FIRE BEHAVIOUR IN CONIFER PLANTATIONS IN ISRAEL (1)

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Introduction

In Israel there are no natural spontaneously forest fires. All fires are caused by man either through malice or through negligence. On the average approximately 400 hectares are burnt, each year. Thus, this represents a very serious problems in our forest management. Fires occur during the long dry season, from late spring throughout the summer and until the first strong rainfall. Fires have been known in our region throughout history and are considered a part of the ecosystem in a dry Mediterranean climate (Naveh, 1977).

The spread of fire after ignition depends on a complex of interrelated factors, as described schematically in Figure 1. The main factors which influence the spread of fire are : Fuel Biomass, forest conditions, fire control efficiency, climate, and environmental conditions.

The purpose of this paper was to determine the relative contribution of various independent variables of forest conditions to fire spread after ignition.

Materials and methods

The study is based on all fire events (n = 223) which occurred in the conifer plantations in Israel during 1985. Each event was analyzed on the basis of forest conditions found prior to fire ignition. Technically, this was done by integrating the computer data of fire events with those of a forest survey. The survey is routinely conducted for general purposes and the available data included only some of the variables indicated by the model in Figure 1. The dependent variables which described the extent of fire spread are the number of burnt trees, the size of the burnt area, and their log-transformations.

The list of independent variables describing forest conditions which were studied is as follows :

1. Tree species — *Pinus halepensis, Pinus brutia* and *Cupressus sempervirens.*
2. Age of plantation.
3. Plantation density (trees.ha^{-1}).
4. Basal area (m^2.ha^{-1}).
5. DBH (cm).
6. Tree height (m).
7. Percent of tree's canopy cover.
8. Percent of bare area.
9. Percent of forest floor vegetation : shrubs, small shrubs and annuals.
10. Number of thinnings.
11. Height of minimal and maximal pruning.
12. Percent of slope steepness.
13. Exposition of slope.
14. Number of years since last fire.

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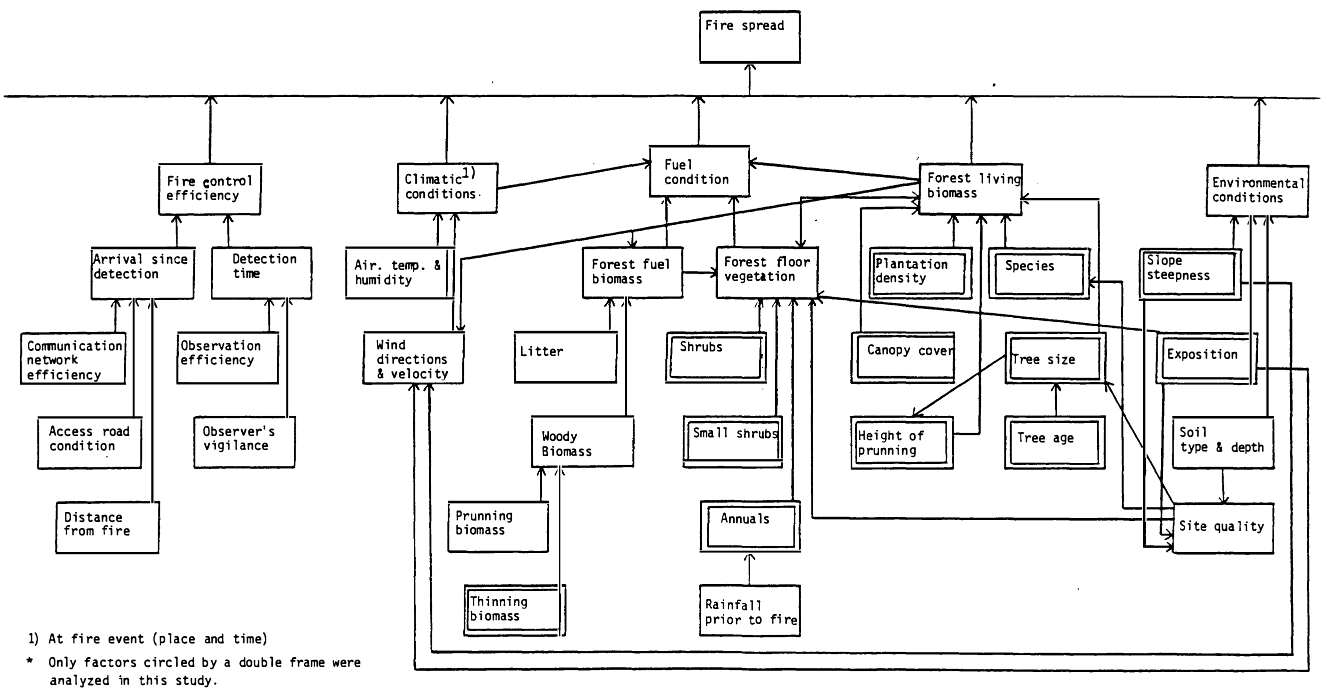


Figure 1. — A model of factors affecting forest fire spread after it's ignition.

The following statistical analyses were performed :

1. A correlation analysis between each of the independent variables (mentioned above) and the number of burnt trees and the size of the burnt area. Analyses were performed separately for *P. halepensis* plantations, *P. brutia,* and for all three species (there were relatively few fire events in *C. sempervirens* plantations).
2. Multiple regression : A search for meaningful regression equations was carried out of the dependent variables including also the logarithmic values of the number of burnt trees and the size of the burnt area on the set of the independent variables. These equations were developed separately for *P. halepensis* and *P. brutia.*
3. General linear model (GLM) : With this method we looked for a general model, in a trial and error mode, which was to include only those variables significant for all species but which allow for differences in coefficients for the different species. The final model led to the main factors affecting fire spread (from the set available) and also indicated the relative sensitivity of the species to fire.

Results

The correlation coefficients (Table I) between forest conditions and fire spread were generally rather low, as was to be expected from the nature of the data. Nevertheless, the signs of the coefficients were consistent in all species, e.g. a positive relation was found for both species regarding plantation density and a negative relation regarding plantation age. All variables which are related positively to tree age were found to be related negatively to fire spread. The coefficients for *P. brutia* were consistently higher in absolute values than those for *P. halepensis.*

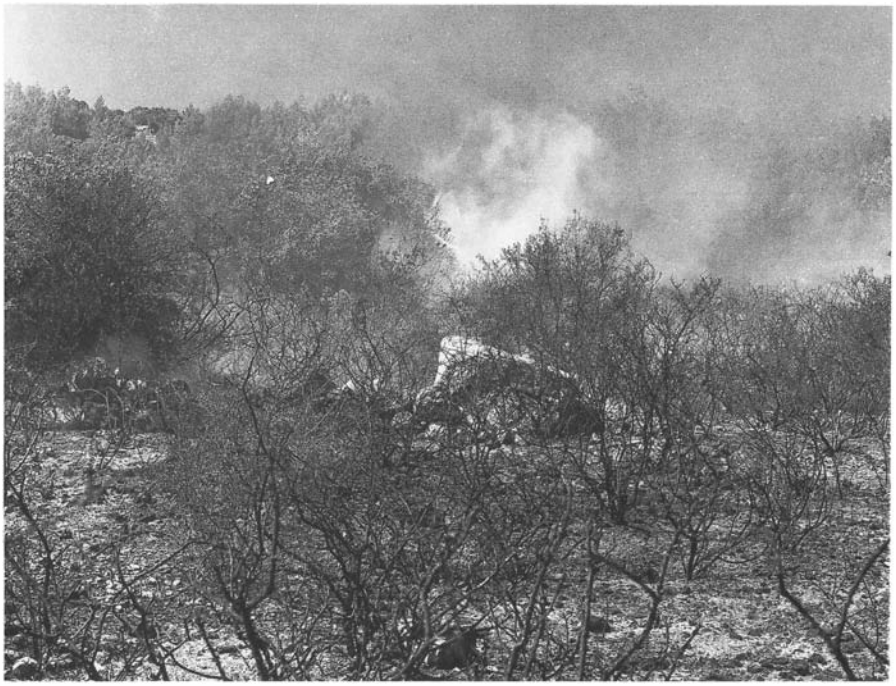
The significance of all relationships increased when considering the number of burnt trees, as opposed to the total size of the burnt area. Table 1 points out the simple linear relationships of the individual forest survey variables with fire spread, ignoring the interrelationships among the variables.

In order to analyze all the information, a set of statistical models was developed which determined and identified the main factors affecting fire spread just after ignition (Tables II, III and IV).

The best linear regressions for each of the two species *P. halepensis* and *P. brutia* are presented in Table II.

The multiple correlation coefficients for the regression of the logarithmic values of the number of burnt trees were significantly higher than those of the log of total area burnt for both species.

The main factors which influenced fire spread of *P. halepensis* were found to be : negative relation to plantation age, percent of canopy cover and percent of shrub cover on forest floor and



Photos 1 et 2. General views of forest fire in conifer plantations in Israel.

Fire spread variable / forest survey variable	Pinus halepensis: Number of burnt trees	Pinus halepensis: Size of burnt area	Pinus brutia: Number of burnt trees	Pinus brutia: size of burnt area	All species: No. of burnt trees	All species: size of burnt area
Number of fire events	135-172		36-52		168-223	
Age of plantation	-.17*	-.10	-.47*	-.15	-.18*	-.08
Plantation density	.22*	.20*	.35*	.11	.19*	.14**
Basal area	-.12	-.05	-.50**	-.23	-.15*	-.06
Tree diameter (DBH)	-.16	-.08	-.49**	-.18	-.18*	-.07
Tree height	-.13	-.05	-.52**	-.21	-.16*	-.05
Percent of canopy cover	-.05	.01	-.41*	-.35*	-.10	-.05
Percent of bare area	-.18*	-.13	-.17	-.07	-.16*	-.11
Percent of floor vegetation						
shrubs	-.06	-.10	-.09	.01	-.03	-.07
small shrubs	.01	-.03	-.03	.09	.00	-.03
annuals	-.06	-.03	.16	.13	-.04	-.01
Number of thinnings	-.25[b]	-.15	.25[a]	.07	-.21	-.10
Height of pruning:						
Minimal	-.21[b]	-.24			-.22[b]	-.09
Maximal	-.12	-.06	-.56**	.03	-.12	-.04
Percent of slope	-.06	-.05	.10	-.03	-.03	-.03
Exposition of slope	-.08	-.01	.06	.14	-.06	.01
Years since last fire	-.08	-.04	-.35*	-.02	-.12	-.04

[a]Number of fire events less than 50% of the total - [b]Number of fire events less than 10% of the total
* $P < 0.05$ ** $P < 0.01$

Table I. Correlation coefficients between each of the forest survey variables and the variables representing fire spread.

Species	Dependent variables	df	R^2	Intercept	Canopy cover	Bare area	Plantation density	Plantation age	Basal area	Exposition	Percent of floor vegetation: Shrub	Percent of floor vegetation: Small shrubs	Percent of floor vegetation: Annuals
Pinus halepensis	Log (number of burnt trees)	117	0.33***	2.90	-0.02**	-0.01	0.004*	-0.03***					
	Log (size of burnt area)	143	0.11**	0.01			0.002*			0.09*	-0.01**		
Pinus brutia	Log (number of burnt trees)	31	0.62***	2.56	-.001				-.001***				0.06
	Log (size of burnt area)	42	0.36**	0.84	-.001***		0.002					-.001*	0.02

* $P < 0.05$
** $P < 0.01$
*** $P < 0.001$

Table II. Regression equations for the log values of the number of burnt trees and the size of burnt areas in models developed for each species.

Photo 2.

a positive relation to plantation density and to the level of the stress condition at the slope exposition.

A similar analysis for *P. brutia* revealed a negative relationship between fire spread and the percent of tree canopy cover, basal area, and percent of small shrub cover on forest floor.

Statistical analysis involving all three species, based on GLM (Table III) produced the critical factors influencing fire spread after ignition, namely, a positive relation with forest density and a negative relation with tree age and with the percent of tree canopy cover. Table 3 also point out the differences between the species as to their resistance to forest fire. *P. halepensis* was found to be the most fire sensitive of the three species.

GLM analysis (Table IV) emphasized the advantage of using logarithmic values of the number of burnt trees, instead of using their absolute values or the total area burnt.

Discussion

This study analysed for the first time all fire events which occurred in all the conifer plantations (70,000 ha) in Israel during one year. All statistical tests and models are based on the three main species comprising conifer plantations : *P. halepensis, P. brutia* and *C. sempervirens*. The relative frequency of fire events out of the total number of fires in the plantation of these species was : 71 %, 23 % and 6 %, respectively. Such a distribution of fires is approximately proportional to the relative frequency of these species within our conifer plantations.

This similarity emphasizes the randomness of fire events. This finding supports the hypothesis that fires are caused mostly by man, either accidentally or on purpose, but in either case at random in respect to the specific location at which the fire is started.

The purpose of this work was to investigate the main factors influencing fire spread. Our analysis involved all available factors related to forest conditions from forest survey data. We are aware that it is necessary to include more factors which are involved in fire events (Albini and Anderson, 1981; Rothermel, 1983). Figure 1 demonstrates a model of these factors.

The statistical analysis was conducted in several stages. The first stage was to calculate correlation coefficients between each of the independent variables which describe forest conditions and the dependent variables which express fire spread.

The simple correlation coefficients explained only a small part of the total influence of all parameters.

In order to identify the relative contribution of the various parameters to fire spread, we developed a set of statistical models which determine the most critical parameters and express their level of significance. As a preliminary stage for these models we examined the distribution of burnt trees and of total burnt area. It was found that the first variable was much more positively skewed than the second, mostly because of the large variation in the size of the fires. The analysis included ten big fires in which tens of thousands of trees were burnt, while the number of burnt trees in all of the other fires was estimated as hundreds to thousands of trees. In order to moderate the skewness, we transformed the values of number trees to their logarithmic values. The use of a logarithmic scale in forest fires is not just a "statistical exercise" but reflects the acceleration in the number of burnt trees as a result of the speeding up of the fire fronts. Such an effect is proportional to the number of burnt trees.

The use of logarithmic values in the regression equation (Table II) and in the general linear model GLM (Ta-

Dependent variables	Intercepts for species: Pinus halepensis	Pinus brutia	Cupressus sempervirens	Coefficients of continuous variables: Plantation age	Canopy cover	Planation density
Size of burnt area	7.46	4.06	3.51	-0.014	-0.055	0.043
Number of burnt trees	617	324	198	-10.004	-8.211	5.675
Log (number of burnt trees)	2.32	1.95	2.02	-0.034	-0.008	0.004

Table III. Main effects of the independent variables on three measures of fire spread in a general linear model (GLM) for all three species.

Dependent variable	Number of observation	Squared multiple correlation (R^2)	Coefficient of variation	Marginal sum of squares: Species	Plantation age	Canopy cover	Plantation density
Size of burnt area	223	0.046	160	541	4	210	708*
No. of burnt trees	186	0.09*	278	$39x10^5$	$19x10^{5s}$	$41x10^5$s	$110x10^5$**
Log (No. of burnt trees)	186	0.26***	59	4.49^s	21.27**	3.95*	6.08**

s P < 0.10
* P < 0.05
** P < 0.01
*** P < 0.001

Table IV. Statistical data of three measures of fire spread in a GLM for all three species (*Pinus halepensis, Pinus brutia* and *Cupressus sempervirens*).

ble III and IV) improved the level of significance of the findings and the fit of the dependent variables, and emphasized the difference between species.

As noted above, *P. halepensis* was the most sensitive to fire, *C. sempervirens* was the most resistant, as determined by two out of the three parameters. These findings match fire resistance data for these species as determined under controlled conditions in the laboratory, using the Epiradiator system according to Delabraze et Valette, (1974) and Zohar, (in preparation). This leads us to recommend to increase planting of cypress along forest access roads and to increase their proportion within the pine plantations.

The critical factors influencing fire spread after ignition as determined by GLM from the present data are : positive relation to forest density and negative relation to tree age and to the percentage of tree's canopy cover. The operative conclusion which should be derived from these findings is to intensify the fire protection in young and dense plantations.

The above factors account for 30 % of the variance in data on fire spread. Therefore, the highest priority in future research will be derive additional factors (Fig. 1) which should account for a higher percent of the variance. Special attention should be given to identify the level of danger of the fuel material on the forest floor. This material should be controlled by mechanical collection, grazing, or by prescribed burning (Liacos, 1977; Green, 1977).

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Y.Z., A.W.
A.G., A.G.

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Summary

This study investigated the factors contributing to, or restricting, fire spread, based on all fire events which occurred during 1985 in all conifer plantations in Israel. Altogether 223 fires were analyzed. The fire spread was characterized by the number of trees burnt, and the size of the total area burnit. The variables which might affect fire behaviour were tree species and other forest conditions, which were routinely recorded for forest survey.

The main factors influencing fire-spread after ignition were found to be forest density, tree age, and the percentage of the tree's canopy cover. The first related positively, and the two others negatively, to fire spread. These factors account for about 30 % of the fire spread variance. Therefore, the highest priority in future studies will be to measure, record and derive additional factors, in order to account for a higher percent of the variance which amounts to have a better understanding of the factors affecting fire spread. Among the tree species, Pinus halepensis *was the most sensitive to fire, whereas* Pinus brutia *and especially* Cupressus sempervirens *were more fire resistant.*

Résumé

Le comportement du feu dans les plantations de conifères en Israël.

Cette étude recherche les facteurs qui soit contribuent à la diffusion du feu soit la ralentissent à partir des éléments recueillis sur touts les incendies advenus en 1985 dans toutes les plantations de résineux en Israël. Ainsi, 223 feux ont été analysés. La diffusion du feu est caractérisée par le nombre d'arbres brûlés et la surface brûlée. Les variables qui peuvent affecter le comportement du feu sont les espèces et les autres aspects de la forêt qui sont relevés par les services forestier de manière habituelle.

Les principaux facteurs qui influent sur la diffusion du feu, après la combustion, sont apparus être la densité, l'âge des arbres et le pourcentage de recouvrement du sol. Le premier facteur est en relation positive avec la diffusion du feu, les deux autres en relation inverse.

Ces facteurs interviennent pour environ 30 % sur la variabilité de la diffusion du feu. Par conséquant, la plus grande priorité dans les futures études sera de mesurer, d'enregistrer et d'examiner les autres facteurs de manière à accroître ce pourcentage et à avoir une meilleure compréhension des phénomènes intervenant dans la diffusion du feu. Parmi les espèces, Pinus halepensis *a été le plus sensible alors que* Pinus brutia *et plus encore* Cupressus sempervirens *ont été plus résistants au feu.*

Resumen

Desarollo del fuego en las plantaciones de coniferas en Israël.

Investigata ese estúdio los factores que contribuyen tanto en la propagación como en la detensión del fuego, y eso, gracias a elementos recogidos en todos los incendios ocurridos en 1985 en todas las plantaciones de coníferas en Israel. Así pués, se han analizado 223 fuegos. Se caracteriza la propagación del fuego por el nombre de árboles quemados y por la superficie quamada. Lo que afecta el desarollo del fuego son las diversas espécies y los otros aspectos del bosque que los sevicios forestales apuntan regularmente.

Los principales factores que influyen en la propagaciòn del fuego, después de la combustión, aparecen ser la densidad, la edad de los arboles y el potcentaje del solape. El primer factor está en relación positiva con la propagación del fuego, los dos siguientes van en relación inversa.

Esos factores intervienen con unos 30 % en la variabilidad de la propagación del fuego. Por consiguiente, en los estudios futuros la mayor prioridad sera de medir, de registrar y de examinar los otros factores de manera a aumentar ese porcentaje y llegar a tener un mejor entendimiento de los fenómenos que intervienen en la propagación del fuego.

Entre las espécies, Pinus halepensis *ha sido el más sensible en cuanto que* Pinus brutia *y más aún* Cupressus sempervirens *han sido más resistentes al fuego.*