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# Fire, landscape and biodiversity: An appraisal of the effects and effectiveness

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## PREScribed FIRE: STRATEGIES AND MANAGEMENT

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### Introduction

Prescribed burning is the deliberate and exact application of fire to forest fuels under specified conditions, such that specific and well-defined management goals are attained (Wade & Lunsford 1989). Prescribed fire, PB hereafter, has the following features (Pyne et al. 1996):

- A prescription (the desired fire environment) and a burn plan (the procedures involved in the operation) are specified as a function of the burn objectives;
- the prescription translates burning conditions into fire behaviour and fire behaviour into fire effects;
- the prescription, preburn operations and ignition pattern determine the character of the burn and the degree of human control over it;
- an important difference between PB and the traditional use of fire is that the former comprises evaluation activities that allow future technical refinements.

A wide spectrum of objectives can be accomplished by PB, including site preparation for tree regeneration, silvicultural improvements, range and wildlife habitat management, control of weeds, insects and diseases, and biodiversity maintenance (Kilgore & Curtis 1987, Wade & Lunsford 1989). But the main motivation for PB remains the reduction in wildfire hazard to protect forests and other valuable resources and improve human safety (Haines et al. 1998).

PB was introduced in Southern Europe (Portugal, Spain, France) in the early 1980's, 40 years after its official endorsement by the USDA Forest Service in the southeastern forests of the U.S. (Wright & Bailey 1982). The practice of PB is nowadays well established in North America to manage both public and private land and the amount of area treated annually is increasing (NIFC 2001). Extended PB programs in the mediterranean corner of Western Australia have precluded major wildfires since 1961 (Sneeuwjagt 1994). Two decades of experimentation in several vegetation types of Southern Europe have shown that detrimental effects arising from PB are unlikely, and the technique has been adapted, more than adopted, to the specificity of the region. However, PB is still at its infancy in the Mediterranean and its management potential is far from being fulfilled: the use of PB is restricted to parts of Portugal, Spain and France, being illegal in Greece and Italy. Foresters and land managers tend to perceive only the negative side of fire, probably because of its historical misuse and abuse.

The aim of this presentation is to give a general picture of the management issues of PB. The success of a burning program is largely dependent upon adequate planning and evaluation. Such process and the tools available for its implementation are described, and PB in NW Portugal pine stands is presented as an evaluation case study. Some guidelines are given concerning the efficiency and optimisation of PB in hazard-reduction, as well as the minimisation of its conflicts with conservation of natural resources, especially where biodiversity maintenance is the main goal and when PB is extensively used at the landscape scale.

### **Planning, conducting and evaluating prescribed fire**

PB is a planned activity, including the definition of objectives, constraints, desired fire behaviour and effects, ignition technique, etc. A burning plan and an evaluation report are therefore extremely important to reach the stated management objectives and monitor the results.

A PB operation has five stages: analysis, prescription, preparation, execution and evaluation. A written plan is needed and it should be completed before the burning season and include: explicit objectives, quantified if possible; scheme of the burning unit; equipment and personnel; the prescription; season; time of day; firing plan; alternative prescriptions; preparation work; impact of smoke; escaped fire plan; control and mop-up; evaluation; identification of the person(s) who prepared the plan.

The first step to a successful PB is a stand by stand analysis, determining the needs of each stand and what actions should be taken to meet such requirements. It is followed by the definition of the weather conditions compatible with a given burning objective and the firing technique. Preparation is essential to obtain maximum benefits at acceptable costs, and consists of all steps necessary in making the area ready for firing and of having all tools and equipment operational. An initial burn evaluation should immediately follow the operation, and a second evaluation should be made during or after the first post-fire growing season.

The evaluation of PB has the overall goal of improving the performance of subsequent burns such that management objectives are increasingly satisfied, and is possible only when the burn objectives are clearly defined and "contain a measurable factor that determines the degree of success" (Bunting et al. 1987). This means that a general objective such as "the improvement of wildlife habitat" will be of little use for both fire planning and evaluation. After analysing the monitored data — pre-fire, fire and post-fire variables — the following evaluation outputs should be obtained (van Wagtenonk et al. 1982):

- how well the objectives have been accomplished,
- a basis to improve economic efficiency,
- data that allows replication of results,
- validation of fire behaviour predictions,

- opportunities to tune prescriptions based on accumulated experience,
- a basis for assessing long-term effects of PB.

The process of gathering data to evaluate PB should be selective, i.e. focused on specific needs, management objectives and techniques, and should give information on the long term. Evaluation elements may vary from subjective and qualitative data to sophisticated quantitative data, covering prescription (fuels, weather, topography), fire behaviour and fire effects (vegetation, atmosphere, water, soil, wildlife, economics) variables. An evaluation report may include both qualitative and quantitative elements. Qualitative remarks can describe the operation, the problems encountered and their resolution, or the probable reasons for marginal burning results. Quantitative assessments determine the degree of change from the pre-burn condition and provide a way of making direct comparisons with the objectives or with the results of burns with similar objectives.

Applied models of fire behaviour –that seek to predict the physical properties of a moving line of fire, namely its rate of spread, flame dimensions and rate of heat release– are an important basis for PB operations. Fire behaviour models can be classified as theoretical or physical, laboratory or semi-physical, and empirical or statistical. Of the three modelling approaches, only the second and third have provided management agencies with usable fire behaviour estimates. Tools to estimate fire behaviour in the U.S., Europe and South Africa are largely based on the laboratory model of Rothermel (1972). The Canadian Forest Fire Behaviour Prediction System (Forestry Canada Fire Danger Group 1992) and the Australian systems (McArthur 1966, 1967; Sneeuwjagt & Peet 1985) are purely empirical. Models for shrub vegetation types –where Rothermel's model performance is poor– have been derived from recent field studies in both Australasia (Mardsden-Smedley & Catchpole 1995, Catchpole et al. 1998) and Europe (Vega et al. 1998, Fernandes 2001), and cooperative efforts to develop a model for universal application are being made. If available, empirical models should be preferred in PB, not only because their higher resolution can cope with the accuracy and reliability demands of the PB activity, but also because they are simple and integrate the effect of numerous variables (Burrows 1994).

Decision-support tools for a rational, efficient and safe use of PB can take several shapes, and operate at different levels (space, time) and spatial scales (plot, stand, landscape). PB guides contain generic prescriptions and offer, in the U.S. case, descriptions of the operational procedures, while Australian guides are concise and privilege the quantitative features of PB. They consist in slide rules, tables and graphs that are used sequentially to estimate values for the operationally important parameters (fuel loading, fuel moisture, fuel reduction, fire behaviour, tree damage), and are complemented by rules-of-thumb. Two PB guides were developed in Europe according to the philosophy of the Australian guides, respectively for shrubland (Botelho & Fernandes 1999) and maritime pine (*Pinus pinaster*) (Fernandes et al. 2000).

Fire behaviour simulators such as the BEHAVE (Andrews 1983) are especially useful when the prescription uses fire behaviour descriptors rather than weather variables. However, such programs are unable to inform on the burn objectives fulfilment or on fire effects other than tree damage. FOFEM (Reinhardt et al. 1997) is a quite comprehensive program that addresses the direct (or first-order) effects of fire –fuel consumption, mineral soil exposure, tree mortality, smoke production– for several ecosystems in the U.S. PB is strongly conditioned by weather, which prompted the development of tools that help the identification of burn opportunities (e.g. Brackett et al. 1997).

The strategic spatial planning of PB can nowadays benefit from the development of GIS and resort to fire growth simulators in the landscape (e.g. FARSITE, Finney 1994). Other software tools (FFE-FVS, Beukema et al. 2000) relate vegetation and fuel dynamics with fire behaviour and enable the temporal analysis of fuel management options at the stand level.

The secondary effects of PB –tree regeneration, vegetation succession, productivity changes– arise from the interaction between first-order fire effects and several environmental factors, and decision-support in PB does not consider them. Fire ecology databases (FEIS, Fischer et al. 1996), and process-models of vegetation dynamics (e.g. Keane et al. 1990) with the ability to simulate the long-term results of differing fire regimes are useful in this domain.

Expert systems that use artificial intelligence techniques can perform tasks that once were reserved to experts in a given field, and have the double capacity of combining decision rules with mathematical models. The two most interesting expert-systems for PB are the one developed by Reinhardt et al. (1989) to write specific prescriptions as a function of local conditions and management objectives, and the PB training and decision support system (PB TDSS) (Rigolot et al. 2000) that was built in the frame of the European research project FIRE TORCH. The PB TDSS is organised in six modules emphasised on the managers main needs –regional statistics, precautions, ignition, fire effects, constraints, and smoke management– and allows easy access ([http://www-cindy.cma.fr/europe/firetorch/firetorch\\_fr.html](http://www-cindy.cma.fr/europe/firetorch/firetorch_fr.html)) to the state of the art on PB operational issues and effects on the Mediterranean.

#### **Evaluation of a prescribed fire program: hazard-reduction burning in pine stands in Portugal**

Prescribed underburning of pine stands –*Pinus pinaster* essentially, but also *P. sylvestris*– to reduce fuel hazard was operationally implemented in Portugal during the late 1970's. We used as data source the Forest Service PB field form that is currently filled for each management burn, which enabled the establishment of a standardised database after compiling near 500 forms that cover the period 1978 - 2000. The forms include data on location, date, site, stand and fuel characteristics, weather, ignition technique, fire behaviour, fuel reduction, costs variables, and qua-

litative remarks, and some additional variables could be derived from the information contained in the forms. The actual practice was compared to a general prescription that gives the optimum and acceptable ranges of variation in weather and fire behaviour variables and ranges for additional variables were set based on the best available knowledge.

The number of burns that falls out of prescription for a given parameter is quite reduced. As a direct consequence of the atlantic and sub-atlantic climatic characteristics of the region, 9% of the forms report that “fuels are too wet”, and the balance between optimum and acceptable fuel reduction shows that marginal moisture conditions are frequent. Duff reduction is usually poor, implying reduced smoke production, absence of negative effects in the root system of the trees and mineral soil, and maintenance of site productivity. Crown scorch levels are also modest and not likely to cause growth rate decreases nor mortality. All things considered, 46% of the burns respect all the prescription intervals, while the percentage of burns with one, two and three variables out of prescription is 32, 15, and 7%, respectively

The pines vulnerability to *Scolytidae* infestation is usually mentioned as the major drawback of PB in Portugal. Excessive stand age determines that one fifth of the burns is out of prescription for this variable, even if 60% of the operations in those conditions are conducted during the optimum months of the year. This is no longer a major concern, because PB is currently restricted to stands younger than 25 years. 45% of the burns were carried within the optimum range for both age and season, but it is important to stress that the prescriptions for this variables are not obligatory: the willingness to assume a given amount of mortality risk by bark beetles should therefore guide the user decision on this subject.

A cluster analysis was undertaken to identify individual PB patterns considering all the prescription variables. Four consistent and clearly defined groups were obtained, with the following characteristics:

- 23% of the burns are efficient in fuel reduction, cause no impact in duff, but have relatively high levels of fire intensity and crown scorch for the standards of a PB.
- 18% of the operations are acceptable in what concerns fuel reduction, fire intensity and tree damage, but consume duff in excess.
- 44% of the burns have no negative impacts and reduce the fire hazard.
- in 12% of the operations –those conducted with marginal fuel moisture content, in situations where fuel accumulation is high and shrubs are tall– fuel consumption is insufficient and duff is unaffected, but fire intensity is moderate and the effects on trees are notorious.

None of the above groups experiences tree mortality as a direct effect of the fire.

Approximately half of the burns is conducted under optimum conditions and yields good results. As a general conclusion, and despite the existence of some pro-

blems and deficiencies, the overall balance of PB in Portuguese pine stands is positive. The burns meet the objective of reducing fuels without harm to the ecosystem. The whole planning and evaluation process of PB should be improved in the future, profiting from more detailed and complete data collection, namely concerning long-term effects; a new field form, developed in the frame of FIRE TORCH, will hopefully improve data collection in management burns.

### **Prescribed burning effectiveness as an hazard-reduction tool**

The rationale for hazard-reduction burning is obvious: weather, topography and fuels determine the behaviour of a fire, but management actions to restrict its negative consequences are limited to fuels. Current fire fighting technology hardly deals with multiple fire events, and cannot cope with wildfires under severe weather conditions, i.e. fire intensity limits fire suppression effectiveness.

Fuel loading reduction from a PB treatment is expected to rise the probability of wildfire control because it lowers the magnitude of fire behaviour, but also because it provides better access for fire fighters and anchor points for suppression actions. The routine use of PB will hopefully change the wildfire regime toward smaller and less severe fires from both the ecologically and the economically perspectives.

Fuel accumulation and wildfire activity are related in both the Mediterranean basin (Rego 1991) and the European boreal forest (Schimmel & Granström 1997). The uncontrollable and highly damaging wildfires in today's conifer ecosystems of the western U.S. have evolved from almost a century of fire exclusion and fuel build-up (e.g. Brown et al. 1994). The premise that PB gives a valuable contribution to forest protection is frequently mentioned in abstract or as a known fact and it is seldom questioned, even if the effect of fuel on fire behaviour has not been quantified in high-intensity fires dominated by extreme weather conditions.

Burning plans usually specify how much and what categories of fuel should be removed, which implies pre and post-burn fuel assessments. Several alternative techniques are available to determine pre-burn fuel quantities, while fuel consumption can be described or quantified by harvest, direct or indirect measurement, visual estimates, and comparison with photo series. Regardless of the method used to assess fuel reduction, few examples exist where quantitative information on fuel reduction is translated into classifications of effectiveness.

Because fuel consumption is weather-dependent, the outcome of PB is quite variable; optimisation of fuel reduction can be attempted in the planning phase by using predictive models that use fuel moisture content and pre-burn fuel loading as inputs (e.g. Brown et al. 1991).

The BEHAVE system is frequently used to predict and compare the fuel management effects on fire hazard, using custom fuel models to describe the pre and post-treatment fuel-complex. Simulations with BEHAVE generally point to fire

intensity reductions of 80% to near 100% of the pre-PB values, being brought down to a level that makes possible wildfire containment by direct attack with hand tools. Such values concern the immediate impact of PB, but dynamic fuel models can be used to assess the evolution of hazard with time since treatment.

The benefits of extending the simulations from the plot/stand scale to a landscape scale are obvious. The association of GIS technology to fire behaviour models makes detailed predictions possible at landscape levels. FARSITE is useful to analyse the implications of fuel changes under specified ignition and weather scenarios. Among the now numerous examples of its application, van Wagendonk (1996) can be mentioned: under severe weather conditions PB reduced the average intensity of a wildfire by 76% and its burned area by 37%, avoiding torching, spotting or crowning phenomena.

Well-documented case studies do not provide scientific evidences about the effectiveness of PB, but testify both the virtues –decrease in fire intensity, reduction in tree damage and mortality, minimisation of property loss, easier fire control– and limitations (under the windier and drier fire weather range) of PB in hazard reduction. Rigolot (1997), Silva (1998) and Lambert et al. (1999) present European case studies that show the benefits of PB.

In parts of the U.S. and Australia with extended and sustained PB programs it is possible to appreciate the impact of PB impacts on the wildfire regime. Such modifications are currently the best way to evaluate the practice, but do not allow direct statistical confirmation, and it is impossible to isolate the effect of PB from the effect of the whole fire management process. The existing studies show that wildfire size increases with time since the last PB (Koehler 1993) and that larger fires occur in non-treated areas (Good 1996).

A very small percentage of the total number of wildfires accounts for the majority of the burned area and is driven by synoptic-scale weather events (Strauss et al. 1989). It is reasonable to assume that the control of fire by fuel is an over-simplification and is restricted to non-extreme weather conditions. Hazard-reduction effectiveness of PB will vary by ecosystem according to the relative impacts of fuels and weather on fire behaviour. It will be lower in regions that have higher likelihood of experiencing strong winds during extended periods of drought, and higher where wildfire propagation is constrained by landscape and land use diversity and by natural or man-made obstacles.

Fuel recovery after PB can be so fast that fuel management may be futile or even counter-productive in some vegetation types. A number of factors can accelerate fuel dynamics, namely the amount of remaining and created fuel (conversion of live to dead fuel, post-burn litter fall), changes in vegetation composition such that it becomes more flammable, and reduction of the decomposition rate after PB.

The size, shape and spatial arrangement of the treatment units can strongly affect PB efficiency on a landscape scale. The spatial pattern of hazard reduction burning can be quite varied, comprising treatments dispersed in the landscape, extensive application to large areas, or strategic use to link or expand discontinui-



ties such as fuel breaks and non-flammable areas. The advantages of large-scale PB are not proven, and simulations with FARSITE suggest that disperse and small treated areas are preferable to network-type treatments, because shorter distances will result between individual fuel-reduced areas thus limiting wildfire growth more effectively (Finney et al. 1997).

Finney (2000) gives a set of equations that optimise the width and length of a rectangular treatment unit regarding the propagation of a fire. Feasible and effective spatial arrangements of PB should result in treatment units that partially overlap in the direction of fire spread. Selection of treatment areas currently relies on combined functions of several factors (values at risk, ignition potential, suppression capability, fire behaviour potential), but such approaches will likely originate arbitrary or random spatial patterns with a poor influence on wildfire growth. Sound, well-established methods to design the spatial patterns of PB are still missing.

PB programs are strongly constrained by a number of factors: suitable weather for burning and favourable landscape in terms of topography and vegetation continuity (Bradstock et al. 1998), liability risks and the necessity to comply with environmental protection, smoke management and air quality regulations and laws (Haines et al. 1998). The opportunities to carry PB operations are greatly reduced by these restrictions, thus compromising hazard-minimisation in fire prone regions. Unwanted ignitions are predominantly associated to areas where human pressure is high, posing additional social constraints on the use of PB.

PB reduces but does not eliminate the wildfire threat. Mitigation of fire's negative effects is a matter of an integrated approach combining adequate stand and fuel management practices with prevention of human-caused fires and efficient fire detection and suppression.

### **Conciliating hazard reduction and biodiversity conservation**

PB has direct and indirect ecological effects, and proper use of the technique requires knowledge of its impact on the various ecosystem components. Several studies during the past two decades investigated those consequences in Mediterranean ecosystems, usually concluding that the immediate effects of PB are minimal and short-lived, and state-of-the art reviews were recently produced in the frame of the FIRE TORCH project. However, most of those studies were carried in planted forests with quite low conservation value that can, in fact, be temporarily increased by PB. Table I displays the time required for several ecosystem descriptors in *Pinus pinaster* plantations of NW Portugal recover after PB; a five year return interval can be used to conciliate protection and biodiversity, even if dangerous fuel levels can be reached as early as three years after PB. Much less is known about the cumulative temporal effect of PB on biodiversity and productivity, and about these impacts in natural forests, even where PB is a widespread practice.

The current supremacy of technological information over ecological knowledge can induce confusion between the achievement of a prescription for fuel reduction with the achievement of ecological goals. This means that generic fire use recommendations may not apply to similar vegetation types, to similar species, or even to the same species in different sites, and that extended PB programs should not be attempted if adequate ecological information is lacking. Ecological knowledge gaps are especially important when fire is used for more specific objectives, e.g. to manage a threatened species.

Table 1. Variations in the time to recovery to pre-burn levels of ecosystem components in maritime pine stands, NW Portugal.

Parameter	Time to recovery, years
Litter loading	~10
Forest floor nutrients	~5
Forest floor fauna	~3
Forest floor fungus	~2
Forest floor microbial populations	~1
Vegetation cover	~10
Vegetation biomass	~10
Bird diversity	~10

The conflicts between the more utilitary purposes of PB and its ecological effects are widely debated in the Australian literature. Whelan & Muston (1991) are of opinion that PB is applied without enough knowledge of the long-term effects on the biota, and in a regime that is different from the historical fire regime. This new fire regime is characterized by:

- fires too frequent, changing species composition, with decline or local extinction of obligate seeder species and the dominance by resprouter species, an overall decrease in biodiversity (Rose et al. 1999), and the creation of more flammable communities (Fensham 1992),
- fires too small, implying higher pressure by herbivores,
- fires too cool (because they have lower intensity and are carried in a different season of the year) that will reduce the germination of seeds (Bradstock & Auld 1995).

The conventional practice of dividing an area into blocks that are scheduled to burn under a fixed fire regime is conducive to spatial homogeneity and loss of biodiversity and should be avoided. Variation of the PB regime in space and time is therefore a good principle (Brockett et al. 1999). In order to conciliate protection and conservation objectives, Gill & Bradstock (1994) suggest to cross information on fuel accumulation rate and seeder plant species that can become extinct with too

frequent fires. Detailed research is required concerning the population responses of selected (indicator) species to fire (Whelan & Muston 1991). Burrows et al. (1999) propose a framework to design fire regimes that satisfy both ecological and social requirements. Their approach is based on the combination of the information given by several types of climatic, historic and biological variables, and it is expected to result in consistent strategies enabling the formulation of practical and adequate fire regimes. Finally, in some cases, both observation (Morrison et al. 1996) and simulation (Bradstock et al. 1998b) indicate that it is impossible to adopt an approach to fire management that represents a compromise between ecosystem biodiversity and hazard-reduction, which means that both objectives cannot be achieved simultaneously.

The main motive for the application of PB in the western U.S. is, in half of its annual area, ecosystem sustainability and the preservation of unique species and habitats (Barrett et al. 2000). But the reestablishment of landscape fire as an ecological process (rather than regarding it as a tool) is complex, in both theory and practice (Pyne et al. 1996). The restoration of *Sequoiadendron giganteum* forests in California national parks with fire is a story of success (Haase & Sackett 1998), but it also exemplifies the difficulties that a program of this kind must face (Caprio & Graber 2000). The differences between the historical fire regime that has been re-established and a PB regime for protection purposes are slight in this case, but will tend to be larger as the historical fire regime moves from frequent, low to moderately intense surface fires to infrequent, high intensity stand-replacement fires. It is clear that intense fires may be a management option in areas where biodiversity conservation is more valued than commercial forestry, but the way to proceed is not so clear. E.g., in the mixed *Quercus* - *Pinus* forest of the eastern U.S. high-intensity fire prescriptions to maintain the pine component are difficult to implement (e.g. Outcalt & Greenberg 1998).

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