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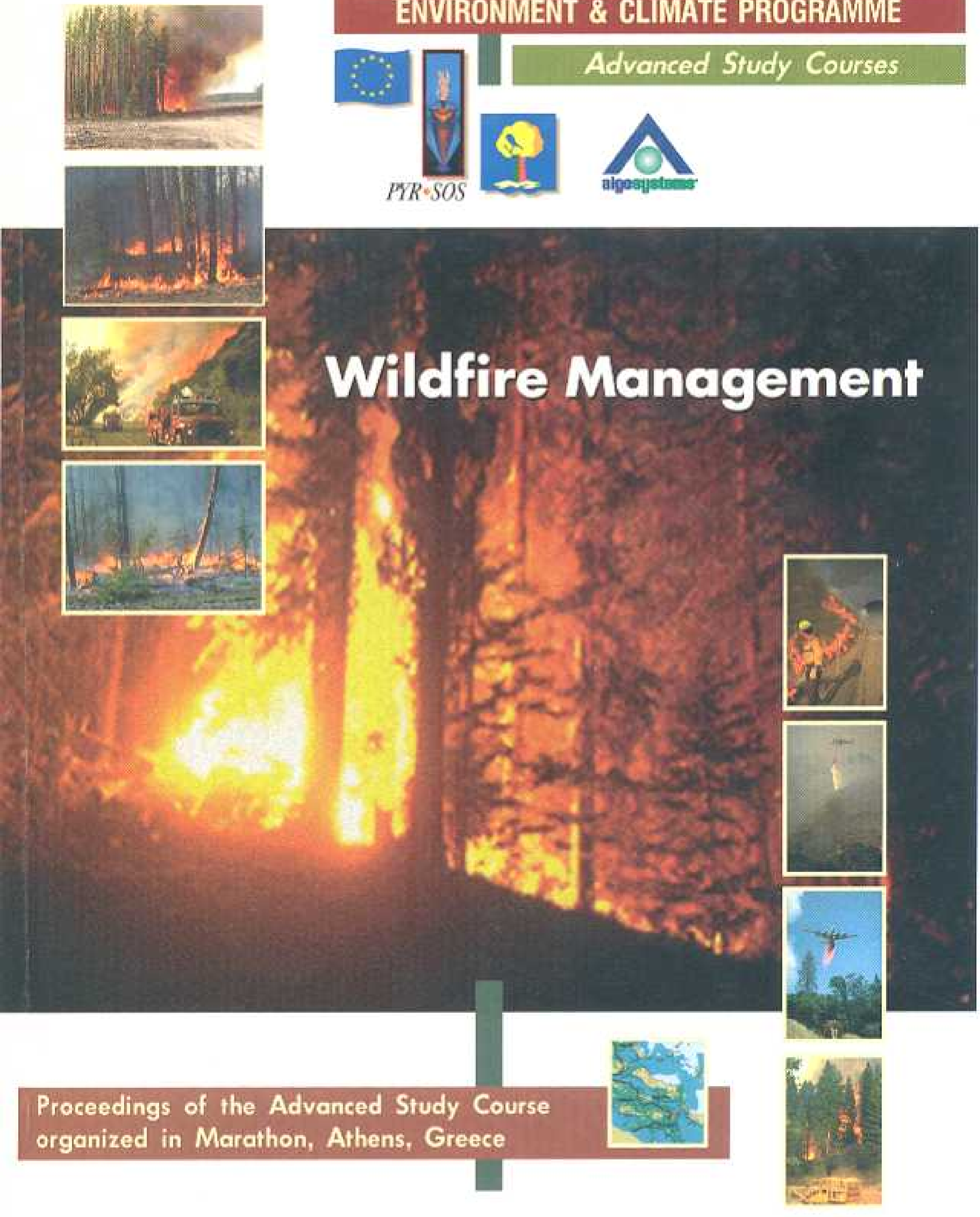

Wildfire Management

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FOREST FUEL MODELING

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Abstract

Wildland fuel accumulation is a stochastic process not easy to quantify, due to fire and other disturbances in the lifetime of a wildland ecosystem. Fuel models represent sets of parameters which systematically define fuel characteristics to various fire behavior modeling schemes. Fuel data needed for accurate fire behavior prediction include the physical description of the fuel complex (loading by size class, live and dead; mean surface-area-to-volume ratio of size classes; mean depth of fuelbed; horizontal and vertical arrangement), chemical properties (heat of combustion, mineral content, density) and fuel moisture content. Fuel classification schemes contain fire behavior, fire danger rating, cover type, photo series, rate-of-spread/resistance-to-control, dynamic and custom models.

Keywords: *Wildland Fire Fuels;* Modeling; Forest Fires; Fire Management; Mediterranean Ecosystems.

Introduction

Wildland fire behavior is determined by vegetative fuel, weather and terrain; these complex environmental determinants need to be synthesized or modeled into easy-to-use input parameters for fire behavior prediction. Thus, a fuel model represents a set of parameters which define fuel characteristics to various fire behavior modeling schemes (e.g., the mathematical fire spread model by Albini 1976, and Rothermel 1972). This paper describes the wildland fuel complexes and outlines fuel classification schemes appropriate for fuel modeling.

Fuel Characteristics

Forest fuel is live and/or dead plant material that can ignite and burn. Fuel is encountered in different kind, amount, size, shape, position and arrangement in wildland ecosystems. These physical properties and characteristics of fuels vary considerably over time and space, and thus, produce variable fire behavior. A systematic approach to view the fuel complex is to analyze it into three levels: i.e., ground, surface and aerial fuels.

Ground fuel is all combustible material beneath the surface including duff, roots, rotten buried logs and other organic components. Surface fuels are all materials lying on or immediately above the ground including needles or leaves, grass, dead wood, and low shrubs. Aerial fuels include all green and dead materials located in the upper forest canopy (e.g., tree branches and crowns, snags, and high shrubs) that have the potential to sustain crown fires.

The fuel data needed for accurate fire behavior prediction include the physical description of the fuel complex (e.g., loading by size class, live and dead; mean surface-area-to-volume ratio of size classes; mean depth of fuelbed; horizontal and vertical arrangement), chemical properties (e.g., heat of combustion, mineral content, density) and fuel moisture content. These fuel characteristics affect the ignition, spread, intensity, spotting, torching and crowning potential of wildfires. For example, small diameter fuels are first to ignite and have the lowest moisture content with the highest surface-area-to-volume ratio.

Various modeling schemes distinguish among variable, fixed and calculated fuel characteristics; the following definitions among them have been extracted from Rothermel's fire spread model, but they are valid in a generic sense. Variable characteristics include:

- fuel loading which is the oven-dry weight of fuels per unit area (*t/ha* or kg/m^2);
- diameter which is broken into size classes for analysis purposes (*cm*);
- fuel bed depth which is the average height of surface fuel that is contained in the combustion zone of a spreading fire front (*m* or *cm*); and
- moisture of extinction which is the fuel moisture content at which a fire will not spread (%).

Fixed characteristics usually define the density, mineral content, ash content and heat of combustion of the forest fuels, expressed with constant numbers in various modeling approaches. Calculated are the following fuel characteristics:

- surface-area-to-volume ratio which is the ratio of the surface area of a fuel to its volume, using the same linear unit for measuring volume (cm^{-1});
- bulk density which is the ratio of the fuel loading to the fuel bed depth (kg/m^3);
- packing ratio which is the fraction of a fuel bed occupied by fuels, or the fuel volume divided by bed volume (*dimensionless*).

In reality, most fuel properties change over time (i.e., seasonally, annually, or even over decades) based on a plethora of factors. Fuel accumulation is generally a function of plant species, age, density and decay rates, where decay is primarily controlled by temperature and moisture. Nevertheless, fuel accumulation has been found to be a stochastic process not easy to quantify, due to fire and other disturbances in the lifetime of a forest stand (Brown 1975, Lyon 1984, Muraro 1971).

Fuel Classification

A fuel model is set of numbers that describe the fuel in terms that a fire model can use. An excellent historical perspective on the evolution of fuel models can be found in Anderson (1982) referring to fire behavior, fire danger rating, dynamic and custom fuel models. In terms of fire behavior prediction, the following major fuel types can be grouped:

1. Grass - generally fine grass is the primary carrier of a low intensity fire with rapid burnout, and quick moisture and wind responses.
2. Shrub - mixed dead and live shrub fuels carry the fire with low to extreme spread rates, controlled by fuel moisture and chemical content.
3. Timber - litter, leaves, needles to large branchwood produce from slow burning to running surface fires with occasional torch-outs and possible running crown fires.
4. Slash - logging residue of all sizes and shapes give moderate to high rates of spread and intensities that may generate firebrands, dependent upon fuel arrangement.

Grass and shrub fuel groups are considered vertically oriented models for fire behavior prediction purposes, whereas timber and slash fuel models are depicted by horizontally oriented arrangement.

Shrub and timber fuel models for characteristic vegetation cover types of Mediterranean ecosystems are illustrated in Figure 1 (fuel model profiles) and Figure 2 (simulated fire behavior prediction). The shrub model presents shrublands of maquis or evergreen-broadleaved species with no tree overstory; the timber models characterize Aleppo pine (*Pinus halepensis*) and Stone pine (*Pinus pinea*) forests with understory of maquis, and Black pine (*Pinus nigra*) stands with fern (*Pteridium aquilinum*) understory.

Cover types (Bradley et al. 1992, Fischer and Bradley 1987, Fischer and Clayton 1983) and photo series (Fischer 1981) are other fuel classification schemes utilized to analyze and quantify fuel complexes and associated fire behavior potential. Custom fuel models have also been constructed to simulate wildfire rate-of-spread/resistance-to-control parameters and assess fuel hazard reduction treatments (Kalabokidis and Omi 1994, Omi and Kalabokidis 1993, Wakimoto et al. 1988).

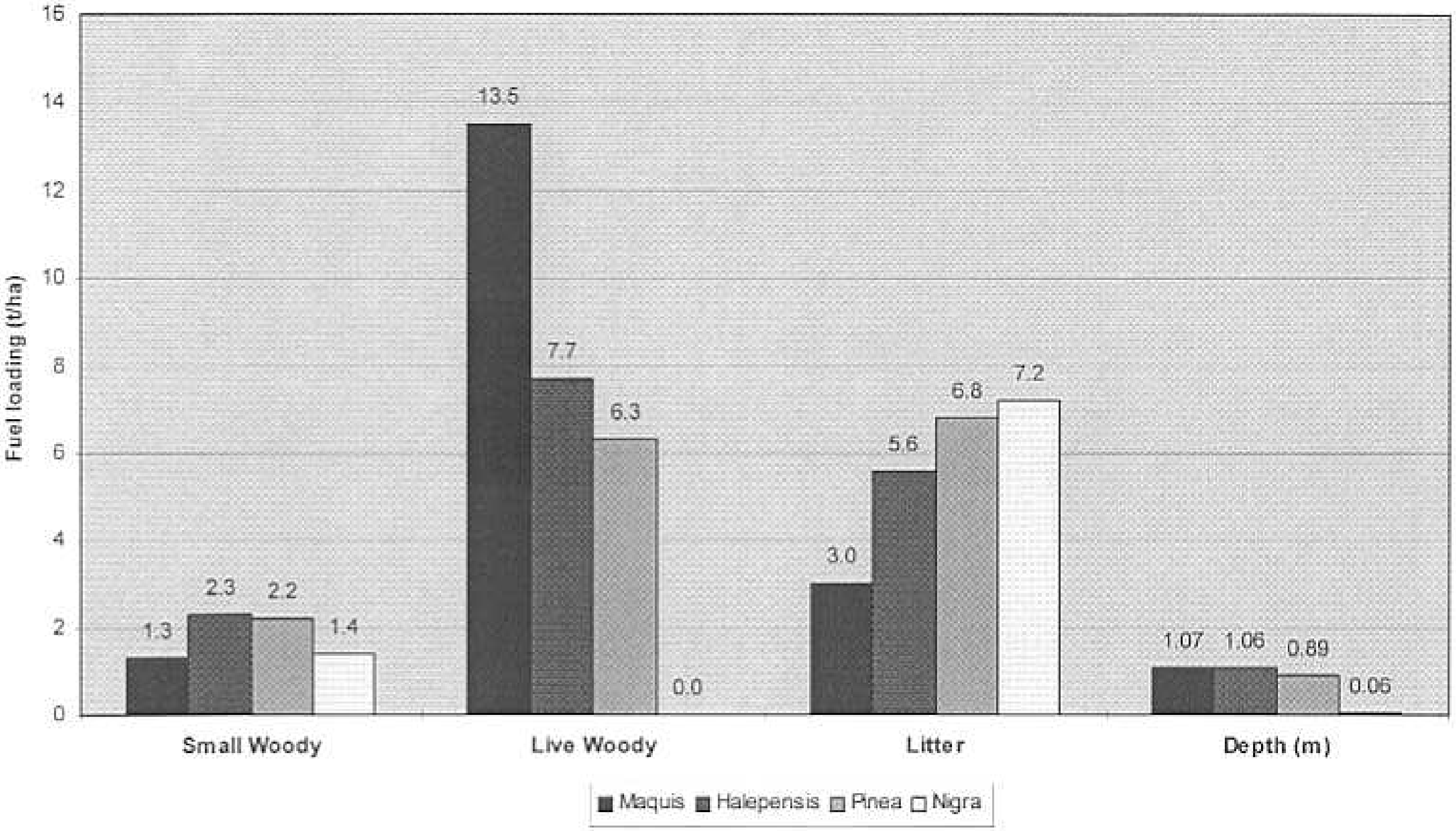

Figure 1. Shrub and timber fuel model profiles of Mediterranean cover types.

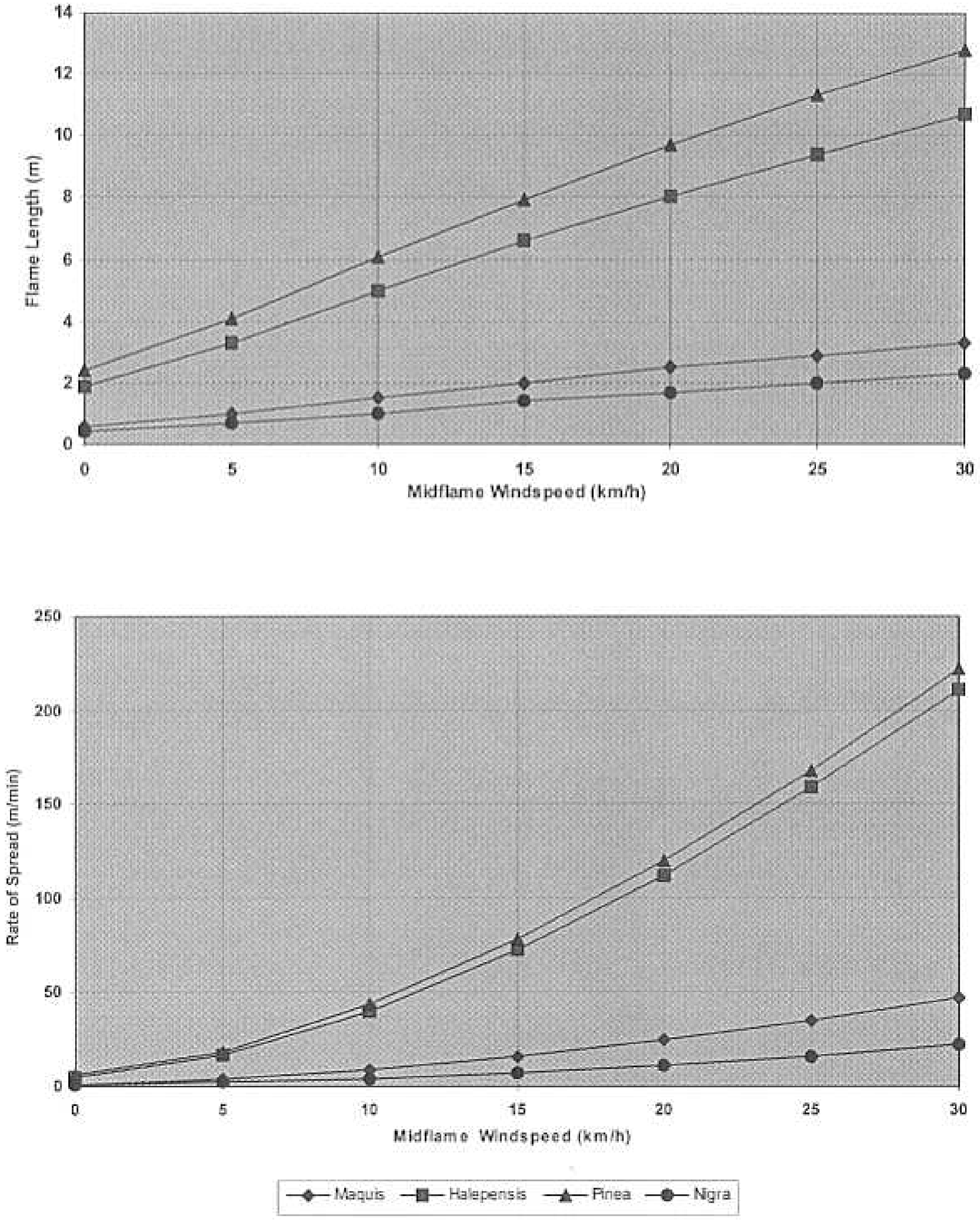

Figure 2. Simulated fire front flames and spreads for shrub and timber fuel models of Mediterranean cover types.

Conclusion

A fire environment that presents a potential hazard to fire personnel is generally attributed to unpredictable and erratic fire behavior, indicated in real-life scenarios by the fuel characteristics, fuel moisture, fuel temperature, terrain, wind, atmospheric stability, and fire behavior itself. More specifically, the fuel indicators that predetermine problematic fire behavior are:

- unusually dry fuels (e.g., by prolonged drought or direct sunlight);
- large amounts of continuous fine fuels (shrubs, grass, needles);
- ladder fuels that allow a surface fire to move into the crowns of shrubs or trees;
- tight crown foliage dried by surface fire; and
- concentration of snags.

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