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WILDLAND FIRES PARTICULARLY IN TROPICAL REGIONS

by

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This report prepared by CAgM-VII Rapporteur (Dr A B Oguntala) on Wildland Fires particularly in Tropical Regions has been approved for circulation to members of CAgM. A copy of the report* is therefore attached for information.

* The report is reproduced from the original.

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APPENDICES

1.1 BACKGROUND

The VIIth Session of the Commission for Agricultural Meteorology noted the WMO Special Report No. 11 "Systems for evaluating and predicting the effects of weather and climate on wildland fires" by Professor W. E. Reifsnyder (WMO Publication No. 496).

The Commission considered that:

(a) Although forest or bush fires are frequent and destructive in many tropical areas, systems of combating them are relatively undeveloped in these areas;

(b) Development of forest fire weather forecasting and development of a fire-danger rating system are necessary and possible in tropical regions.

The Commission consequently decided to appoint a Rapporteur to study the problem and submit a report to the President of the Commission not later than six months before the Eighth Session of the Commission. Dr. A. B. Oguntala (Nigeria) was appointed to act as Rapporteur. (Resolution 14 CAgM-VII).

The terms of reference of the Rapporteur were:

(a) To collect and collate up-to-date information on the extent and importance of wildland fires particularly in tropical regions;

(b) To review existing knowledge on the conditions of weather and vegetation in which fires occur and spread in tropical regions;

(c) To make a proposal for future work in the field of study.

1.2 INTRODUCTION

Fire has been a factor of the human environment since time immemorial. In many parts of the tropics man has used fire for centuries to modify the vegetation for grazing by livestock and continues to do so right to the present day.

Burning is often used to stimulate out-of-season green grazing. Wildland fire has also been used in shifting cultivation practices in rain forest regions. Both practices have been responsible for the drastic deterioration of extensive areas of tropical range and forest land.

As a result of the historical distribution of broad climatic belts, common pools of plants or 'vegetation types' have developed all over the world (Ibrahim 1978). The relationship between climates and vegetation, especially in the tropics, has long been recognized, although not always understood. Phytogeographical divisions of the tropics have been made using climatic parameters as one of the criteria.

There has been an increasing demand for an objective method of delineating or defining areas of the tropical world, that experience similar climatic conditions from the standpoint of potential fire behaviour, in order to apply meteorology and climatology to wildland fire control (Fosherg and Furman 1973).

A few studies made on wildland fire problems in the tropics are from areas scattered over different continents; a general synthesis of available information in this field has long been overdue. Such studies include delineating similar vegetation zones of the tropics and the description of general climatic conditions in the different zones.

In the tropics, climate conditions under which fires are most likely to occur, also incorporating inter-relationships between climate, vegetation and fire, have received very little attention.

Annual burning occurs in most tropical savanna grasslands (Afolayan 1978). Some ecologists, including Richards (1957), Nye and Greenland (1960), West (1965) and Stern and Roche (1974) believe, for instance, that African grasslands are examples of "fire climax" vegetation. The economic advantages of using fire to manage tropical vegetation for crop farming, domestic and wild animal cultivation have long been recognized. Many range managers in the tropical savannas use fire successfully to improve the quality and quantity of grass in the habitats, Rains (1963), West (1965), and Herlocker (1971).

Burning unacceptable grass material in tropical grasslands and savanna subtropical forest occurs every year at the end of the growing season. In this practice the 'season' of burning is known only in a general form.

In the temperate regions, when the adverse effects of wildland fires become economically important, various efforts had been made to control the phenomenon. Forest fire dangers which have been increasingly important in the temperate regions, for instance, have necessitated the establishment of fire-danger stations.

Recognition of forest flammability (as well as wildland fires) have shown up in schemes to extrapolate flammability conditions beyond the area immediately surrounding a measuring station (Barrow 1951).

Hayes (1941) investigated the influence of elevation and aspect on fire danger. This was a significant step in quantifying the variations in the climate associated with fire danger. The United States has one of the oldest histories in the development of fire climates now culminating in a US National Fire Danger Rating System (Reifsnyder 1978). Similarly, by 1946 Beall had produced 'provisional' forest fire Danger Tables for Canada to check on personal estimates by summing up in a single figure the effects of the more changeable and hard-to-estimate items of fire danger and also to provide a consistent scale of fire danger on which plans for fire-control action may be built within a given area on a comparable basis (Beall 1946).

While in the United States, Canada, Australia and West Germany, national fire rating systems have been developed, in Africa, Latin America, Asia and the Mediterranean region most of which are fire-prone regions, the fire-danger rating system has hardly been developed, Reifsnyder (1978).

FAO and UNEP have proposed a global programme for the "detection and control of forest fires for the protection of the human environment".

The object of this report is therefore to bridge the gap in knowledge for the development of a global programme in fire-danger rating and fire-weather-forecasting systems. Some of the recent attempts at producing a universal fire-danger rating system and forest fire weather-forecasting systems at global level include those of Turner et al. (1961), FAO (1953) and Reifsynder (1978).

The present study highlights the necessity and feasibility of developing forest fire weather forecasting and the development of a fire-danger rating system particularly in tropical regions. The study was done with the use of questionnaires, consultations and references to literature.

2. METHODS OF SURVEY

This survey is an attempt to review the problem of wildland fires in 'dry' lands of the world reputed to cover 48 million Km^2 (Meigs 1957), 71% of which occur in Africa and Asia (see Figure 1). An effort has been made to assess in respective countries existing knowledge on the conditions of weather and vegetation in which fires occur and spread and also to assess the impact on the economy of these countries. Particular attention was paid, as much as possible, to more objective and quantitative information rather than on general estimates or personal impressions. In order to accomplish as much as possible of these various objectives the survey adopted several approaches.

2.1 CORRESPONDENCE

Questionnaires were sent out ot 98 WMO member countries in December 1980 (under the auspices of WMO) in the affected areas and 31 responses were received giving an approximately 32% response. Myers (1980) considered a 22% response to a similar survey on the conversion of the Tropical Moist Forests a satisfactory survey. This present exercise may therefore be considered fruitful. Follow-up inquiries requesting more substantive evidence clarifications from institutions and the like were done for a more valid assessment of the problem, while many countries recognized the need for detailed statistical inventories, some also acknowledged that their data were generally incomplete at best.

2.2 LITERATURE SURVEY

Although there is a wealth of professional literature on the tropical wildland areas, most of it deals with ecology, forestry, climatology and scientific aspects of similar sort. All too little deals with the present status of wildland fires in this region.

During the course of the survey, publications, reports and monographs emanating from several conference proceedings, technical forestry meetings at national, regional and global levels were studied. Publications from various international agencies and associations including WMO, Unesco, UNEP and FAO were perused, apart from publications in learned journals.

2.3 CONSULTATIONS AND DISCUSSIONS

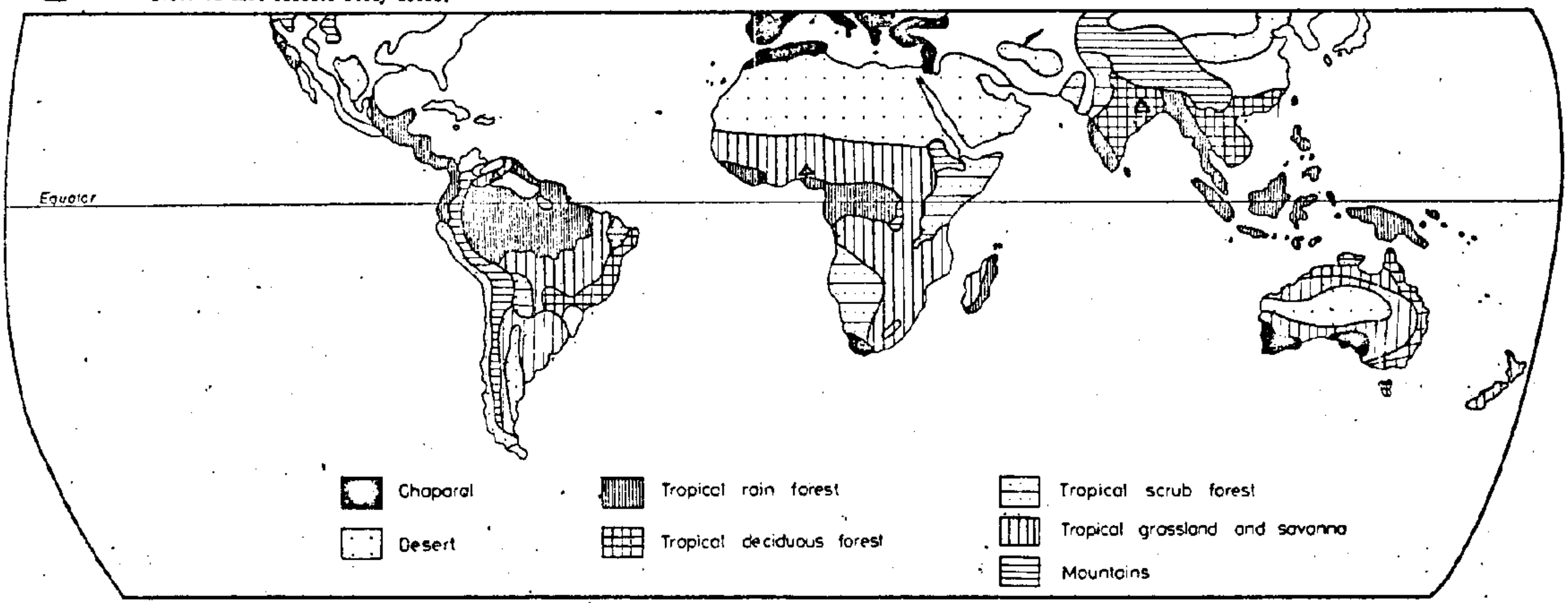
Consultations and discussions played a major part in the survey. Many individuals divulged their knowledge and opinions through personal interview and in writing.

During the course of the survey, the author was also able to attend the XVII IUFRO World Congress in September 1980 in Kyoto, Japan, and the Silver Jubilee Symposium of the International Society for Tropical Ecology at Bhopal, India, in October 1980. There was the opportunity to hold in-depth discussions with experts from different countries on the problem.

On the whole the inquiry was productive, even though some countries contributed much information, others virtually none. This, however, must be expected from this type of survey.

Fig. I - A map of the biomes of the World indicating the positions of the annually burnt grassland/Savannah in relation to other vegetation types. Africa has the largest land area affected by wildland fires.

△ - Selected fire Climate study sites.



3.1 VEGETATION AND LAND-USE PATTERNS

The classification systems of tropical climates employ distinct names for the predominant vegetation types in the different climatic regions of the tropics. The five general categories are savannas and other grassland (43% of the area); this is the most fire-susceptible vegetation type in the tropics and it is the largest in terms of size; broad-leaved evergreen forests (30%), this is the most fire-resistant vegetation type in the world, which however is being converted into other vegetative types at an alarming rate (Myers 1980). Other vegetation types in the tropics are the semi-deciduous forests and shrubs (11%); deciduous forests and shrubs (11%). These latter two types are described as fragile vegetation types by Frankworth and Golley (1978). The desert shrubs and grasses (7%) do not constitute much fire risk as the vegetation cover is extremely low and chances of fire are extremely low.

The fire susceptible savannas, which range from pure grass stands to tree savannas with trees and grasses comprise approximately 28% of the American tropics, 57% of the tropical Africa and 34% of tropical Asia and the Pacific (mostly in Australia), Eyre (1962).

The grass dominated savannas are found in areas with seasonal rainfall and pronounced dry season. Large tracts of tropical forests are being converted to savannas by shifting cultivation.

Golley and Leith (1972) give the mean annual increases in dry matter production of the tropical savannas as 7 tons per ha. with a range of 2-20 tons per ha.

Table 1 gives the major climatic regions of the tropics. The anually burnt savanna and the deciduous forest occupy approximately 2,430 million ha., about 50% of the total land area. The extent of annually burnt area in the tropics is therefore enormous. This figure excludes areas within the rain forest and forest region being systematically made fire prone through shifting cultivation practices.

Other vegetation types have the following dry matter production values in tons/ha. with the range in brackets; tropical rain-forest 20 (10-35); tropical deciduous forests 15 (6-35); temperate deciduous forests 10 (4-25) and croplands 6.5 (1-40) (Golley and Leith, 1972).

Land-Use Patterns

Table 2 indicates land-use patterns and population in the tropical zones of the world. The major occupation is farming, with 70-90% of the people on the land in rural areas. In spite of this the area of land cultivated in the tropics is very low, ranging from 5-27% of the total land area. Most of the uncultivated tropical land, therefore, lies under the categories of deserts, forest and wild savanna lands subjected to annual vegetation burning. According to Myers (1980) the farming systems of the tropics can be grouped into five major categories: shifting cultivation, covering 45% of the area; settled subsistence farming (17% of the area); nomadic herding (14%), livestock ranching (11%) and plantation systems (4%).

Shifting cultivation occurs usually in the least developed areas, and more than 250 million people depend on it as their means of subsistence.

A characteristic common to all forms of shifting cultivation is that farmers clear a patch of forest of virtually all its trees and then usually burn the wood (locally the larger logs may be sold). In the practice farmers follow a locally migratory way of life by virtue of rational agriculture: felling and burning a patch of forest, raising crops for 2 or 3 years until the soil has lost its fertility or

TABLE I: DISTRIBUTION OF MAJOR CLIMATIC REGIONS IN THE TROPICS BASED ON THE LANDSBERG-TROLL CLASSIFICATION (MILLION Ha.)

CLIMATE	HUMID MONTHS	PREDOMINANT VEGETATION	TROPICAL AMERICA	TROPICAL AFRICA	TROPICAL ASIA	TOTAL	PERCENT
Rainy	9.5 - 12	Rain-forest and forest	646	197	348	1191	24
Seasonal	4.5 - 9.5	Savanna or deciduous forest	802	1144	484	2430	49
Dry	2 - 4.5	Thorny shrubs and trees	84	486	201	771	16
Desert	0 - 2	Desert and semi-desert	25	304	229	558	11
TOTAL:	..	.. ..	1557	2131	1262	4950	100

SOURCE:- Sanches (1976).

TABLE 2 LAND-USE (MILLION Ha) AND POPULATION IN THE TROPICAL AREAS

TOTAL	TOTAL LAND AREA	CULTIVATED AREA	PASTURES AND MEADOWS	FORESTS	AREA CULTIVATED %	POPULATION (1969) MILLIONS	CULTIVATED AREA[a] PER CAPITA $
Tropical America	1,683	83	282	914	5	239	0.35
Tropical Africa	2,212	166	652	517	8	275	0.60
Tropical Asia and Pacific b	931	256	21	412	27	956	0.26
Tropics	4,826	505	955	1843	10	1470	0.34
World	13,392	1424	3001	4091	11	3647	0.41
Percent Tropics	36	35	32	46	-	40	-

SOURCE: Sanchez (1976)

(a) Annual and perennial crops

(b) Except Australia

Table 3 DISTRIBUTION OF SOILS IN THE TROPICS BY CLIMATIC REGIONS (MILLION Ha)

Soils Groups (Soil Taxonomy Equivalents)	Rainy (9.5 - 12)*	Seasonal (4.5-9.5)*	Dry and Desert	Total	Percent of Tropics
1. Highly weathered, leached soils (Oxisols, Ultisals Alfisols)	920	1540	51	2511	51
2. Dry sands and shallow soils, (Psmamments and lithic groups)	80	272	482	834	17
3. Light-cdoured, base-rich soils (Aridisols and aridic groups)	0	103	582	685	14
4. Allurial soils (Aquepts, Flurents and others)	146	192	28	366	7
5. Dark-coloured, base-rich soils (Vertisols Mollisols)	24	174	93	291	6
6. Moderately weathered and leached soils (Audepts Tropepts and others)	5	122	70	207	5
TOTAL AREA	1175	2403	1306	4894	100
PERCENT OF TROPICS ...	24	49	27	100	

Source: Sanchez (1976)

until weeds encroached, then moving on to repeat the process in another patch of forest, eventually returning to the original location. Initially the problem had no adverse effects on the local environment. Now, however, in many countries, the number of shifting cultivators has increased to a point where there are three or more times as many people per square kilometer as formerly, leading to a more intensive land-use which does not allow local ecosystems to recover. Soils then rapidly become exhausted, and fire susceptible grass dominated vegetation develops.

Shifting cultivation is practised all over the tropics; in West and Central Africa, the Amazon Basin, Central America and the hill slopes of South-east Asia.

3.2 CLIMATIC FEATURES

The semi-arid and sub-humid climates which predominate mainly in the tropics characterize the areas mostly susceptible to wildland fires.

The semi-arid climate can be sub-divided into three main types:

(a) the tropical savanna climate;

(b) the sub-tropical Mediterranean climate;

(c) the steppe climate.

3.2.1 Savanna Climate

The savanna climate which prevails in the largest part of the inter-tropical zone is warm throughout the year. During the dry season a recession of vegetative growth occurs. Perennial species shed their leaves and annuals die.

The mean annual temperature of the zone varies from 25-33°C.

Two main types of wind predominate the tropical savanna climate:

(a) seasonally dry tropic continental; and

(b) moist tropical maritime air, the trade winds and the monsoon.

The relative humidity in the zone varies from 86-90% during the wet season and 40-60% in the dry season. The ratio of potential evaporation to actual evaporation, that is $\frac{Ep}{P} \geq 1$.

The total annual rainfall is 500-1,500 mm per annum, with main two seasons and 6-8 dry months. The growing period extends from 4-6 months.

3.2.2 Sub-Tropical Mediterranean Climate

The sub-tropical Mediterranean climate by contrast has a mild but well-defined winter during which maximum rainfall occurs. The summer is typically hot and rainless, making the vegetation susceptible to fire effects. The Mediterranean climate does not cover very large areas, but is scattered around the world at the fringes between the tropical and the temperate.

3.2.3 Semi-Arid Climates

Semi-arid regions have characteristics even more variable than those of arid regions and thus it is difficult to define a single climatological group en-

Several climatological entities can be included under the pragmatic definition: the tropical savanna climate, the sub-tropical Mediterranean climate and the steppe climate.

Tables 4-6 give some aspects of the climates of the tropics in which wildland fires occur. The countries have a range of 3-5 months of negligible rainfall, during which the lowest humidity values are also recorded. The rainfall pattern is seasonal, most of which occurs in May-October, with a few exceptions like Peru, Sao Tome and Principe and Seychelles, which have their dry seasons between June and September. In some countries like Sudan and Nigeria, wildland fire zones have higher evapo-transpiration than the rainfall values, leading to annual water deficit experienced mostly during the dry or fire season. The dry season rainfall in these countries is generally low, some months are completely without rain.

The maximum temperature of most tropical countries is generally high, over 30°C throughout the year. In some countries values approaching 40°C are experienced.

It is clear that there is a favourable 'fire climate' in the tropics, especially during the dry season.

4.1 EXTENT AND ECONOMIC IMPORTANCE

According to Sanchez (1976) the savanna or deciduous forest (Table 1) covers 2,430 million ha. or 49% of the total land area of the tropical lands. In Africa alone it covers a strip of land over 5,000 km long and over 300 km wide. The percentage of savanna in different tropical countries also varies from less than 5% in Gabon to over 85% in neighbouring Nigeria.

Many workers have concluded that annual burning occurs in most tropical savanna vegetation Afolayan (1978). Lamotte (1975) in Africa, San Jose and Medina (1975) in South America. It is also believed that many savannas are fire climax vegetation types, Richards (1957) and West (1965).

4.2 REGIONAL REVIEW - AFRICA

In Africa, 15 countries responded to the questionnaire on wildland fires out of which seven countries (47%) in the continent provided an estimate of the extent as well as the economic losses (Table 7).

Two countries, Mauritius and Zambia, stated that wildland fires do not occur in their countries, while Sao Tome and Principe reported that less than 1 km^2 of the country is affected. Senegal had the largest area of land affected (among countries that provided estimates) - 2,324,575 km^2/year (1978/79) with about US $60,000,000 loss every year. The range therefore seems very wide within the continent, depending largely on the amount of wildland available for burning. In many countries, forest plantations are seriously affected by wildland fires.

4.3 MIDDLE EAST/ASIA

In this region three countries, Saudi Arabia, Hong Kong and Afghanistan, responded (Table 8). The area of land affected is relatively small, about 30 km^2 in Hong Kong with about $1,000,000 loss annually. Saudi Arabia provided an estimate of US $80 million loss from an area ½ km^2 in 1980! In Australia, thousands of kms of land and millions of dollars are involved.

Table 4 Rainfall Characteristics in Some Tropical Countries

Country	Station	Long.	Lat.	No. of Rainy Days	Months of No of negligible rainfall	Total Annual	Rainfall (mm) Rainy Season Total	Dry Season Total
Bahamas	New Province Island	77° 25'	25° 03'	141.7	Nov. - April	1,341.63	1,073.66	267.97
Cambia	George Town	13° 32'	14° 46'	66.68	Nov. - April	921.15	913.35	7.80
Kenya	Eldoret	00° 31°	35° 17'	-	Dec - March	1124.0	992.0	132.0
Kenya	Nanyuki	00° 01°	37° 04'	-	Dec - March	759.0	668.0	91.0
Nigeria	Borgu Game Reserve	09° 45'	10° 23'		Nov - March	1,100		
	Ibadan	03° 54'	07° 26'	114	Nov - March	1,337	1154.0	183.0
Peru	Ayabaca	79° 43'	4° 38'	-	July-Sept.	1141.6	1096.2	45.4
Sao Tome & Principe	Riodo Curo	6° 43'	0° 23'	97	June - Aug.	998.3	994.4	3.9
Seychelles	International Airport	4° 40'	55° 31'	200	June - Sept.	2324	1942.0	382
Sudan	Juba	31° 36'	04° 52'	108.2	Nov - March	988	978.0	10
Sudan	Wau	28° 01'	07° 42'	99.7	Nov - March	1174	1133	41

Table 5 - Evaporation and Potential Evapo-Transpiration Values in Some Tropical Countries

Country	Station	Long	Lat.	Evaporation (mm)		Potential Evapo-transpiration (mm)	
				Annual	Dry Season	Annual	Dry Season
Bahamas	New Province Island	77° 25'	25° 03'	-	-	-	-
Gambia	George Town	13° 32'	14° 46'	7.38	7.8	-	-
Kenya	Eldord	00° 32'	35° 17'	1555	628	-	-
Kenya	Nanyuki	00° 31'	37° 04'	1691	644	-	-
Nigeria	Borgu Game Reserve	09° 45'	10° 23'			1390.6	644.0
Peru	Ayabaca	79° 43'	4° 38'	-	-	-	-
Sao Tome & Principe	Riodo Coro	6° 43'	00° 23'	2.5	3.0	-	-
Seychelles	International Airport	4° 40'	55° 31'	6.1	7.1	-	-
Sudan	Juba	31° 36'	04° 52'	2336	1119	-	-
Sudan	Wau	28° 01'	07° 42'	2628	1590	-	-

Table 6 - **Relative Humidity and Wind Velocity Values in Some Tropical Countries**

Country	Station	Long.	Lat.	Relative Humidity % Mean Annual	Relative Humidity % Season Dry	Relative Humidity % Season Rainy	Wind Velocity Km/h Annual	Wind Velocity Km/h Season Dry	Wind Velocity Km/h Season Rainy
Bahamas	New Province Island	77° 25'	25° 03'	78.7	78.2	79.3	14.5	15.5	59.2
Gambia	George Town	13° 32'	14° 46'	56.0	42.6	70.68	30.49	27.8	106.0
Kenya	Eldoret	00° 32'	35° 17'	60.0	50.0	70.0	-	-	-
Kenya	Nanyuki	00° 31'	37° 04'	61.0	53.0	65.0	-	-	-
Nigeria	Borgu Game Reserve	09° 45'	10° 23'	59.66	43.88	70.92	3.39	3.07	6.21
Peru	Ayabaca	79° 43'	4° 38'	71.96	-	-	-	-	-
Sao Tome & Principe	Rio do Curo	6° 43'	00° 23'	75.0	72	80	8.2	14.0	-
Scychelles	International Airport	4° 40'	55° 31'	80.5	79	82	15.26	21.09	44.5
Sudan	Juba	31° 36'	04° 52'	60	48	72	4.0	4.0	175.0
Sudan	Wau	28° 01'	07° 42'	52.5	37	68	7	7	151.0

TABLE 7 - THE EXTENT AND ECONOMIC IMPORTANCE OF WILDLAND FIRES IN AFRICA

COUNTRY	AREA AFFECTED (in Km^2)	ECONOMIC LOSS in (US $)
Mali	200,000	-
Senegal	2,324,575	60 million
R. Central Africa	- No estimate	-
Mauritius	- Does not occur	-
Zambia	- " " "	-
Ghana	- No estimate	
S. Tome and Principe	Less than 1 km^2	Negligible
Mozambique	Unknown	Incalculable
Malawi	50,100	Unknown
Seychelles	-	-
Sudan	-	-
Kenya	150 km^2	670,000
Upper Volta	-	-
Tanzania	650	3,600,000
Gambia	-	-
Nigeria	Not less than 400,000	Incalculable

TABLE: 8 **THE EXTENT AND ECONOMIC IMPORTANCE OF WILDLAND FIRES IN S. E. ASIA AND AUSTRALIA**

Country	Average Annual Area of Land burnt (Km^2)	Annual Loss In US $
Hong Kong	30	1,000,000
Saudi Arabia	0.5	86,000,000
Australia	'Thousands'	'Millions'

4.4 CENTRAL AND SOUTH AMERICA

Colombia reported the largest area under annual wildland fires 380,200 km^2 in the region without giving the financial losses (Table 9). In Suriname the area of land affected varied every year: in 1964, for instance, 5,000 km^2 of land was affected costing about US $250,000 per annum and in 1974 it was only 7 km^2 of land that experienced the phenomenon and the cost then was $100,000 (only for vegetation loss). Argentina recorded the highest loss economically in the area, about US $62.2 million per 594.4 km^2, representing over US $10,000 per km^2 per annum, followed by Chile which had US $30 million loss per annum from a burnt area of 300 km^2. In the Bahamas less than 1 km^2 of land is burnt annually, while in Costa Rica no annual wildland fire is experienced.

This survey does not provide a full analysis of the extent and importance of wildland fires in the tropics due mainly to the relatively low response and lack of detailed studies of the problems in countries that responded. A more detailed direct assessment of the extent and importance of wildland fires in the tropics would be useful.

An assessment of the economic importance of preventing the destruction of farmlands, plantations and houses in some cases through burning (i.e. protection of life and property) could also be made.

4.5 SEASONALITY OF OCCURRENCE

In countries that reported that they experience wildland fires, most stated that the phenomenon is confined to the dry season period and is usually associated with drought.

Suriname, however, reported that wildland fires are not annual occurrences. However, these occur at a periodicity of 12-14 years during intensive and extended dry seasons, for instance, when the absence of the short rainy season generally results in an extended dry period from mid-August to end of April.

In Peru wildland fires are reported throughout the year. Thus the season of wildland fire occurrence varies throughout the tropics.

TABLE: 9 - EXTENT AND ECONOMIC IMPORTANCE OF WILDLAND FIRES IN LATIN AMERICA

COUNTRY	AREA AFFECTED (IN Km^2)	ECONOMIC LOSS (in US $)
Colombia (Amazonia)	380,200	Not Obtainable
Suriname	5,000	250,000
Bahamas	Less than 1 km^2	-
Domrnican Rep.	0	
Chile	300	30 million
Argentina	594.4	62.2 million
Costa Rica	-	No wild fire
El Salvador	10	Not available

5.1 FIRE WEATHER IN THE TROPICS

All savannas burn repeatedly at intervals varying from a few months to several years, and the great majority of them burn at least once every year or two years. The main period of burning is during the last half of the 'dry season' or during short rainless intervals. The dry season climate and period vary from country to country. Fires occur in wildland vegetation types when the weather condition has brought about a sufficient quantity of fuel to a dry and flammable state. Tropical savannas are said to be the result of a particular climate. This climate is defined by Koppen (1931) as tropical wet and dry or savanna climate. The key operative factor in the savanna climate is the constantly high temperature throughout the year, with alternation of a very rainy season and a prolonged, almost completely rainless season. During the dry season a strong water deficit prevails with rainfall much lower than potential evapotranspiration. Major fires in the tropics occur under these prevailing climatic conditions. In order to be able to develop a system for predicting the occurrence of fire in the tropics, it is necessary to give further details of these weather variables as obtaining in the different ecological zones of the tropics. This is also necessary because the 'dry season' period during which fires are generally expected have different characteristics and calendar months in different zones, particularly in the tropics.

5.2.1 Africa

Ivory Coast: The fire weather of some savanna types in Africa have been described (Lamotte 1975). (Lat. 6° 13'N, Long. 5° 02'W), the mean monthly temperatures are remarkably constant.

There is also lack of variation in the mean daily temperature, which fluctuates between 24° and 30°C in the dry season and between 25° and 28°C in the wet season. The diurnal variation in temperature is high, the minimum temperature does not go below 16°C nor the maximum 34°C. The maximum variation 18°C occurs during the dry season (December-January), the minimum variation 8°C occurs during the wet season (July-August).

Rain is a predominant environmental factor. Annual rainfall averages 1,300 mm but may be as low as 900 mm and as high as 1,700 mm. A strong difference exists between the dry season which generally lasts from November or December to the end of February and the rainy season of more than eight months, which may be interrupted in August by a short dry season.

5.2.2 Zaire

The fire weather climate of annually burnt 'miombo' ecosystem - savanna (woodland/savanna) has been described by Malaisse et al. (1975). It is characterized by one rainy season (November to March) one dry season (May to September) and two transition months (October and April). July and August are always without rain. Total rainfall is about 1,270 mm with a range of 895 to 1,551 mm for the period 1918-1970. The average yearly temperature is about 20°C. Temperature is lowest at the beginning of the dry season. September, October and sometimes November are the warmest months. The mean yearly solar radiation is 16.8 x 10^9 kcal/ha/yr. The minimum mean daily radiation occurs during the rainy season due to the high cloudiness 394 cal/cm^2/day in December and increases progressively until May. The maximum occurs during the warm dry season 533 cal/cm^2/day in September.

In the environs of Lubumbashi 'bush' or wildland fires are most common in September-November, especially September, the peak of the dry season, when maximum temperature and solar radiation are experienced.

During August-September, maximum litter fall averaging approximately 100g/m^2 is available for combustion. The occurrence of fire can therefore be predicted from the month of September. The weather conditions that influence such behaviour are, therefore, predictable.

5.2.3 Nigeria

The phenomenon of annual natural and artificial burning has been well studied in Nigeria's Kainji Lake National Park, similarly the fire-weather climate of the area has also been defined, with the view of determining the time and frequency of burning. These problems have been confronting the management and research workers of the Park for a long time (Afolayan 1978).

Borgu section of the Park is the largest developed wildlife reserve in Nigeria. It occupies an area of about 4,000 km^2 which lies between latitudes 9° 45'N and 10° 23'N and between longitudes 3° 40'E and 4° 32'E. The Park receives (mainly between April and October) a total annual rainfall of 1,000-1,200 mm. The hottest months are March and April when the maximum temperature reaches about 34°C, while the coldest months are December and January during the harmattan period. The relative humidities are lowest between November and March, when values at 1500 hours fall as low as 2%, especially in February.

Monthly estimates of the potential evapotranspiration for the area varies between 70-175 mm. The highest values occur late in the dry season during March and April while the lowest values occur during August and September, the cloudiest period of the year. Estimated total annual evapotranspiration for the area is about 1,500 mm, which is higher than the annual rainfall.

Scanty information is available on wind movements in the area. The harmattan winds prevail in the area from mid-November to mid-February. The wind speed is highest during the beginning of the rainy season when it reaches over 6 km/hr. The distinct wet and dry seasons have effects on the quantity and quality of plant growth.

At the beginning of the wet season (in May) grass growth is linear for three to four months, reaching a peak in September to October when the rains begin to stop. Thus with the onset of the north-east dessicating harmattan winds in November fire susceptibility increases. Indeed, the early man-induced burning occurs from this period. It is, however, in January-February when the relative humidity is at its lowest (up to 20%) and temperature and potential evaporation are at their highest in February/March that the highest fire risks occur.

5.3 ASIA

Udaipur - India

Grasslands are found in extensive patches all over India forming important aspects of the natural vegetation. The weather fire of Udaipur area of India (Latitude 24° 35'N and Longitude 75° 49'E) has received some attention, Shrimal and Vyas (1975). The climate of the area is monsoonal. The area receives a mean annual rainfall of 660 mm distributed over 41 rainy days. Most of the rainfall (92%) is received during the rainy season, which extends from the middle of June to September. Mean maximum temperature varies from 24.3°C (January) to 38.6°C (May), while the mean minimum temperature varies from 17° (January) to 25.4°C (June).

The vegetation is composed of 17 species of flowering plants, including eight species of grasses, four species of legumes, and five species of other herbs. On the basis of cover and density, the grassland community is dominated by Heteropogon contortus and Dichonthium annulatum.

In the study area plant biomass increases from June to September following the rainfall pattern. In September most of the species reach maturity and start dying, causing a decline in the biomass from the month of October. The total biomass was found to vary from 103 in May to 240 g/m^2 in September in the fire unprotected land and from 102 in May to 204 g/m^2 in September in the protected one. There is a steady accumulation of litter from the month of September and in November and December the amount of litter exceeds that of the green and non-green biomass combined. There is a correlation between the pattern of rainfall and plant biomass. Negligible rainfall during winter and summer months limits production through soil moisture deficit. A decrease in biomass after September is the result of the normal decline following maturity with the approach of dry season. The negative values of net production obtained in the dry months show that in these months growth is very little as compared to the losses from respiration drying and withering owing to dry, hot conditions. The conditions for vegetation burning are therefore ripe during these dry months of January to May, when maximum temperatures reach as high as 38.6°C and maximum dry combustible material is available.

Therefore, from the climatic and vegetation characteristics it is also possible to predict when bush fires or wildland fires are most likely to occur in such environments as here described.

5.4 LATIN AMERICA

The tropical Latin American fire climate also supports an annual burnt savanna vegetation in extensive areas. This climate is defined by Koppen (1931) as a tropical wet and dry or savanna climate. The key operative factor (similar to those of the African and Asian climates) is the constantly high temperature throughout the year with alternation of a very rainy season and a prolonged almost completely rainless season. During the rainy season a large water surplus occurs (Thornthwaite 1948) while during the rainless season a strong water deficit prevails with rainfall much lower than potential evapotranspiration.

Studies of the fire weather characteristics at Calabozo, Venezuela (Latitude 8° 56' and Longitude 67° 25'W) have been done (San Jose and Medina 1975). The average rainfall in Calabozo is 1,334 mm, but is highly variable 580 mm to 1,990 mm falling mainly between April and November. The highest temperature and lowest humidity and least rainfall are observed during December to March, especially in March. Evapotranspiration is also highest during the period.

In addition the workers observed that soil-water content is highly correlated with rainfall. The least values of soil-water content of less than 100 litres/m^2 in a column of 0.7 m^2 was observed during March when there was hardly any rainfall. Peak values of living above ground biomass 415 g/m^2 in a burnt plot and 325 g/m^2 in an unburnt plot occurred between July and August with decrease in soil-water content from October, decrease in plant production was observed, also in relation to a decrease on transpiration rate. From October onwards the leaves dry out as the water reserves are exhausted or limited and other domestic parameters like high temperature and low humidity prevail.

Fire, whether natural or man-induced, at the mid dry season period is therefore most likely to occur and can be predicted, when accumulated litter was at its peak.

5.5 CAUSES OF TROPICAL WILDLAND FIRES

The determination of causes of wildland fires could also assist in the development of a system of predicting fire occurrences in the tropics. As stated by Reifsnyder (1978) the physical laws that control the behaviours of wildland fires are the same everywhere on Earth, what varies is the relative importance of natural and man-made fires in the tropics. For a long time fire has been an important factor in the management of tropical habitats of domestic and wild animals. The land-use system of the tropics is confined to agriculture and grazing. Shifting cultivation is the main type of agriculture practised while grass vegetation is developed for livestock rearing, especially of cattle, sheep and goats. In both systems, fire is an important tool of land management. Similarly many wildlife rangers in the tropics use fire annually to improve the quality and quantity of grass in the habitats. Fire is also used to manage water catchment areas and to dispose of refuse in the tropics. Although there are no statistical data to evaluate the causes of wildland fires in the tropics, it is certain that over 90% of the fire is caused by man. Fire occurrence during the 'fire' or dry season as a result of lightning in the tropics is very rare.

6.1 DEVELOPMENT OF FOREST FIRE WEATHER FORECASTING

Fire Weather Elements

Properly standardized weather observations taken daily and at locations where readings are not seriously affected by unrepresentative features (e.g. rock outcrops, small bodies of water, etc.) are effective predictors of daily fire potential, or Fire Weather Index.

According to Turner and Lawson (1978) the weather elements needed for Fire Weather Index calculations are those that influence (i) the ease with which fires can be started, (ii) the rate of spread and difficulty of control of fires which are burning, and (iii) the effects of fire on the environment.

6.1.1 Precipitation

Precipitation (rain-fall) is one of the elements of weather used to predict fire occurrences, because of its direct relationships with fuel moisture content within wildlands or forest stands.

In the tropics, where there is a well-defined fire season that is a period of low or no precipitation, the date of the last rainfall would have relationship on aspects of the moisture content of the available combustible fuel. The number of rainy days in the tropics is usually short, while the number of rainless days, especially in the dry season, is considerably long. It is therefore feasible to record the possibility of a wildland fire starting when caused by an ignition source. Fine dry fuels also respond to changes in ambient temperature and humidity conditions.

6.1.2 Temperature

Although there may be little or no rain for a fairly long period, other climatic factors like high humidity and low temperatures may delay or prevent fine fuel ignition. The climates of the tropics (Tables 4–6) however, indicate that during the dry or fire season, the highest temperatures and lowest relative humidity values are recorded. After the effects of rain have been overcome, temperature and relative humidity and wind speed have direct effects on the moisture content of the fine fuel of plant materials (Van Wagner 1974).

The drying factor is required for the prediction of a fire-danger index. Temperature affects the evapotranspiration process, it therefore speeds up the rate at which dry combustible plant matter is made available for ignition.

6.1.3 Relative Humidity

Relative humidity has been used for long periods in temperate countries to give a quick assessment of the degree of fire danger. Air relative humidity calculated at noon has influence on the state of the dryness of available combustible plant matter. In addition to temperature and wind speed relative humidity has influences on the fire weather.

6.1.4 Wind Speed

Fire weather index is also influenced by wind speed by affecting the rate of drying of the combustible fuel and the rate of spread of the fire, which is also influenced by the moisture content of the fire-susceptible fuels.

6.2 PROBLEMS WITH OBSERVATION

Most tropical countries (from this study) have inadequate personnel and equipment to monitor fire climates, consequently over 80% of the countries do not have meteorological observations recorded in the areas where wildland fires occur. Most of these countries also reported that their meteorological services do not prepare forecasts of fire-weather elements or provide fire-weather services. The reasons given for this include scant networks; communication problems; lack of experience and basic studies, lack of instruments, etc. In most of these countries there is little or no economic analysis of the losses due to fire which could serve as a basis for deciding on making studies and providing a forecast service. The responses from these tropical countries did not indicate lack of meteorological stations in their countries, indeed all the countries have been making meteorological observations for decades. The real problem therefore involves the lack of knowledge of the application of meteorological data to predict wildland fires in this region.

The replies also indicate the lack of adequate synoptic weather stations for monitoring fire weather in different parts of a country.

The size of an area which a single fire-weather station can reliably represent varies considerably. A range of 40-100 km^2 has been mentioned by Williams (1963) and Lawson (1972).

There is no simple rule for choosing the location for fire-weather station (Turner and Lawson 1978). Until suitable automatic fire-weather stations are available, weather stations will be located where people can attend to them daily and on time. Each station should, however, be located where it can best represent the area it is intended to cover.

Other factors apart from distance have effects on the reliability of a particular station. Elevation, for instance, can be more important in limiting the area represented by any given station in an uneven terrain.

Hayes (1941) investigated the influence of elevation and aspect on fire danger. He recognized and described three elevation zones with different degrees of fire danger. He attributed these zones to the diurnal influences associated with elevation and aspect.

Fosberg and Furman (1973) calculated the minimum size of an average station spacing in the south-west of the U.S.A. In this zone forest climatic stations are approximately 50 km apart and the fire climate areas being monitored are about 40,000 km^2. The time when observations are taken is also important. It ranges from 12 noon to 5 p.m. (Turner and Lawson 1978).

It is necessary to standardize observing practices as much as possible if effective management decisions are to be based on the results. These standards are essential for relatively permanent fire-weather stations which are part of a regional network, designed to be used for future calibration studies.

6.3 THE IMPORTANCE OF A FIRE DANGER INDEX

The Fire Danger Index is intended to take the place of that experience and judgment by which the seasoned forester is able to "size up" the effect of all these items and estimate the prevailing fire danger. The Danger Index does, however, assist the protection service in the following ways:

1. It sums up in a single figure the effects of more changeable and hard-to-estimate items of fire danger. It is therefore of particular use to junior personnel, but should serve as a check on personal judgment in any case.

2. Because it takes the same items into account in the same way, it gives the same results when used by different people. This is by no means true of personal estimates even among experienced men.

3. It provides a consistent scale of fire danger on which plans for fire-control action may be built up within a district, a region, or a whole province, on a comparable basis.

4. It permits comparisons of the severity of fire seasons in different regions or in different years.

5. It supplies a consistent method of making fire danger forecasts when weather forecasts are available.

6. Records taken over a period of years provide an impartial basis for comparing fire-control effectiveness in different regions, or in the same region in successive years. Such records may some day be necessary for calculating insurance risks on standing timber.

6.4 THE FIRE DANGER INDEX AND ITS USES

'Fire danger' includes all the items which determine whether fires will start, spread and do damage, and how difficult they will be to control.

The Fire Danger Index takes into account each day, for a particular area as a whole, the following:

(a) The kinds of burnable material, or fuels, in the region;

(b) The effect of wind on the behaviour of fires;

(c) Seasonal changes in the length of the day and the development and withering of leaves, plants and the grasses.

A Fire Hazard Index may also be worked out for particular forest types. The Index takes into account the amount and natures of fuels in those types only and the amount of moisture they contain. If required, this Hazard Index may be adjusted to include the effect of wind on fire behaviour.

7. FIRE DANGER FORECASTS

7.1 HOW TO FORECAST FIRE DANGER FROM WEATHER FORECASTS

(a) If the weather forecast for tomorrow gives actual values of the expected wind, temperature and relative humidity, these figures may be used in the Dry Weather Tables to work out the expected Tracer Index for tomorrow, today's Tracer Index being used as the Starting Index. The amount of water or moisture contained in the uppermost layer of dead leaves, grass and twigs on the forest floor, in which most fires start and spread is shown by the Tracer Index. The figures should be treated as though they were 2 p.m. weather readings. The expected Danger Index can then be worked out.

(b) If the weather forecast does not include figures, but describes the expected weather in such terms as light winds, moderately warm with low humidity, change these terms into actual values by means of tables. Then work out the Tracer Index and Danger Index.

(c) If the weather forecast covers more than one day ahead, the same method may be used to forecast the Danger Index for as many days as the weather forecast will allow.

(d) If rain is forecast with such terms as 'possibly', 'probably', 'scattered', 'local', etc., it is safest to overlook the rain in preparing the Fire Danger Forecast. When rain is definitely predicted low or nil, Danger may be expected. For details see Reifsnyder (1978).

7.2 FIRE DANGER RATING SYSTEMS IN OTHER PARTS OF THE WORLD

In many temperate countries, various fire-danger-rating systems have been developed specifically for each locality or country. Reifsnyder (1978) has proposed a Universal System of Fire Danger Rating and Fire Weather Forecasting, based mainly on the United States System. This National Fire Danger Rating System, based on the work of Deeming et al. (1974) is hereby described (Figure 2). It has seven levels, as follows:

Level 1: Ignition. An ignition index indicates the ease with which fine fuels can be ignited from a simple ignition source such as a match, cigarette, or lightning strike. It can be used by the forest manager as a measure of the liklihood that wildland fires would start accidently from the activities of man in wildland areas.

Level 2: Occurrence. The occurrence index is defined as a number related to the potential fire incidence within a specific area. It is related to the number of potential ignition sources within the area and to the ignition index. It gives the forest manager an indication of the relative number of fires that may occur in the rated area. It can be used, for example, as a guide to the level of detection services required.

Level 3: Spread Index. A spread index predicts the forward rate of spread of a fire in a particular fuel type when subjected to specific meteorological conditions. It can be used as a guide to estimate the time that deliberately set controlled fires will take to cover the area within a controlled burn. It can be used to estimate the speed with which control lines must be built in order to contain a fire.

Level 4: Energy release. The energy release index, as its name implies, indicates the combustion rate and heat output in a given fuel type for a given complex of fuel-moisture contents. It indicates how close to the fire edge fire-control crews can work and thus may be used as a single effective attack method.

Level 5: Burning Index. The burning index is defined as a number related to the contribution that fire behaviour makes to the potential amount of effort needed to contain a fire in a particular fuel type within a rating area. It can thus be used to estimate the number of fire-control personnel, kind and quantity of suppression equipment and so forth.

Level 6: Fire Load. The fire-load index, combining the burning index and the occurrence index, indicates the potential fire-control job that may be faced by a forest manager in an area on a particular day. It provides an indication of the likely total fire-suppression effort required in an area to meet the stated forest-management objectives.

Level 7: Seasonal Severity. The seasonal severity index is a seasonal summation of fire-load indices and is useful as an administrative tool for apportioning suppression forces and services among various units of a wildland area.

7.3 FIRE-WEATHER FORECASTING SERVICES

Reifsnyder (1978) also recommended a hierachy of fire-weather services. This also seems adaptable to tropical conditions. There are three levels in the systems:

Level 1: Fire-weather warnings.

At the very minimum, a weather forecast office that has responsibility for fire-weather services should be prepared to issue forecasts of dry and/or windy conditions that may occur during fire seasons. Depending on the arrangement with the forestry service, these warnings can be issued to the public or communicated directly to the forestry organization or both.

Liaison must be established between the forecast criteria, modes of communication and so forth. In general, such forecasts will be prepared by the regular forecasting staff.

Level 2: Fire-danger-forecasts

If a forest-fire service has an operational fire-danger-rating system, the forecast office may be charged with the responsibility of either forecasting the danger rating directly or forecasting the specific weather elements that are used in calculating the fire-danger rating. These forecasts may be prepared either by the regular shift forecaster or by the forecasters of a special fire-weather unit. In the former case, shift forecasters should receive some special requirements of the fire services. Forecasts of other meteorological elements important in determining the severity of wildland fires may also be required. These elements may include lightning, winds, frontal passages and so forth. Special forecasts may also be required for specific fires or for controlled burns. Close collaboration between the forecasting unit and the forest-fire services is required.

Level 3: On-site Forecast Services

A forestry organization that has a highly developed fire-control organization may require the services of a fire-weather unit operating at the site of existing fires or of planned controlled burns. Fire-weather forecasters with special training may take mobile observation and forecast units into field to operate with the forest officials managing control operations on large fires, whether planned or wild. This requires a forecasting unit with special training and skills in forecasting local winds and other local phenomena important in fire behaviour and fire control, as well as the forecasting of routine meteorological events. Specialized communications and observing equipment are necessary, mounted on mobile offices which can be towed or driven to a fire site. Personnel associated with such units will normally have routine fire-weather-forecasting duties as well and will frequently engage in research on fire-weather forecasting during non-fire seasons.

7.4 FIRE WEATHER AND FIRE DANGER FORECASTING IN CANADA

Weather forecast services are provided in Canada at several levels. Turner and Lawson (1978) suggested that meteorological personnel should form an integral part of the fire control organization.

Sophisticated computer technology is used to provide weather outlooks for several days ahead. Although lacking in detail, the forecasts could still be used as planning guides. The direct contact between the meteorologist and fire control officer ensures that the former is kept informed of changing weather requirements as they develop, and the fire control officer could then request specific details of forecast information.

Six components make up the Canadian Fire Weather Index:

1. Fine Fuel Moisture Code (FFMC) is a numerical rating of moisture content of litter and other cured fine fuels in a forest stand.

2. Duff Moisture Code (DMC) represents moisture content of loosely compacted organic (duff) layers of moderate depth.

3. Drought Code (DC) represents moisture content of deep compact organic layers.

4. Initial Spread Index (ISI), a combination of wind speed and FFMC, representing fire spread rate without the influence of variable fuel quantity.

5. Build-up Index (BUI), a combination of DMC and DC that represents total amount of fuel available to the spreading fire.

6. Fire Weather Index (FWI), a combination of ISI and BUI that represents the intensity of a spreading fire energy output rate per unit length of fire front. Detailed descriptions of all FWI components are provided by Van Wagner (1974a).

One basic value of the Fire Weather Index is calculated per day, to represent fire danger conditions during the mid-afternoon peak period, assuming a normal diurnal pattern. For a rainy day, calculation of the various codes has been standardized by first taking into account the effect of rain, followed by the appropriate degree of drying.

Routine calculation of the FWI, with its component codes and indices is normally performed daily for the regional fire weather network using a computer programme (Van Wagner and Picket 1975).

8. SUMMARY

Wildland fires are experienced in most tropical countries which enjoy clearly marked wet and dry seasons during the year. Although wildland fires are very extensive in these areas covering about 50% of the tropical land, the huge economic losses due to the problem have not been fully assessed in most countries. Thus the significance of the problem has not been properly brought up for adequate government action in these countries.

Wildland fires, initiated mainly by man in the tropics is largely uncontrolled, due to lack of adequate fire-fighting equipment and in many cases there is no real desire to control the fire. The damages from such fire to forest plantations, farmlands and houses are extremely high.

Prediction of wildland fires is almost non-existent; while synoptic meteorological stations are inadequate, the data collected are not processed and utilized for making fire danger forecasts even where this is feasible. This is due mainly to the lack of knowledge of the application of meteorology to solving the problem.

A study of the existing fire danger forecasting and rating systems in the United States, Canada and Australia indicate that the physical laws that control the behaviour of wildland fires are the same as those of the tropics. It is therefore feasible to develop systems for fire danger forecasts and ratings in the tropics.

It will, however, be necessary first to develop the weather stations in the tropical countries up to the level where data collected would be reliable and sufficiently detailed to be used in predictive models for these regions. In addition to the provision of standard equipment, manned by well-trained staff, it will be necessary to have the operation of various governmental agencies, like the

Departments of Meteorology, Forestry and Communications, to bring about a successful fire danger control system.

At the international level, United Nations agencies like WMO, UNEP, FAO and Unesco should organize courses, seminars, workshops, etc., for relevant personnel in the tropics to make wildland fire control possible, particularly in the tropics.

9. PROPOSALS FOR FUTURE WORK

There is a great potential for the development of forest fire-weather forecasting and fire-danger rating systems in the tropics. Before this could be realized, however, certain measures would have to be taken.

9.1 LEVEL OF AWARENESS

The level of awareness of the danger posed by the indiscriminate use of fire in the tropics is extremely low, especially from the environmental viewpoint. There is an urgent need to inform the people through formal and informal educational systems the dangers associated with bush-burning. It is also pertinent to assess economic losses in each country associated with the problem. The present study has revealed that in many countries no such studies have been carried out, consequently very little knowledge is available of the extent of damage to lives and property as a result of wildland fires. This is a pre-requisite to the improvement of the level of awareness of the dangers associated with wildland fires.

9.2 IMPROVEMENT OF METEOROLOGICAL AND FORECASTING SERVICES

It would be necessary to establish in each country a network of specialized fire-weather observing stations, where a network of standard weather observing stations in protected areas is sparse or non-existent. These will generally be installed and serviced by the National Meteorological service but operated by the National Forestry service. The observing practices are the WMO Guide to Meteorological Instrument and Observing Practices.

9.3 TRAINING AND TECHNICAL ASSISTANCE

The operation of forest fire weather stations, as well as the systems for predicting fire danger, is a highly technical service requiring adequate training of personnel to be effective.

Training of meteorological staff could be done at local or international level depending upon the facilities available in each tropical country.

Before embarking on training programmes for the development of sound systems for evaluating and predicting wildland fires, it would be necessary to first carry out a survey of staff requirements necessary for the successful implementation of the programme. A systematic training programme could then be embarked upon.

It is certain that various tropical countries would benefit from such training programmes if organized and co-ordinated by the World Meteorological Organization in conjunction with other United Nations agencies. Experts could be sent to these countries or in the alternative co-ordinated regional training programmes could be worked out.

9.4 INTER-DEPARTMENTAL CO-OPERATION

The success of a forest-fire predicting system depends a great deal on the co-operation at local level between various related inter-disciplines. In many tropical countries such disciplines work in isolation. For example, many tropical countries in their response to our questionnaires stated that their Meteorological Services do not provide fire-weather forecasts, while many others also stated that the forestry sector does not request for such services, and the forecasts are, therefore, either not made or broadcast to appropriate users. This is a local problem that can be solved through the integration of various projects in the agro-meteorological divisions of the Departments of Meteorology and Agriculture.

9.5 COMMUNICATION

In order to make effective forest fire weather forecasts an efficient communication system would have to be developed in affected countries. The most effective communication system in the tropics is the radio system; especially with the development of wireless transistor radios.

The telephone system of the tropics, when fully developed, would also improve communication between producers and users of fire-weather forecasts.

The telegraphic system or tele-types would provide hard data which could also be communicated and stored by officials in separate offices, and retrieved when necessary.

9.6 RESEARCH AND DEVELOPMENT

In the tropics there are various research institutes and universities carrying out various ecological research activities related to vegetation/wildlife management and fire. Very few of such studies are related to the development of predictive models for wildland fires. The attention of these institutions needs to be drawn to the gap in knowledge in this field in the tropics. Thus, whether on the level of individual researcher or that of an institution at national level, there is a great potential for wildland fire studies in the tropics, especially from the meteorological viewpoint.

It is only at this level that models for evaluating and predicting forest/wildland fires could be developed before they are adapted by the locality or the country. Already this study, as well as that of Reifsnyder (1978) has indicated the feasibility of such studies in the tropics and universally.

The development of a "research attitude" by forecasters has been stressed by Reifsnyder. This is necessary in obtaining any relevant information about the problem from any source.

A higher level of organization by various United Nations agencies particularly WMO, UNEP, FAO and Unesco to tackle this problem in the tropics is also long overdue. It seems in fact that these agencies, in many cases, would have to initiate the development of these systems in the tropics before handing over to the countries concerned. Tropical countries with sufficient knowledge of the problem and adequate infrastructure could establish their own systems without waiting to be prompted by an outside body.

APPENDIX 1

WEATHER STATIONS

In general, Fire Weather Station standards conform to those recommended by the World Meteorological Organization for agrometeorological observations in forest areas (WMO 1968).

1. Location Standards

Fire weather station should be:

(i) located where it represents topography, vegetation and local weather patterns of the general area of concern. Avoid sheltered valleys and exposed peaks and ridge tops. Level or nearly level ground is preferred. Avoid north and east exposures (aspects) and concave or dish-shaped topography;

(ii) located at centre of forest clearing with diameter at least ten times the height of surrounding timber;

(iii) at least 100m from any water source;

(iv) at least 10m or twice the height of the object away from reflecting and radiating surfaces, such as parking lots or white buildings;

(v) at least a distance equal to 1.5 times the height of the object away from any large building, tree or dense vegetation;

(vi) at least 5m from any road;

(vii) at least 50m from any source of dust;

(viii) located windward of any of the above features;

(ix) fended with open pole or wire fencing not higher than 1.2m.

2. Instrument Exposure Standards

(a) Wet and dry bulb thermometers must be ventilated.

(b) These thermometers, together with maximum thermometers if used, must be mounted in a Stevenson-type screen. The screen should be:

(i) wooden, double louvered sides, double roof;

(ii) painted white;

(iii) rigidly mounted on wooden framework with floor 115cm above ground and door, facing north.

3. Recording instruments, such as hygrothermohydrographs, should be in a separate screen from the thermometers.

4. Precipitation gauges must be:

(i) rigidly mounted at current height for specific gauge;

(ii) level;

(iii) not closer to any obstruction than twice the height of the object.

5. Wind should be measured with anemometer exposed as follows:

(i) 10m above open level ground, if nearest timber edge is at least five times the height of the timber away from the anemometer mast;

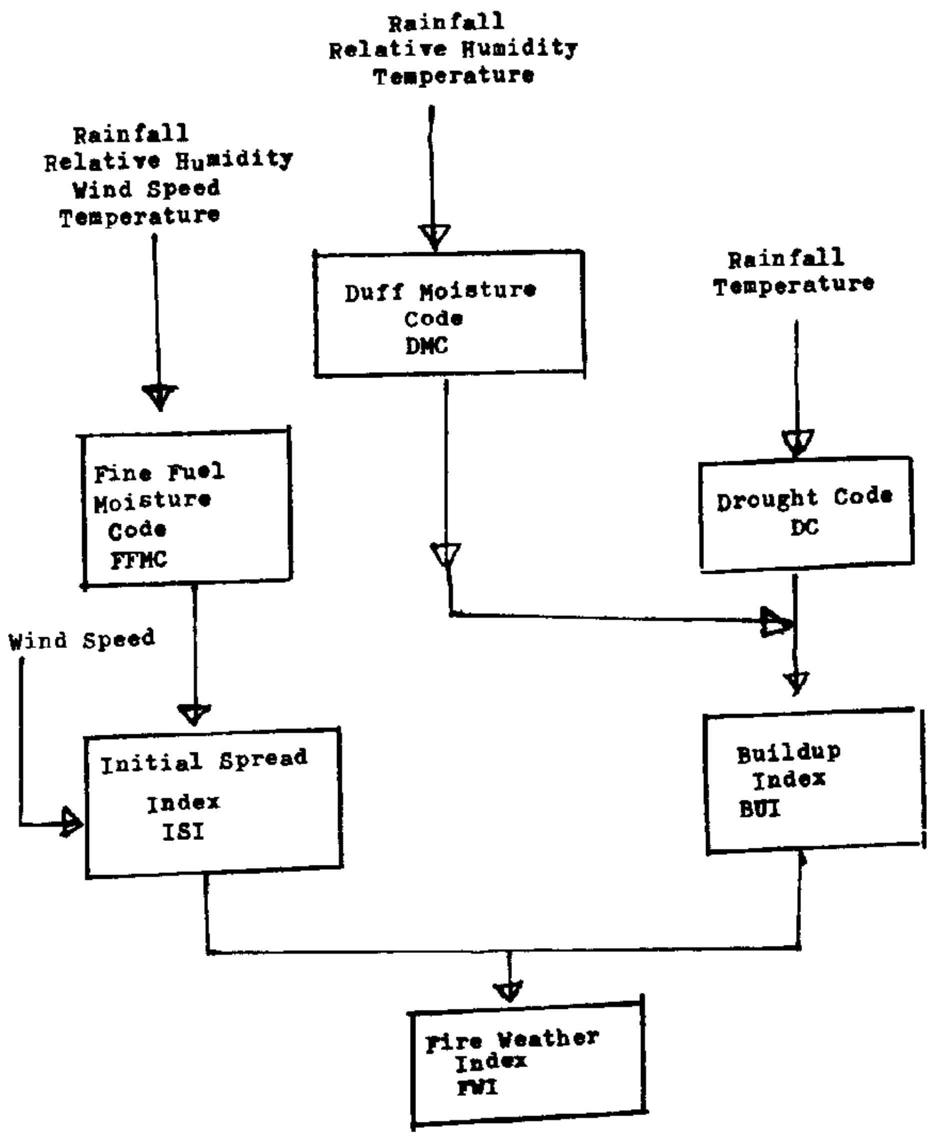
(ii) 10m above average treetop level in a forest stand if no clearing is available;

(iii) if smaller clearings than specified in (i) are used, anemometer masts should be raised above the 10m standard;

(iv) if anemometer site is not on open level ground, irregularities like brush, slash, hummocks, should be corrected for by mast height.

APPENDIX 2

Components of the Canadian
Forest Fire Weather Index



Source: Turner and Lawson (1978)

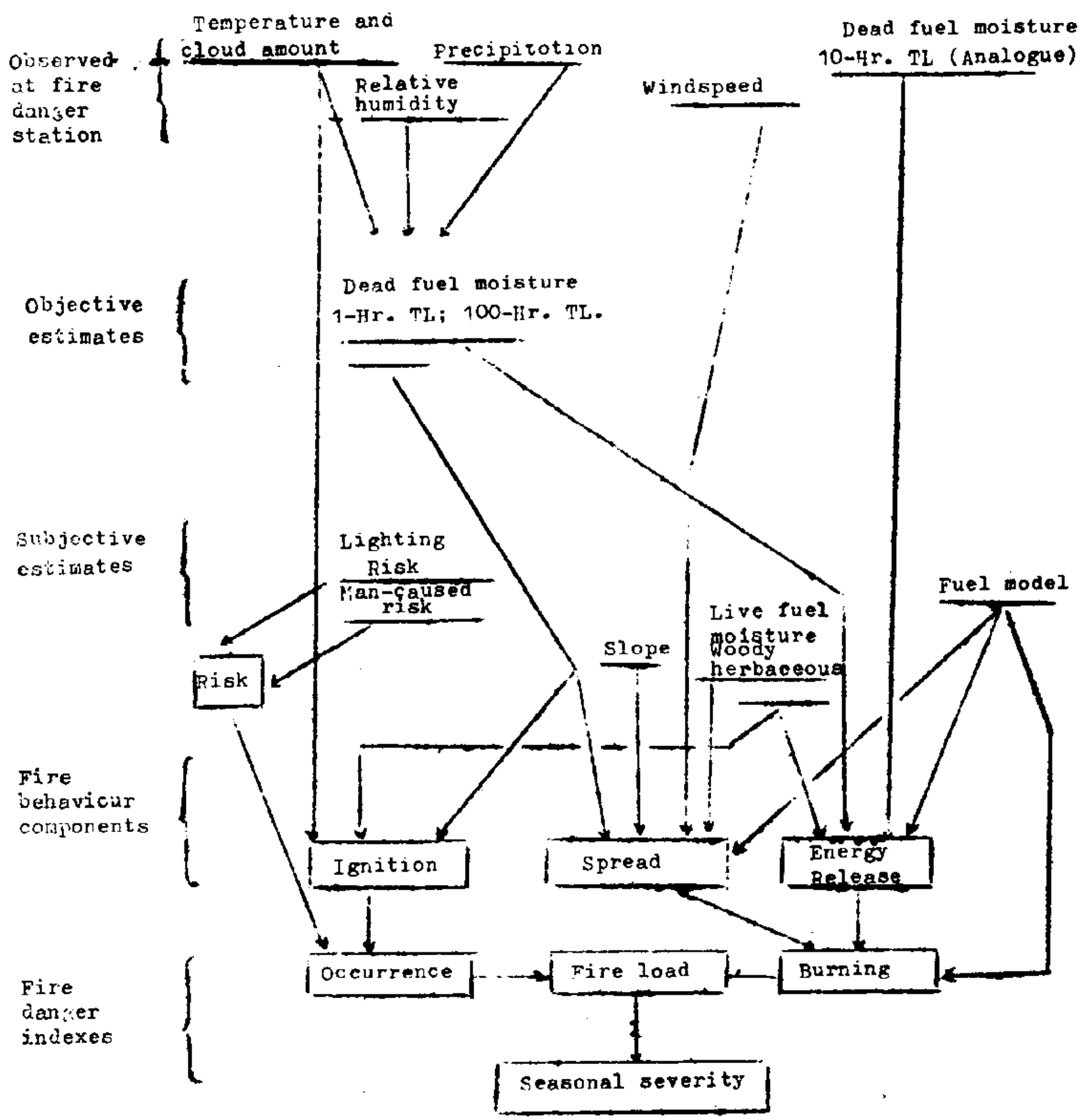
APPENDIX 3

The Wright (Canadian) Fire Danger Scale (Beall 1946)

Index	Zone	Description
0	Nil	Generally safe from man-caused fires. Lighting fires may start and fires already burning may not go dead out, but will not spread.
1 - 4	Low	Fires spread slowly from slash piles, camp-fires and other large senices of heat, but are easily controlled.
5 - 8	Moderate	Fires often start from matches and tend to spread more rapidly as the increase in size. Control is not usually difficult if action is prompt.
9 - 12	High	Fires start readily from matches and may start from glowing embers or cigarette butts. Rate of spread is rapid and control difficult.
13 - 16	Extreme	Fires may start from all sparks; they burn fiercely and 'spot' readily. Conditions are often called explosive.

APPENDIX 4

Structure of the National Fire Danger Rating System in the U.S.A.



(Source: Deeming et al., 1974)

APPENDIX 5

US. National Fire Danger Rating System -

Fine-fuel moisture (per cent) - fully cured or dead

State of Weather	Temperature °C		Relative Humidity 0–4	5–9	10–14	15–19	20–24	25–29	30–34	35–39	40–44	45–49	50–54	55–59	60–64	65–69	70–74	75–79	80–84	85–89	90–94	95–99	100
SUNNY (Cloudiness 0-5/10)	-12	-2	1	2	2	3	4	5	5	6	7	8	8	8	9	9	10	11	12	12	13	13	14
	-1	9	1	2	2	3	4	5	5	6	7	7	7	8	9	9	10	10	11	12	13	13	13
	10	20	1	2	2	3	4	5	5	6	6	7	7	8	8	9	9	10	11	12	12	12	13
	21	31	1	1	2	2	3	4	5	5	6	7	7	8	8	8	9	10	10	11	12	12	13
	32	43	1	1	2	2	3	4	4	5	6	7	7	8	8	8	9	10	10	11	12	12	13
	44+		1	1	2	2	3	4	4	5	6	7	7	8	8	8	9	10	10	11	12	12	13
CLOUDY (Cloudiness 6/10 or more)	-12	-2	1	2	4	5	5	6	7	8	9	10	11	12	12	14	15	17	19	22	25	25+	25+
	-1	9	1	2	3	4	5	6	7	8	9	9	11	11	12	13	14	16	18	21	24	25+	25+
	10	20	1	2	3	4	5	6	6	8	9	9	10	11	11	12	14	16	17	20	23	25+	25+
	21	31	1	2	3	4	4	5	6	7	8	9	10	10	11	12	13	15	17	20	23	25+	25+
	32	43	1	2	3	3	4	5	6	7	8	9	9	10	10	11	13	14	16	19	22	25+	25+
	44+		1	2	3	3	4	5	6	6	8	8	9	9	10	11	12	14	16	19	21	24	25+
RAINING	all		25+ .... 25+																				

Source: Reifsnyder (1978).

APPENDIX 6

U.S. National Fire Danger Rating System –

Fine-fuel moisture corrected for state of curing

Fine fuel moisture (from Table I) Percent moisture content	Percent of fine fuels that are green and living								
	0 ↓ 4	5 ↓ 14	15 ↓ 24	25 ↓ 34	35 ↓ 44	45 ↓ 54	55 ↓ 64	65 ↓ 74	75 ↓ 100
1	N	2	3	4	5	8	13	18	21
2	O	3	4	5	7	10	16	19	22
3		4	5	7	9	14	18	20	22
4	C	5	6	8	12	16	19	21	23
5	H	6	8	11	14	18	20	22	23
6	A	7	10	13	16	19	20	22	23
7 - 8	N	9	12	15	18	20	21	22	23
9 - 10	G	12	15	17	19	20	22	23	24
11 - 12	E	14	17	18	20	21	22	23	24
13 - 14		16	18	19	20	21	22	23	24
15 - 16		17	19	20	21	22	22	23	24
17 - 18		19	20	21	21	22	23	23	24
19 - 21		21	21	22	22	23	23	24	24
22 - 24		24	24	24	24	24	24	24	25
25 - 25+		25+	25+	25+	25+	25+	25+	25+	25+

Source: Reifsnyder (1978).

APPENDIX 7

U.S. National Fire Danger Rating System –

Ignition Index

State of Weather		Corrected fine fuel moisture content (from Table 2)														
SUNNY Temp. °C	CLOUDY Temp. °C	1	2	3	4	5	6	7 → 8	9 → 10	11 → 12	13 → 14	15 → 16	17 → 18	19 → 21	22 → 24	25 → 25+
-12 → -7	-12 → 4	88	75	64	54	46	39	30	21	14	9	5	2	0	0	0
-6 → -2	5 → 9	90	77	66	56	48	41	32	22	15	9	5	2	0	0	0
-1 → 4	10 → 15	93	80	68	58	50	42	33	23	16	10	6	3	0	0	0
5 → 9	16 → 20	95	82	71	61	52	44	35	25	17	11	7	3	1	0	0
10 → 15	21 → 26	98	85	73	63	54	46	36	26	18	[illegible]	7	4	1	0	0
16 → 20	27 → 31	100	87	76	65	56	48	38	28	19	13	8	5	1	0	0
21 → 26	32 → 37	100	90	78	68	58	50	40	29	21	14	9	5	2	0	0
27 → 31	38 → 43	100	93	81	70	61	53	42	31	22	15	10	6	2	0	0
32 → 37	44 → 48	100	97	84	73	63	55	44	32	23	[illegible]	11	7	3	0	0
38 → 43	49+	100	100	87	76	66	57	46	34	25	[illegible]	12	8	4	0	0
44 → 48		100	100	90	79	69	60	49	36	27	19	13	9	4	1	0
49		100	100	92	80	70	61	50	37	28	20	14	9	5	1	0

Source: Reifsnyder (1978)

APPENDIX 8

Countries and Key People Consulted

Questionnaires were sent to 100 member nations of the World Meteorological Organization, out of which responses were received from 30 countries. These countries were:

Argentina, Australia, Bahamas, Central African Republic, Chile, China, Costa Rica, Dominican Republic, El Salvador, Gambia, Ghana, Hong Kong, India, Ivory Coast, Kenya, Malawi, Mali, Mauritius, Mozambique, Peru, Philippines, Saudi Arabia, Senegal, Singapore, Sudan, Suriname, Tanzania and Zambia.

In addition, the following people were consulted:

Australia:

Director
Forest Research Institute
Forestry and Timber Bureau
Canberra ACT 2600

Mr. N. P. Cheney
CSIRO
Division of Forest Research
Canberra

Mr. J. Robley
State Bush Fire Control Officer
Bush Fire Board
Perth

Mr. R. J. Taylor
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CSIRO
Aspendale, Victoria 3195

Canada:

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Federal Republic of Germany:

Dr. A. Baumgartner
Director, Federal Republic of Germany
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