Using PiroPinus to assess fuel reduction effectiveness of prescribed burning in a *Pinus halepensis* plantation in Southern Italy

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Abstract

PiroPinus was developed in Portugal as a decision support-tool to prescribed burning use in *Pinus pinaster*. Although tailored for site-specific conditions, it is empirically-based and so its performance outside the environmental range of development is uncertain. The objective of the present study is to test PiroPinus 2.2 utilities to define prescriptions, implement and evaluate prescribed burning for fire hazard reduction in *Pinus halepensis* plantations. The study site was located in the Cilento and Vallo di Diano National Park, one of the most fire-prone areas of Southern Italy. The experimental design consisted of 3 burn plots (BU), 0.2 ha in size, and 2 controls (CO). In all plots the plantation presented high fire risk. Pre-burn surface fuels (5.2±1.3 t ha^{-1} of litter, and flammable *Ampelodesmos mauritanicus*) and elevated fuels (dominated by *Erica arborea*) presented horizontal and vertical continuity. Objectives for the burn were: (1) reduce surface fuels; (2) create vertical discontinuity. PiroPinus was used as a reference guide to define burning windows. All plots were burned in May 2009. Most of burning parameters fell within the PiroPinus prescriptions. Fire behaviour was assessed with a microplot scale approach. Observed average surface litter moisture was 17%; rate of spread 0.22±0.06 m min^{-1}; flame length range 0.2-1.0 m; fireline intensity 52±10 kW m^{-1}. PiroPinus provided an accurate estimate of observed values: 17%, 0.25 m min^{-1}, 0.5 m and 48 kW m^{-1} respectively. Prescribed burning objectives were achieved to some extent. According to the PiroPinus fire interpretation table the burn was conducted at the upper limit of moisture conditions. In fact, in summer 2009 surface fuels in BU were reduced only in part. Major changes were observed in elevated fuels whose cover decreased from 58% to 3%; the vertical continuity was remarkably reduced. Finally, PiroPinus was used to model post-treatment fire behaviour under different weather conditions. It predicted a remarkable mitigation of fire behaviour in BU vs. CO for all weather scenarios. Under the 97.5^{th} scenario, simulated rate of spread, flame length and intensity in BU were respectively 75%, 31% and 12% of the CO values. PiroPinus resulted a useful tool to support prescribed burning in *Pinus halepensis* plantations of the Cilento Park. Despite constraints (research issues to address are outlined), this study showed that experimental data can be used to improve the performance of PiroPinus, extending its use as a reference guide for Mediterranean pine forests other than *Pinus pinaster*.

Keywords: Prescribed burning; PiroPinus; Pinus halepensis plantation; Fuel management

1. Introduction

Pine plantations in the Mediterranean Basin are remarkably flammable (Fernandes, 2009; Moreira et al., 2009).

Prescribed burning for wildfire hazard reduction in European pine plantations has been thoroughly studied (Liacos, 1986; Fernandes and Botelho, 2003; Rigolot, 2004; Fernandes and Rigolot, 2007; Fernandes et al., 2008), and is currently applied in strategic areas to facilitate fire suppression and limit wildfire severity in several Mediterranean countries of Europe (Lázaro and Montiel, 2010). Nevertheless, its application and effectiveness in reducing fire hazard in new geographical areas has to be assessed (Rego et al., 2010), above all in those countries where forest managers are interested in implementing prescribed burning, but scientific and operational experiences are scarce, such as Italy (Leone et al., 1999; Ascoli et al., 2009; Lázaro and Montiel, 2010).

In the absence of the required information, fire modelling and analysis can be useful to develop burn prescriptions (Fernandes and Botelho, 2003), and, despite simulation limitations (Fernandes, 2009), can be adopted to evaluate the fuel treatment effectiveness under alternative scenarios of fuel and weather conditions, both at the stand (Stephens et al., 2009) and landscape levels (Suffling et al., 2008).

Several decision-support tools have been developed to design and assess fuel treatments for wildfire hazard abatement (Xanthopoulos et al. 2004), with a particular focus on prescribed burning. These tools firstly require detailed inputs about fuel characteristics and structure (Andrews, 2009; Krivtsov et al., 2009). A second issue that must be addressed is the short and medium term forest fuel dynamics both in treated and unburnt areas (Fernandes, 2009; Krivtsov et al., 2009). Finally, fire behaviour models calibration is fundamental to correctly analyse simulations and interpret their management implications (Arca et al., 2007; Fernandes, 2009).

PiroPinus is a all-in-one user-friendly tool that integrates models based on observed fire behaviour and effects and has been developed in Portugal as a decision-support tool to prescribed fire planning and evaluation in *Pinus pinaster* Aiton plantations (Fernandes, 2003; Fernandes, 2010). Although tailored for site-specific conditions, PiroPinus is empirically-based and so its performance outside the environmental range of development (namely in other Mediterranean pines) is uncertain. The objective of the present study is to test PiroPinus 2.2 as a decision-support tool to define prescriptions, implement and evaluate the short-term effectiveness of prescribed burning for stand-level fire hazard reduction in *Pinus halepensis* Miller plantations in Southern Italy.

2. Methods

Experimental design

In the frame of the FIRE PARADOX project (Rego et al., 2010), a prescribed burning training course and its experimental application have been carried out in May 2009 in the Cilento and Vallo di Diano National Park (hereafter Cilento Park), one of the most fire-prone areas of Southern Italy (Mazzoleni et al., 2001; Ricotta et al., 2006). The burn objective was to reduce fire hazard in a *Pinus halepensis* coastal plantation placed at the Wildland Urban Interface, and defined as a priority area for fuel treatments by the Fire Management Plan of the Park (Regione Campania, 2007).

The experimental design consisted of three burn plots, placed along a tourist road, and two untreated nearby control plots. All plots were 0.25 ha in size, 90 m a.s.l., NW aspect, 15% in slope, and were divided each-other by thalwegs. In all plots the stand was a *Pinus halepensis* plantation, ~ 60 years old, planted to protect the soil and facilitate the establishment of late-successional hardwoods. The stand structure and composition were assessed within permanent 20-m radius circles (1 per plot): *Pinus halepensis* was the dominant tree species with an average (±SE) height of 10.5 ± 0.5 m; average crown base height of 7.2 ± 0.5 m; diameter at breast height of 20.5 ± 0.7 cm; density of 882 trees ha^{-1} and stem basal area of 32.6 ± 4.6 m^2 ha^{-1}. No silvicultural post-plantation operations have been carried out to date.

Fuel characterization

The fuel complex was constituted by surface and elevated fuels. The surface layer comprised *Pinus halepensis* litter, dead woody fuels and herbs, mainly *Ampelodesmos mauritanicus* (Poir.) Dur. & Schinz. Elevated fuels were constituted mainly by a shrub layer dominated by *Erica arborea* L. Pre-burn fuel characterization combined destructive and nondestructive sampling techniques. The structure of understory fuels was assessed along permanent planar transects, 30 m in length (n=1 per plot), along which surface litter depth, grass height, shrub individual height and crown base height were measured at 1-m intervals. The surface litter and lower litter were collected through destructive sampling in a 0.0625-m^2 square (n=3 per plot); sampling of the herbaceous layer and dead woody fuels was based on a 1-m^2 square (n=3 per plot). All samples were randomly located. Dead and live fuels were separated in two size classes (I class: < 0.6; II class: 0.6-2.5 cm), and oven-dried at 60°C for 24 hours to estimate the fuel load. The shrub layer fuel load was quantified by sampling 3 *Erica* individuals whose height equaled the average height assessed along the transects; all fuel elements of each individual were cut within a volume defined by the projection of a 1-m^2 square from the base to the top of the individual. Finally, the oven-dried fuel loads of dead and live components, separated in I and II size classes, were weighted by the transect-based shrub layer cover. Post-fire fuel sampling was conducted in late summer 2009 adopting the same methodology described before.

Post-burn fuel loads means were compared between burnt and control plots with the t-test (2 tails). Significant differences were tested at the 5% level. Data were examined for homogeneity of variance (Levene test).

Prescribed burning

All three plots were burned the 14th of May 2009. Objectives for the prescribed burning treatment, other than training, were to (1) reduce surface fuels and (2) create vertical discontinuity between surface fuels, elevated fuels and the tree canopy. Such objectives were to be achieved without causing *Erica* and pine mortality.

In each of the three burned plots, surface litter and lower litter samples were collected just before burning to determine moisture contents on a dry weight basis. Ignition technique was a backfire, i.e. downslope and against the wind. Burning last from 10.30 to 16.30 hours. On-site weather data was measured every 30 minutes with a portable weather station. Average environmental conditions during the burn were: air temperature 20°C; relative humidity 46%; wind speed 4 km h^{-1}; days since last rain: 5; surface litter moisture: 17%. Except for the air temperature, which was at the upper limit, all others parameters fell within the optimum burning window defined in PiroPinus. Rate of fire spread was estimated using the Simard et al. (1984) methodology. This method calculates a value of rate of spread within a triangle knowing the time of arrival of the fire front to the vertexes of the triangle. Two equilateral triangles, 2-m side, were randomly placed within each plot, visualizing vertexes with marked rods. At each vertex a set of 3 thermocouples, K-Type, connected to buried Onset HOBO Thermocouple Data Logger, were positioned at the surface litter, within the lower litter, and at 1-m height respectively. Temperature residence time profiles were recorded for the entire duration of the burning, both to track the time of arrival of the backfire to each triangle vertex, and to correlate fire behaviour to effects on soil properties and vegetation (Catalanotti et al., Proceedings of this Conference). Flame length was also estimated. Fireline intensity was calculated according to Byram (1959), adopting a high calorific value for *Pinus halepensis* litter of 22.094 kJ kg^{-1} (Mårell et al., 2008).

Fire behaviour simulation

PiroPinus was used to model both prescribed burning and potential fire behaviour under different fuel and weather conditions. To run the prescribed burning simulation, pre-burn estimates of fuel components loads (lower litter; surface litter; dead woody fuel; herbs) were entered; the shrub layer was not involved in the combustion process and so it was not considered in the simulation. Observed air temperature and humidity, and days since last rain, were input. As May is associated with the minimum burnt area within the Cilento Park (Mazzoleni et al., 2001), and as spring 2009 showed uncharacteristically abundant precipitation, to set the PiroPinus moisture scenario we entered in the model the late winter-spring variable, rather than the early summer one. Finally, a moisture correction factor for aspect (N), slope (0-30%), hour (10.00) and shading (<50%, because the plots were near the forest edge) was applied. Fuel moisture and fire behaviour output variables, which include surface fine dead fuels moisture content, rate of spread, flame length and fireline intensity, were compared with moisture contents and fire behaviour descriptors observed during the burn.

To run the wildfire simulation, estimates of fuel loads in burnt and control plots carried out in late summer were respectively entered; differently from the prescribed burning simulation, the shrub layer load was included as it is going to contribute to the wildfire front propagation. Three alternative weather scenarios were addressed that correspond to moderate, high and extreme fire weather, defined by the 75^{th}, 90^{th} and 97.5^{th} percentiles of surface fine dead fuels moisture contents, as estimated by PiroPinus. The percentiles were calculated from 2007 weather data (the year with the highest burnt area within the Cilento Park in the last 10 years - Ministero Ambiente 2009), from Ascea, on the coast, 15 km north from the study site.

3. Results and discussion

Before the prescribed burning in May 2009, the average total fuel load was 19.3 t ha^{-1}, of which 10.7 t ha^{-1} were surface fuels and 8.6 t ha^{-1} were elevated fuels. No significant differences were found between plots. Average (±SE) values of fuel components load are reported in Table 1 according to the PiroPinus terminology.

The surface litter covered 100% of the ground, thus providing horizontal continuity for the spread of the backfire. About 95% of the area to be treated was burned. The combustion process involved mainly the litter, downed woody and herbs fuel components. No shrubs torching were observed. This expected result was due both to a gap between surface and elevated fuel strata (Figure 1), and to the adopted burn prescription: backfire spread and the moisture contents of the surface litter maintained flame height well below the *Erica* crown base. Observed average surface litter moisture content was 17%; average (±SE) rate of spread was 0.22 ± 0.06 m min^{-1}; flame length range was 0.2-1.0 m; average (±SE) fireline intensity was 52 ± 10 kW m^{-1}. PiroPinus provided an accurate estimate of observed surface litter moisture content and fire behaviour descriptors, which were respectively 17%, 0.25 m min^{-1}, 0.5 m and 48 kW m^{-1}.

Table 1 Average (±SE) fuel load of live and dead components, divided in I (< 0.6 cm) and II (0.6-2.5 cm) size classes, as estimated in BU and C plots before treatment. Data are set according to PiroPinus terminology.

Fuel component	**Live vs. dead/size**	**Cover (%)**	**Depth/height (cm)**	**Load (t/ha)**
Surface litter	Dead - I class	100	3.9	5.2 ± 1.3
Lower litter	Dead - I class	100	-	3.9 ± 0.8
Dead woody fuel	Dead - I class	-	-	0.4 ± 0.16
	Dead - II class	-	-	0.4 ± 0.17
Herbs[1]	Live - I class	24	32	0.3 ± 0.08
	Dead - II class			0.5 ± 0.10
Shrub layer	Live - I class	58	283 – total height 170 – crown base	1.9 ± 0.08
	Dead - II class			0.4 ± 0.09
	Dead - II class			6.3 ± 0.49

[1] Non woody understory fuels in PiroPinus terminology.

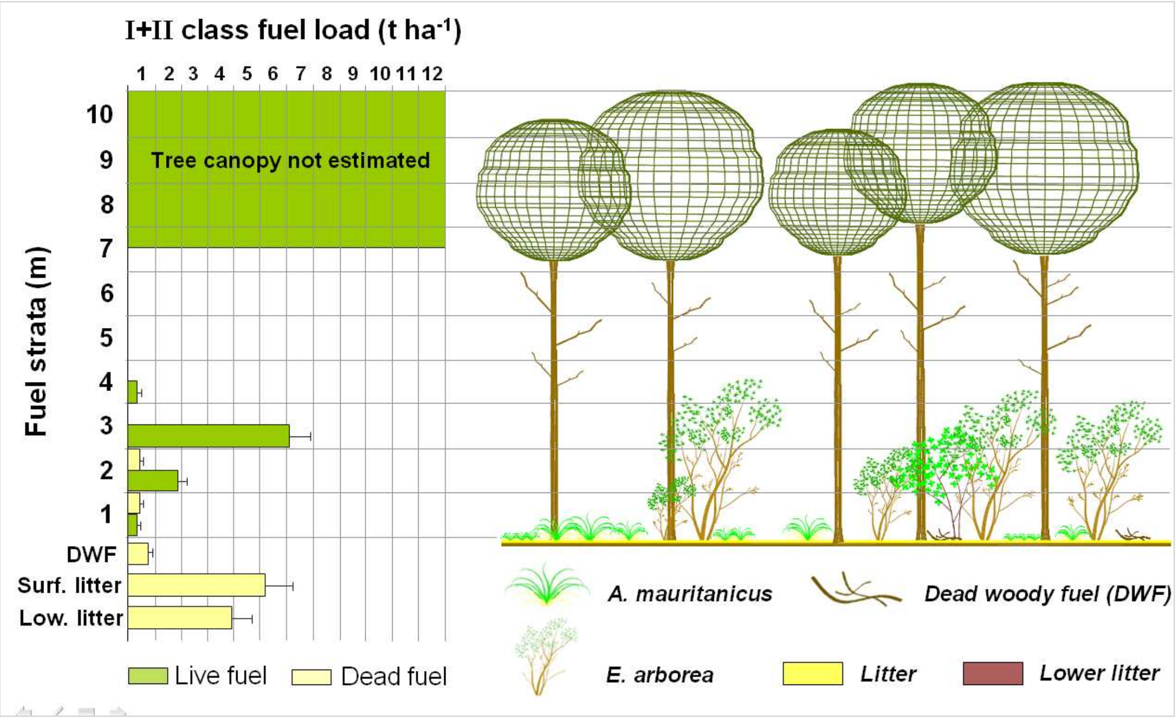

Figure 1 Distribution of live and dead fuels loads, divided in I-II size classes, along vertical strata (left), and illustration (Autocad) showing the fuel complex structure as assessed along one of the transects (right).

Prescribed burning objectives were achieved to some extent. According to the PiroPinus fire intensity interpretation table, the burn was conducted at the upper limit of marginal moisture conditions, consequently fuel consumption was lower than expected. In fact, in late summer, surface fuels in burnt areas (BU) were reduced only in part, in comparison with the control (CO). Nearly significant differences were found between surface litter loads in BU and CO (P=0.052), whose averages (±SE) were 2.8 ± 0.4 t ha^{-1} and 5.0 ± 0.5 t ha^{-1} respectively. Differences were not significant for dead woody fuels, both for I (P=0.833) and II (P=0.797) size classes. Diversely, significant differences were found for herbs (P=0.001), which were 0.06 ± 0.03 t ha^{-1} versus 0.85 ± 0.04 t ha^{-1} in BU and CO respectively. This last result was due to the poor post-fire recovery of *Ampelodesmos mauritanicus*, despite its fire adaptation traits (Mazzoleni and Esposito, 1993), probably as a consequence of the high tree cover.

Major changes were observed in elevated fuels. In BU plots 95% of *Erica* individuals showed stem mortality due to the cambium kill. In comparison with CO, the cover of live crowns was reduced from 24% to 3%, the average crown height from 2.8 m to 1.6 m, and the I class live fuel load from 1.9 t ha^{-1} to 0.3 t ha^{-1}. Consequently, the vertical continuity among fuel strata was remarkably reduced in BU (Figure 2).

Finally, according to stated burn objectives, no mortality and crown scorch were observed in the tree layer, and most *Erica* stumps resprouted (Figure 2), indicating individual survival (Catalanotti et al., Proceedings of this Conference).

Figure 2 Picture showing the border between one of the control plots (left half) and a burnt one (right half). In the burnt half it is possible to observe surface fuels reduction, mainly due to the *Ampelodesmos mauritanicus* control, a higher vertical gap between fuels strata, due to the *Erica* crown mortality, and its resprouting from stumps (Photo: Ascoli D.).

To evaluate the effectiveness of the prescribed burning treatment in reducing fire hazard, we compared the potential wildfire behaviour simulated with PiroPinus in BU versus CO. Fuel components loads estimated in late summer were input. Moderate, high and extreme fire weather conditions were simulated corresponding to 70th, 90th, 97.5th

percentiles of fine dead fuel moistures as estimated by PiroPinus, which were, 8%, 9% and 11% respectively. Also 70th, 90th, 97.5th percentiles of average wind speed 2007 series, measured at 10 m height in the open, were input after PiroPinus correction for in-stand conditions, and were 5.8 km h^{-1}, 8.7 km h^{-1}, 11.6 km h^{-1} respectively.

PiroPinus simulations of potential fire behaviour descriptors in BU and CO are reported in Figure 3. In the control, depending on the fuel moisture scenario, the predicted headfire flame length ranged from 4.8 m to 6.5 m, and fireline intensity from 3367 kW m^{-1} to 5764 kW m^{-1}. These values are realistic considering the fuel complex characteristics and structure in the study area. In fact, fire propagation from surface to elevated fuels seems highly plausible considering the high flammability of *Pinus halepensis* litter (Mårell et al., 2008) and *Ampelodesmos mauritanicus* (Mazzoleni and Esposito, 1993), together with the low average vertical distance (~140 cm) between herbs and the *Erica arborea* crown base (Table 1). Moreover, the fuel properties of *Erica arborea* presents among the highest values in surface to volume ratio and heat content (Mårell et al., 2008), together with the low foliar moisture contents (down to 47%) during prolonged dry periods (Ubysz and Valette, 2010), induce high flammability and likelihood of tree torching and crown fire (Dimitrakopoulos et al., 2007). According to these results, a wildfire occurring in the studied untreated *Pinus halepensis* plantation would determine the mortality of the entire stand (Peterson and Ryan, 1986; Rigolot, 2004; Fernandes et al., 2008), both under extreme, high and even under moderate weather conditions.

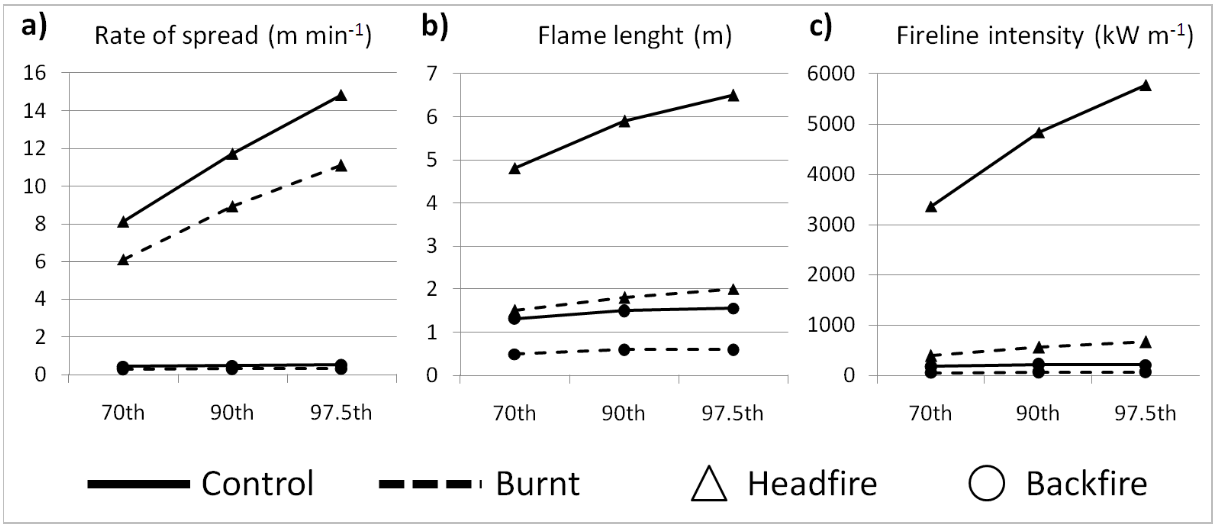

Figure 3 PiroPinus simulations of headfire (triangles) and backfire (circles) fire behaviour descriptors under 70th, 90th, 97.5th fuel moisture scenarios: a) rate of spread (m min^{-1}); b) flame lenght (m); c) fireline intensity (kW m^{-1}). Results are displayed for CO (black line) and BU (grey line).

PiroPinus predicted a remarkable reduction of potential fire behaviour in BU vs. CO for all weather scenarios (Figure 3). Under the 97.5th scenario, simulated headfire rate of spread, flame length and fireline intensity in BU were respectively 75%, 31% and 12% of the CO values. These results are due, to a minor extent, to the surface fuels loads reduction, but principally to the vertical discontinuity among fuel strata. Despite the fire hazard mitigation, which determined a predicted fire behaviour level near the upper limit of direct attack capability, fireline intensity was still critical for *Pinus halepensis* survival, both under the 97.5th and 90th scenarios, according to published post-fire mortality probability models (Peterson and Ryan, 1986; Rigolot, 2004; Fernandes et al., 2008). Nevertheless, under the 70th scenario, predicted fireline intensity was lower than 390 kW m^{-1}, thus decreasing the probability of mortality for the average tree (i.e. DBH=20 cm; H=10m) to less than 80% (Peterson and Ryan, 1986; Rigolot, 2004; Fernandes et al., 2008).

4. Conclusions

This study evidenced that PiroPinus can be a useful support tool to define prescriptions, and to evaluate the effectiveness of prescribed burning treatments for fire hazard reduction in *Pinus halepensis* plantations of the Cilento Park. Nevertheless, further experiments need to be designed and carried out to test its accuracy (i.e. near the prescription range limits) and refine the predictive relationships involved. Research issues to address are: i) development of allometric models to integrate in PiroPinus for a non destructive estimation of surface and elevated fuel loads; ii) calibration of surface fire behaviour models under different fuel loads and cover (i.e. *Ampelodesmos mauritanicus*), moistures scenarios and ignition techniques; iii) considering the higher sensitivity of *Pinus halepensis* needles and buds to heat exposure (Rigolot, 2004), and its overall minor resistance to fire, when compared to *Pinus pinaster* (Fernandes et al., 2008), it would be useful to integrate in PiroPinus scorch height estimates and mortality models which fit the fire resistance traits of *Pinus halepensis*.

The prescribed burning mitigated fire hazard at the stand-level, but it did not achieve a satisfactory surface fuels reduction: predicted fire behaviour level in BU for high and extreme fire weather scenarios was near the upper limit of direct attack capability, and the probability of tree mortality was still high. Moreover, fuel dynamics have to be monitored on a medium term, to assess litter accumulation rates, and the regeneration capability *Erica arborea* and *Ampelodesmos mauritanicus*.

More demanding fire prescriptions are posed by multi-layered fuel complexes. Despite the constraints, this study showed that experimental data can be used to improve the performance of PiroPinus, extending its use as a reference guide for Mediterranean pine forests other than *Pinus pinaster*.

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