FOREST FIRE RISK ASSESSMENT

INTRODUCTION

Forests are subjected to various kinds of injuries out of which forest fire is the most consequential doing incalculable harm to the forests. After deforestation, forest fire is the most important cause of worldwide colossal damage to extensive forest area destroying seed, seedlings and young trees. Forest fires causes loss of timber, damage to life and property, loss of recreational value and destruction to wildlife etc. Repeated fires lead to partial or even total loss of woodlands and ultimately to the vegetation cover and humus. In India about 2-3% of the forest areas are affected annually of fire and on an average over 34000 ha forest areas are burnt by fire every year (Anon 1991).

Fire has also been a major influence for the development of many of the world's forests and on their management. Some forest ecosystems have evolved in response to frequent fires from natural causes, but most others are susceptible to the effects of wildfire, and every year millions of hectares of the world's forests are consumed by fire, resulting in enormous losses to the economy in timber burned and real estate degraded, damage to environmental, recreational and amenity values, high costs of suppression and even loss of life. The vast majority of today's fires in forest and woodlands are caused by humans, mainly as the result of the use of fire as a land management tool e.g. for conversion of forests into agricultural lands, for maintaining grazing lands or for facilitating the extraction of non-wood forest products. Forests are also burnt to clear the land for mining, industrial development or resettlement. Forest fires can result from personal and ownership conflicts. (FAO, 2001).

Although fire has been the primary agent of deforestation, as a natural process it has an important function in the health and maintenance of certain ecosystems. Thus the traditional view of fire as a destructive agent requiring immediate suppression has given way to the view that fire can and should be used to meet land management goals under specific ecological conditions. (FAO, 2001).

FOREST FIRE - THE GLOBAL SITUATION

Every year, large areas of savannah-type, mixed forest/grassland formations are affected by fires, particularly in the dry zones of Africa and South America. Forests in the humid tropics, although less prone to fire, are also affected by large fires, the most serious in recent times being in Indonesia in 1983 which burned 3.6 million ha in East Kalimantan, and the current (1997-8) fires. Coniferous forests in the humid tropics are often affected by fires. Fire is also a permanent threat to forests in the sub temperate and temperate zones of North Africa and South America while from 1950 to 1990 fires in China are reported to have affected annually an average of 890,000 ha. In the former USSR the total area burned on forest and other land from 1991-1995, was more than 5 million hectares. In North America, notwithstanding extensive, highly sophisticated prevention and control efforts, more than 2.3 million hectares of forest land still burn each year (FAO, 2001).

Globally, 1997 and 1998 were the worst years for wildfires and forest fires in recent times. Although forest fires occur every year in the arid and semi-arid zones of the world, nearly all types of forests burned in 1997-1998, even some tropical rainforests which had not burned in recent memory. Droughts associated with the EL Nino, weather pattern turned moist forests into drier habitats and increased the flammability of forest vegetation, thus increasing the number, frequency, size, intensity and duration of fires (FAO, 2001).

In 1997, wildfires raged in Indonesia, Papua New Guinea, Australia, Mongolia, the Russian Federation, Colombia, Peru, Kenya, Rwanda and other parts of Africa. By mid-1998, fires were reported in Indonesia, the Amazon, Mexico and Central America, USA, Western Canada, Russian Far East and parts of Europe. National disasters were declared in many of these places and national and international resources were mobilized to fight the fires. Neighbouring countries, international organizations and NGOs all responded. In March 1998, the Secretary General of UN requested UNEP to coordinate the UN system's response to the situation arising from the outbreak of forest fires in Indonesia (FAO, 2001).

Low rainfall in much of the Amazon attributed to the El Niño weather pattern contributed to a prolonged fire season (beyond the usual July - early October period) and an unusually high number of fires. In 1997, over 2 million ha of rainforest in Brazil burned. Analysis of satellite data from US National Oceanic and Atmospheric Administration showed an increase of over 50 percent in the number of fires from July to November 1997 compared with the same period in 1996, and an 86 percent increase in a 100-day period (June to early September) in 1998 compared with the same period in 1997. Most of the fires occurred in Mato Grosso and Pará states (FAO, 2001).

Some Brazilian forests of particular ecological or cultural significance were affected. In March 1998, fires burned over 600,000 ha of rainforest in Roraima, including parts of the Yanomami Indian reserve, near the border with Venezuela . In late September 1998, raging fires destroyed a large area of the Brasilia National Park, killing wildlife and smothering the Brazilian capital with smoke. The park is a sanctuary for rare species from Brazil's central savannah region. Earlier in the month, fire in the state of Mato Grosso threatened to move into the Xingu National Park, home to 17 indigenous groups, until rains extinguished the fire (FAO, 2001).The fires of 1997-1998 in Indonesia burned millions of hectares of Sumatra and Kalimantan. The exact area is still unknown. One estimate is that about 2.0 million ha (including savannah with grassland) burned in 1997 alone. Several organizations have begun the lengthy and complex task of interpreting satellite images to determine the total area burned . Large quantities of smoke generated by ground fires fed by slow burning fuels affected neighbouring countries, negatively influencing human health, interfering with transportation systems, and disrupting the multi-million dollar tourist industry, all of which contributed significantly to the

economic and social cost of the fires. Many underground fires continued to burn into mid- 1998 in natural peat/coal beds, threatening new outbreaks of fire(FAO,2001).
Some available information on the forest fires elsewhere in the world, provided as a representative sample only, include the following(FAO, 2001):

- Fires in Mexico and Central America burned a reported1.5 million ha. These generated large quantities of smoke which blanketed the region and spread into the USA as far as Chicago.
- From January to June 1998, about 13,000 fires burned in Mexico alone, consuming nearly 500,000 ha, and killing more than 70 fire-fighters and local residents.
- Between December 1997 and April 1998, more than 13,000 fires burned in Nicaragua, the most in any Central American country, destroying vegetation on more than 800,000 ha of land. There were over 11,000 fires in the month of April 1998 alone.
- Severe fires in Florida in southeast USA in 1998 burned a reported 200,000 ha of forest by May 1998
- More than 150,000 hectares of coniferous forest and farmland were burned in various parts of Greece in August 1998, including the black pine forest on Mount Taygetos, site of more than 160 endemic species and 36 endangered species of fauna.
- In July 1998, devastating forest fires affected more than 100,000 ha in the Far Eastern Russia. Coniferous forest burned in more than 150 places around Vladivostok, Sakhalin and Kamchatka Peninsula. Fires in the Southwest Volgograd region destroyed 9 000 ha of forest, at an estimated cost of US$6 million. In September, fires swept across Russia's Pacific Island of Sakhalin, burning over 25,000 ha by the end of the month.

Although some data on fires is available from some countries, most data is incomplete thus it is difficult to provide an overall estimate of the annual extent of fires in forests and other wooded lands. There is thus considerable interest in the collection of information on forest fires globally, driven by a number of interrelated concerns and initiatives e.g. Joint FAO/ECE Timber Division, Eurpoean Commission (DG VI), Global Vegetation Fire Inventory (GVFI), University of Freiburg and FAO (FAO,2001).

The fires of 1997 and 1998 have stimulated various international efforts related to fires. A global system of early warning to indicate the potential fire risk related to climatic conditions is being investigated by several international organizations, including World Health Organization (WHO), IUCN, UNEP and FAO. A national system for advance warning by radio linked to meteorological forecasts from satellite imagery has been successfully tried in Burkina Faso. Guidelines for Forest Fire Emergencies have been produced by WHO. Many national and international meetings have been organized in 1998 for fire fighting and health experts, potential donors and, perhaps more significant, policy-makers to address the control, effects and underlying causes of fires. UN agencies which have organized fire meetings in 1998 include, UNEP and the UN Office for the Coordination of Humanitarian Affairs (Geneva, April 1998), WHO and the

Pan American Health Organization (Lima, Peru, August 1998) and FAO (Rome, October 1998 on "Public Policies Affecting Forest Fires") FAO, 2001.

FIRE AND SMOKE RESEARCH MANAGEMENT IN SOUTH EAST ASIAN REGION

The application of fire in land-use systems in the ASEAN region has reached unprecedented levels and has been leading to increasing environmental problems. Traditional shlash-and-burn systems in the shifting agriculture mode have been replaced by modern large-scale conversion of forest into permanent agricultural systems which are partially maintained by fire, and into forest plantations. Wildfires escaping from land-use fires are becoming more and more regular. The impact of land-use fires and wildfires are detrimental to biodiversity and the atmospheric quality at SE Asian regional scale. Within the ASEAN region a joint, concerted approach is needed to cope with the problem of transboundary pollution caused by vegetation burning. However, since fire is an essential tool in land use in the tropics a response strategy must be developed in which the benefits from fire use would be encouraged, at the same time the negative impacts of fire be reduced. A regional fire management action plan must take into consideration the complexity and diversity of fire uses in different vegetation types and land-use systems (Goldammer,1997)

Fire has been present in the SE Asian biota since the Pleistocene. Long-term climate variability (glacial vs. non-glacial climate) and short-term climate oscillations caused by the El Niño - Southern Oscillation (ENSO) event have repeatedly created conditions that make even rain forest subjected to wildfires. The occurrence of wildfires is increasing with modern land-use changes. Forest degradation and repeated fires lead to the formation of fire climax grasslands (alang-alang) of low productivity and short-return interval fires. In monsoon forests of mainland South Asia annual fires during the dry season have shaped the composition and productivity of this forest environment by selecting fire-tolerant species. Severe problems of land degradation (erosion, loss of nutrients) are the consequence of fires in these seasonally dry forests. Fire protection (fire exclusion) leads to a progressive development towards a more species-rich forest ecosystem. Fire climax pine forests are found in all SE Asian mountain regions. Burning of agricultural crop residuals, especially rice straw burning, add to the smoke generated by conversion fires and wildfires (Goldammer, 1997).

The fire events of in SE Asia in the seasons of 1982-83, 1987, 1991, and 1994 led to several national and international initiatives, especially in Indonesia.A strong pan-ASEAN Fire Management Programme is proposed. This program should take advantage and coordinate all national fire management programs in the region, through the "ASEAN Forest Fire Management Action Plan", and include various other initiatives in fire research and management.The program will contribute to meet the objectives of various agreements and activities under the auspices of the United Nations, e.g. the United Nations Food and Agriculture Organization (FAO), the United Nations Environmental Programme (UNEP), the International Tropical Timber Organization (ITTO), the International Decade for Natural Disaster Reduction (IDNDR), the United

Nations Educational, Scientific and Cultural Organization (UNESCO), the United Nations Disaster Relief Organization (UNDRO), and the United Nations Commission on Sustainable Development (CSD) (Goldammer, 1997).

THE FIRE ENVIRONMENT IN SOUTH EAST ASIA (FIRE, CLIMATE CHANGE AND CLIMATE OSCILLATIONS)

Fire in the different South East Asian vegetation types is closely related with the effects of climate variability and human influences. The climatic variability in SE Asia are linked with the El Niño-Southern Oscillation (ENSO) phenomenon. The ENSO phenomenon is regarded as one of the most striking examples of inter-annual climate variability on a global scale. It is caused by complicated atmospheric-oceanic coupling. The event is initiated by the Southern Oscillation, which is the variation of pressure difference between the Indonesian low and the South Pacific tropical high. During a low pressure gradient, the westward trade winds are weakened, resulting in the development of positive sea surface temperature anomalies along the coast of Peru and most of the tropical Pacific Ocean. The inter-tropical convergence zone and the South Pacific convergence zone then merge in the vicinity of the dateline, causing the Indonesian low to shift its position into that area. Subsequently, during a typical ENSO event, the higher pressure over Malaysia leads to a decrease in rainfall and the trapping of emissions from forest and other vegetation burning in the lower troposphere. The severity of the dry spells depends on the amplitude and persistence of the climate oscillations (Goldammer, 1997).

In the rain forest biome these prolonged droughts drastically change the fuel complex and the flammability of the vegetation. Once the precipitation falls below 100 mm per month, and periods of two or more weeks without rain occur, the forest vegetation sheds its leaves progressively with increasing drought stress. In addition, the moisture content of the surface fuels is lowered, while the downed woody material and loosely packed leaf-litter layer contribute to the build-up and spread of surface fires. Aerial fuels such as desiccated climbers and lianas become fire ladders potentially resulting in crown fires or "torching" of single trees (Goldammer, 1997).

Peat swamp forests found in the lowlands of Borneo represent another fuel type. With increasing precipitation deficit and a lowering of the water table in the peat swamp biome, the organic layers progressively dry out. During the 1982-1983 ENSO, various observations in East Kalimantan confirmed a desiccation of more than 1 to 2 m (Johnson 1984). While the spread of surface and ground fires in this type of organic terrain is not severe, deep burning of organic matter leads to toppling of trees and a complete removal of standing biomass. It is further assumed that smoldering organic fires may persist throughout the subsequent rainfall period, to be reactivated as an ignition source in the next dry spell (Goldammer and Seibert ,1990).

Long-lasting fires in coal seams extending to, or near, the surface, are found in various rain forest sites in East Kalimantan and are another important source for wildfires spreading into the surrounding forest (Goldammer and Seibert 1990; Bird 1995).

FIRE REGIMES AND SMOKE SOURCES TROPICAL RAIN FORESTS

In the rain forest ecosystems of SE Asia the prevailing source of fire and smoke is linked to human land-clearing activities (Goldammer, 1997):

- Temporary forest conversion by traditional slash-and-burn systems
- Permanent forest conversion for establishment of agricultural land-use systems
- Conversion of natural forest (mainly exploited or otherwise degraded secondary forest) into forest plantations
- Wildfires: Uncontrolled fires escaping from land-use fires into surrounding natural forest and forest plantations

The droughts of 1982-83, 1987, 1991, and 1994 favored land clearing activities as well as the spread of wildfires. While the fire season of 1982-83 was characterized by large-size wildfires on several million hectares, caused by escaped land-use fires, the situation was different in the following years. The smoke emitted from the Indonesian archipelago in 1987, 1991, and 1994 came mainly from land-use fires.The data on the extent of burning in 1994 in Indonesia, collected and released by the Ministry of Forestry, are a good example for the source of smoke in that particular year. The survey indicates that a total land area of 5.1 million ha had been affected by fire. The extent of uncontrolled forest fires was small as compared to land-use fires (Table 1) (Goldammer, 1997).

Table 1: Vegetation and land-use systems subjected to fire in Indonesia during the 1994 fire season.Source: Ministry of Forestry, Indonesia.

Vegetation / Land-Use Type Affected by Fire	Area Burned (ha)
Traditional dryland farming	2,800,000
Shifting cultivation	1,500,000
Transmigrant farming	260,000
Plantations	221,000
Transmigrant settlements	39,500
Reforestation areas	20,500
Timber estates	17,000
Natural forests	8,000

FIRE IN SEVERELY DISTURBED (SAVANNIZED) VEGETATION

It is generally observed that disturbed rain forest is aggressively invaded by grasses. In SE Asia the most important post-disturbance invader is *Imperata cylindrica*. Large tracts of tropical lowlands formerly occupied by rain forest are now degraded *Imperata* grasslands. It has been estimated that in Indonesia alone more than 50 million ha disturbed sites are covered by *Imperata* fields. These grasslands become highly flammable during dry spells and are maintained by short fire-return interval fires (predominantly 1-yr fire intervals) in a fire climax stage which is characterized of low biodiversity and productivity. The fires are intentionally set by rural people in order to keep down the regrowth of bush and secondary forest. Escaping agricultural burns are the other main cause of alang-alang fires.

FIRE IN SEASONALLY DRY FORESTS

The occurrence of seasonal dry periods in the tropics of South Asia increases with distance from the prehumid equatorial zone. The forests gradually develop to more open, semi-deciduous and deciduous formations (e.g., dry dipterocarpus forest, mixed deciduous forest, dry evergreen forest, hill evergreen forest). The main fire-related characteristics of these formations are seasonally available flammable fuels (grass-herb layer, shed leaves) which allow the spread of surface fires. Grass species, understory plants (shrub layer) and the overstory (tree layer) are adapted to regular fire influence. The fires usually develop as surface fires of moderate intensity and tend to spread over large areas of forested lands. The tree layer is generally not affected by the flames, although crowning may occur earlier in the dry season when the leaves are not yet shed. In some cases fires may affect the same area two or three times per year, e.g., one early dry season fire consuming the grass layer and one subsequent fire burning in the shed leaf litter layer (Goldammer 1993).

The effects of the annual wildfires in the seasonal forests are different from those occurring in moist forest ecosystems: The surface fires in the seasonal forests consume less fuel per area unit, thus producing different quantities of emissions. The area regularly affected by wildfires in the seasonal forests, however, is very large as compared to the wildfires in the near-equator forests.

SUBMONTANE AND MONTANE FIRE CLIMAX PINE FORESTS

In mainland South Asia and Insular SE Asia the pines (*Pinus* spp.) are largely confined to the zone of lower montane rain forest. They are usually found on dry sites and prefer a slight to distinct seasonal climate. Most tropical pines are pioneers and tend to occupy disturbed sites, such as landslides, abandoned cultivation lands and burned sites. Besides the pioneer characteristics, most tropical pines show distinct adaptations to a fire environment (bark thickness, rooting depth, occasionally sprouting, high flammability of litter) (Goldammer and Peñafiel, 1990). The tropical pure pine forests of South Asia, e.g., *Pinus khesyia, Pinus merkusii, Pinus roxburghii*, most often are the result of a long history of regular burning. As in the tropical deciduous forests, fires are mainly set by graziers, but also spread from escaping shifting cultivation fires and the general careless use of fire in rural lands. Fire return intervals have become shorter during the last decades, often not exceeding one to five years(Goldammer,1997).

CROP RESIDUAL BURNING: RICE FIELDS, WEED AND SUCCESSION CONTROL AND WASTE DISPOSAL

The burning of vegetation residues and the use of fire for weed control and other regular burning takes place all over SE Asia's lands which have been permanently converted into agricultural and pastoral land-use systems. Burning of agricultural waste finally adds to the manifold open fires in the region.

FUNDAMENTAL OF FOREST FIRE

The occurrence of forest fire can be linked with the terrestrial vegetation and the evolution of the atmosphere, making it one of nature's oldest phenomena. Evidence of free burning fire has been found in petrified wood and coal deposits formed as early as the Paleozoic Era, approximately 350 million years ago.) Fire is also a cultural phenomenon. It probably was the first product of nature that humans learned to control. Early societies used fire to kill game for food, to clear land for agricultural activities, to create smoke as a communication device and to fight enemies. More recently, beginning with the Industrial Revolution, fire was harnessed in engines to power machinery. Initially, lightning ignited most wildfires. They became more widespread once humans began to use fire. Today, lightning starts about 40 per cent of the wildfires in Ontario, and people cause the rest. Unquestionably, fire greatly impacts the Earth's natural and social environments. However, such change cannot be fully understood until the process of fire in forests itself is understood. (Anon, 1999).

WHAT IS FOREST FIRE?

Fire is a rapid combination of fuel, heat and oxygen. All the three elements have to be present before a fire can start and continue burning. It is a chemical reaction of any substance that will ignite and burn and leads to a release of energy in the form of heat and light .An external source of heat is generally needed to start a fire.

The fire triangle (Fig. 1) demonstrates that air (oxygen), heat and fuel, in proper proportions, are all required to create a fire. A fire needs at least 16 per cent oxygen in the air supporting it - generally, air contains about 21 per cent oxygen. Heat is energy in disorder, and the degree of that disorder is measured as temperature. Fuel is considered any material capable of burning. In forests, this includes living vegetation, branches, needles, standing dead trees, leaves, and human-built wooden structures (Anon,1999).

TYPES OF FOREST FIRES

Forest fires can be natural or manmade. Natural fire may occur due to lighting, rolling stones or rubbing of leaves with each other. Most of the fires are caused by biotic interference either intentionally by person’s negligence/carelessness or deliberately and intentionally. These fires could be creeping fire (burning of dry leaves), ground fire (burning of herbaceous plants and low shrubs), surface fires (undergrowth also) and crown fire (crowns of trees and branches). However, their occurrences are mainly influenced by certain circumstances like inflammable material, topography, direction of winds etc.

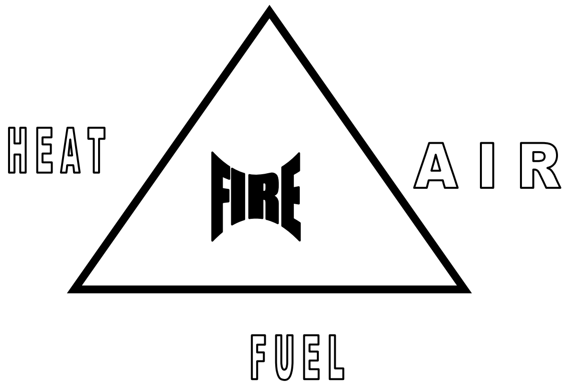

Fig.1: Fire triangle.

FIRE BEHAVIOUR

The manner in which fuels ignite, flames develop and wildfire spreads is collectively referred to as fire behaviour. It is determined by the quantity and type of fuel, the weather conditions and the region's topography (Anon 1999). Out of the many fuel composition is the most important. Fuel composition is further divided by size, chemical make-up, density and arrangement. These determine the amount and type of fuel to burn. The moisture level of the fuel i.e. the forest types is other most important consideration in fire behaviour . A high moisture level will slow the fire because much of the heat energy is used to eliminate this moisture. Live trees usually contain a great deal of moisture; dead trees have very little. Weather, past and present, determines the moisture content of the fuels. The chemical makeup of fuel also determines how readily it will burn. Some plants, shrubs and trees contain oils and resin that promote combustion, making them burn more easily.

Finally, density and the arrangement of a fuel influences flammability. If the fuel is close together, the fire can spread quickly-unless the fuel is packed so tightly that it cuts off air circulation which will slow the blaze. Weather conditions include wind, temperature, humidity and rainfall. Wind is one of the most important factors because it can bring a fresh supply of oxygen and also push the blaze toward a new fuel source. Temperature is important because fuels ignite and burn faster at higher temperatures. When humidity levels are low, which means there is less water vapour in the air, fuels will be drier and will ignite faster (Anon,1999).

MAIN FACTORS RESPONSIBLE FOR FOREST FIRE AND ITS SPREAD

The main factor affecting the spread of forest fire is the inflammable mateirial i.e., type and characteristics of vegetation. Both overstorey and understorey are crucial as they present the total fuel available for the fire. This consists of under composed lead litter, fallen twigs and branches, logs, grasses, herbs, tree seedlings and low shrubs. Surface fuels, being the most common carrier of forest fire, behaves differently in different forest types due to differences in fuel particle, properties and compactness.

Topography is also one of the main factor influencing the fire behaviour. The impact of elevation, aspect and slope in fire behaviour have been widely reported (Brown and Davis, 1973; Artsybashev, 1983; Antoninetti *et al*., 1993). Among all these factors slope is considered to be the most critical. Steep slopes increase the rate of spread because of a more efficient connective preheating and ignition by point contact. The spread of fire is more quick on south and south west slopes due to direct rays of the sun making them warmer and dry. Elevations are also influencing the occurrence of forest fire. Fire tends to be less severe on higher elevation because of greater rainfall and other factors.

Fires can spread in three distinct ways:

1. Sub-surface fires burn organic matter in the soil beneath surface litter, and are sustained by glowing combustion.
2. Surface fires spread with a flaming front and burn leaf litter, fallen branches and other fuels located at ground level.
3. Crown fires burn across tree tops which are also known as the canopy or crown. They depend on strong winds and dry fuels which makes them the most intense and the hardest fires to control. The burning of the ground level fuels create convection currents which lift and move the flames across the crowns.

Depending on how long or how intensely it burns, a wildfire will affect the environment above and below the surface of soil. In some cases, the amount of moisture and organic matter in the soil will determine how it will be affected by a fire. Fire burns more quickly uphill; this is because the flames are closer to the fuels and they are heated more readily (Anon, 1999).

FIRE SEASONS

Forest fire seasons vary according to location. In India most of the fires occur during February to June. In western Canada and western United States, the season is from April to October, while in the south-eastern United States it is from March to May. Most fires in the New England states occur in late fall. In Ontario and Eastern Canada, most wildfires occur between April and October (Anon, 1999).

INFORMATION NEEDED FOR EARLY DETECTION SYSTEM

For creating the information system of the early fire detection following information are needed to be considered (Anon, 2001):

l) Active fires
- detection and count
- smoke condition

2) Geographic distribution
- location of fires
- distribution patterns

3) Temporal dimension
- continuity
- spatial dynamics (movement. expansion)
- seasonal evolution and relationships with climate parameters

4) Target vegetation
- type and biomass
- seasonality, phenology
- regrowth regeneration after fire

5) Land use
- types of land use practices

6) Impact
- area affected by burn
- severity of burn

FIRE POTENTIAL INDEX

D:\DESKTOP_FOLDERS\FOLDERS\Courses\IIRS\IFS_course_27-31_August2012\IFS_LEcture Note Updated\current\My Web Sites\http www.usgs.gov themes Wildfire fire.html\www.usgs.gov\themes\Wildfire\fig3.htmlThe Fire Potential Index (FPI) is a valuable fire management tool that has been developed by USGS scientists in collaboration with scientists at the USFS. The FPI characterizes relative fire potential for forests, rangelands, and grasslands, both regionally and locally, so that land managers can develop plans for minimizing the threat from fires. The FPI combines multispectral satellite data from NOAA with geographic information system (GIS) technology to generate 1-km resolution fire potential maps. Input data include the total amount of burnable plant material or fuel load derived from vegetation maps), plus the water content of the dead vegetation, and the fraction of the total fuel load that is live vegetation. Water content of dead vegetation is calculated from temperature, relative humidity, cloud cover, and precipitation, and the proportion of living plants is derived from the greenness maps described above. The FPI is updated daily to reflect the changing weather conditions and is posted by the USFS on their web site (USGS, 2001).

The Bureau of Land Management (BLM), Bureau of Indian Affairs, and USFS are working with the USGS to validate the model. Fire management staffs in Oregon, Nevada, and California are using the FPI in their decision-making process daily to supplement their traditional information sources. They use these data for purposes such as establishing priorities across the area for prevention activities to reduce the risk of wildland fire ignition and spread, and planning the allocation of suppression forces to improve the probability that initial attack will control fires occurring in areas of high concern. The FPI is also being tested in Argentina, Chile, Mexico, and Spain with the support of the Pan American Institute for Geography and History (USGS 2001).

ROLE OF REMOTE SENSING AND GEOGRAPHICAL INFORMATION SYSTEM

Remote sensing has a tremendous scope in forest fire mapping. The first application of forest fire date from 1960 when several aerial infrared scanners were tested for fire spot detection (Chuvieco and Congalton 1989). After the launch of earth resources satellites several studies have been done for forest fire and burnt area assessment (Tanaka *et al.* 1983, Rome and Despain 1989). In addition to forest fire mapping remote sensing data has been effectively used for fire hazard rating system. In many fire hazard rating critical factors were vegetation, slope, aspect and elevation. Deeming *et al.* (1978) have used landsat MSS image to obtain fuel oriented vegetation maps. The remote sensing can help in three important ways in forest fire mapping, monitoring and management:

1. Active fire mapping
2. Burnt area mapping
3. Fire prone area mapping i.e.Fire Risk Zonation

Geographical Information System (GIS) is an important tool for storage, analysis and display of geo-referenced spatial and non-spatial data, which makes it possible to integrate number of variables in a meaningful way and spatial modelling to solve problems related to forest resources management.

SPATIAL MODELING FOR FIRE RISK ZONATION - A CASE EXAMPLE

Geospatial modeling technique can be effectively utilized for identifying the areas prone to forest fire To demonstrate the application of Geospatial modeling techniques, several studies have been done in forestry and Ecology Division of Indian Institute of Remote Sensing Dehradun . The findings of these studies are providing essential inputs for fire management by prescribing infrastructure for fire fighting operation, fire lines, watchhuts and communication network etc. Following is a part of case studies done by F&E Division of IIRS in part of Motichur and Dhaulkhand range of district Dehradun, India.

I. **Motichur Range**: The study area covering approx. 115 sq. km and is a part of Rajajee National Park and is situated between 29º-59'-30" to 30º-05'N latitudes and 78º-04'-30" to 78º-15'-30"E longitudes respectively. Topographically the area is extremely rugged and broken with many steep and precipitous slopes. The climate is subtropical type with three distinct seasons viz., winter, the summer and rains. May and June are the hottest months. The temperature varies from about 13.1ºC in January to about 38.9ºC in May & June. Monsoon usually breaks about in the middle of June and continues till mid of September. The annual rainfall varies between 1200-1500 mm.

As per revised classification of forest types of India by Champion and Seth (1968), the forest area falls under :

- North Indian Moist Deciduous Forest dominated by Moist Siwalik Sal Forest and moist mixed deciduous forest.
- Northern Dry Mixed Deciduous Forest dominated by miscellaneous species and dry deciduous scrubs.
- Himalayan sub-tropical Chirpine Forest dominated by Siwalik Chirpine forest and
- Khair-Sissoo Forest

The park has largest population of elephants in Uttar Pradesh (India). It also has a healthy population of tigers and leopards. The herbivorous game animals are generally belonging to deer family. Out of these, Cheetal (*Axis daxis*) and *Axis oxieben* are more common. Among omnivora wild bores are abundant in the park.

II. **Dhaulkhand Range**: Dhaulkhand Range is located in Rajaji National Park in Uttar Pradesh. It lies within longitude 77º55'35" – 78º04'42"E and latitude 29º59'45" – 30º08'48"N covering an approximate area of 150 Km^2. The topography and climate of the area is similar to Motichur Range.

DATA USED

- Landsat Thematic Mapper (TM) False Colour Composite (FCC) band 4, 3, 2 on 1:50,000 scale
- IRS-1A LISS II FCC
- SPOT PAN data and
- Ancillary information from SOI topographical sheets and compartment history, management plan etc.

SOFTWARE PACKAGE/PROGRAMME USED

- **Integrated Land and Water Information System (ILWIS)** – A PC based GIS has been used. The system is capable of linking table with the maps and useful for spatial modelling.
- **PAMAP GIS** – It is a commercial PC based Canadian GIS package available on DOS and WINDOWS.

For studies in number of other areas software like INTERGRAPH, ArcView and ArcInfo etc have been used.

METHODOLOGY

Generation of Primary Map Layers using Satellite Image Interpretation and Ancillary Information

For inputting spatial data in Geographical Information System, it is necessary that the resources information are in the form of map, hence the mapping of the thematic layers is one of the primary requirement. Remote sensing coupled with limited ground check is the most ideal way for generating resources maps. Data available in tabular form can also serve as a good geographic database if it is geographically referenced. Methodology for using satellite remote sensing data for generating forest resources information layers is well established in India and abroad (Jadhav *et al.* 1988, Roy *et al.*, 1991, Porwal *et al.* 1995 etc.) Landsat TM FCC band 4, 3, 2 on 1:50,000 scale has been interpreted using specifically generated image interpretation key and a forest cover type map was prepared. Likewise SPOT-PAN (Geocoded) image on 1:50,000 scale has been used for generating a forest density map.

Survey of India (SOI) topographical sheet on 1:50,000 scale has been used to generate a contour map and road network. However the information about the roads has also been updated using remote sensing data and field investigation. In all, following layers have been generated.

- Forest cover type map
- Forest density map
- Contour map
- Road network

DATA INPUT TO GEOGRAPHICAL INFORMATION SYSTEM (GIS) DIGITISATION AND GENERATION OF COMPUTER READABLE MAPS

Any spatial data in the form of map has to be digitized on digitising table or by other digitising methods, so that the map data can be transformed into machine readable form. The thematic layers generated above were digitized manually using digitising peripherals available with the system. Initially a frame of base map has been made and digitised to bring all the resources layers in the base mask for further analysis. After digitisation topology has been built and attributes were assigned to each cover class. Later the vector information was converted into raster form using rasterisation module for display and spatial modelling. During this process itself an information table was created which was later converted into attribute table. This table was later used for reclassification of maps for generating index maps as required in fire risk model (Fig. 2). These index maps are described later. Finally the rasterised maps like Forest type map, Forest density map, Contour map and Roads and Transport map have been created and stored in GIS for further analysis and modelling.

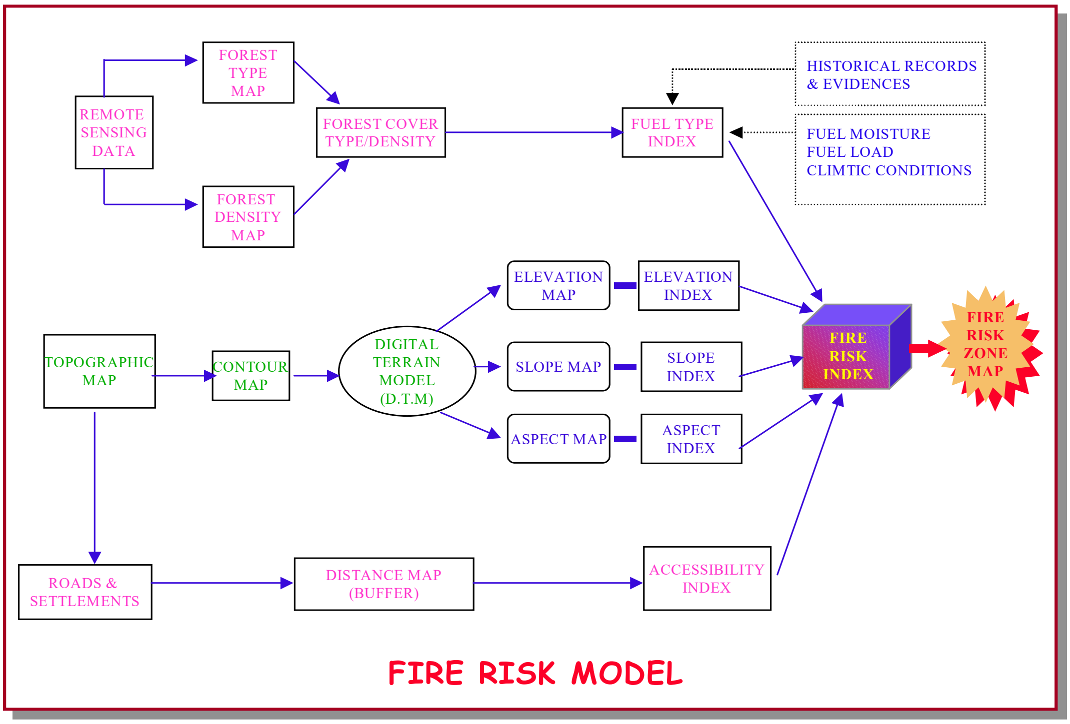

Fig.2: Fire Risk Model.

GENERATION OF DIGITAL ELEVATION MODEL (DEM), SLOPE, ASPECT AND ELEVATION MAP

As evident from the introduction given in the beginning, topography like slope, aspect, elevation etc., are the most important variables influencing the occurrence and spread of fire in addition to fuel type etc., which are mapped above. Digital Elevation Model (DEM) has been generated by using spatial modelling function after interpolation from isolines i.e., the digitised and rasterised contour map. Finally this DEM has been used to generated slope, and aspect map. Slope percentage map and the aspect map have been generated by using different option available in GIS softwares used in particular study. For Motichur raange map calculation module of ILWIS was used to generate slope and aspect class map which was later used later while integration of thematic layers.

GENERATION OF DISTANCE CLASS MAP

The main causes for the forest fires are the human activities inside the forest area. The sources of fire initiation could be traced from settlements and the roads/foot path etc. The areas nearer to roads are more prone to fire hazards than those away from it. Hence a distance map was generated after creating buffer of various distances around the existing roads.This map was later converted into accessibility index map after reclassification.

GENERATING FUEL TYPE MAP

This map was generated by crossing/overlaying the forest type and forest density map generated earlier using GIS. The new class values have been assigned to each cover type and density combination by using a two dimensional table generated by the authors. Total 24 new fuel type classes shown as forest types in the present study having both type and density information were obtained. This map was later converted into fuel class index map.

A stratified random sampling approach was followed in order to estimate the fuel content value in different homogeneous vegetation strata (HVS). In each HVS sample plot of 10 m x 10 m were laid for the purpose of studying the community structure (species composition and density) and 1 m x 1 m quadrates were laid quantify the surface fuel (Jain *et al.,* 1996). Litter (leaf, twig and branch) and herbaceous grasses were collected and separated out. The fuel content (fuel load) per unit area (Kg m^2) in each stratum was estimated after over drying the collected samples. The presence of middle level fuel consisting of herbs/shrubs larger than 2 m was also considered. The fuel load was considered as the criterion for deciding the ratings of different vegetation classes.

GENERATING INDEX VALUE MAPS

In the study done for Motichur range the map layers generated above after analysing the primary thematic maps using GIS viz., fuel type map, slope map, aspect map, distance map and DEM have been reclassified using classify Table 1 and 2 and the index maps like accessibility index map, elevation index map, slope index map, aspect index map, and fuel class index map have been generated. These index maps are required to be used in Fire risk model described later. While assigning index values to the distance class higher values are given to the areas nearer to the roads (upto 500 metres in the present study) because people can easily approach these are and there are more chances of fire occurrence. Although chances of fire are usually less on higher elevation due to many climatic factors, but in the present study higher index values are assigned to areas having higher elevation because the highest elevation in the area is only around 700 metres and these areas are having good grass used for rope making by local people hence are having more chances of fire. Since the steep increase the rate of spread of fire more efficiently due to convective per heating and ignition, they are given higher values. Because of warmer condition due to direct rays of sun in south and south western aspects, these are more prone to fire and are given higher values. Other than all the factors mentioned above fuel type have got the maximum influence on fire occurrence because forest fire behave differently in different forest types. Low and degraded forests are having maximum chances of forest fire because they contain maximum grasses and undecomposed leaf litter. Fire incidences in the past have also helped, while assigning values to various fuel types. Dry mixed (medium, low and degraded), mixed (degraded) and the degraded sal forest areas are given higher index values because they contain maximum dry inflammable material.

FIRE RISK MODELLING

In Motichur range (Porwal *et al.*, 1997) spatial modelling has been done to obtain the combined effect of fuel type index, elevation index, slope index, aspect index and the accessibility index. Different weightages have been assigned as per the importance of the particular variable. In this case highest weightage has been given to fuel type index because fuel contributes to the maximum extent because of inflammability factor. The second highest weightage has been given to aspect because sun facing aspects receives direct sun rays and make the fuel warmer and dry.

The model output i.e., cumulative fire risk index values map obtained by using map calculation function is as follows:

CFRISK = ELI, + SLI * 2 + ASI * 3 + ACI + 4FUI

where,

CFRISK	=	Cumulative fire risk index value
ELI	=	Elevation index
SLI	=	Slope index
ASI	=	Aspect index
ACI	=	Accessibility index
FUI	=	Fuel type index

The fire risk index values in this map (crfisk) were ranging up to 66. Based on statistics of different weightage classes, this map was reclassified in to final fire risk zone map.

In Dhaulkhand range (Jain *et al.*, 1996) integration of various influencing factors has been done by following a hierarchical system. On the basis of experience and the opinion of experts in the fields weightage were assigned to different variables considered for fire risk analysis on a 1-10 scale. The equation used in the fire risk modelling and mapping the fire risk areas is as follows :

$$FR = [10\ V_{I=1\text{-}10}\ (5H_{j=1\text{-}4} + 5R_{k=1\text{-}5} + 3S_{I=1\text{-}4})$$

where FR is the numerical index of fire risk, V is the vegetation variable with (1-10 classes), H indicates proximity to human habitation, (with 1-4 classes), S indicates slope factor (with 1-4 classes) and R is road/fire line factor (with 1-15 classes). The subscripts i,j,k l indicate subclasses based on importance in determining the fire risk.

Table 1: Classification tables used for generating index maps.

Elevation Index Map (ELI)		Slope Index Map (SLI)	
Elevation (in mts)	**Index Value**	**Slope Classes**	**Index Value**
280-360	1	0-5%	1
361-400	2	6-10%	2
401-480	3	11-20%	3
481-560	4	21-40%	4
561-620	5	41-60%	5
>620	6	>60%	6
Aspect Index Map (ASI)		**Accessibility Index Map (ACI)**	
Aspect Class	**Index Value**	**Distance Class (m)**	**Index Value**
N, NE	1	>2500	1
NW, W	2	2001-2500	2
E	3	1501-2000	3
SE	4	1001-1500	4
SW	5	501-1000	5
S	6	Upto 500	6

Table 2: Classification table for generating fuel type index map.

Fuel Class (Cover & Density Classes)	Index Values
R1, AG, HB, BL	1
S1, RF2, RF3, RF4	2
S2, M1, M2, C2, CM2	3
CM3, CM4, PT, SM1, SH	4
S3, S4, SM2, SM3, M3, SC	5
SM4, M4, DM2, DM3, DM4	6

ANNOTATIONS

S1	=	Sal (*Shorea robusta*) Forest dense
S2	=	Sal (*Shorea robusta)* Medium dense
S3	=	Sal (*Shorea robusta)* Open
S4	=	Sal (*Shorea robusta*) degraded
SM1	=	Sal Mixed Forest (Dense)
SM2	=	Sal Mixed Forest (Medium)
SM3	=	Sal mixed Forest (Open)
SM4	=	Sal Mixed Forest (Degraded)
M1	=	Mixed Forest Dense
M2	=	Mixed Forest Medium
M3	=	Mixed Forest Degraded
M4	=	Chirpine (*Pinus roxburghii*) Dense
C1	=	Chirpine (*Pinus roxburghii*) Medium

C2	=	Chirpine Mixed (*Pinus roxburghii)* Medium
CM2	=	Chirpine Mixed (*Pinus roxburghii*) Medium
CM3	=	Chirpine Mixed ((*Pinus roxburghii*) Open
CM4	=	Chirpine Mixed (*Pinus roxburghii*) Degraded
R1	=	Riverine Forest
PT	=	Plantations
SC	=	Scrubs
SH	=	Shrubs
AG	=	Agriculture
HB	=	Habitation/Settlement
BL	=	Blanks

Integration of the spatial data layers was done to obtain a single fire risk index which was later used for mapping fire risk areas. The fire risk zone map was obtained after reclassifying the fire risk index .

Table 3: Weights and ratings assigned to variables and classes for fire risk modeling.

Variables	**Classes**	**Ratings**	**Fire sensitivity**
Vegetation (weight = 10)	Miscellaneous Plantation Mixed Sal Chir pine Miscellaneous with slope grasses Chir pine with slope grasses Sal Riverine Scrub Agriculture	10 9 8 8 7 7 7 3 1 1	Very high High High Moderate Moderate Moderate Moderate Low Low Low
Habitation (weight = 5)	<1000 m corridor 1000-2000 m 2000-3000 m >3000 m	10 8 6 1	Very High High Moderate Low
Road/fireline (weight = 5)	<100 m corridor 100-200 m 200-300 m 300-500 m >500	10 8 6 4 1	Very High High Moderate Moderate Low
Slope (weight = 3)	0-5° 5-20° 20-45° >45°	3 5 6 10	Low Moderate High Very High

CONCLUSIONS

Finally the fire risk map generated in the above studies were compared with the actual sites effected by fire in the past. It is observed that the areas identified as under high/moderate risk were having agreement with the burnt area on the ground during previous year.

These studies conducted at IIRS concludes that the approach of combining field observations, remote sensing and GIS can be efficiently used for fire prone area zonation.

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