values of 0.27 and 1.71 ton ha^{-1} , respectively. However, Akaakara *et al.* (2004) found only 4 ton ha^{-1} of average for fuel loads in DDF at HKKWS. The fuel load measured by Akaakara *et al.* (2004) was

Table 1 Fire behavior, fuel and weather in experimental plots of dry deciduous dipterocarp forest at Huai Kha Khaeng Wildlife Sanctuary.

Plots	Fire behaviors			Fuels					Weathers		
	Ros	I _B	Fl	Lod	Lol	Mod	Mol	Dep	Tem	RH	Win
	(m min ⁻¹)	(kWm ⁻¹)	(m)	(ton ha ⁻¹)	(ton ha ⁻¹)	(%)	(%)	(cm)	(°c)	(%)	(km h ⁻¹)
1	2.74	348	1.18	4.96	1.71	11	77	20	33	58	5.47
2	2.32	254	1.02	5.08	0.68	16	67	21	33	66	4.88
3	2.97	294	1.09	3.72	1.36	13	75	20	27	48	4.58
4	3.01	309	1.12	4.67	1.13	10	82	20	30	37	4.17
5	3.00	206	0.93	3.21	0.46	12	81	10	27	41	4.80
6	2.28	154	0.81	2.88	0.64	11	111	6	29	38	4.48
7	1.69	204	0.92	4.89	0.46	7	73	20	34	75	2.88
8	3.24	372	1.22	4.60	0.93	8	78	20	35	57	3.94
9	0.85	64	0.54	3.66	0.27	11	91	5	35	68	2.98
10	1.13	120	0.72	4.88	0.63	12	103	6	34	70	3.31
11	1.61	163	0.83	5.01	0.43	9	69	10	39	57	4.51
12	2.50	203	0.92	3.85	0.35	10	65	10	37	58	4.13
13	3.94	340	1.17	4.32	0.55	12	43	25	39	69	5.17
14	0.81	106	0.68	5.58	1.12	15	92	5	37	55	3.07
15	2.07	222	0.96	4.28	1.44	11	98	20	36	70	3.75
16	0.88	131	0.75	7.70	0.51	13	97	10	36	57	1.99
17	0.66	52	0.49	4.03	0.63	10	122	7	39	48	2.26
18	1.21	141	0.78	5.10	0.46	12	98	7	37	53	2.18
19	0.86	107	0.69	5.49	0.45	15	89	7	32	59	1.41
20	0.57	36	0.41	3.76	0.39	25	122	5	37	69	1.77
21	1.35	172	0.85	5.79	0.68	18	48	10	37	69	2.90
Mean	1.89	190	0.86	4.64	0.73	12	85	13	34	58	3.55
c.v.(%)	52.91	52.24	26.74	22.63	54.79	32.42	24.71	52.77	10.82	19.17	33.82

Abbreviations: Ros = rate of fire spread; I_B = fireline intensity and; Fl = flame length Lod = loading of dead fuel; Lol = loading of live fuel; Mod = moisture content of dead fuel; Mol = Moisture content of live fuel; Dep = fuel bed depth; Tem = weather temperature; RH = relative humidity; Win = wind velocity; c.v.= Coefficient of variation.

composed of litter, twigs, grass and undergrowth, while the current study added live herbs into the fuel loads.

The average moisture content of dead fuel was 12.43%, with minimum and maximum values of 7 and 25%, respectively. The average moisture content of the live fuel was 84.81%, with minimum and maximum values of 43 and 122%, respectively. Fuel bed depth is sometimes called fuel bed bulk depth. The average fuel bed depth was 12.57 cm, with minimum and maximum

values of 5 and 25 cm, respectively. Details of fuel factors in each burn plot are presented in Table 1.

Weather factors (temperature, relative humidity and wind velocity) were determined during burning. Table 1 shows that the average weather temperature was 34.43°C, with minimum and maximum values of 27 and 39°C, respectively. The average relative humidity was 58.19%, with minimum and maximum values of 37 and 75 %, respectively. The average wind velocity was 3.55 km h⁻¹, with minimum and maximum values of

1.41 and 5.47 km h⁻¹, respectively. The details of weather factors in each burn plot were also recorded (Table 1).

The Forest Fire Research Centre (2006) reported average, minimum and maximum values of weather temperature from January to March inclusive of 26.92, 19.72 and 33.87°C, respectively, and average relative humidity as 84.57%. The average temperature during this study was close to the maximum value in the whole area, but the relative humidity was lower because fire behavior data collection was conducted between 10:00 am and 3:00 pm. There was high temperature and low relative humidity at the burning site.

The relationships between fire behavior and environmental factors

Fire behavior is the manner in which a fire reacts to the influences of fuel, weather and

topography. The study paid attention to only the fuel and weather factors, due to the limited range in the topography of the study area. The results of regression analysis revealed that the rate of fire spread was correlated positively with wind velocity in an exponential model, with the fuel bed depth in a power model and negatively correlated with the moisture content of live fuel in the exponential model, as presented in Figure 1. Based on the results of regression analysis, wind velocity and fuel bed depth affected positively to the rate of fire spread. Consequently, the rate of fire spread will increase as an exponential equation when the wind velocity increases and will increase as a power equation when the fuel bed depths increase. On the other hand, the moisture content of live fuel affected negatively the rate of fire spread. Consequently, the rate of fire spread will decrease exponentially, when the moisture content of the live fuel increases.

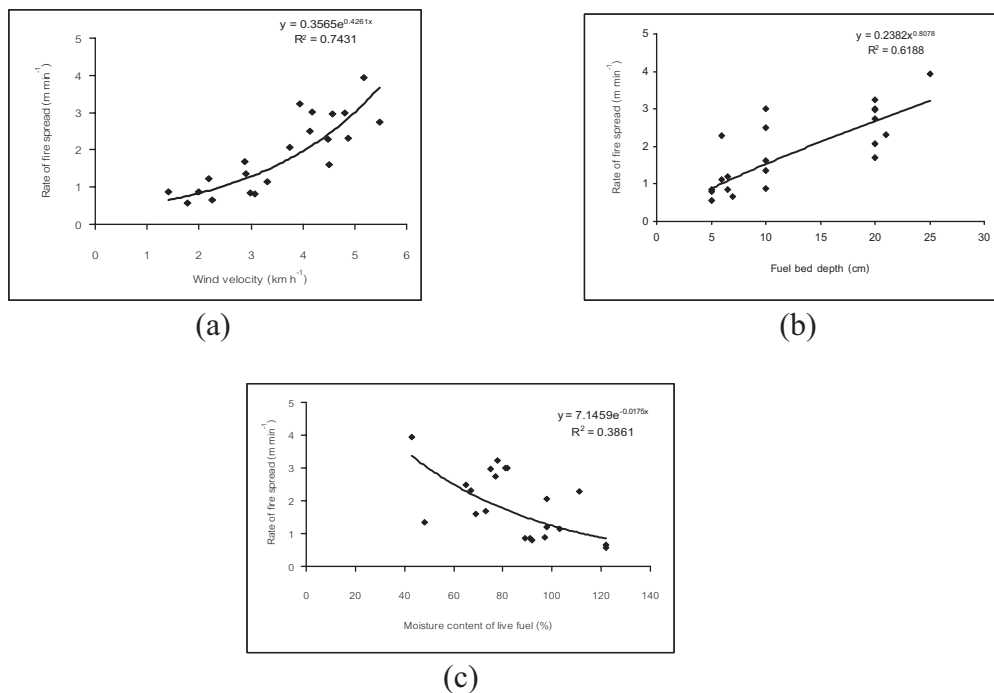


Figure 1 The correlation between rate of fire spread and (a) wind velocity; (b) fuel bed depth; and (c) moisture content of live fuel in dry deciduous dipterocarp forest at Huai Kha Khaeng Wildlife Sanctuary.

Akaakara *et al.* (2003) reported forest fire in DDF at HKKWS and found that the rate of fire spread was correlated positively with weather temperature. Fireline intensity correlated positively with loading of undergrowth and weather temperature. Flame length was correlated positively with the grass loading. For instance, Bilgili and Saglam (2003) reported that rate of fire spread of maquis fuels was correlated positively with wind velocity and fuel bed depth.

DISCUSSION

According to the fire control interpretation of Andrew (1980), fire behavior in DDF at HKKWS was classified as being of low to moderate fire intensity. The rate of fire spread, fireline intensity and flame length was 1.89 m min^{-1} , 190 kWm^{-1} and 0.86 m , respectively. Chaiwatana (2003) reported that fire behavior in DDF at HKKWS had a rate of fire spread, fireline intensity and flame length of 0.95 m min^{-1} , 227.48 kWm^{-1} and 1.15 m , respectively. Sompoh (1998) also studied fire behavior in DDF at HKKWS and found that fireline intensity was 110.71 kWm^{-1} and flame length was 0.70 m . Fires in DDF at HKKWS were usually surface fires that consumed the fuel on the ground, such as fallen leaves, grass, herbaceous plants and twig; thus, the fire behavior was not severe and serious, like in a crown fire. In addition, the wind velocity in DDF was not strong, due to the tree density that acted as a natural windbreak.

The rate of fire spread was correlated positively with wind velocity because the wind directly affected the rate of oxygen supply to the burning fuel. In addition, strong wind tilts the flames closer to unburned fuel, increasing the heat flux to the unburned fuel by increasing effective flame radiation and heat convection. Fuel depth is affected by bulk density, which is used to describe the compactness of the fuel bed. The bulk density of a fuel bed can be used as a measure of the

oxygen availability and distance between particles across which heat must be transferred to ignite additional fuel (Fahnestock, 1960). For example, the moisture content of live fuel was correlated negatively with the rate of fire spread, as the higher fuel moisture content took longer to ignite. Any moisture released from the fuels absorbs some heat energy from the fire, limiting the combustion temperature.

Based on the results of the study, fire suppression in DDF at HKKWS could generally be attacked at the head by firefighters using hand tools, such as fire swatters or fire beaters supported by backpack pumps or knapsack sprays. A hand line at least 4 m wide could hold the fire, with readiness at top alert when strong winds were expected. Reducing the fuel bed depth and maintaining high moisture content in the live fuel were recommended for fuel management.

CONCLUSION

Fire behavior in DDF at HKKWS was classified as low to moderate fire intensity, with the average rate of fire spread, fireline intensity and flame length being 1.89 m min^{-1} , 190 kW m^{-1} and 0.86 m , respectively. The loading of dead and live fuel was 4.64 and 0.73 ton ha^{-1} , respectively; the moisture content of dead and live fuel was 12.43 and 84.81% , respectively and fuel bed depth was 12.57 cm . The rate of fire spread was correlated positively with wind velocity and fuel bed depth and negatively with the moisture content of the live fuel. Fires with low to moderate intensities could generally be attacked at the head by firefighters using hand tools. A hand line at least 4 m wide could hold the fire, with readiness at top alert when strong winds were expected. Reducing the fuel bed depth and maintaining high moisture content in the live fuel were recommended for fuel management.

LITERATURE CITED

- Akaakara, S. 2000. **Forest Fire Control in Thailand**. Forest Fire Control Office, Royal Forest Department, Bangkok.
- Akaakara, S., K. Wiriya and T. Tongtan. 2003. **Fire Behaviors in Dry Dipterocarp Forest at Huai Kha Khaeng Wildlife Sanctuary**. Research Report, Forest Fire Research Centre, National Park, Wildlife and Plant Conservation Department, Bangkok.
- Akaakara, S., K. Wiriya, T. Tongtan and P. Nuchaiya. 2004. **Fuel Characteristics in Dry Dipterocarp Forest at Huai Kha Khaeng Wildlife Sanctuary**. Research Report, Forest Fire Research Centre, National Park, Wildlife and Plant Conservation Department, Bangkok.
- Andrew, P. L. 1980. Testing the fire behavior model. *In Proceedings Sixth Conference on Fire and Forest Meteorology. April 22-24, 1980*. Seattle, WA. Society of American Foresters.
- Bilgili, E. and B. Saglam. 2003. **Fire Behavior in Maquis Fuels in Turkey**. Faculty of Forestry, Karadeniz Technical University, Trabzon, Turkey. Available Source: www.sciencedirect.com, May 27, 2007.
- Brown, A.A. and K.P. Davis. 1973. **Forest Fire: Control and Use**. McGraw-Hill Book Company, New York.
- Byram, G.M. 1959. Combustion of Forest Fuels. Chapter 3, 61-69. *In* K.P. Davis (ed.), **Forest Fire: Control and Use**. McGraw Hill Book Company, New York.
- Chaiwatana, S. 2003. **Effects of Forest Fire on Seedling, Sapling and Some Herbivores Utilization in Dry Deciduous Dipterocarp Forest, Huai Kha Khaeng Wildlife Sanctuary, Uthai Thani Province**. M.Sc. Thesis, Kasetsart University, Bangkok.
- Countryman, C.M. 1964. Mass Fires and Fire Behavior. **USDA Forest Service Research Paper PSW-1**. Pacific Southwest Forest and Range Experiment Station, Berkeley, California.
- Faculty of Forestry. 2000. **Reviewing Fire Management Policy in the Conservation of the Thung Yai and Huai Kha Khaeng Wildlife Sanctuaries and World Heritage Areas of Thailand**. A Final Report Submitted to National Committee for the Protection of the World Cultural and Natural Heritage of Thailand. Faculty of Forestry, Kasetsart University, Bangkok.
- Fahnestock, G.R. 1960. Logging slash flammability. **USDA Forest Service Research Paper International - 58**. Intermountain Forest and Range Experiment Station, Ogden, Utah.
- Forest Fire Research Centre. 2006. **Meteorology Report in 2001-2005**. Forest Fire Control Office, National Park, Wildlife and Plant Conservation Department, Bangkok.
- Kaitpraneet, S. 1983. **Forest Fire and Controls**. Faculty of Forestry. Kasetsart University, Bangkok.
- Mendes-Lopes, J.M.C., J.M.P. Ventura and J.M.P. Amaral. 1998. Rate of Spread and Flame Characteristics in a Bed of Pine Needles. pp. 497-511. *In III International Conference on Forest Fire Research 14th Conference on Fire and Forest Meteorology Volume I*. Luso.
- Sompoh, B. 1998. **Fuel Complex in Dry Deciduous Dipterocarp and Mixed Deciduous Forest at Huai Kha Khaeng Wildlife Sanctuary, Changwat Uthai Thani**. M.Sc. Thesis, Kasetsart University, Bangkok.
- Sunyaarch, S. 1989. **Effects of Fire on Vegetation and Soil in Dry Dipterocarp Forest, Sakaerat, Nakhon Ratchasima**. M.Sc. Thesis, Kasetsart University, Bangkok.
- Teie, W.C. 1997. **Fire Officer's Handbook on Wildland Firefighting**. Deer Valley Press, Rescue, California.