Third International Symposium on Fire Ecology

Freiburg University, Federal Republic of Germany

16 - 20 May 1989

Sponsored by the Volkswagen Foundation

Part I: 3rd European Symposium on Fire Ecology

16 - 17 May 1989

Part II: Fire in the Tropical and Subtropical Biota

18 - 20 May 1989

Organization: Johann G.Goldammer, Institute of Forest Zoology
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Introduction

In 1977 the Volkswagen Foundation sponsored the first European Symposium on Fire Ecology at Freiburg University. The aim of the congress was to create a communication platform for wildland fire scientists at a time when fire ecology was not yet recognized and established in Europe. Meanwhile the scientific interest and the public demand on more and reliable information about the role of fire in ecosystem processes have grown considerably. After the second meeting in 1983 it was timely to update mutual information on recent research activities.

In the first part of the symposium (European sessions) most contributions deal with fire impact on soil and site and the fire effects on Mediterranean vegetation. The papers presented by researchers from overseas countries are necessary complements for our state of knowledge.

The second part of the symposium is aimed to fill a gap of knowledge and consciousness about the role of fire in tropical and subtropical biotas. Tropical and subtropical forests and other lands are increasingly affected by wildfires. Approximately 600 million hectares or more of tropical/subtropical tree savannas, bushland and grasslands are swept by fire each year. In addition, the conversion and clearing of tropical closed forest by fire is accelerating continuously and exceeds considerably the deforestation rates assessed in the early 1980's.

The local and regional impact of the wildfires within the tropics and subtropics results in many cases in severe forest degradation, overall loss of species, soil denudation and erosion. The most sensitive watersheds within the tropics and in the vicinity of the tropics (i.e. the Himalayas) become increasingly influenced by regular fire occurrence causing large-scale deforestation in the uplands and flooding and siltation in the lowlands. Plantations as well as other valuable resources at the wildland/residental interface are subjected to a high wildfire risk.

In addition to deforestation processes in the lower latitudes, the burning of tropical/subtropical biomass becomes a source of smoke particles, CO_2 and other gases that generates increasing effects on atmospheric stability and global climatic change.

The human factors contributing to the increasing fire occurrence and land area affected by uncontrolled wildfires have to be sought in the socio-cultural and economic conditions in the developing countries within the subtropical/tropical belt and the adjoining regions. Population explosion, increasing demand for agricultural land, change of traditional land treatment practices and uncontrolled forest use in the wake of over-exploitation of forests bring a tremendous fire pressure on the natural vegetation.

On the other hand, through fire ecology research sophisticated fire management strategies and prescribed burning programs have been developed for various types of fire-adapted forests, plantations, bushlands and savannas.

With the formation of the "International Geosphere-Biosphere Program" (IGBP) it appears timely to review approaches and to relate the state-of-the-art knowledge on subtropical/tropical wildland fire effects to global environmental changes. Vice-versa, there is an initial need to determine what effects the changed atmospheric chemistry and increased variability of the physical and chemical climate have on the fire regimes and/or fire severity of various terrestrial ecosystems.

The results of the symposium findings will be laid down in a monograph "Fire in the Tropical and Subtropical Biota" on which about 25 scientists will elaborate. It will be published by Springer Verlag, Heidelberg.

Freiburg, May 1989 Johann G. Goldammer

Program

Tuesday, 16 May 1989

09.00 - 12.00	Registration Institute of Forest Zoology, Department of Forestry, Freiburg University (Bertoldstr.17; Old University Building, 1st Floor)	
14.00 - 14.30	Opening address by J.P. Vité, Director of the Institute of Forest Zoology Introductory remarks by Johann G. Goldammer, Institute of Forest Zoology, Section Fire Ecology and Fire Management	

Part I: 3rd European Fire Ecology Symposium

14.30 - 17.30	Session 1: Mediterranean and Northern Biotas Chair.: R.E. Martin	
14.30 - 15.00	Z. Naveh (Israel)	Fire in the Mediterranean: a landscape-ecological perspective
15.00 - 15.30	B. van Wilgen (South Africa)	Fire ecological research in fynbos ecosystems
Coffee Break		
16.00 - 16.30	Ju Ende and Di Xueying (P.R. of China)	The forest conflagration of May 1987 in Northeastern China
16.30 - 17.00	J. Goldammer (F.R. of Germany)	Fire and forest development in the montane-boreal coniferous forest of Northeastern China
17.00 - 17.30	O. Zackrisson (Sweden)	Fire and successional patterns in the North Swedish boreal forest

Wednesday, 17 May 1989

09.00 - 13.00	Session 2: Fire impact on soil and site	
	Chair: J.P. Vité	
09.00 - 09.30	**M.G. Weber (Canada)**	**Selected ecosystem processes in a *Pinus resinosa* Ait. forest in relation to other fire-affected eastern North American forest ecosystems**
09.30 - 10.00	**E.B. Rueda (Spain)**	**Solute loss and soil erosion in burnt soil, Galicia (NW-Spain)**
10.00 - 10.30	**Th. May (F.R. of Germany)**	**Vegetation development and surface runoff after fire in a catchment of Southern Spain**
Coffee Break		
11.00 - 11.30	**P. Kutiel (Israel)**	**The effect of wildfire on soil nutrients and vegetation in an Aleppo pine forest on Mt.Carmel, Israel**
11.30 - 12.00	**J. Garty (Israel)**	**Re-establishment of lichens on chalk rocks after a forest fire in the Carmel Mountains, Israel**
12.00 - 12.30	**C. De Ronde (South Africa)**	**Impact of prescribed fire on soil properties: comparison with wildfire effects**
12.30 - 13.00	**G. Giovannini (Italy)**	**Beneficial and detrimental effects of heating on soil quality**
Lunch Break		
14.30 - 18.00	Session 3: Fire in mediterranean ecosystems	
	Chair: Z. Naveh	
14.30 - 15.00	**L. Trabaud (France)**	**Fire effects on mediterranean vegetation**
15.00 -15.30	**M. Basanta and M. Casal (Spain)**	**Post-fire dynamics in experimental plots of shrubland ecosystems of Galicia (NW-Spain)**
15.30 - 16.00	**S. Mazzoleni (Italy)**	**Post-fire regeneration of mediterranean macchia in Southern Italy**

Coffee Break

16.30 - 17.00	M. De Lillis (Italy)	Dynamics of a fire-disturbed mediterranean community of Southern Italy
17.00 - 17.30	R. Tárrega and E. Luis-Calabuig (Spain)	Forest Fires and climate features in León Province, Spain; fire effects in *Quercus pyrenaica* ecosystems
17.30 - 18.00	R.E. Martin (U.S.A.)	Systematizing and enhancing fire ecology knowledge with expert systems

Part II: Fire in the Tropical and Subtropical Biota

Thursday, 18 May 1989

09.00 - 11.30 Session 4: Basic Papers

Chair: D. Mueller-Dombois

09.00 - 09.30	D. Mueller-Dombois and J. Goldammer (U.S.A./F.R.G.)	Introduction
09.30 - 10.00	B. van Wilgen (South Africa)	Fire in tropical and subtropical regions of Africa
10.00 - 10.30	A.M. Gill (Australia)	Fires and their effects in the wet-dry tropics of Australia

Coffee Break

11.00 - 11.30	J. Goldammer (F.R. of Germany)	Fire ecology and fire regimes in forest dynamics and degradation in tropical Asia

11.30 - 15.30 Session 5: Fire in tropical and subtropical savannas

Chair: B. van Wilgen

11.30 - 12.00	C. Menaut (France)	The role of fire on grass production and on woody communities regeneration and spatial distribution in the savannas of Ivory Coast: Interactive processes
12.00 - 12.30	L. Coutinho (Brazil)	Fire as an ecological factor in the brazilian Cerrado

Lunch Break

14.30 - 15.00	**P.A. Thomas (U.K.)**	**Response of cacti and other succulents to fire**
15.00 - 15.30	**M. Imort (F.R. of Germany)**	**The influence of fire, grazing and lopping on a tree-shrub savanna in Kayes Region, Mali**

Coffee Break

16.00 - 16.30	**S.Penafiel (Philippines)**	**Fire in pine forests and grasslands of Luzon, Philippines**
16.30 - 17.00	**W. Werner (F.R. of Germany)**	**Fire in pine forests and savannas of Northern Thailand**
17.00 - 17.30	**D. Schmidt-Vogt (F.R. of Germany)**	**Fire in the high-altitude forest of the Nepal Himalaya**
18.00 - 19.00	**H. Remmert** **J. Goldammer**	**Editorial meeting for monograph** *Fire in the Tropical and Subtropical Biota*

Friday, 19 May 1989

09.30 - 10.30 Session 7: Fire in the tropical rain forest

Chair: M. Gill

09.30 - 10.00	**J. Goldammer and B.Seibert (F.R. of Germany)**	**Fire disturbance and post-fire regeneration of lowland tropical rain forest in East Kalimantan, Indonesia**
10.00 - 10.30	**P.M. Fearnside (Brazil)**	**Fire in the tropical rain forest of the Amazon Basin**

Coffee Break

11.00 - 12.00 Session 8: Historical and prehistorical perspectives

Chair: S. Penafiel

11.00 - 11.30	**W. Schüle (F.R. of Germany)**	**Landscapes in prehistory: Interaction of wildlife, man and fire in prehistoric times**
11.30 - 12.00	**S.J. Pyne (U.S.A.)**	**Fire conservancy: The origins of fire protection in British India, Australia and America**

Lunch Break

13.30 - 14.30	Session 9: Industrial plantations	
	Chair: L. Trabaud	
13.30 - 14.00	**R.V. Soares (Brazil)**	**Forest fires in brazilian industrial plantations and protected public land**
14.00 - 14.30	**C. de Ronde (South Africa)**	**Prescribed burning in pine stands of South Africa; some effects on forest floor dynamics**
Coffee Break		
15.00 - 18.00	Session 10: Monitoring tropical fires	
	Chair: P. Crutzen	
15.00 - 15.30	**J.P. Malingreau (Italy)**	**The contribution of remote sensing to the global monitoring of fires in tropical and subtropical ecosystems**
15.30 - 16.00	**Y. Kaufmann (U.S.A.)**	**Remote sensing of biomass burning**
16.00 - 16.30	**S. Langaas (Norway)**	**NOAA AVHRR and GIS based monitoring of fire activity in Senegal - a provisional methodology and potential application**
16.30	**Discussion**	
19.00	**Reception and optional dinner (no-host)**	

Saturday, 20 May 1989

09.00 - 12.30	Session 11: Impact of biomass burning	
	Chair: J.P. Malingreau	
09.00 - 09.30	**D.E. Ward (U.S.A.)**	**Factors influencing the emissions of gases and particulate matter from biomass burning**
09.30 - 10.00	**M.O. Andreae (F.R. of Germany)**	**Ozone production from biomass burning in tropical Africa**
10.00 - 10.30	**G. Esser (F.R. of Germany)**	**Direct and indirect contributions of biomass burning to the global carbon cycle in the past 125 years**

Coffee Break

11.00 - 11.30	**P.J. Crutzen and Wei Min Hao (F.R. of Germany)**	**Estimates of gaseous emissions from worldwide biomass burning and their influence on atmospheric chemistry**
11.30 - 12.00	**R.W. Wein (Canada)**	**The importance of widfire to climate change: hypotheses for northern ecosystems**
12.00 - 12.30	**M. Fosberg (U.S.A.)**	**Global change: effects on forest ecosystems and wildfire severity**
12.30	**J. Goldammer**	**Closing remarks**

14.00 - 15.00 **Formation of a Working Group**
Fire Ecology within the Geosphere-Biosphere Program (IGBP)

16.00 **Press conference**

ABSTRACTS

Part I: 3rd European Fire Ecology Symposium

Session 1: Mediterranean and Northern Biotas

Fire in the Mediterranean: A landscape-ecological perspective

Zev Naveh

Due to its destructive combination with uncontrolled grazing and other land abuses, fire has been regarded in the Mediterranean as a wholly condemnable element which has to be prevented at all costs and at all times. But at the same time wildfires are becoming more devastating in spite of the great efforts and heavy expeditures invested in fire fighting and prevention. Its important role as a major driving force in the co-evolution of paleolithic man and Mediterranean landscapes has been overlooked and its potential use as a beneficial tool in vegetation management has not been recognized. Because of the irrational, total ban on fire, even for research purposes, ecologists and land managers are lagging far behind in the systematic study of its effects on the landscape, its biotic and abiotic components and functions.

Fire, like any other ecological disturbance factor, must be studied in a systematic scientific way with clear distinctions between wildfire and prescribed fire types, their timing, frequencies and temperatures, the size of the burned areas, its vegetation, fuel and ecological and meteorological conditions. A clear distinction must also be made between the different perceptional windows through which fire events are viewed. For the single organism in a pine and sclerophyll forest or maqui, fire may mean death, but for *Pinus halepensis* and many other species in this plant community it may mean the only way to ensure their natural rejuveniation, and for their ecosystems biological productivity and efficient nutrient cycling. Finally, for the landscape as a whole it may be the most efficient way to retain its heterogeneity and dynamic flow equilibrium in space and time. For the pastoralist such a fire means more lush grass and sprouts for his livestock, and for the forester an opportunity to plant a monospecies pine forest; but the recreationist and nature lover will see only the scorched, black scenery left behind.

The time is ripe to replace all prejudiced, short-sighted and one-sided approaches to fire in the Mediterranean with the more comprehensive view of the landscape ecologist, in order to study its effects at all levels of the ecological and perceptional hierarchy and to learn how to employ it in a judicous way as a cheap and efficient tool for the prevention of destructive wildfires and the conservation of the biological diversity and attractiveness of our open landscapes in fireinduced, variable aged plant communities, ecotones and corridors.

Fire ecological research in Fynbos Ecosystems

B.W. van WILGEN

This presentation reviews the history of fire ecological research in South African fynbos shrublands and presents the major findings to date. The management of fynbos shrublands is aimed at water production through catchment conservation, and at nature conservation. Research began in the 1930s, but it was only in the 1960s that the Department of Forestry began a formal research programme on fynbos ecology. Two significant factors boosted the research programme in the 1970s. Firstly, the introduction of prescribed burning as a policy in 1975 (as opposed to protection from fire) necessitated further research into fire and its effects. Secondly the formation of the Fynbos Biome Project in 1978, created to disseminate funds for ecological research on fynbos, brought about a large measure of coordination between government departments and universities.

Major findings with regard to the correct season and frequency of fire have resulted from the programme. In addition, studies on fire behaviour prediction and fire management systems have been done. These findings are reviewed briefly in the presentation.

The forest conflagration of May 1987 in Northeastern China

JU ENDE and DI XUEYING

The 1987 wildfires affected several million hectares of forest lands in the territories of the USSR and the People's Republic of China north and south of the Heilonjiang river. The paper describes the extent of the one million ha fire in the Heilongjiang Province, Northeast China. Special attention is given to the fire behaviour and the ecological effects of the fire.

Fire and forest developement in the Northern Daxinganling Montane-Boreal Coniferous Forest, Northeast China

J. GOLDAMMER

In May 1987 a major wildfire swept through the Daxinganling Mountain Region, Heilongjiang Province, Northeast China. The fire affected a total land area of 1.14 million ha, thereof 870,000 ha was forest land. Worldwide attention was caused because of the high loss of human lives and property. Forest fires, however are a natural phenomenon. During the past 20 years of forest exploitation and land exploration lightning still amounts to more than one third of all known wildfire causes. This implies that fire must have played an important role in the forest development of the region, especially during the presettlement period.

In this preliminary study a model on the fire ecology and the role of the fire regimes in forest dynamics in Daxinganling is presented. Based on fire history data and field observations natural fire return intervals range between 6 and 170 years. The composition of larch, pine, birch and spruce forest is determined by the fire frequency which mainly depends on the topography and site conditions. The boundary of the natural range of spruce is limited by fire.

Fire and successional patterns in the North Swedish boreal forest

O. ZACKRISSON

(Abstract not yet received)

Session 2: Fire impact on soil and site

Selected ecosystem processes in a *Pinus resinosa* Ait. forest in relation to other fire effected eastern North American forest ecosystems

M.G. WEBER

This study examines litterfall, decomposition, organic matter turnover and forest soil respiration (CO_2 evolution) in a mature (75 yrs) eastern Ontario red pine (*Pinus resinosa* Ait.) ecosystem and compares the estimates with similar eastern North American fire-affected forest types.

Decomposition was quantified using the litterbag technique. Respiration was determined in situ by measuring the amount of CO_2 evolved with soda lime. The understorey vegetation, by virtue of its greater litter nutrient concentration compared to overstorey litter (needles), was shown to exert a greater influence over nutrient cycling than its proportional biomass would indicate.

Litterfall patterns were shown to be variable seasonably as well as from year to year. Annual littermass inputs varied from a high of 5300 to a low of 2400 kg x ha^{-1} during the three-year observation period. Nutrient inputs through litterfall followed mass input patterns.

Organic matter turnover rates, or residence time, were between 19 and 16 years for the three red pine stands studied. This represents intermediate values between such rapid rates as 2 to 3 years for south central Wisconsin forests and 43 years for jack pine (*Pinus banksiana* Lamb.) ecosystems in Northern Brunswick. Strong climate control over ecosystem processes, exceeding that of substrate quality, is implicated in the observed variability among forest types. It is pointed out that climatic controls will assume added importance in studies of ecosystem structure and function in light of the anticipated global greenhouse warming.

Soil respiration was shown to be very similar to levels observed in adjacent jack pine forests. Seasonal respiration means in red and jack pine forests with various fire histories were around 4300 mg of CO_2 / m^2 x yr. In comparison, local fire-origin aspen stands had soil respiration rates in excess of 5000 mg CO_2 / m^2 x yr, reflecting better nutritional status of the aspen site. Temperature appeared to be the overriding controlling factor in determining substrate respiration patterns. Soil moisture content and rainfall proved to be poor predictors of respiration activities in this study.

Solute and soil erosion in burnt soil, Galicia (NW-Spain)

E.B. RUEDA

An experimental site of *Ulex europaeus* shrubland was subjected to a light fire. Burnt and unburnt (control) plots were prepared for measurement of subsequent erosion. The marked hydrophobia of the soil led to a runoff of about 20 % after the first post-burn rainfall. This figure fell to a level of 5 - 10 % in the following months. Burning changed soil characteristics in the top 2 cm, where phosphorus and ammoniacal nitrogen contents and pH increased and nitric nitrogen content, bulk density and water retention at pF < 2,5 decreased. Soil loss was equivalent to 271.6 Kg/ha in the burnt plot as against 189.1 kg/ha in the control plot. Runoff sediment from the burnt plot had higher phosphorus, carbon and clay contents than the burnt soil, and soluble elements ranked in the order NA > K > Mg > N > Ca > P with respect to the quantity lost by the burnt plot in runoff. Most losses of soluble elements in runoff occurred during the first month after burning.

Vegetation developement and surface runoff after fire in a catchment of Southern Spain

Th. MAY

In a hydrological catchment of about 46 km^2, runoff in a relation to precipitation events was analysed during a period of 12 years. Within this period, the catchment which was covered to a large extent with pine woodlands of spontaneous origin was affected by three subsequent fires. After the first, largest fire, a considerable increase of surface runoff could be observed. However as soon as three or four years after the fire, despite the relativly unfavourable conditions for vegetation recovery, hydrological behaviour had reverted to pre-fire conditions.

After the two following fires, no clearly detectable increase of surface runoff could be noticed. This may be due to a different type of vegetation in the understorey of the pine woodland (greater proportion of resprouting species), or also to the minor extent and the differing topographic conditions of burnt areas.

The effect of wildfire on soil nutrients and vegetation in an Aleppo pine forest on Mt. Carmel, Israel

P. KUTIEL

The seasonal and annual trends of availability of nitrogen and phosphorus in an aleppo pine (*Pinus halepensis*) forest following a hot summer wildfire were studied.

Every two months, from September 1985 until May 1987, seven soil samples were analyzed both from burnt and unburned plots. Carbon, total and available forms of nitrogen, total and water soluble phosphorus, electrical conductivity (EC) and pH were determined.

pH and EC increased while organic matter decreased significantly and remained lower during the two years of study. A significant rise in NH_4^+-N concentration in the soil was observed in early winter, five months after the fire, while NO_3^--N was at its maximum ten months after the fire, during late spring. Water soluble P increased also for a short period, two months after the fire.

These results were supported by laboratory experiments, on soils from the same forest, which showed also that the nutrient increase rates are a function of the fire temperature and pre-fire plant composition.

The plant regeneration rate was lower, despite the enrichment with available nutrients, due to less than normal rainfall totals and longer dry spells. Presumably, this caused the loss of the temporary advantages of the fire for the ecosystem.

Re-establishement of lichens on chalk rocks after a forest fire in the Carmel Mountains, Israel

J. GARTY

Four years after a forest fire in the Carmel Mountains, Israel, we observed on burned surfaces of chalk rocks small holes, 30 - 50 m^{-6} in diameter, colonized by unicellar green algae. New thalli of the lichen *Xanthoria parietina* which is in general epiphytic in the study area, colonize the horizontal surfaces of the burnt rocks four years after the fire. New thalli of the epilithic lichen *Caloplaca aurantia*, bearing apothecia, colonize burnt surfaces of chalk rocks four years after the fire. Clusters of ascospores produced by this lichen were observed on the discs of the lichen apothecia and on the rock surfaces. The most common numbers of ascospores of *Caloplaca aurantia* in each cluster found on the surfaces of both discs and rocks, are seven and eight. It is suggested that, under field conditions, lichen ascospores are liberated from the asci in clusters of eight. Fungal hyphae were observed close to *Caloplaca aurantia* ascospores on the rock surfaces.

Impact of prescribed fire on soil properties: comparison with wildfire effects

C. de RONDE

While it is relatively easy to measure fire behaviour parameters such as flame length and rate of spread during prescribed burning, measuring similar fire characteristics during wildfires is almost impossible and unrealistic. From a tree bark scorch database a model was developed to make it possible to determine flame height from bark scorch measured after the wildfire has occurred, making it feasible to calculate fire intensity parameters such as fireline intensity and heat per unit area. This now opens the door to more accurate wildfire appreciation.

By using these fire intensity models, it is now possible to compare prescribed burning with wildfire effects. The impact of two wildfires on the nutrient status of the system will be discussed and compared with the recorded effects of prescribed burns on nutrients.

The major conclusion that can be drawn is, that fires in general have a more drastic effect on nutrients with increase in fire intensity, but that most above-ground nutrients lost are replaced by more available soil nutrients. Percentage consumption of the forest floor will to a large extent determine how significant this nutrient transfer will be.

Beneficial and detrimental effects of heating on soil quality

G. GIOVANNINI

The passage of a fire is normally accompanied by a heat wave that effects the soil. Many farmers, timber managers and shepherds believe that the heating of soil is advantageous to plant growth; many burnt soils, however, appear profoundly eroded and intensely degraded. This paper is an attempt to discuss and to understand, whether there is a distinguishable limit between the beneficial and detrimental effects of the soil heating.

Some italian soils were subjected to an artificial heating, arranged according to the true thermal reactions occurring in soils, in order to ascertain the modifications induced in the physicochemical parameters related to soil erodibility, soil fertility and plant growth.

The obtained results indicate that the most striking modifications occur in concomitance with the combustion of the organic matter with the decrease of the buffer and exchange capacity, the volatilization of the nitrogen, the mineralization of the organic phosphorus with the increase of its availability and with the increase of the water solubility of various cations; all these conditions improve the plant growth.

The heating beyond this limit produces, on the contrary, a very high alkalinity of soils and the release of cations at toxic level, decreases to soil porosity, elasticity, promotes the aggregation of finer soil particles into sand-sized particles very hardened, but not linked. All these conditions are unfavourable to plant growth and may induce a very high hazard for soil erosion.

Session 3: Fire in mediterranean ecosystems

Fire effects on mediterranean vegetation

L. TRABAUD

Fire is an important ecological factor in shaping the Mediterranean landscape. Vegetation was studied in *Quercus coccifera* garrigue, a plant community frequently encountered in the western part of the Mediterranean Basin.

Permanent plots burned by wildfires were observed for ten years. Floristic richness followed a simple and general model: it reached its maximum during the two years after fire, then decreased and became stable. There was no succession (in the general sense of the word), but a progressive reappearence of the species belonging to the original community. After fire the quantitative growth of vegetation tended back towards a structure similar to that which existed before.

An experiment was set up in a garrigue 10 km north of Montpellier to analyze the impact of burning frequencies and seasons. Burns were lit either in spring or in autumn. The burning frequency was two, three and six years. Higher burning frequency lowered the production of phytomass until an equilibrum was established between the plant production and the fire frequency. The influence of the burning season was reflected by a decrease of woody plant mass and an increase of herbaceous plant mass with autumn burns. Besides the season, pre-fire canopy structure mostly affected resprout vigour. The biomass of the belowground system allowed vigorous resprouting of the oak.

The relative importance of the fire in the *Quercus coccifera* garrigue seems to be rather superficial. It does not lead to large modifications in the community dynamics. This relative stability and resistance can be explained by the fact that most of the species, present before fire, regenerate principally by vegetative means and have developed survival traits to withstand fire.

Post fire dynamics in experimental plots of shrubland ecosystems, Galicia (NW-Spain)

M. BASANTA and M. CASAL

Vegetation dynamics have been analysed in atlantic shrublands after controlled burning. For this study, eight experimental plots of 4 x 20 m were established. Data recorded include frequency, linear cover and above ground phytomass for pre-fire and post-fire vegetation.

Pre-fire vegetation can be described as tall, thick shrubland, composed mainly of spiny (*Ulex europaeus, Ulex minor*) and ericoid species (*Erica cinerea, Erica umbellata, Calluna vulgaris, Daboeica cantabrica*). Two shrub strata, with high overlayering, can be distinguished. The ground is discontinuously covered by a third stratum composed by mosses and herbs, most of the soil surface being protected by a thick litter layer.

Important changes in soil protection can be observed soon after fire: most of the soil surface is covered by a thin layer of burnt moss and litter, whereas almost 20 % has no protection at all. A stratum composed by herbs and mosses begins to recover. With regard to shrub species, *Ulex europaeus* predominates, recovering from both seeds and sprouts. Dominance relations among the different shrub species are the same as in the pre-fire community.

Overall, the structure and stability of the previous vegetation is destroyed and characterized by a strong decrease in height, cover and phytomass, which reduces the protective role of the vegetation and increases the erosion risk.

Post-fire regeneration of Mediterranean macchia in Southern Italy

S. MAZZOLENI

Different types of macchia vegetation of the coasts of the Campania region in southern Italy are described and the results of experimental burning during summer 1987 and 1988 are reported.

Differences were found among dominant species in the capacity of vegetative regeneration and in the relative success of establishment in the two years.

The regeneration patterns of *Euphorbia dendroides* L. and *Erica arborea* L. are discussed and related to the different and relatively restricted distribution of these two species in the region.

Dynamics of a fire-disturbed mediterranean community of Central Italy

M. DE LILLIS

Two permanent transects have been established on the untillable uplands of the Mediterranean area in central Italy, since the last fire burned in Summer 1984. By its recurrence fire is an important factor for the dynamics of this vegetation. High σ-diversity of plants has been observed on this mosaic-like vegetation dominated by *Pistacia lentiscus* L., *Myrtus communis* L. and *Ampelodesmos mauritanicus* (Poiret) D.S. .

Both floristic or structural variations, observed between 1984 and 1988 in twenty burned and unburned plots, showed that perennial species belonging to the original communities successfully competed with invaders , particularly due to the reproductive strategy. ß-diversity reached a peak value in the second year after fire consistently with the highest species richness. The overall vegetation dominance concentration fails to show significant changes after the disturbance, whereas the relative dominance among the perennial herbs increases through time. This community seems to recover very fast towards the original stage. The preliminary observations carried out up to now suggest that fire could help a stage of autosuccession of this disturbed vegetation rather than the substitution of the original community by another one. The high resilience of this vegetation is related to the woody species of *Quercion ilicis* in the first stages of fire influence. Low frequence of fire causes the hemicryptophyta of *Thero-Brachypodion* to be dominant.

Forest fires and climatic features in Leon Province, Spain. Fire effects in *Quercus pyrenaica* ecosystems

R. TARREGA and E. LUIS-CALABUIG

Leon is one of the provinces in Central Spain most affected by forest fires. The majority of the province has a Mediterranean climate with a high fire risk during the dry and hot summers. This study shows the close relationship between weather, above all aridity, and forest fires, comparing several climatic indices with the number and size of fires during the same period. Among other observations it was noted that the majority of fires occur in August and September, although July and August are the driest months. This can be explained by the slow drying process of life fuel moisture.

The most affected natural forest are the *Quercus pyrenaica* communities, which are only surpassed by pine afforestations. These communities have been changed by burning, felling and shepherding. Most species have traits to survive such as vegetative sprouting capability, which leads to an autosuccession process after fire. However, the increase of fire frequency during the last decades is the main impediment towards the development to ripe (climax) communities.

Systematizing and enhancing fire ecology knowledge with expert systems

R.E. MARTIN

Expert systems have the potential to help us use and systematize our knowledge of fire ecology. This is true for temperate ecosystems, and may be even more true for tropical systems where our knowledge is more limited. In contrast to thinking of expert systems - or neural networks - as omnipotent systems, we should look at them as another tool to help us build knowledge bases which will help us understand fire in ecosystems.

The paper uses examples of how expert systems can help in both quantitative and qualitative ways. Quantitative information can be used make first estimates of fire effects in systems in which we have no fire effects information to draw on. Second, expert systems can be constructed to draw on the knowledge of persons experienced in a given ecosystem to consolidate and pass on that knowledge. Thus, both quantitative and qualitative knowledge can be organized to make it more available and systematic.

Part II: Fire in the Tropical and Subtropical Biota

Session 4: Basic papers

Fire in the Tropical and Subtropical Biota: An Introductory Outline

J.G. GOLDAMMER

Climatic changes and oscillations as well as natural and anthropogenic fires have been influencing the dynamics of tropical and subtropical vegetation since the late Pleistocene. It is evident that disturbances such as fire have played an evolutionary role not only in the development of savanna and grassland ecosystems, but also in the pertubation, diversity and distribution of closed forests such as the tropical rain forest.

With continuing and accelerating human pressure on the natural resources within the tropics, the forest lands and other vegetation are subjected to dramatic changes due to overexploitation and degradation. Wildland fires occuring in the wake of various land-use techniques play an increasing role in the overall process of forest conversion and vegetation degradation.

The fire regimes in today's tropical forests and other vegetation are related to ecosystem stability. Whereas only a few forest types can be regarded as stable fire ecosystems, most other forest land is undergoing continuous degradation characterized by loss of diversity and productivity.

The role of forest conversion and biomass burning in the tropics may have a considerable impact on supra-regional and global ecological processes such as climatic change and global warming. The scientific base for a better understanding of these processes is still very weak, mainly because of following uncertainties:

- Extent of forest conversion and loss of biomass within the tropics

- Size of land area and amount of biomass burnt each year

- Role of secondary vegetation in carbon fluxes

- Gross and net fluxes of tropical carbon between biosphere and atmosphere; net contribution to global warming

- Impact of global warming on a tropical wildland fire scenario

In an interdisciplinary approach this symposium intends to bring together fire scientists from terrestrial fire ecology, bio-geochemistry, atmospheric chemistry and climatology in order to define the post-modern role of wildland fire in ecological processes.

Fire in tropical and subtropical regions of Africa

B. van WILGEN

We have classified the vegetation of Southern Africa (south of the Zambesi and Cunene Rivers) broadly into moist and arid savanna, grasslands, fynbos shrublands, desert and karoo, and forest. We deal with fire in each of these major systems seperately.

In fynbos shrublands, the major objectives of management are to produce sustained yields of high quality water, nature conservation, and to reduce fire hazard. Prescribed burning and the control of invasive woody weeds are the two major management activities. The scientific basis for current management policies is reviewed with special reference to the use of fire. Data from the Cape fynbos catchment areas are used to illustrate the constraints associated with the application of theses policies. Major constraints to management by prescribed burning include a short suitable ecological fire season and rare suitable weather conditions, coupled with constraints offered by large, inaccessable areas. The presence of alien weeds poses further problems. The net result is, that planned prescribed burns are often not completed, and wildfires are still common. The control of woody weeds is constrained mainly by inaccessable terrain and unplanned wildfires, as well as by effects of control operations on natural species diversity.

Grasslands are considered as climax, fire climax and edaphic climax grasslands. The distribution of each is discussed, and related to the major management aims for each zone. The fire ecology of montane grasslands, with special emphasis on the Natal Drakensberg catchment areas, is outlined as an example of a well-studied area. Constraints to the management of these areas is far less than those in fynbos catchments due to lower fuel loads and a longer burning season.

A distribution map of savannas in southern Africa is given. The natural and current fire regimes in arid and moist savannas are discussed. Examples of current fire regimes from the agricultural areas of the eastern Cape, and conserved areas in the Kruger National Park and the Nylsvley Reserve in the Transvaal, the Etosha National Park in Namibia, and the Hluhluwe Game Reserve in northern Natal are given. The fire ecology of these regions is discussed in relation to climate, grazing and invasion by alien invasive plants. While the dynamics of grass communities is reasonably well understood, the dynamics of woody elements of the vegetation is poorly understood. The management of savanna ecosystems using fire is reviewed from both an agricultural and a nature conservation point of view.

The ecology of fire in Africa north of the Zambesi and Cunene Rivers will be discussed, again with special emphasis on areas for which data are available. Conclusions regarding the dominant fire regimes and how they are changing with regard to increasing human influences will be given. We will also attempt to review gaps in knowledge, both in a geographical and an ecological sense.

Fire ecology and fire regimes in forest dynamics and vegetation degradation in tropical Asia

J. GOLDAMMER

An overview is given on the role of fire and the fire impact on forest and other vegetation in tropical Southern Asia. The adjoining regions north of the tropic of cancer are included because of the prevailing influence of the tropical monsoonal climate and the similarity of socio-economic and cultural conditions.

The increase of population and the enhanced demand for agricultural land has created a tremendous fire pressure on all kinds of vegetation. Allmost all forest fires and other wildland fires are caused by the rural population (slash-and-burn agriculture, grazing, hunting, improving yield or collection of non-wood forest products).

The main interactions between fire and forests are shown along a transect between the high-altitude forest of the Himalayas and the lowland tropical rain forest in insular Southeast Asia:

- High-altitude forest (upper montane coniferous and subalpine forest): Pasture and hunting fires affecting *Juniperus* spp. and *Rhododendron* spp. forests (occasional stand replacement fires)

- Submontane coniferous forest: Fire climax pine forest (*Pinus* spp.) along the Himalayas and in continental and insular South Asia (short-return interval fires)

- Semi-evergreen and dry deciduous forest: Fire-adapted Sal (*Shorea robusta*) and teak bearing (*Tectona grandis*) forests and dipterocarp savanna forest formations (short return interval fires)

- Lowland tropical wet evergreen forest: Shifting agriculture, forest conversion and other long-return interval fires in the dipterocarp (*Dipterocarpaceae*) rain forest

- Degraded forest lands: Grasslands (e.g. *Imperata cylindrica*) with short-return interval fires

Detailed case studies will be given in the contributions of S. PENAFIEL, W. WERNER, D. SCHMIDT-VOGT and J. GOLDAMMER et al.

Fires and their effects in the wet-dry tropics of Australia

A.M. GILL

The extensive wet-dry tropics of Australia are dominated by forests and woodlands of *Eucalyptus*. Understories are typically grassy. Fires occur annualy or biennially over large areas. Grassy fuels reach about 5 t x ha^{-1} in weight in the first year after fire. They will support mild fires in the early dry season, as the grasses desiccate, and high or low intensity fires in the late dry season. Two years fuel accumulation - to say 8 t x ha^{-1} - may allow fires to run in the wet season and have substantive effects on the common annual grasses particularly on *Sorghum intrans.* Annual or biennial early or late dry season fires have a little effect on species composition in eucalypt forests and woodlands. Exclusion of fire alters species' performances and, probably, composition. Most plant species have developed adaptations to survive recurrent fires, but *Callitris*, a native conifer tree which can grow in eucalypt areas, is fire sensitive and may be quickly eliminated by repeated fires. Rainforests, which occur in wetter sites, may suffer attrition due to fire encroachment on their margins; after cyclone damage, the whole community may be exposed to fires. Seasonally inundated areas may be exposed to fires in the dry season but very little is known of fire effects in such areas.

A feature of fires in northern Australia is their association with birds: predatory birds are attracted to insects and small animals fleeing flames while others may be attracted to killed insects or to seeds, the latter being made more available by passage of the fire.

Conservation management in world heritage Kakadu National Park is aimed mostly at the restoration of Aboriginal fire regimes (mostly early dry season burning). Burning to encourage growth and reduce residue is a technique which may be used to advantage in the commercial raising of cattle. Timber interests may be concerned with fire exclusion from stands of the main timber species, *Callitris intratropica*. Early dry season burning each year is a useful technique for the protection of lives and property near towns and cities.

Session 5: Fire in tropical and subtropical savannas

The role of fire on grass production and on woody communities regeneration and spatial distribution in the savannas of Ivory Coast: Interactive processes

C. MENAUT

The pattern of tree and shrub distribution in the humid savannas of Ivory Coast is generally considered to be determined by soil characteristics and fire behaviour (intensity and regime). Yet, no initial soil features have been found to explain a preferential establishment of tree and shrub seedlings. A hypothesis is that species biological attributes induce an internal dynamics within the communitiy which results in the occurrence of clumps with relatively few isolated individuals. This dynamics, regulated by competition and fire, could finally be shaped by periodic events breaking up the clumps.

A simulation model of the community dynamics has been built on data collected over 20 years on plots with different tree densities and fire regimes. The model couples the study of tree and shrub population dynamics with the spatial analysis of the ability of an individual to establish on a given site, grow and recruit. The performance of each individual is studied in relation to the number of its neighbours and to fire intensity which mainly depends on the available fuel provided by grass biomass.

Preliminary results show the tendency to produce clumps which should progressively develop and cover the savanna on the long term. Fire does not seem able to stabilize the system: variations in initial density and fire regime modify the speed but not the nature of the process. Clumps dynamics seems regulated by internal competition with large long-living individuals and by the death of cohorts of shrubs with shorter life-span.

Fire as an ecological factor in the brazilian Cerrado

L. COUTINHO

Cerrado *sensu lato* may be considered as a physiognomical complex of vegetation, ranging from cerradao (a scleromorphous seasonal forest) to campo limpo (a pure grassland without trees or shrubs). Cerrado *sensu stricto*, campo cerrado and campo sujo are intermediary savannic forms. This gradient of plant biomass and of structural complexity is determined primarily by a gradient of soil fertility and fire action.

Natural fires have not been registered on a scientific basis, although it is presumed they may occur as a consequence of electrical storms. Fire is usually set on cerrado vegetation by man from May to September (period of drought), with a frequency of once each two years.

A very few experimental research has been done on the ecological effects of fire on cerrado ecosystems. The available data show that air temperature during fires may locally rise up to 800-1000°C. Soil temperature is much less affected, even at soil surface. Nutrient cycling is strongly accelerated by vegetation burnings. In a campo cerrado most of the ash nutrients deposited on the soil surface were reabsorbed within a few months by the superficial roots suggesting that fire transfers nutrients from trees and shrubs to herbs and undershrubs. Leaf-cutting ants of the genus *Atta* seem to partially antagonize this process. As an average of 6 experimental campo cerrado burnings, near 50 % of most nutrients present in plant biomass were lost to the atmosphere as ash particles and gases. After 3 years the same amount of nutrients returned to the soil through rainfall and gravity.

Together with soil fertility, presence of superficial hardpans and other human activities, fire may be responsible for the type of cerrado physiognomy, particularly the more open ones. Protection against fire in a small campo sujo area during 43 years favoured a vegetation succession to a cerradao physiognomy.

Primary production of the herbaceous undergrowth layer is estimulated by fires, as well as flowering and seed dispersion. Data on ecological effects of fire on animal populations are very scarce and fragmentary.

Response of cacti and other succulents to fire

P.A. THOMAS

Many succulents live in fire-prone habitats with fire frequencies ranging from 1 - 3 years (Canadian Prairies) to > 250 years (Sonoran Desert). How do they cope? Most available information is for the Cactaceae.

A few species evade fire by growing in low-fuel refugia, but most live surrounded by fuel. Areas accidentally missed by fire are frequent but insufficient to ensure mass survival.

Postfire mortality is often > 50 %; especially for dehydrated plants in high intensity fires. The primary cause of death is heat penetration killing phloem and cambium and, to a lesser extent, apical meristems. Survival is highest in species with greatest protection of the vascular tissue, and for taller individuals within a species.

Surviving plants usually resume growth from the apex. New lateral shoots from either above or below ground are comparatively rare except in genera such as *Agave* or *Aloe*. Cacti functionally severed from the ground may produce new growth and flowers using internal reserves for several years, obscuring true postfire mortality. Spine removal may indirectly increase mortality from grazing and freezing of the apical meristems.

Recruitment from seed is governed primarily by weather patterns. There is little evidence of fire stimulated flowering or seed production. *Opuntia* spp. may spread by rooting of broken fragments. Long term effects of repeated fires on succulent populations are largely undocumented.

Session 6: Fire in tropical deciduous and coniferous forests

The influence of fire, grazing and lopping on a tree-shrub savanna in Kayes Region, Mali

M. IMORT

This study examines the effects of wildfires, browsing and lopping on stands and natural regeneration of *Acacia seyal* Del., *Combretum glutinosum* Perrott ex DC., *Balanites aegyptiaca* (L.) Del. and other sahelian trees in a forest near Kayes in western Mali. The sahelian vegetation was statically inventorized on 17 plots of 0.4 ha each, rendering a N-S cross-section of roughly 20 km. The characteristics sampled included: species, size spatial distribution and damages. In addition general aspects like soil, herbaceous vegetation and land-use form were considered.

With climatic conditions being basically identical, observed differences could be expected to be mainly due to different degrees of human influence. Distinct differences in species frequency and damages were found between the 4 southermost plots, where population and cattle density were highest, and the remainder. It was found that *Acacia seyal* and *Balanites aegyptiaca* were frequently damaged but appeared to be more capable of regenerating than other species. This is assumed to account for their comparative abundance on the more pressured plots close to the settlements, outweighing the natural forces of species distribution. Natural regeneration was very sparse with only 3 species present in it, *Combretum glutinosum* being by far the dominant one.

Fire could not be shown to exert a discriminating influence on regeneration per se. It is assumed that the annual recurrence of bushfires started intentionally and by negligence in the entire region examined can be held responsible for the lack of intra-plot differences. All plots are evenly burnt, thereby influencing the vegetation as a whole but not locally or regeneration in particular. On the whole the number of species appears to be declining when compared to former inventories, whereas *Acacia*, *Balanites* and *Combretum* seem to gain ground, where pressure is high. In areas less intensely utilized *Sterculia setigera* Del. and *Sclerocarya birrea* (A. Rich.) Hochst. are increasing. Grazing lopping are thought to be factors more responsible for local species selection and individual physiognymy, while fire determines the general conditions of growth and regeneration which are equally critical for all species, as there is no truly fire-adapted tree present.

Fire in pine forests and grasslands of Northern Luzon, Philippines

S. PENAFIEL

In the Northern Luzon part of the Philippines the *Pinus kesiya* forests and grasslands are annually affected by fires. Fires occur frequently because of the climatic pattern, which is characterized by a distinct dry season of six months and a short rainy one. Plants in the grassland and pine forest ecosystems start to dessicate or shed their leaves in December, and atmospheric temperatures rise up to 32°C at noontime.

In the western portion of Northern Luzon, fires are all man-caused. The major causes are swidden farming, pasture burning and incendiarism. Organized fire control crews are only active during the fire season. Most fires (79 %) occur during the period of 9.00 and 19.00 hours. Forest fires usually reach a fire size as large as 2,000 ha running for 3 - 4 days before they are suppressed. The common method used for fire break construction is cutting the vegetation in strips of about 8 - 12 meters wide.

Fires in *Themeda-Imperata* grasslands increase the seed availability of short grass, legumes and other broadleaf species and seedlings in newly burned areas. An increase of seedlings by 30 % was observed in burned areas at the start of the rainy season. The net primary productivity of *Themeda* also increased from 15.31 g $0.5m^{-2}$ x 90 $days^{-1}$ to 67.46 g x $0.5m^{-2}$ x 90 $days^{-1}$ during the dry months. The tillering capacity of *Imperata* was found to be promoted by burning. In the pine and open dipterocarp forests, annually burned areas had higher soil erosion and surface runoff during the rainy months, but as grass regrow and aerial biomass recover soil erosion and surface runoff tend to approximate pre-burned conditions. Studies on ants (*Diacamma* sp.) also show that they are adoptable to grasslands which are regularly burned. Ant mounds in grasslands normalized from pre-burn to 6 months after the fire. Observations also show the high incidence/occurrence of *Ips calligraphus* among burned pine stands causing the deaths of trees which survive forest fires.

Fire in pine forests and savannas of Northern Thailand

W. WERNER

During the dry season, fires are a common phenomenon in the deciduous and montane oak forests of Northern Thailand. The pine species *Pinus merkusii* and *Pinus kesiya* profit from the forest fires, as their stems are protected by a thick bark and their seedlings find open space to establish. Natural fire causes are rare. Man is mostly responsible, and he has various reasons, e.g. providing fresh grass for his cattle. Many fires spread unintentionally from other areas.

In those forests, where fires occur almost every year, they are confined to the dry litter or the undergrowth. Thus, the trees with their thick bark are not harmed, and the leaves, which may get scorched, are shed anyway. The litter fires make available nutrients from the shed leaves, which are sclerophyllic and would decompose very slowly, and from dead wood on the forest floor. Most of the young seedlings and herbs are killed by the fire. This leads to the development of an open forest , in which the forest floor is covered by grass. The dry deciduous dipterocarp forest therefore may be called a savanna forest.

A problem arises from high grass and bamboo and those fuels which are accumulated after the fire exclusion of several years. In both cases high fire intensity may develop and become dangerous even for this fire-adapted form of vegetation. This must be considered, once fire-protection is organized in a forest area. Regular fires help to clear the forest floor. A fire frequency of 3 or 4 years would allow to establish enough tree seedlings.

In regions with sufficient rainfall, fire should be totally prevented, as without the influence of fire , evergreen or seasonal rain forests would establish in many areas, which are covered by deciduous and open forest communities now. Even the lower montane oak forest, with or without pines, is a sort of secondary vegetation, replacing lower montane rain forest.

Fire in the high-altitude forests of the Nepal Himalaya

D. SCHMIDT-VOGT

The term high altitude forest denotes:

- upper montane coniferous forest (2600 m - 3600 m), *Abies spectabilis* and *Tsuga dumosa* in the overstorey, *Rhododendron* spp. in the understorey;

- subalpine forest (3400 m -3800 m), *Betula utilis, Rhododendron campanulatum, Juniperus* spp.

These forests are situated on the southern slopes of the Nepal Himalaya, exposed to a monsoonal climate modified by orography-moist conditions prevail over most of the year, except for a short dry season in winter - and subject to considerable human pressure from a dense and growing population. Though generally located above the upper limit of farming and of settlements (ca. 2000 m) high altitude forests are nonetheless intensely used.

Fire is a frequent seasonal phenomenon in the high altitude forest. Forest fires occur mainly in the late dry season (from December to March). They are mostly confined to rather small areas, but large fires destroying several km^2 of forest were also recorded.

Most forest fires are caused by man. The principal reasons are:

- burning on pastures and in bamboo groves, practiced to stimulate new growth; fire often spreads to adjacent forests;

- intentional burning of forest to increase grazing area;

- the use of fire by hunters to drive game into traps;

- campfires left unguarded.

Fire causes loss of forest cover and vegetation change. Most forest is lost in the subalpine zone, where grazing pressure and fire hazard are greatest. *Juniperus* forests are particularly susceptible to burning and have been replaced by pasture over large areas. *Betula* forests are more resistant. However, once killed by fire, they are replaced by bamboo. Bamboo also arises when montane coniferous forest is burned. Fire seems to play an important part in breaking up pure *Rhododendron* stands, which have evolved from mixed *Rhododendron*-coniferous forests, and which prevent regeneration of any species by accumulating a dense litter-layer. Opening up the canopy and consuming this layer, fire prepares the ground for the reestablishment of mixed forest.

Session 7: Fire in the tropical rain forest

Fire disturbance and post-fire regeneration of lowland tropical rain forest in East Kalimantan (Borneo), Indonesia

J. G. GOLDAMMER and B. SEIBERT

Paleoclimatological and palynological evidence shows that during the last glacial epoch in the pleistocene and during the holocene the tropics have experienced for the most part cool and dry periods. Even if the vegetation of the wet tropical lowlands may not have changed substantially during the glaciations, it can be assumed that the overall drier conditions have favoured the expansion of dry savanna-type forests in which fire has played a major role.

Recent climatic fluctuations like the "El Niño - Southern Oscillation" (ENSO) have been causing periodic droughts in Southeast Asia which have favoured the occurrence and spread of fires in the lowland rain forest. The extensive rain forest fires in East Kalimantan, which occurred after the drought of 1982-83 were largely regarded as a "catastrophic" event. It was assumed that the fire-affected rain forest would have been completely extincted.

On the other hand, it is evident that the permanent presence of fire burning surface coal seams in the eastern part of Borneo (East Kalimantan) and the climatic fluctuations under the influence of extreme ENSO have been triggering frequently rain forest fires during the past.

In order to proof the historical occurrence and influence of repeated fire disturbances of the rain forest in East Borneo, a series of investigations on fire history and forest regeneration after fire were initiated. ^{14}C dating of charcoal found in deep mineral soil under undisturbed rain forest made evident that fires have occurred at least between 350 and 17,510 B.P. Abundant and extensive layers of kaolinite on top of coal seams were transformed to burnt clay ("baked mudstone") by the extreme high temperatures of the sub-surface fires. The final age determination of the burnt clay by thermoluminescence method is underway at present. First analyzes give evidence that the coal layer fires have been burning at least since 4,000 and 10,000 B.P. .

The regeneration of the lowland dipterocarp rain forest after fire was investigated on several experimental plots which had been surveyed before and after the 1982-83 fires. The forest development shows the typical successional occurrence and dominance of pioneer species. However, about five years after fire the amount of competitive regeneration of dipterocarps leads to the conclusion that the rain forest affected by drought and fire may recover and re-establish itself, if not disturbed furthermore within the next future.

Fire in the tropical rain forest of the Amazon basin

P.M. FEARNSIDE

(Abstract not yet received)

Session 8: Historical and prehistorical perspectives

Landscapes in prehistory: Interaction of wildlife, man and fire in prehistoric times

W. SCHÜLE

Fire is recognized as an important selective agent in terrestric plant and animal evolution. Plants react to animal- and fire-aggression with defense-strategies. Herbivores have to develop systems to overcome plant self-defense, mainly with more effective dentitions and digestion. Efficient herbivores and high fire frequency prevent accumulation of fire potential. Both depend on the climate, which is modified by their influence on carbon circulation-systems. These interdependent effects are reflected in consecutive paleontological circles. Miocene savannization in Africa confronted hominoids with trophic problems and high fire-frequencies. Overcoming their genetic pyrophobia, terrestrial hominoids profitted from wildfires. Plio-/Pleistocene homiminds used thrusting-spears to kill fearless megaherbivores, which lead to increasing fire potential in the forests. Approximately 1.5 myr B.P., they evidently began to use fire for protection against carnivores by night, fire frequency increased substantially. Consequences are discussed.

Equipped with spears and fire, *Homo erectus* expanded over the Eurasian tropics and sub-tropics during the Middle Pleistocene. Effects on megafauna, vegetation and fire-regime were the same as before. Rain-forests densened, fire-tolerant savannas spread. Further expansion was limited climatically, an eutrophic line formed, with bad climatic and good trophic conditions for *Homo erectus* and later for *Homo sapiens* spec. In the hinterlands, the man-made fire regimes continued. The same process was repeated about 40,000 B.P. in Australia, 11,500 B.P. in America, and all further primary settlements.

Fire conservancy: The origins of fire protection in British India, Australia and America

S. PYNE

The export of forestry from western Europe required the simultaneous export of fire protection technologies. Fires - wildfire and routine anthropogenic burning both - were usually the first and most violent problems faced by foresters as they tried to transplant European institutions and practices outside the social and environmental context of western Europe. Without fire protection, formal forestry was impossible. Natural regeneration appeared hopeless, and plantation forestry unthinkable. Fire control thus became an essential precondition for the establishment of forestry in developing nations, and an illuminating allegory for the general question of industrialisation. This is as true today as it was a century ago.

Decisions about fire protection were made consciously. They were debated in public forums, often over the span of decades; the outcomes of these controversies were far from obvious; and the different paths taken by nations reflect more their varying environmental, social, economic and political contexts than purely technical criteria. As a historical paradigm, it is usefull to consider three episodes in English-speaking nations - British India, America and Australia.

Each began experiments in the 19th century. India was first (1860s), where the issue was known as "fire conservancy" - that is, conservation about appropriate fire practices. In British India, this discussion focused on the role of "early burning"; in America, on "light burning"; in Australia, on "burning off". Each adopted different solutions. After vigorously promoting fire control, British India retreated into a compromise between fire use and fire control, even withdrawing formal fire protection from Burma and Assam. Thanks to historical accidents associated with the 1910 fires, America adopted a strategy of aggressive fire control known as "systematic fire protection" and beat down proponents of light burning until accomodations were finally forced onto the system, first in the South (during the 1940s), then, during the 1970s, throughout most of the public lands subject to protection. Australia wavered incompletely between Indian and American examples, accepting total fire exclusion as an ideal but exploiting fire as a necessary tool of practical management. Then during the 1950s, its foresters adopted controlled burning as a general strategy for fire protection.

Between them the three episodes show the spectrum of options open to developing nations, and they demonstrate the critical influence of social as well as environmental circumstances and the impact of chance. It is clear that no policy can rely exclusively on fire control or fire use. Each choice brings its own special liabilities, but some choice is mandatory; not to choose is itsself a decision with considerable environmental consequences.

Forest fires in brazilian industrial plantations and protected public land

R. SOARES

Although fire had periodically caused serious problems to forested areas in Brazil, until 1983 no attempt was made in order to collect statistics about fire occurrence in the country. In that year, a research work aiming to compile forest fire statistics in the whole country was initiated. The objective of the work was to identify some highly important fire characteristics for control systems planning, such as locality and date of occurrences, main groups of causes, estimated burned areas, types of burned vegetation and size classes. Forms were mailed to all private and public forest companies, national parks and national forests, requesting informations on forest fire occurrences. As many institutions did not keep records of the occurrences, the collected data do not represent the total number of fires occurred in the country in the studied period: 1983 to 1987. However, the quality and quantity of informations has improved throughout the years due to the progressive consciousness of the forest managers to the fire problem.

In that five year period 1,754 fires were recorded, totalizing 134,107.31 hectares of burned lands. Minas Gerais (25.3 %), and Espirito Santo (18.4 %), states of the southeastern region, ranked first and second, respectively, in number of fires. Regarding the burned area, Minas Gerais (43.5 %) was still the first, but the Federal District (11.2 %) ranked second, and Espirito Santo (2.0 %) occupied the nineth place among the states, demonstrating higher efficiency in fire fighting, because in spite of the high number of fires, the total burned area was small. Almost 83 % of the fires , accounting for 97.3 % of the burned area, occurred in the last six months of the year, and August and November can be considered the critical period. The exception to this behaviour was Espirito Santo, where fire occurrences were more uniformly distributed through the year. Debris burning (33.6 %), and incendary (29.8 %) were the two leading causes of fires, corresponding to 63.7 % and 14.7 % of the burned areas, respectively. Campfires and smokers were important causes in Amapá and Paraná states.

Concerning the burned vegetation, 50.0 % of the fires occured in *Eucalyptus* spp. plantations, 11.9 % in pine plantations, and 32.1 % in other types of vegetation (mainly grassland and savanna), that responded for 58.2 % of the burned area, while eucalyptus accounted for 33.8 %. Results also showed that most fires (41.1 %) were classified in size class II (0.1 to 4.0 ha), followed by size class III (4.1 to 40 ha) with 29.1 %, size class IV (40.1 to 200 ha) with 12.3 %, size class I (< 0.1 ha) with 10.5 %, and size class V (over 200 ha) with 6.7 %, yet this last class accounted for 77.5 % of the total burned area.

Prescribed burning in pine stands of South Africa. Some effects on forest floor dynamics.

C. de RONDE

Apart from the role of aerial fuels (understorey vegetation, draped fuels), the structure of the forest floor layers is an important factor to be considered, when prescribed burning is applied. The magnitude or absence of humus (H-layers) will determine the moisture gradients in the fuel bed before the fire and the extent of protection of the soil surface or the probability of ground fires.

Sharp contrasts in forest floor structure have been recorded in Southern Africa, and these will be illustrated. Decomposition ranged from almost nil to complete. Problem areas have been identified, in which the selected use of prescribed fire is recommended.

Variation in forest floor structure will also determine how nutrients are distributed in the different layers and how this will affect nutrient availability after prescribed burning. The fire impact on nutrient budgets will also vary with forest floor structural differences. Some recorded results will be given.

Session 10: Monitoring tropical fires

The contribution of remote sensing to the global monitoring of fires in tropical and subtropical ecosystems

J.P. MALINGREAU

It is increasingly recognized, that fire is a growing agent of change in tropical and subtropical ecosystems. Population pressure on land, coupled with climatic events of the last few years, have led to an increase in fire-related events with drastic consequences upon local environments. Biomass burning related to tropical deforestation and agricultural practices of the tropics thus represent a growing contribution to atmospheric chemestry and global climatic change.

Better assessments of the frequency and magnitude of prescribed or natural fires in the tropics requires the development of an adequate information system. Remote sensing techniques from space can partially answer this requirement. The paper describes the approach based upon the NOAA-AVHRR satellite data. Recent examples of large scale burning in the tropics are analyzed with particular reference to Kalimantan, the Amazon Basin and West Africa. The difficulties in evaluating the accuracy of the interpretations are discussed; proposals are made to improve existing capabilities for consistently monitoring fires and their impacts throughout the tropical belt.

Remote sensing of biomass burning

Y. KAUFMAN

A new method is being developed for the global assessment of the contribution of biomass burning due to deforestation to climate change (trace gases and particulates emission). The method is based directly on remote sensing of one emitted product-particulates. It uses the inexpensive daily meteorological satellite data (the National Oceanographic and Atmospheric Administration - AVHRR) with resolution of one km^2. The visible (0.63 m^{-6}) and near IR (0.84 m^{-6}) bands are used to determine the mass of particulates in the emitted smoke, and to estimate the relative contribution of flaming and smoldering to the smoke. The mid-IR (3.7 m^{-6}) and the IR (11 m^{-6}) channels are used to detect and count fires, in order to integrate the smoke result on the whole season and the whole area of interest. The IR channels are sensitive enough to detect flaming fires as small as 10 m x 10 m and smoldering fires as small as 30 m x 30 m. The detected mass of emitted particulates is converted into the mass of the emitted trace gases using published relations between the emitted particulates and trace gases, for the flaming and smoldering phases. The technique can be applied to regions where intensive biomass burning takes place. It is capable of monitoring the extent of current deforestation, to discover new deforestation frontiers (unknown otherwise), and to estimate the quantitative contribution of the biomass burning to changes in the atmospheric composition.

The method is applied to a limited area where strong deforestation takes place. Analysis of the 1987 burning season shows that in Brazil (in a limited area between 6.5° - 15.5° south and 55°-76° west), during the three months of the dry season (July 1 till Sept. 30) there are up to 8000 fires a day, observed from space, each contributing 4,500 tons of CO_2, 750 tons of CO and 28 tons of CH_4 to the atmosphere. During the dry season of 1987, it is estimated that 240,000 fires were burning in this area, resulting the emission of 1×10^{13} gr of particulates, 7×10^{12} gr of CH_4, 2×10^{14} gr of CO and 1×10^{15} gr of CO_2. A comparison to estimates of global emissions is given.

NOAA AVHRR and GIS based monitoring of fire activity in Senegal - a provisional methodology and potential applications

S. LANGAAS

Bushfires can be defined to be **any fire occurring in the rural landscape, but generally implies that it is out of control.** These fires are annually occurring over large areas in savanna zones of Africa. This is also the case for Senegal. The fires can be considered cultural phenomenas due to two facts:

- almost all fires are set, deliberately or accidentally, by the local population, and
- the fires highly influence the welfare of the population due

to their impact on the renewable natural resources, particularly the (natural) vegetation.
Due to this, quite large resources (manpower, equipment, finances) are employed to reduce the number of those fires considered destructive, and to promote the use of controlled and less destructive or beneficial fires as a management tool.

Quantitative information on fire activity for different geographical levels has hitherto been scanty or unreliable on regional and national levels in Africa. Most statistics have been derived from incomplete reports from field staff. This presentation reports on the development of a national/regional fire activity monitoring system for Senegal.

The major datainput is coarse resolution (spatially), but inexpensive satellite data from the NOAA AVHRR satellite sensor system. Preliminary investigations on the potential of this datasource for multi-temporal mapping of burnt affected areas, strongly indicate a high potential. In situ measurements of temporal dynamics of spectral reflectances from burnt surface, as well as airborne coincident aerial photos and radiometer measurements strongly support the assumption that high frequency data, as provided by the NOAA AVHRR satellite sensor system, are required to discriminate **burnt** from **non burnt** surfaces. However, due to spectral confusion with other non-vegetated surfaces, the satellite data will be used in a Geographical Information System in order to utulize ancillary information, e.g. roads or administrative boundaries (political, economic, management),it may be possible to generate management relevant maps on a timely basis during the fire season, showing where fires have occurred. Reliable statistics on a national and regional level may also be generated.

Session 11: Impact of biomass burning

Factors influencing the emissions of gases and particulate matter from biomass burning

D.E. WARD

Trace Gas and particulate matter emission factors for some fuel types burned in the United States are compared with measurements for other regions, globally. Some information is available concerning the effect of fuel chemistry of biomass and fire behaviour interactions on the production of smoke emissions. These data have been largely developed through empirical measurements using a variety of techniques including: airborne, surface towers, combustion laboratory, and controlled combustion and pyrolysis aparatuses. From the work, correlations and trends have been established.

For example, the rate of heat release affects the size of particles injected into the atmosphere. Results suggest that oxides of nitrogen are produced proportional to the nitrogen content of the biomass and for some sulfur compounds (e.g. carbonyl sulfide) may be produced proportional to the sulfur content of the biomass consumed by the fire. Methyl chloride is released in proportion to the chlorine content and inversely proportional to the rate of heat release. Hydrocarbons (e.g. formaldehyde and benzo[a]pyrene) are released proportinal to carbon monoxide and inversely proportinal to combustion efficiency.

These relations suggest that new information concerning the correlation of combustion efficiency, rate of heat release, and chemistry of the biomass consumed with the emissions released will provide globally valid estimates of emissions for many compounds. Work is underway at the Intermountain Fire Sciences Laboratory to provide new information concerning the production of trace emissions and air toxic substances from the combustion of biomass fuels.

Ozone production from biomass burning in tropical Africa

M.O. ANDREAE

The DECAFE (Dynamique Et Chimie Atmosphérique en Forêt Equatoriale) - project was set up to study meteorological and chemical processes in and above the equatorial rain forest of equatorial Africa. A combination of aircraft, balloon, and ground measurements was used to study these processes. The DECAFE-88 experiment was carried out in the Northern Congo near Impfondo during February 1988.

The distribution of ozone was measured from the surface up to 4 km altitude. Simultaneous determinations of meteorological parameters and various trace components, including Aitken nuclei, CO, CO_2, organic acids, and NO_x were carried out. A pronounced ozone maximum with concentrations up to 70 ppbv was found at altitudes between 1 and 3 km. This maximum coincided with high levels of CO, CO_2, organic acids, and Aitken nuclei. While these high levels aloft persisted during the entire measurement campaign, a distinct diel variation of ozone was observed at lower altitudes.

Measurements of the meteorological parameters revealed a complex pattern, indicating the presence of several layers of differing origins. They suggest that the ozone-enriched layer may be formed from air masses which originate in northern Africa subsequently advect over dry tropical regions where large amounts of aerosols, CO, NO, and hydrocarbons from biomass burning are introduced. These air masses become trapped in the equatorial region between the near surface monsoon flow from the southeast and the easterly flow above 3-4 km. Photochemical reactions involving the oxidation of CO and hydrocarbons in the presence of oxides of nitrogen lead to the production of ozone in this layer. Diurnal variability in the vertical distribution of ozone is driven by removal of O_3 by surface uptake and reactions with NO and hydrocarbons, leading to surface O_3 mixing ratios near zero at night and a steep O_3 gradient through the sub-cloud layer. During the day, this gradient is reduced by convective mixing and by photochemical production of ozone. The ozone-enriched layer observed during DECAFE is sufficient to explain the tropospheric ozone anomaly observed by remote sensing in this region.

Direct and indirect contributions of biomass burning to the global carbon cycle in the past 125 years

G.ESSER

Biomass burning during shifting cultivation and other human activities contributes to the global carbon budget in various ways. The carbon release through burning and subsequent decomposition of the litter residues is considered to be a main source for atmospheric CO_2. During the burning process, minerals which were accumulated in the biomass are released and partly incorporated in the soil as a fertilizer for the agricultural use. Within 2 - 10 years, depending on soil type and climate as well as human impacts, minerals are leached to ground water and subsequently surface water bodies, where phosphat enhances the primary productivity of aquatic plants. As a consequence, the transport of carbon into sinks in the river and ocean sediments may also be enhanced. These effects interact on the other side with the dynamics of soil organic carbon and vegetation regrowth as well as climatic changes.

The author used the Osnabrueck Biosphere Model to estimate the possible spans of the contributions of the various direct and indirect effects of biomass burning to the global carbon budget within the past 125 years.

Estimates of gaseous emissions from worldwide biomass burning and their influence on athmospheric chemistry

P.J. CRUTZEN and
WEI MIN HAO

Annual emission estimates for CO_2 (at 5° x 5° grid) and other trace gases from deforestation and savanna fires in the tropics during the period of 1976 - 1980 have been determined based on the FAO survey by Lanly (1982). About 2.3×10^{15} g C of CO_2 per year was produced by burning biomass in the tropics, implying annual releases of 2.3×10^{14} g CO-C, 2.7×10^{13} g CH_4-C, 2.9×10^{13} g non-methane hydrocarbons-C, 5.3×10^{12} g NO_x-N and 1.2×10^{12} NO_2-N. The uncertainty in these estimates is about ±50 %. The work suggests that savanna fires are much larger sources of atmospheric emissions of CO_2 and other trace gases than deforestation in the tropics. More than half of the total source is attributed to fires in African savannas. Because the FAO statistics were derived for the period of 1975 - 1980, the emissions during the present decade may have been substantially larger due to the increasing demands for agricultural land and fuelwood by the growing populations in tropical regions. In comparison to the CO_2 from biomass burning, the net release of CO_2 in the tropics ist estimated to be 0.8 - 2.6 x 10^{15} g C per year based on the FAO statistics and the report of the National Academy of Sciences. The net release of carbon is mainly caused by the changes of land use from forests to shifting cultivation, pasture, agricultural lands and roads.

The importance of wildfire to climate change: hypotheses for northern ecosystems

R.W. WEIN

Global circulation models have explored broad spatial dimensions of climate change given doubling of the atmospheric CO_2 levels over the next 30 to 50 years. Throughout the northwestern part of Canada, predicted increases in temperature of 1.5 to 4.5°C suggest that forest will come under increasing stress and wildfires will increase in frequency and intensity not only because of the warmer and drier weather conditions, but because stressed trees will die, thereby increasing fuel loads.

Proxy data are accumulating from past climatic change analogues. The warm and arid conditions from 7000 - 500 B.P. and from the 15th and 16th centuries A.D., are examples from northwest Canada. Proxy data ware open to criticism because the climate changes predicted are much more rapid than any previous changes in the earths history.

Simulation modelling approaches remain the most useful in exploring climate change/wildfire hypotheses; yet this approach has limitations as well.

To identify climate change effects in the field, benchmark areas in major ecotones must be established and monitored on a regular basis for changes in the sensitive indicators of climate change.

Global change: effects on forest ecosystems and wildfire severity

M. FOSBERG

Since the beginning of the industrial revolution mankind has altered the chemistry of the atmosphere. We have increased the concentration of trace gases in the atmosphere to the extent that we have altered the climate of planet earth. Gases such as carbon dioxide, methane and water vapor trap a portion of the earth's infrared radiation to space to balance the energy from incoming solar energy. Concentrations of trace gases in the atmosphere, such as carbon dioxide have increased by 25 % from burning fossil fuels. This increase of radiactivlely active gases are predicted to increase the atmospheric temperature by 3 to 5 degrees Celsius. In the past 3000 years, the earth's temperature has only varied by 1.5 degrees Celsius, and this includes the little ice age of the fifteeth century.

Impacts of the predicted greenhouse warming include direct effects on the ecosystem, where the climate will become inhostible to plant reproduction, and where the climate will become more hostible, and where we will see shifts in vegetation patterns over the next 50 to 100 years.

Secondary impacts, particularly those induced by trauma (insect, disease and fire) will also become important in the future. Host-preditor relations will change. Severity and frequency of trauma will change.

Endangered species, and biodiversity in general will be threatened by changed habitat as a consequence of climate change.

The lessons of paleo-ecology have taught us, that systematic climate change (Holocene to the present) can alter the face of the biosphere in dramatic fashion. The climate change form of the last ice age, 12,000 years ago to 7,000 years ago, a period of 5,000 years, is expected to take place within the next 50 to 100 years. A rate 10 times as fast as earth has ever experienced.

Industrial forestry, conservation of natural resources and maintenance of biodiversity are issues that must be addressed. Policies to conserve, mitigate and adapt need to be developed.

Predicted impacts on North American forests are less biomass, changes in forest structure and compositions. Also, threatened and endangered species may become extinct. Additional threat from trauma is likely to change. Insect and disease threats will be altered by temperature and moisture changes from climate change. Fire frequency and fire severity will increase because of the predicted climate change.

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