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One-year effects of stand age, pre-fire treatments, and hillslope aspect on recovery of plant diversity and soil properties in a Mediterranean forest burnt by a severe wildfire

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16 **One-year effects of stand age, pre-fire treatments, and hillslope aspect on recovery of plant**
17 **diversity and soil properties in a Mediterranean forest burnt by a severe wildfire**

18

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36

37 **ABSTRACT**

38

39 Although several management options are adopted to redirect post-fire forest ecosystems towards
40 less vulnerable and more resilient and functional communities, little is known about the interactions
41 among tree stand age, pre-fire forest management, and slope aspects, and their consequences for
42 plant species and soil properties recovery immediately after severe wildfires. To address this
43 knowledge need, this study evaluates the post-fire changes in species richness and diversity (with a
44 specific focus on regeneration mechanisms and life forms) of regenerating plants as well as the
45 main physico-chemical and biological properties of burned soils with the reciprocal relations. Plant
46 cover and diversity, and many soil properties have been monitored in forests of southeast Spain
47 with mature, middle and young stands, presence of pre-fire treatments or not, and north and south
48 hillslopes about one year after the fire. To this aim, the reciprocal relationships among soil
49 properties and plants were evaluated adopting a combination of statistical techniques

50 (PERMANOVA, Non-metric Multi-Dimensional Scaling, Distance-based Linear Modelling,
51 Distance-based Redundancy Analysis, and Spearman correlation analysis). The damage to soil and
52 vegetation was so high that both plants and pre-fire soil properties slowly recovered. Only a few life
53 forms of vegetation (geophytes and herbaceous chamaephytes) were influenced by the stand age. If
54 combined with soil aspect, stand age resulted in significantly lower germinating species in mature
55 stands and lower resprouters in young stands, both on south hillslopes. Plant diversity was high, and
56 the post-fire regeneration did not change the species richness and evenness. The post-fire changes in
57 soil properties were limited, and only slight small differences in pH and betaglucosidase among
58 stands of different age were found. No evident associations between soil properties and plant
59 diversity were revealed by the low correlation coefficient. The low variance in plant cover and
60 diversity, as well as in soil properties, resulted in a low accuracy of the dbRDA model to reproduce
61 its variability among sites with different pre-fire characteristics.

62

63 **Keywords:** stand maturity; plant cover; enzymatic activities; organic matter; species richness;
64 evenness; post-fire recruitment.

65

66 1. INTRODUCTION

67

68 Severe wildfires frequently impact forest ecosystems by removing almost all vegetation (trees,
69 shrubs, herbs and litter) with high losses of biodiversity (Stinca et al., 2020; Lucas-Borja et al.,
70 2022), and strongly altering several soil properties, such as the contents of organic matter and
71 nutrients, stability of aggregates, electrical conductivity, and level of soil hydrophobicity (DeBano,
72 1981; Certini, 2005; Zavala et al., 2014). In addition to fire disturbance, also topography and forest
73 management generate spatial and temporal variations in the burned landscapes. This variability
74 affects plant and soil characteristics, which produce a biological and environmental heterogeneity at
75 the local scale (He et al., 2019). More specifically, forest management can intentionally alter stand
76 structure and plant biomass density, thus catalysing the behaviour and impact of wildfires.
77 Moreover, it is important to note the key influence of the hillslope aspect, since plant survival and
78 growth of most regenerating species are largely controlled by climatic conditions and
79 morphological factors (Pigliucci, 2001). Depending on these factors, plants may respond differently
80 to climatic and pedologic constraints (e.g., sunlight or soil water content) that limit the success of
81 soil and plant recovery after wildfires (Su et al., 2019; De Frenne et al., 2021).

82 The impacts of fire, climate, topography and management can lead to severe alterations in many
83 ecosystem functions of forests associated to plant diversity and soil characteristics (Stavi, 2019;

84 Nelson et al., 2022). Alteration of soil properties after severe wildfires plays an essential role in
85 degradation rates of forests. For instance, organic matter is a key property to support the
86 equilibrium between chemical and biological properties (Entry and Emmingham, 1998; Bastida et
87 al., 2007). Vegetation diversity increases the heterogeneity of forest resources, such as litter
88 composition and root exudates (Lucas-Borja and Delgado-Baquerizo, 2019). In this regard,
89 composition of tree and herbaceous species regulates the accumulation and consumption of organic
90 matter and the cycles of nutrients in forest soils (Entry and Emmingham, 1998; Byrnes et al., 2014).
91 Moreover, plant composition significantly influences the enzymatic activities that are related to the
92 cycles of nitrogen, phosphorus, carbon, and sulphur (Bastida et al., 2008; Hedo et al., 2015), as well
93 as the growth and activity of microbial communities (i.e., dehydrogenase activity and soil
94 respiration). Post-fire vegetation regeneration is supported by the plant capacity to resprout
95 (resprouting species) or by fire stimulation of their recruitment (seeders or germinating species)
96 (Bodí et al., 2012).

97 The literature related to the wildfire impacts on forest ecosystems is wide and eminent (e.g.,
98 Gouveia et al., 2010; Zituni et al., 2019; Nolan et al., 2021), but the majority of these studies have
99 separately analysed post-fire soil property dynamics and vegetation regeneration (e.g., soils: Zavala
100 et al., 2009; Carmona-Yáñez et al., 2023; biodiversity: Reilly et al., 2006; Burkle et al., 2015; Miller
101 and Safford, 2020). In contrast, the studies that have jointly explored the post-fire dynamics of soil
102 properties and vegetation regeneration are much less existing (Garrido-Ruíz et al., 2022; Granged et
103 al., 2011; Spanos et al., 2005). In this context, there is the need to better understand the recovery
104 capacity of the forest ecosystem after severe wildfires focusing on three important drivers, such as
105 the wildfire-affected stand age, presence of pre-fire silvicultural treatments and the hillslope aspect.
106 Since the most severe changes in vegetation and soil processes occur a few months after fire
107 occurrence, and a prompt management action may enhance a balanced recovery of both soil
108 properties and plant diversity. However, very scarce studies have adopted a comprehensive
109 approach that explores the effects of the aforementioned factors on post-fire changes in soil
110 properties and plant diversity, as well as the relationships between these components of forest
111 ecosystems. In this regard, only Capitanio and Carcaillet (2008), who investigated the effects of
112 silvicultural works on differences in Aleppo pine recruitment after a wildfire, found that species
113 diversity is not related to time since the last fire, but to site location with a progressive transition
114 from initial, through transitional, to mature vegetation stages, each one characterized by different
115 species density. In spite of this isolated experience, there is the need to explore how some key
116 natural or human-induced factors, such as stand age, pre-fire treatments, and hillslope aspect,
117 influence post-fire recovery of plant diversity and restoration of soil properties in semi-arid forests.

118 It can be, therefore, hypothesised that these post-fire drivers of forest ecosystem evolution (i.e.,
119 stand age, pre-fire treatments and hillslope aspect) play a noticeable influence on life forms and
120 regeneration mechanisms of vegetation as well as on physico-chemical and biochemical properties
121 (with a particular reference to organic carbon, enzymatic activities and basal respiration) of soil.
122 To fill this literature gap and address this hypothesis, this study analyses the short-term effects of
123 stand age, pre-fire treatments (tree biomass reduction) and hillslope aspect on recovery of plant
124 diversity and soil properties in a Mediterranean forest burnt by a severe wildfire. In more detail, the
125 post-fire changes in species richness and diversity (with a specific focus on regeneration
126 mechanisms and life forms) of regenerating plants, as well as in a large set of physico-chemical and
127 biological properties of burned soils, have been evaluated in forest sites of Vall d'Ebo (Alicante,
128 South East Spain) with three different stand ages (mature, middle and young), the presence of pre-
129 fire treatments or not, and north and south aspects of hillslopes. In spite of the short monitoring time
130 of the study and the lack of further analysis on key soil health indicators (e.g., microbial biomass),
131 information about the relationships among those forest features, and soil and vegetation
132 characteristics is essential for forest managers, as it may support the most effective actions aimed at
133 a quick recovery of the burned ecosystems in the Mediterranean area with similar characteristics as
134 the study area.

135

136 **2. MATERIAL AND METHODS**

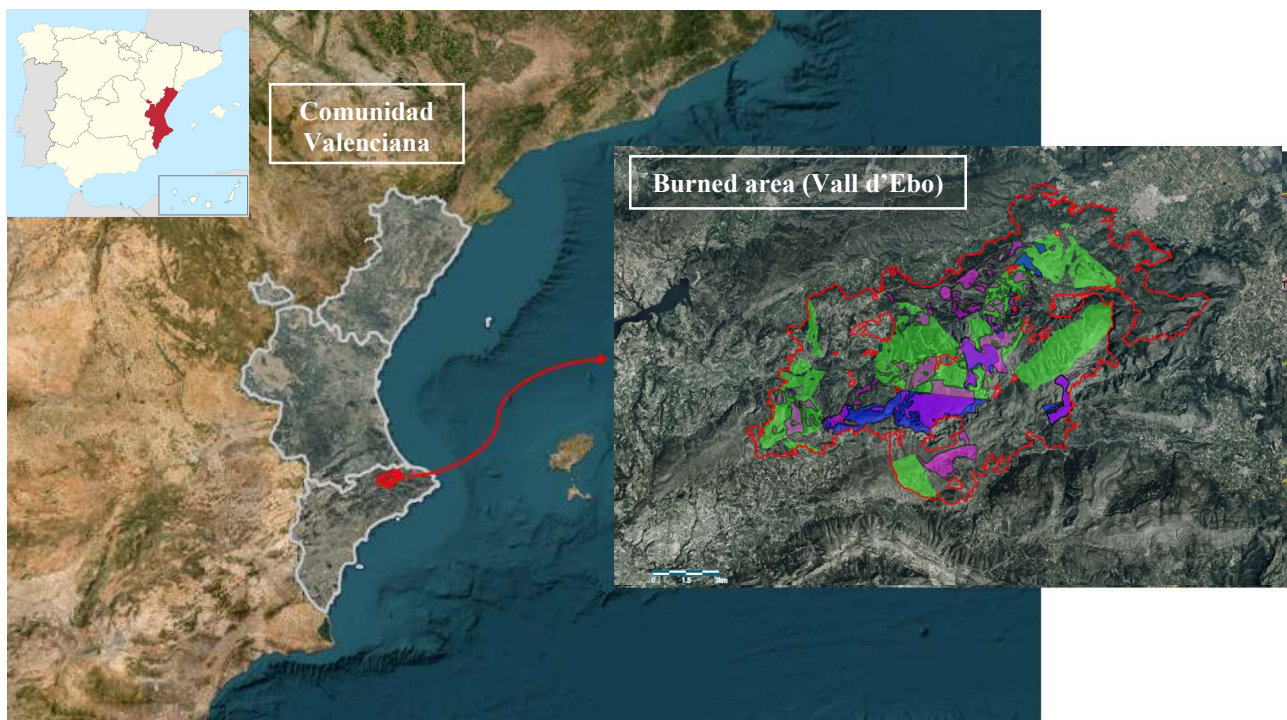
137

138 **2.1 Study area**

139

140 The study area is located in the north-east of the Province of Alicante, in Comunidad Valenciana
141 (Southern Spain) (Figure 1). The altitude ranges between 200 and 1165 metres. The climate is semi-
142 arid, Csa type according to the Koppen's classification (Kottek et al., 2006), with mean annual
143 values for precipitation and air temperature of 1220 mm and 18 °C, respectively (Figure 1). Forest
144 is one of the main types of land use, with *Pinus halepensis* Mill. that have stand ages ranging from
145 10 to 80 years. Shrub vegetation mainly consists of *Chamaerops humilis* L., *Quercus coccifera* L.,
146 *Juniperus oxycedrus* L., *Rhamnus alaternus* L., *Daphne gnidium* L., *Cistus albidus* L., *Ulex*
147 *parviflorus* Pourr., *Rosmarinus officinalis* L., and herbaceous layers include *Brachypodium retusum*
148 (Pers.) Beauv., and sometimes in the wetter and deeper soils *Brachypodium phoenicoides* (L.)
149 Roem. & Schult. The soil, mainly shallow and chalky with mean contents of 20 ± 5% of sand, 30 ±
150 7% of silt and 50 ± 7% of clay, can be classified as limestone and loamy soil (Nachtergaele, 2001;
151 Soil Survey Staff, 2014).

152 In August 2022, a large wildfire burned a total area of 11604 ha (named “Vall d’Ebo wildfire”). The
153 41% of the area burned has been reforested mainly with *Pinus halepensis*. These reforestations had
154 variable success and when the area was burned only 26% of the total area burned was covered by
155 forest (Figure 1). The wildfire severity was variable depending on different ecosystem factors, such
156 as vegetation or soil type. The wildfire resulted in soil severe burning, according to the visual
157 classification proposed by Vega et al. (2013), which is based on qualitative indicators, e.g.,
158 vegetation burning level, charring, ground colour), as described by Parson et al. (2010).
159



160
161 Figure 1 – Geographical location and map of the three large groups of reforested stands (green:
162 before 1970; blue: between 1970 and 1990; purple: after 1990) in the Vall d’Ebo wildfire
163 (Comunidad Valenciana, Spain).

164 165 2.2 Experimental design

166
167 The focus of this study was ascertaining the impacts of forest management and hillslope aspect on
168 sites burned by severe wildfires. Therefore, the study area was identified in a severely burned site.
169 Here, three forest stands planted on different dates were identified inside the burned area (Figure 1):
170 (i) a mature stand (planted between 1955 and 1960 using manpower with slight device); (ii) a
171 middle-age stand (planted between 1985 and 1990 using slight machinery and manpower); (iii) a
172 young stand (planted between 2005-2010 using both manual work and machinery). In each stand,
173 two pairs of sites were identified, one site was subjected in the past to forest management actions

174 (tree biomass reduction), while the other site was undisturbed by any management. Both sites were
175 at altitudes between 600 and 800 m a.s.l. Forest management was carried out at each stand
176 approximately 20 years after reforestation. For each of these two pairs of sites, two single hillslopes
177 were selected, one with north aspect, and the other exposed to south.

178 In each hillslope/site/stand, three square plots (each of 10 x 10 m, covering 100 m²) were randomly
179 delimited, where soil sampling and vegetation surveys were carried out. The plots were located at a
180 reciprocal distance not lower than 500 m to reduce the problems associated to possible pseudo-
181 replications, and therefore statistically dependent observations or correlations of measurements in
182 time or space. Since the altitude range of plots in the study area was narrow, elevation was not
183 considered as an environmental driver, such as aspect of hillslopes or age of forest stand, and
184 therefore not included as statistical factor.

185 Overall, the experimental design consisted of three forest stand age (mature, middle and young),
186 two soil condition (pre-fire treatment or no action) and two hillslope aspect (north and south) with
187 three replicated plots for each factor, totalling 36 plots.

188

189 **2.3 Data collection**

190

191 *2.3.1 Soil sampling and analysis*

192

193 In May 2023, after removing litter, soil was manually collected in the 0 to 5 cm depth layer in the
194 experimental plots with a hoe. Three samples (each of ca. 200 g) per plot were collected at as many
195 randomly selected points, and then mixed to obtain a composite sample. The composite samples
196 were immediately transported to the laboratory and dried for 48 hours at room temperature. After
197 sieving (2-mm diameter), the samples were kept at 4 °C for 15 days until analysis. The following
198 physico-chemical properties were analysed: (i) pH and electrical conductivity (EC, in distilled
199 water, at a soil solution ratio of 1:2.5 and 1:5, respectively, using a digital pHmeter (LAQUA
200 PH1100, HORIBA, Tokio, Japan) and conductivimeter (Crison 522, Barcelona, Spain); (ii) Total
201 Organic Carbon (TOC, by Walkley and Black, 1934), modified by Mingorance et al. (2007), and
202 measured in a spectrophotometer (Spectronic Helios Gamma UV-Vis, Thermo Fisher Scientific,
203 Massachusetts, USA); (iii) Available plant water (AW), by measuring the wilting point (WP) at -
204 1500 and the field capacity (FC) at -33 kPa by Richards' method (Richards, 1947); (iv) soil water
205 content (SWC), using a VG400 (Vegetronix, Utah, USA) device placed on the soil surface and
206 connected to a data logger (Onset HOBO, Massachusetts, USA).

207 Moreover, the following biological properties were determined: (i) Basal soil respiration (BSR,
208 expressed as mg C-CO₂ kg⁻¹ day⁻¹ of dry soil, and c-BSR expressed as cumulative mg C-CO₂ kg⁻¹
209 values for 32 days of measurement), using an infrared CO₂ sensor (IRGA S151, Qubit Systems Inc.,
210 Canada) on soils held at the same water holding capacity; (ii) Dehydrogenase activity (DHA,
211 expressed as μmol INTF hour⁻¹ g⁻¹ of dry soil), by reduction of p-iodonitrotetrazolium chloride
212 (INT) to p-iodonitrotetrazolium formazan (INTF) following García et al. (1997); (iii) Urease
213 activity (UA, expressed as μmol N-NH₄⁺ hour⁻¹ g⁻¹ of dry soil), using urea as a substrate and a
214 borate buffer at pH = 10 (Kandeler and Gerber, 1988) ; (iv) Alkaline phosphatase (PA) and β-
215 glucosidase (BGA) (both expressed as μmol pNP g⁻¹ of dry soil), using the methods of Tabatabai
216 and Bremner (1969) and Eivazi and Tabatabai (1988), respectively.

217

218 2.3.2 Plant diversity analysis

219

220 During soil sampling, plant species were surveyed at the experimental plots. Three transects 20-m
221 long were delimited along the longitudinal profile of each of the 36 plots, i.e. 108 transects. One
222 transect was setup in the middle part, and the two others on the plot sides. In each transect, plant
223 cover and species were identified using the line intercept method (Canfield, 1941), together with
224 their regeneration mechanism (seeders or resprouters) and their life forms (therophytes,
225 hemicryptophytes, geophytes, phanerophytes, woody chamaephytes, and herbaceous chamaephytes)
226 by field observations. More specifically, a tape was extended along the transect, and the observer
227 identified and recorded plants intercepted by the tape. From these surveys, two plant diversity
228 indices were calculated in each plot: (i) the species richness (S, the total number of the different
229 species); (ii) and the Shannon index (Shannon, 1948). Shannon's index (H) indicates the relative
230 abundance of the different species in a site, and was calculated by the following formula:

$$231 \quad H = -\sum_{i=1}^S p_i \ln p_i \quad (1)$$

232 where $p_i = \frac{n_i}{N}$ is the frequency of “n_i” plants of the “i-th” species compared to the total number of
233 plants “N” in the transect. H varies in the range 0 to ln N; a H is equal to 0 indicates no plant
234 diversity (i.e., only one species in the site), while, when H is maximum, all species have the same
235 number of individuals (i.e., perfect evenness). Finally, the values of the S and H indexes were
236 averaged among the three transects in each plot.

237

238 **2.4 Statistical analysis**

239

240 The reciprocal relationships among the soil properties and plants were evaluated adopting a
241 combination of statistical techniques.

242 First, the statistical differences in measurements were determined by the multivariate permutational
243 analysis of variance (PERMANOVA, Anderson, 2005), using the tree factors (stand age, presence
244 of forest treatments, slope aspect) as factors. Stand age, and slope were chosen as fixed factors,
245 whereas pre-fire forest treatments were fixed and nested in stand age factor). The PERMANOVA
246 tests allow the statistical analysis of a simultaneous response of various variables to one or more
247 factors in an experimental design based on any resemblance matrix, using permutation method.
248 Before PERMANOVA, the matrices with soil properties and plant species cover were square root
249 transformed; the similarity matrix was built using the Euclidean and Bray Curtis distance for the
250 soil properties and plant species cover data, respectively. The sums of squares type were type III
251 (partial) and each factor (or interactions among factors) was a fixed effect. The permutation method
252 used was the unrestricted permutation of raw data and the number of permutations was 999.

253 Second, the Non-metric Multi-Dimensional Scaling (NMDS) and the Kruskal stress formula
254 (minimum stress: 0.01) were applied to plant diversity, to evaluate the similarity level in the
255 individual cases of the dataset.

256 Third, a DISTLM function (distance-based linear modelling) was developed, to determine the
257 relative importance of any soil properties on plant diversity. For the DISTLM function, we
258 developed “marginal” tests of the relationship between the plant diversity and individual variables
259 (soil property), to identify the independent variables that explain the variations in the soil samples.
260 Following the marginal tests, “sequential” tests of individual variables were performed to assess
261 whether adding an individual variable contributes significantly to the explained variation of the
262 response variable.

263 Fourth, distance-based redundancy analysis (dbRDA) was applied to build a regression model
264 against two new response variables (“axis” 1 and “axis” 2), built on the soil properties and covers.
265 The AICc (Akaike, 1974) criterion was adopted to select the best model, and the step-wise
266 procedure was followed to build the model.

267 Finally, a Spearman correlation heatmap including the correlation coefficients between soil
268 properties (EC, pH, TOC, AW, SWC, DHA, BGA, PA, UA, and c-BSR) and plant diversity (S, PI,
269 MDS1 and MDS2, the latter being the axes of the multidimensional scaling analyses of plant
270 diversity) was calculated, in order to explore the relationships between soil and plant diversity.

271 For statistical analyses, PRIMER V7[®] with PERMANOVA add-on (Anderson, 2005) and
 272 Statgraphics Centurion XVI[®] (StatPoint Technologies, Inc., Warrenton, VA, USA) were used. A
 273 significance level of 0.05 was used, unless otherwise indicated.

274

275 3. RESULTS

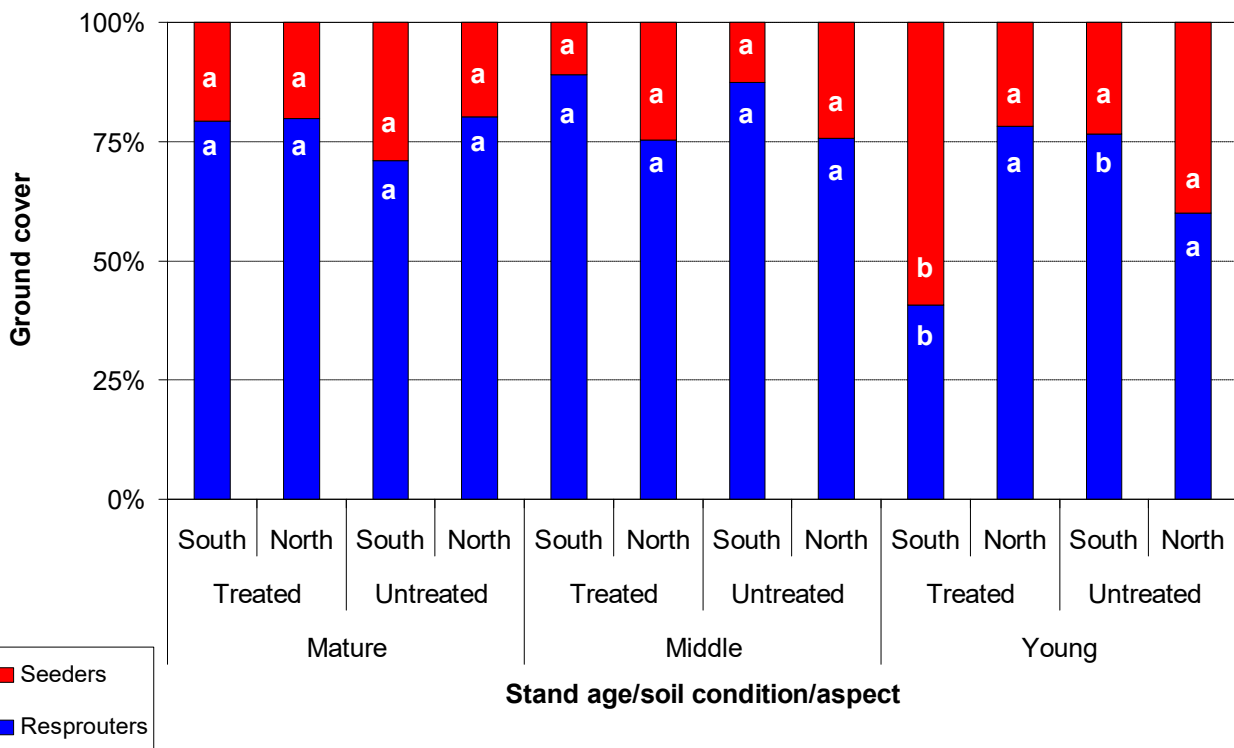
276

277 3.1 Variability of plant cover

278

279 According to PERMANOVA, the only factor generating significant differences in plant cover was
 280 the interaction age and aspect for seeder plants ($p < 0.05$), while the other factors were not influent.
 281 In more detail, the maximum percentage of ground cover by seeders (59.3%) was surveyed in
 282 treated stands with young age exposed to south (Figure 2). Differences in ground cover for
 283 resprouting plants were never significant (Table 1.SI).

284



285

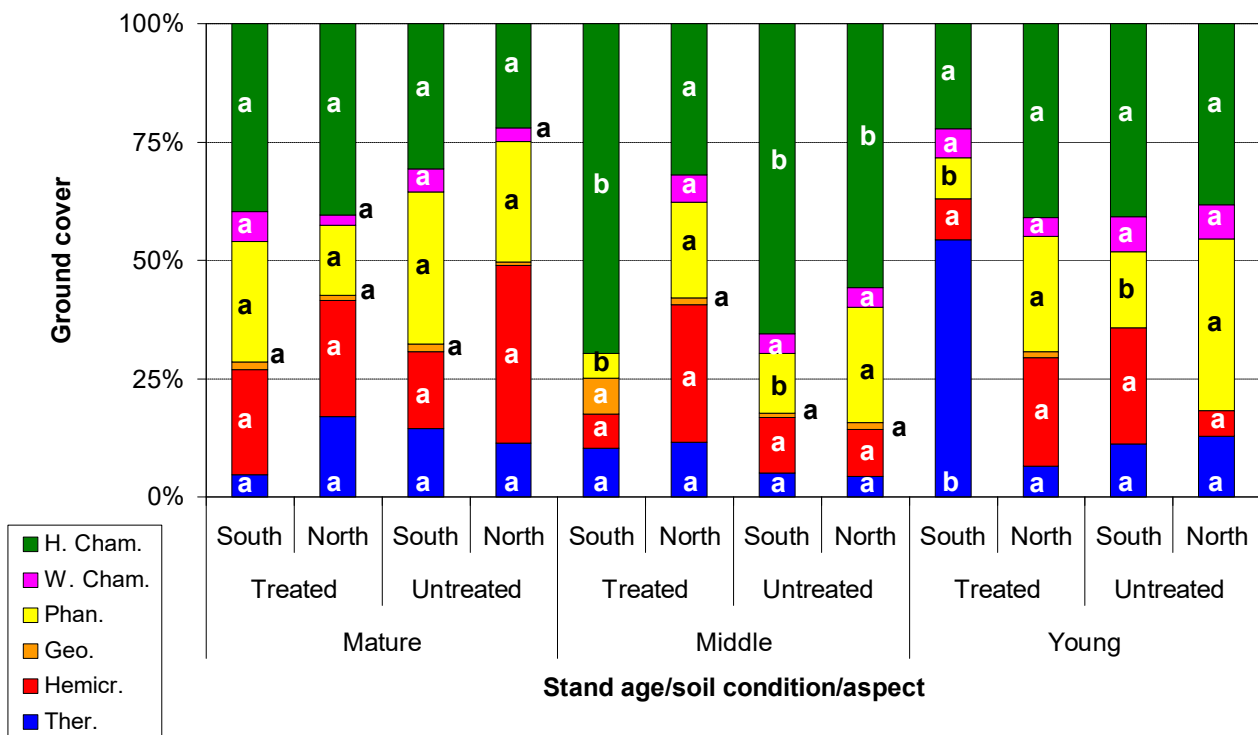
286 Figure 2 – Percent distribution of plant cover according to the regeneration strategy in forests with
 287 different stand age (mature, middle, young), soil condition (with or without treatment) and aspect
 288 (South or North) in the study area (Vall d’Ebo, Comunidad Valenciana, Spain). Different letters
 289 indicate significant differences in pairwise comparisons after PERMANOVA.

290

291 As shown by the results of PERMANOVA, the similarity among stands of different age and aspect
 292 was high in terms of regeneration strategy, except for resprouters, which were significantly different
 293 on hillslopes exposed to south between young and mid-age stands, and seeders, for which the
 294 differences were significant between mature stands on one side, and mid-age and young stands on
 295 the other side, in all cases with south aspect (Table 2.SI).

296 The PERMANOVA showed significant differences in life forms of the surveyed species geophytes,
 297 which were different with stand age. Phanerophytes and herbaceous chamaephytes showed
 298 differences between stands with different age and aspect (Table 3.SI). The rest of life forms did not
 299 show any effect of the analysed factors, Despite of this relatively low significance of the differences,
 300 a prevalence of therophytes (54.3% of the total ground cover) was detected in young stands and of
 301 herbaceous chamaephytes (69.7%) in stands with middle age, both treated and exposed to south. In
 302 contrast, the soil covered by geophytes and woody chamaephytes was generally small in all
 303 treatments (less than 8%) (Figure 3).

304

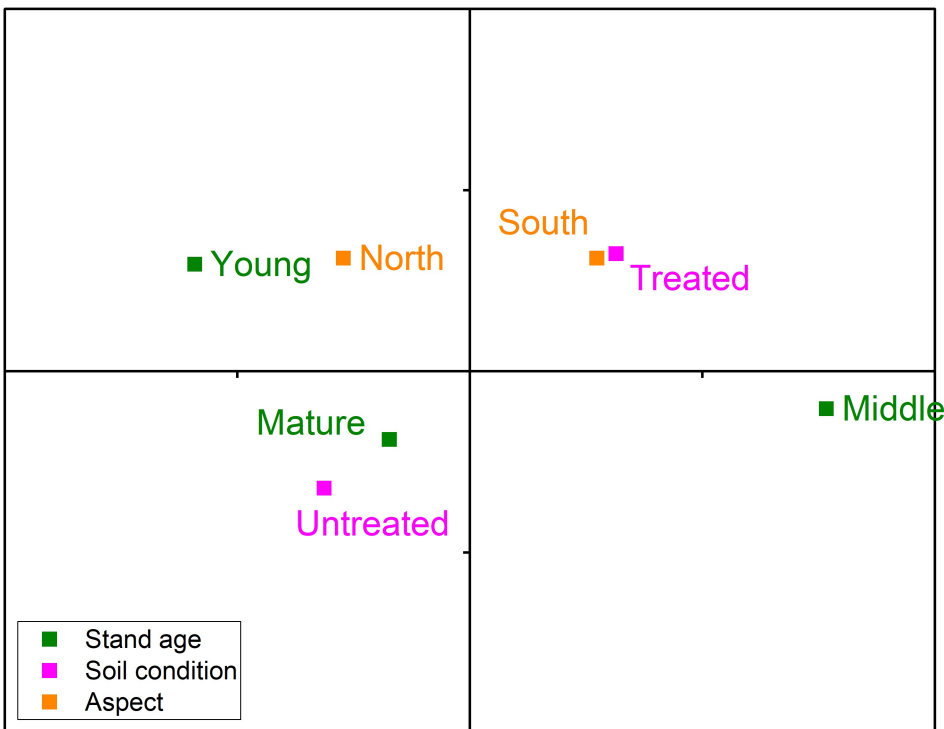
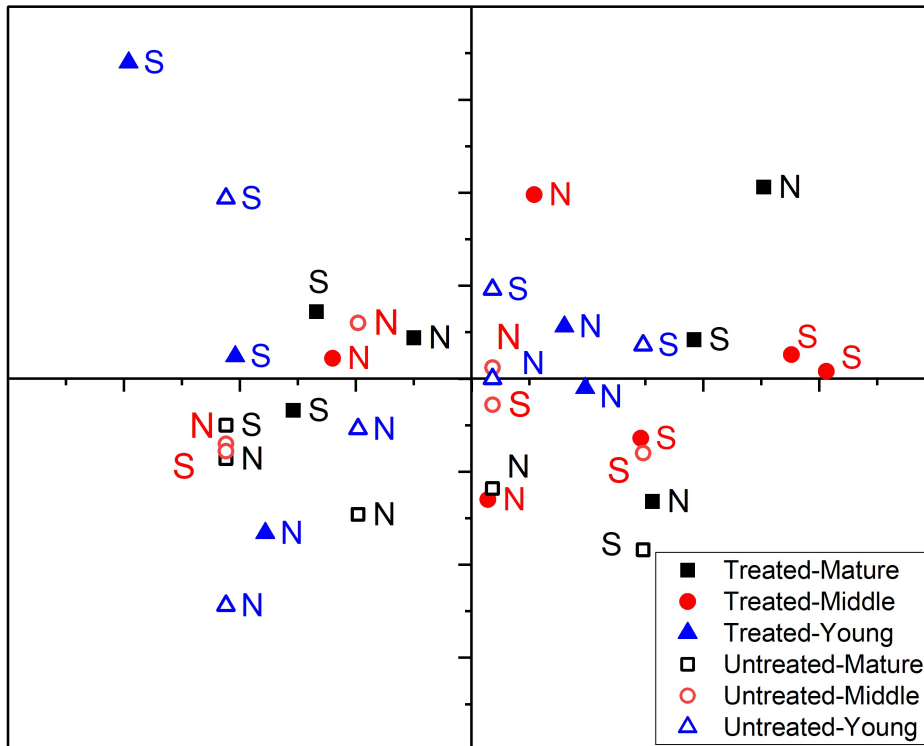


305
 306 Figure 3 – Percent distribution of plant cover according to the life form (Ther. = Therophytes;
 307 Hemicr. = Hemicryptophytes; Geo. = Geophytes; Phan. = Phanerophytes; W. Cham. = Woody
 308 Chamaephytes; H. Cham. = Herbaceous Chamaephytes) in forests with different stand age (mature,
 309 middle, young), soil condition (with or without treatment) and aspect (South or North) in the study
 310 area (Vall d’Ebo, Comunidad Valenciana, Spain). Different letters indicate significant differences in
 311 pairwise comparisons after PERMANOVA.

312

313 All stands with different age were similar regardless of the aspect in terms of life form, except for
314 the herbaceous chamaephytes exposed to south, which was significantly different between young
315 stands and stands of middle age (Table 4.SI).

316 Regarding multidimensional scaling analyses, the NMDS does not show evident clusters of sites
317 according to the factors “stand age” and “aspect” for plant diversity (Figure 4).



318
 319 Figure 4 - Results of nonmetric multidimensional scaling (NMDS) routine applied to plant diversity
 320 in forests with different stand age (mature, middle, young), soil condition (treated or untreated) and
 321 soil aspect (south or north) in the study area (Comunidad Valenciana, Spain) – lower panel reports
 322 the centroids of each group of clusters. Legend: S = south aspect; N = north aspect.
 323

324 **3.2 Variability of plant diversity**

325

326 PERMANOVA did not show any significant difference either in species richness or evenness
327 (measured by Shannon index) among the factors (Table 5.SI). In general, the number of species was
328 in the range 6.33 ± 2.40 (young treated stands exposed to south) to 16 ± 0.88 (mature treated stands
329 exposed to north), while their distribution varied between 1.21 ± 0.49 (treated and young stands
330 exposed to south) and 2.23 ± 0.34 (untreated and mature stands exposed to north).

331 A similarity in plant diversity as found only between mid-aged and young stands with south aspect
332 (Table 6.SI).

333 *Brachypodium retusum*, *Cistus albidus*, and *Ulex parviflorus* were the species that most contributed
334 to the overall similarity among the forest stands, as shown by Table 7.SI, but also *Pinus halepensis*
335 was found mainly in young stands, and secondarily in mid-age plots regardless of soil condition and
336 aspect. Species such as *Euphorbia segetalis* and *Avena sterilis* appear in stands with middle age, but
337 not in stands with younger or older maturity.

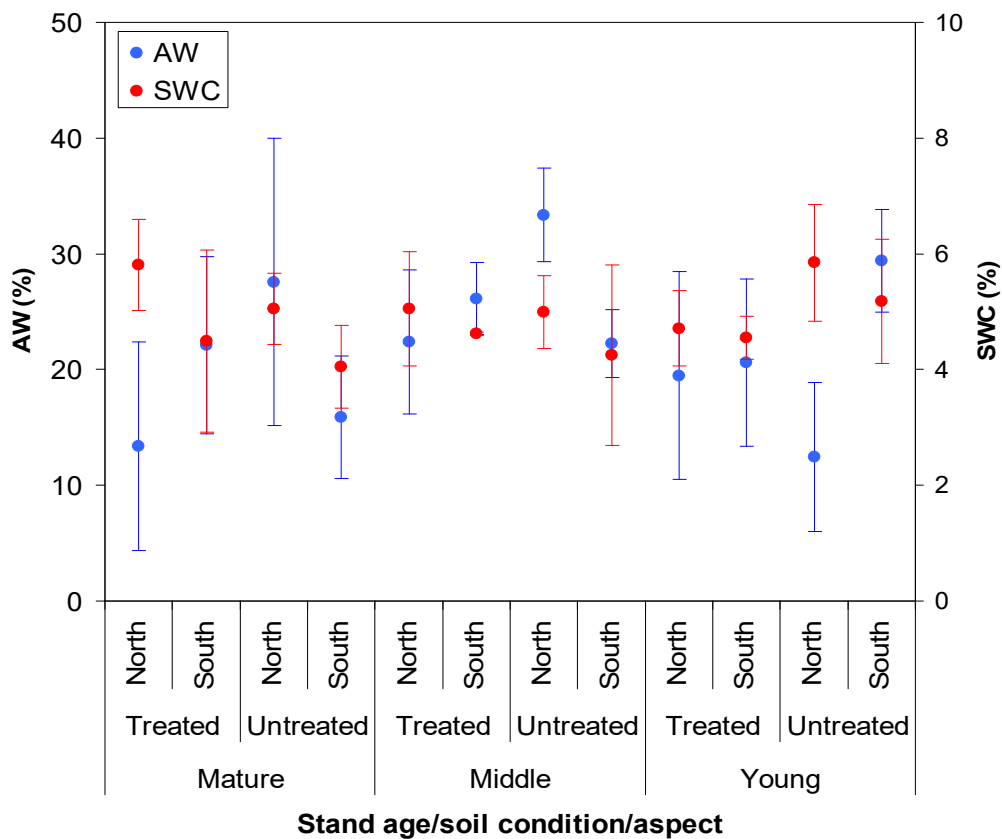
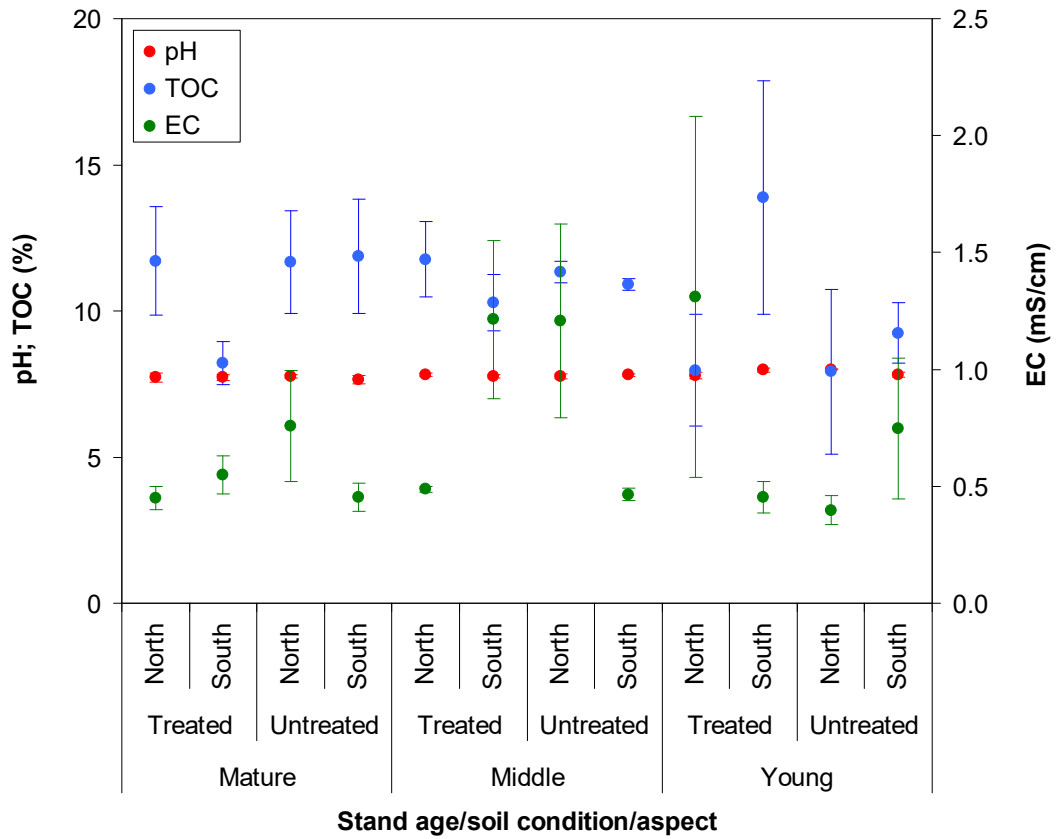
338

339 **3.3 Variability of soil properties**

340

341 None of the analysed physical-chemical properties of soil showed significant differences among the
342 stands of different age, soil condition, and aspect (Table 8.SI). In more detail, among the chemical
343 properties, pH varied in a narrow range (7.65-8), but the changes between young stands ($7.90 \pm$
344 0.11) and stands with older age (7.72 ± 0.05 , mature, and 7.75 ± 0.63) were significant. In contrast,
345 the variability of TOC was from $7.93 \pm 2.82\%$ (untreated young stands exposed to north) to $13.9 \pm$
346 3.99% (treated young stands exposed to south), whereas EC varied from 0.397 ± 0.061 mS/cm
347 (again measured untreated young stands exposed to north) to 1.31 ± 0.77 mS/cm (in treated young
348 stands exposed to north). Regarding the physical properties, also SWC was even affected by a high
349 variability, as shown by the higher changes measured (from $12.5 \pm 6.42\%$ of untreated young stands
350 exposed to north to $33.4 \pm 4.05\%$ of untreated stands with middle age exposed to north for AW),
351 while the variability of SWC was much lower (in the range of 4.05% to 5.85%) (Figure 5).

352



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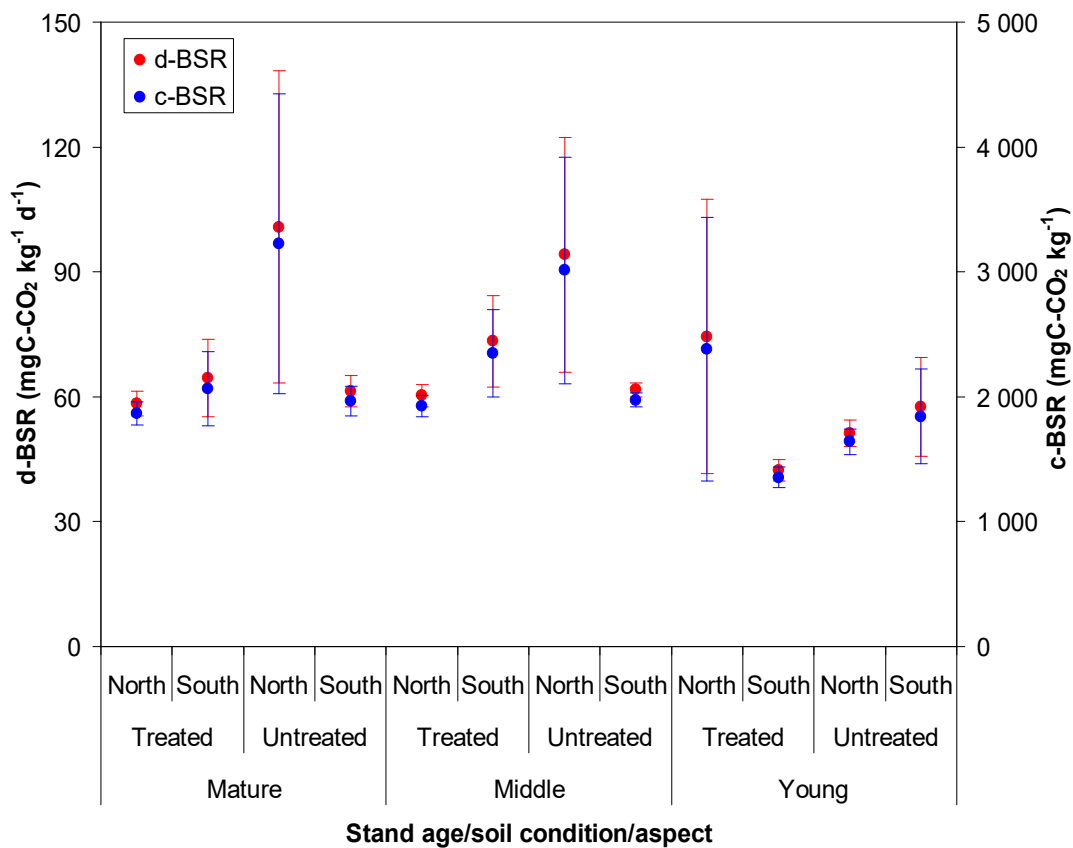
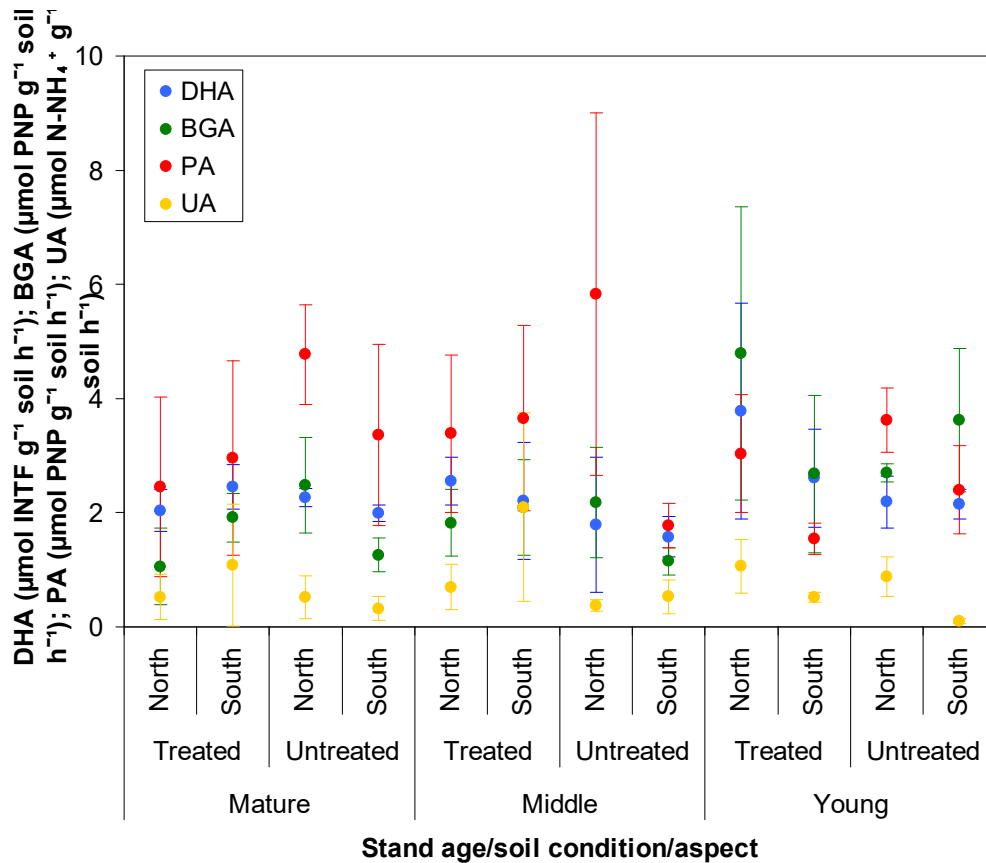
354 Figure 5 – Mean \pm standard error (n = 3) of the main physico-chemical properties of soils (EC =
 355 electrical conductivity; TOC = total organic carbon; AW = available water; SWC = soil water

356 content) sampled in forests with different stand age (mature, middle, young), soil condition (with or
357 without treatment) and aspect (South or North) in the study area (Vall d'Ebo, Comunidad
358 Valenciana, Spain).

359

360 Among the biochemical properties, only BGA was significantly different but only among stands of
361 different age (Table 9.SI). For the other biochemical properties tested, the differences were not
362 significant. More specifically, BGA of young stands ($3.45 \pm 0.89 \mu\text{mol PNF g}^{-1} \text{ soil h}^{-1}$) was
363 significantly higher compared to mature stands ($1.68 \pm 1 \mu\text{mol PNF g}^{-1} \text{ soil h}^{-1}$) and stands with
364 middle age ($1.81 \pm 1.67 \mu\text{mol PNF g}^{-1} \text{ soil h}^{-1}$). DHA, PA and UA were variable between 1.58 and
365 $3.78 \mu\text{mol INTF g}^{-1} \text{ soil h}^{-1}$, 1.55 and $5.83 \mu\text{mol PNF g}^{-1} \text{ soil h}^{-1}$, and 0.1 and $2.1 \mu\text{mol N-NH}_4^+ \text{ g}^{-1}$
366 soil h^{-1}), respectively. Daily and cumulative values of BSR were in the range 42.3 to 100.8 mg of
367 $\text{C-CO}_2 \text{ kg}^{-1} \text{ d}^{-1}$, and 1355 to 3226 mg of $\text{C-CO}_2 \text{ kg}^{-1}$, respectively (Figure 6).

368



369

370 Figure 6 – Mean ± standard error (n = 3) of the main biochemical properties of soils (BGA = β-
 371 glucosidase activity; DHA = dehydrogenase activity; PA = alkaline phosphatase activity; UA =

372 urease activity; d-BSR = daily basal soil respiration; c-BSR = cumulative basal soil respiration)
373 sampled in forests with different stand age (mature, middle, young), soil condition (with or without
374 treatment) and aspect (south or north) in the study area (Vall d'Ebo, Comunidad Valenciana, Spain).

375

376 Marginal tests of DistLM showed that only pH was a significant factor of the model, while the
377 sequential tests revealed that all variables must be added to the best distance linear model ($R^2 =$
378 0.36) to explain the variance of the variables (Table 1). According to the variations (out of the fitted
379 model and out of the total variation) explained by the axes of dbRDA, the axis one (dbRDA1)
380 explained 26.7% of the total variation of the fitted model and 9% of the total variation of the
381 variables, whereas the axis two (dbRDA2) explained 16% of the fitted model and 5.4% of the total
382 variation (Figure 7).

383

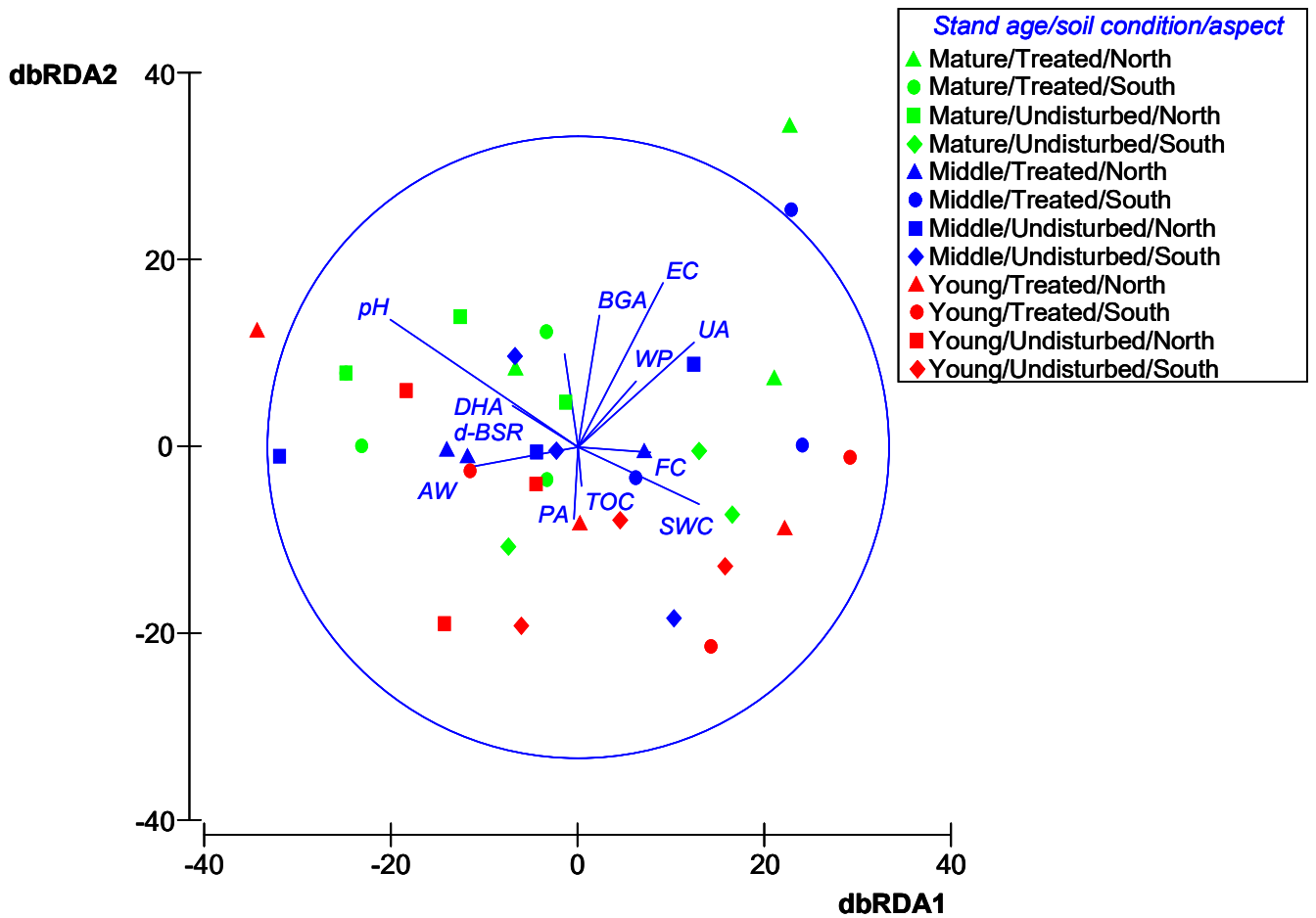
384 Table 1 – Marginal and sequential tests of the relationships between the soil properties sampled in forests with different stand age (mature, middle,
 385 young), soil condition (with or without treatment) and aspect (south or north) in the study area (Vall d’Ebo, Comunidad Valenciana, Spain).
 386

<i>MARGINAL TESTS</i>							
Variable	SS(trace)	Pseudo-F	P	Prop.			
EC	3476	1.363	0.169	0.039			
pH	4854	1.933	0.021	0.054			
TOC	2077	0.801	0.701	0.023			
FC	3297	1.290	0.197	0.037			
WP	3321	1.300	0.164	0.037			
AW	2569	0.996	0.457	0.028			
SWC	1845	0.710	0.817	0.020			
DHA	2576	1.000	0.450	0.029			
BGA	3330	1.303	0.175	0.037			
UA	3560	1.397	0.133	0.039			
PA	1953	0.752	0.776	0.022			
d-BSR	1734	0.666	0.882	0.019			
c-BSR	1734	0.666	0.879	0.019			
<i>SEQUENTIAL TESTS</i>							
Variable	R ²	SS(trace)	Pseudo-F	P	Prop.	Cumul.	Res. df
+EC	0.039	3476	1.363	0.148	0.039	0.039	34
+pH	0.091	4709	1.894	0.020	0.052	0.091	33

+TOC	0.116	2269	0.910	0.582	0.025	0.116	32
+FC	0.147	2826	1.139	0.305	0.031	0.147	31
+WP	0.179	2879	1.166	0.264	0.032	0.179	30
+AW	0.210	2805	1.141	0.302	0.031	0.210	29
+SWC	0.231	1848	0.746	0.765	0.020	0.231	28
+DHA	0.249	1643	0.655	0.859	0.018	0.249	27
+BGA	0.278	2669	1.066	0.364	0.030	0.278	26
+UA	0.304	2309	0.920	0.512	0.026	0.304	25
+PA	0.338	3086	1.241	0.228	0.034	0.338	24
+d-BSR	0.359	1914	0.762	0.734	0.021	0.359	23
+c-BSR	0.359	0	0.000	1	0.000	0.359	23

387 Notes: EC = electrical conductivity; TOC = total organic carbon; AW = available water; FC = field capacity; WP = wilting point; SWC = soil water content; BGA = β -
388 glucosidase activity; DHA = dehydrogenase activity; PA = alkaline phosphatase activity; UA = urease activity; d-BSR = daily basal soil respiration; c-BSR = cumulative basal
389 soil respiration). Bold characters indicate statistical significance ($P < 0.05$).

390



391
 392 Figure 7 - Biplots of dbRDA (distance-based Redundance Analysis) applied to soil properties
 393 sampled in forests with different stand age (mature, middle, young), soil condition (with or without
 394 treatment) and aspect (south or north) in the study area (Vall d'Ebo, Comunidad Valenciana, Spain).
 395 Legend: EC = electrical conductivity; TOC = total organic carbon; AW = available water; FC =
 396 field capacity; WP = wilting point; SWC = soil water content; BGA = β -glucosidase activity; DHA
 397 = dehydrogenase activity; PA = alkaline phosphatase activity; UA = urease activity; d-BSR = daily
 398 basal soil respiration; c-BSR = cumulative basal soil respiration)
 399

400 The Spearman's correlation analysis generally showed low correlations between soil properties and
 401 plant diversity with some exceptions. In more detail, among the soil properties, some enzymatic
 402 activities were correlated each to other with positive Spearman's coefficients (e.g., BGA with DHA,
 403 PA and UA, and PA and UA) as well as EC with pH (negative correlation), BGA and PA (positive
 404 correlations). Moreover, c-BSR was significantly correlated with several other soil properties, such
 405 as EC, pH, AW and PA. Among the parameters related to plant diversity, significant correlations
 406 were only detected between MDS1 and H (-0.50). Finally, no reciprocal associations between soil
 407 properties on one side, and plant diversity were revealed by the correlation analysis, except between

408 H and c-BSR (-0.42) and pH and MDS1 (-0.37), while MDS2 were never correlated to other
 409 variables (Figure 8).

410

	S	H	EC	pH	TOC	AW	SWC	DHA	BGA	PA	UA	c-BSR	MDS1
H	0.14												
EC	-0.13	-0.20											
pH	-0.12	0.17	-0.47										
TOC	0.15	0.13	0.24	-0.19									
AW	-0.29	0.11	0.29	0.07	0.28								
SWC	0.24	0.08	-0.03	-0.12	0.08	-0.03							
DHA	-0.03	0.31	0.30	-0.04	0.03	0.14	0.17						
BGA	0.08	0.00	0.42	-0.16	-0.09	-0.07	0.11	0.47					
PA	0.16	-0.14	0.43	-0.47	0.06	-0.14	0.25	0.41	0.67				
UA	0.23	-0.10	-0.07	-0.03	0.06	-0.32	0.14	0.21	0.38	0.55			
c-BSR	-0.18	-0.42	0.66	-0.56	0.19	0.34	-0.04	0.13	0.29	0.59	-0.01		
MDS1	0.26	-0.50	0.28	-0.37	0.12	-0.22	-0.01	-0.02	0.11	0.18	0.28	0.15	
MDS2	-0.33	0.14	0.02	-0.25	-0.13	-0.12	-0.20	-0.07	-0.26	-0.27	-0.11	-0.20	0.01

411 Figure 8 - Spearman correlation heatmap reporting the correlation coefficients between including
 412 the correlation coefficients between soil properties (EC, pH, TOC, AW, SWC, DHA, BGA, PA, UA,
 413 c-BSR and d-BSR) and plant diversity (S, H, MDS 1 and 2, the latter being the axes of the
 414 multidimensional scaling analyses of plant diversity). Significant coefficients ($p < 0.05$) are shown
 415 in bold. Legend: S = species richness; H = Shannon's index; EC = electrical conductivity; TOC =
 416 total organic carbon; AW = available water; SWC = soil water content; BGA = β -glucosidase
 417 activity; DHA = dehydrogenase activity; PA = alkaline phosphatase activity; UA = urease activity;
 418 d-BSR = daily basal soil respiration; c-BSR = cumulative basal soil respiration)

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4. DISCUSSIONS

4.1 Variability of plant cover and diversity

In this study, the presence/absence of pre-fire treatments did not generally affect plant diversity and soil properties. However, stand age and aspect turned out to be important factors. When we look separately at stand age, the latter only influenced the life forms, with alterations in the distribution of geophytes and herbaceous chamaephytes, these were generally more abundant in mid-age stands. The combined effect of stand age and slope aspect significantly affected the regeneration mechanism. This can be observed in the significantly lower abundance of germinating species in mature stands compared to both young and mid-age stands. This can be caused by the loss seed viability with time. On the other hand, there is a lower abundance of resprouters in young stands compared to stands with middle age. In both cases, the hillslopes were exposed to south. In this case, plant succession processes may be delayed or hampered due to increased aridity conditions.

As for ground cover, the richness and evenness were not affected by stand age, presence of treatments, and hillslope aspect. This may be due to the high number of species surveyed in all different plots, which did not evidence a prevalence of some species over others. Among all species, a prevalence of *Brachypodium retusum*, *Cistus albidus*, and *Ulex parviflorus* was observed, although these species did not affect the overall distribution of all vegetal complexes among the different stands. The noticeable presence of *Pinus halepensis* in stands with younger age may be due to the fact that the percentage of pine cones that remain thanks to serotiny varies with age. On the other hand, it is worrying that the regeneration of *Pinus halepensis* showed such low values, probably due to the low precipitation that has characterized the climate in the 12 months after the fire (Ne'eman et al., 2004; Osem et al., 2013). In this regard, Capitano and Carcaillet (2008) found low recruitment of Aleppo pine – in spite of the high adaptation capacity of this species to fire (Fournier et al., 2013) - in the first year after a wildfire, while 70% and 100% recruitments were observed one and three years after. Lucas-Borja et al. (2017) observed a lower early recruitment of *Pinus sylvestris* compared to *Pinus nigra* in the same environment of this study, while Thanos et al. (1996) reported a progressively declining regeneration of *Pinus halepensis* in the period from few months to three years after a wildfire in Greek mountains. Different factors such as microclimate, seed rain, or seed predation may influence post-fire recruitment (Calama et al., 2017). The finding of the present study indicates the need for monitoring of the future regeneration, which should be supported by proper techniques (e.g., biomass reduction, pruning of tree canopies, prescribed fire),

453 but caring for a limited development of shrub cover, which may lead to more flammable and
454 pyrophytic formations (De Luis et al., 2004; Alloza et al., 2006; Pausas and Moreira, 2012).

455 The scientific literature has widely demonstrated that Mediterranean species are able to regenerate
456 after wildfire through different post-fire strategies, including resprouting, serotiny, soil seed banks
457 or wind seed dispersion into a fire-affected site (e.g., Arnan et al., 2007; Enríquez-de-Salamanca,
458 2023; Rodrigues et al., 2024). Moreover, it is worth mentioning other circumstances, such as the
459 land use prior to the wildfire event, to properly understand plant species composition in the study
460 area. The presence of *Euphorbia segetalis* and *Avena sterilis* in middle-age stands may be due to
461 three reasons: (i) the existence of old crop fields nestled in the mountains, with a seed bank very
462 close to the forest area (which, however, requires further investigation, since there is no evident
463 correlation between seedling emergence from seed banks from burial experiments (Saatkamp et al.,
464 2009); (ii) crushing and incorporating of forest residues into the soil from silvicultural treatments;
465 and (iii) the amount of ashes left by fire, which act as fertilizers (Zavala et al., 2009; Pereira et al.,
466 2018).

467 It is worth mentioning that the low ground cover of the plant species surveyed that emerged the first
468 year after the fire (approximately 27%) is not expected to play an important role in mitigating the
469 possible water erosion from the burned soil (Shakesby, 2011; Moody et al., 2013). Therefore, post-
470 fire management actions targeted at reducing the effects of erosivity of post-fire rainstorms are
471 suggested, in order to avoid the off-site effects of vegetation removal (Lucas-Borja, 2021; Zema,
472 2021).

473

474 **4.2 Variability of soil properties**

475

476 In this study, neither the stand age nor the soil condition (treated or not) or aspect influenced almost
477 all the soil physical-chemical and biochemical properties. Only pH significantly varied between
478 stands, and this different significance may derive from the selective uptake of acids by trees and
479 shrubs of different age (Elliott et al., 2013; Zavala et al., 2014). In this case, the well-known
480 buffering capacity of soil against the pH variations was overcome by this process (Carra et al.,
481 2021), which generates the aforementioned changes in this parameter. Since the wildfire is severe
482 and homogenous in the studies sites, and the organic matter content of soil is not significantly
483 different among the soil conditions, the variability in EC was not noticeable. The small differences
484 in EC among the different sites should be due to the inconsistency of the quality and amount of ash
485 - an important key driver for content of minerals and ions in burned soils - released by a so severe
486 wildfire (Zavala et al., 2014; Prats et al., 2018).. In contrast, no similar effects on TOC and in those

487 physical properties that are strictly associated with changes in organic matter (soil water repellency,
488 aggregate stability, porosity (Doerr et al., 2000; Mataix-Solera et al., 2002; Agbeshie et al., 2022)
489 were as evident as for pH, although both the pre-fire treatments and the soil aspect may have
490 influenced the OM content (Certini et al., 2011; Barančíková et al., 2018). The general lack of
491 influence of hillslope aspect should be due to presence of a stony ground on the experimental soils,
492 which balanced the changes in soil properties and the subsequent response of vegetal complexes
493 other than expected. What might be surprising at first sight is the similar values of SWC among
494 sites of different aspect. However this may be justified by the severity of wildfire, which should
495 have fully dried and compacted the soil, due to the high temperatures while burning (de Jonge et al.,
496 1999; Pereira et al., 2018; Carrión-Paladines et al., 2022) as well as to shrinkage of soil macropores
497 with reduction in porosity (Mirzaei et al., 2023).

498 Among the enzymatic activities and other biological properties of soil, only BGA showed a
499 significant variability between the same stands, presumably due to the different digestion rate of
500 cellulose due to microorganisms recovering after the wildfire, which could be different among the
501 different stand ages and aspects (Carletti et al., 2009; Lucas-Borja et al., 2016; Walkiewicz et al.,
502 2021). The other enzymatic activities and BSR were not affected by different variations of stand age,
503 pre-fire treatment and aspect. An explanation could be the low levels of enzymatic activities due to
504 the extreme damage to microbial communities determined by the high burning temperatures
505 (Mataix-Solera et al., 2009; Rodríguez et al., 2017). The low changes in plant cover and diversity as
506 well as in soil properties may be the main reason of the low accuracy of the dbRDA model to
507 reproduce their variability among sites with different pre-fire characteristics. Finally, it is worthy to
508 mention that the selection of plots burned at high severity may have homogenised wildfire impacts
509 not allowing differences among studied factors (stand age, pre-fire forest management and slope).

510

511 **4.3 Associations between plant diversity and soil properties**

512

513 The negative correlation between H and c-BSR demonstrated by the correlation analysis (Figure 8)
514 indicates a dominance of few species over the background vegetation with increasing soil basal
515 respiration. This result is quite surprising, since a higher biochemical activity should support growth
516 of most species. Presumably, some adverse factors other than soil basal respiration may
517 significantly disturb the weakest species, such as BGA or pH. In overall, the relationships between
518 plant and soil were weak, as demonstrated by the low or lack of influence of soil variables on
519 MDS1 and MDS2 (Figure 8).

520 These results contrast with other studies about associations between plants and soils after burning
521 and post-fire treatments in Mediterranean forests. For instance, Lucas-Borja et al. (2021) found
522 significant relations between ecosystem multifunctionality and plant community species in the
523 same environment, suggesting that fire-related changes in plant diversity can alter many forest
524 functions. Furthermore, Gómez-Sánchez et al. (2023), again in Mediterranean severely-burned and
525 treated forests and in the mid-term after fire, showed more resprouting species in treated sites (due
526 to higher contents of organic matter and nitrogen compared to untreated soils) and more abundant
527 tree and herbaceous species resulting from decreases in pH and increases in organic matter.
528 However, the fire severity of those studies was lower and the treatment intensity (log erosion
529 barriers and contour felled log debris) was more impacting on the ecosystem, which may justify
530 these contrasts compared to our investigation.

531 The low number of associations between parameters that are related to plant diversity on one side,
532 and soil properties on the other side shown by our study reveals that the three factors (stand age,
533 pre-fire treatments, and hillslope aspect) played a limited role on relationships between plants and
534 soils, and this further confirms the high influence of severe wildfires on post-fire recovery of the
535 forest ecosystem. This is an important result, which shows the low resilience of vegetation and soil
536 to an extreme disturbance such as wildfire, despite treatments and other natural drivers, such as
537 stand maturity and north aspect under semi-arid Mediterranean conditions. Other authors have
538 showed that important role of fire severity and post-fire management on both plant diversity and
539 soil properties. For instance, Gómez-Sánchez et al. (2023) reported that increases in OM, N, and pH
540 are associated with clear differences in the regeneration mechanisms as well as layer composition in
541 sites treated with post-fire management techniques. Fires with different severity are associated to
542 variable landscape-level biodiversity by increasing species turnover across landscapes with a
543 diverse mosaic of habitats (Burkle et al., 2015). Fireseverity has a significant influence on soil
544 status, and the microbiological properties show a particular sensitivity to fire characteristics
545 (Fernández-García et al., 2019). Post-fire management play important impacts also on soil
546 properties, and manual operations have less detrimental impacts compared to machinery (Francos et
547 al., 2018).

548

549 **4.4 Practical implications and limitations of the study**

550

551 This study suggests some practical implications that may support a quicker regeneration of
552 vegetation as well as recovery of the pre-fire soil characteristics. First of all, the high percentage of
553 resprouting species (approximately 80%) and the large number of different pioneer species in the

554 first year of regeneration ensure a good response in post-fire regeneration of the Mediterranean
555 forests (e.g., Santana et al., 2012; Méndez et al., 2015; Castro, 2021). Fire is also important for
556 supporting highly diversified fire-dependent plant communities, and its suppression may reduce
557 diversity in Mediterranean forests (Fournier et al., 2020). Second, the pre-fire forest management
558 practices do not negatively interfere with the ecosystem regeneration (as also demonstrated by
559 Capitanio and Carcaillet, 2008), as the soil physico-chemical properties, enzymatic activities, and
560 post-fire vegetation cover and diversity are not altered. Third, and finally, the implementation of
561 silvicultural techniques should be taken into account when aiming to reduce the damage due to
562 future wildfires and to accelerate vegetation and soil properties recovery after wildfire events (e.g.,
563 selection of tree species with serotiny mechanisms, which may ensure seed bank for post-fire
564 regrowth of vegetation).

565 Given the impacts of hillslope aspect on plant regeneration, when reforestation with tree species is
566 necessary to accelerate the recovery of forest ecosystem functions, it is essential to take into account
567 the effect of microclimate, selecting species originating from warmer or drier places (Resco de Dios
568 et al., 2007) and adopting the so-called “assisted migration” process (McLachlan et al., 2007). This
569 process has emerged as a promising forestry strategy to mitigate the impacts of climate change (Xu
570 and Prescott, 2024). As a matter of fact, translocating more conservative species in cooler climates
571 may decrease the buffering capacity of forest canopies and facilitation for understory species as
572 well as increase the wildfire risks with consequent acceleration of climate warming through
573 negative atmospheric feedback (Michalet et al., 2023). This contrasts with the traditional approach
574 that suggested planting based on the suitability of species to thrive under past climatic conditions.

575 A possible limitation of the study is the short monitoring time, which, if it captures the sudden
576 changes in vegetation characteristics, does not allow for a clear understanding of ecosystem
577 dynamics some years after the wildfire, and the time of complete recovery to its pre-fire conditions.
578 Indeed, a short-term monitoring of vegetation recruitment after severe wildfires is less meaningful
579 compared to long-term chronosequences (Fournier et al., 2020) or succession modelling (Retana et
580 al., 2002). Therefore, a long-term monitoring of the trajectory of the burned ecosystem is necessary,
581 since many species that appeared in the first year after the disturbance may disappear in a short time
582 (Fournier et al., 2020). On the contrary, coverage of species that now seem insignificant may take a
583 very important role in the future ecosystem.

584

585

586 **5. CONCLUSIONS**

587

588 In contrast to the working hypothesis, this study has shown that forest stand age, presence of pre-
589 fire treatments and hillslope aspect played a small influence on vegetation cover regeneration, plant
590 diversity, and physico-chemical and biochemical properties of soil in pine forests of Castilla La
591 Mancha (Central Eastern Spain) affected by a severe fire. In general, the damage to soil and
592 vegetation was so high that both vegetation and pre-fire soil properties slowly recovered. These
593 recovery rates were very similar in young to old stands regardless of the presence of pre-fire
594 treatments and soil aspect. Regarding the plant cover, only a few life forms of vegetation were
595 influenced by the pre-fire stand age (geophytes and herbaceous chamaephytes). If combined with
596 soil aspect, stand age significantly affected the regeneration mechanism, resulting in lower
597 germinating species in mature stands and lower resprouters in young stands, both cases on
598 hillslopes exposed to south. The plant diversity at the experimental sites was very high, and the
599 post-fire regeneration did not change the species richness and evenness. Due to the very high
600 temperatures after the uniform burn severity, no significant changes in the physico-chemical and
601 biochemical properties of soil were detected among the burned sites under different conditions,
602 except for some small differences in pH and betaglucosidase among stands of different age. The
603 low variance in plant cover and diversity as well as in soil properties resulted in a low accuracy of
604 the dbRDA model to reproduce its variability among sites with different pre-fire characteristics.
605 Overall, this study contributes to better understand how plant and soil dynamics change in burned
606 Mediterranean environments, which is a matter of primary interest for forest managers, especially in
607 the Mediterranean ecosystems. This knowledge will reduce ecosystem degradation and preserve its
608 health in changing fire and climate contexts.

609

610 **NOMENCLATURE**

611

612 SR = species richness

613 H = Shannon index

614 Ther. = Therophytes

615 Hemicr. = Hemicryptophytes

616 Geo. = Geophytes

617 Phan. = Phanerophytes

618 W. Cham. = Woody Chamaephytes

619 H. Cham. = Herbaceous Chamaephytes
620 EC = electrical conductivity
621 TOC = total organic carbon
622 AW = available water
623 FC = field capacity
624 WP = wilting point
625 SWC = soil water content
626 BGA = β -glucosidase activity
627 DHA = dehydrogenase activity
628 PA = alkaline phosphatase activity
629 UA = urease activity
630 d-BSR = daily basal soil respiration
631 c-BSR = cumulative basal soil respiration
632 distLM = distance-based linear modelling
633 dbRDA = distance-based redundancy analysis

634

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636

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646

647 **COMPETING INTERESTS**

648

649 The authors have no relevant financial or non-financial interests to disclose.

650

651 **DATA AVAILABILITY**

652

653 The datasets generated during and/or analysed during the current study are available from the
654 corresponding author on reasonable request.

655

656 REFERENCES

657

658 Agbeshie, A. A., S. Abugre, T. Atta-Darkwa, and R. Awuah. 2022. A review of the effects of forest
659 fire on soil properties. *Journal of Forestry Research*: 1–23.

660 Akaike, H. 1974. A new look at the statistical model identification. *IEEE Transactions on*
661 *Automatic Control* 19: 716–723.

662 Alloza, J. A., M. J. Baeza, J. De la Riva, B. Duguy, M. T. Echeverría, P. Ibarra, J. Llovet, et al.
663 2006. A model to evaluate the ecological vulnerability to forest fires in Mediterranean
664 ecosystems. *Forest Ecology and Management* 234: S203.

665 Anderson, M. J. 2005. Permutational multivariate analysis of variance. *Department of Statistics,*
666 *University of Auckland, Auckland* 26: 32–46.

667 Arnan, X., A. Rodrigo, and J. Retana. 2007. Post-fire regeneration of Mediterranean plant
668 communities at a regional scale is dependent on vegetation type and dryness. *Journal of*
669 *Vegetation Science* 18: 111–122.

670 Barančíková, G., M. Jarzykiewicz, E. Gömöryová, E. Tobiašová, and T. Litavec. 2018. Changes in
671 forest soil organic matter quality affected by windstorm and wildfire. *Journal of Soils and*
672 *Sediments* 18: 2738–2747.

673 Bastida, F., J. L. Moreno, T. Hernández, and C. García. 2007. The long-term effects of the
674 management of a forest soil on its carbon content, microbial biomass and activity under a
675 semi-arid climate. *Applied Soil Ecology* 37: 53–62.

676 Bastida, F., A. Zsolnay, T. Hernández, and C. García. 2008. Past, present and future of soil quality
677 indices: A biological perspective. *Geoderma* 147: 159–171.

678 Bodí, M. B., A. Cerdà, J. Mataix-Solera, and S. H. Doerr. 2012. A review of fire effects on
679 vegetation and soil in the Mediterranean Basin. *Boletín de la Asociación de Geógrafos*
680 *Espanoles*.

681 Burkle, L. A., J. A. Myers, and R. T. Belote. 2015. Wildfire disturbance and productivity as drivers
682 of plant species diversity across spatial scales. *Ecosphere* 6: art202.

683 Byrnes, J. E., L. Gamfeldt, F. Isbell, J. S. Lefcheck, J. N. Griffin, A. Hector, B. J. Cardinale, et al.
684 2014. Investigating the relationship between biodiversity and ecosystem multifunctionality:
685 challenges and solutions. *Methods in Ecology and Evolution* 5: 111–124.

686 Calama, R., R. Manso, M. E. Lucas-Borja, J. M. Espelta, M. Pique, F. Bravo, C. del Peso, and M.
687 Pardos. 2017. Natural regeneration in Iberian pines A review of dynamic processes and
688 proposals for management. *Forest Systems* 26: eR02S-eR02S.

689 Canfield, R. H. 1941. Application of the Line Interception Method in Sampling Range Vegetation.
690 *Journal of Forestry* 39: 388–394.

- 691 Capitano, R., and C. Carcaillet. 2008. Post-fire Mediterranean vegetation dynamics and diversity:
692 A discussion of succession models. *Forest Ecology and Management* 255: 431–439.
- 693 Carletti, P., E. Vendramin, D. Pizzeghello, G. Concheri, A. Zanella, S. Nardi, and A. Squartini.
694 2009. Soil humic compounds and microbial communities in six spruce forests as function of
695 parent material, slope aspect and stand age. *Plant and Soil* 315: 47–65.
- 696 Carmona-Yáñez, M. D., M. Francos, I. Miralles, R. Soria, S. S. Ahangarkolae, E. Vafaie, D. A.
697 Zema, and M. E. Lucas-Borja. 2023. Short-term impacts of wildfire and post-fire mulching
698 on ecosystem multifunctionality in a semi-arid pine forest. *Forest Ecology and Management*
699 541: 121000.
- 700 Carra, B. G., G. Bombino, M. E. Lucas-Borja, A. Muscolo, F. Romeo, and D. A. Zema. 2021.
701 Short-term changes in soil properties after prescribed fire and mulching with fern in
702 Mediterranean forests. *Journal of Forestry Research*: 1–19.
- 703 Carrión-Paladines, V., M. B. Hinojosa, L. Jiménez Álvarez, F. Reyes-Bueno, L. Correa Quezada,
704 and R. García-Ruiz. 2022. Effects of the Severity of Wildfires on Some Physical-Chemical
705 Soil Properties in a Humid Montane Scrublands Ecosystem in Southern Ecuador. *Fire* 5: 66.
- 706 Castro, J. 2021. Post-fire restoration of Mediterranean pine forests. *Pines and Their Mixed Forest*
707 *Ecosystems in the Mediterranean Basin*: 537–565.
- 708 Certini, G. 2005. Effects of fire on properties of forest soils: a review. *Oecologia* 143: 1–10.
- 709 Certini, G., C. Nocentini, H. Knicker, P. Arfaioli, and C. Rumpel. 2011. Wildfire effects on soil
710 organic matter quantity and quality in two fire-prone Mediterranean pine forests. *Geoderma*
711 167: 148–155.
- 712 De Frenne, P., J. Lenoir, M. Luoto, B. R. Scheffers, F. Zellweger, J. Aalto, M. B. Ashcroft, et al.
713 2021. Forest microclimates and climate change: Importance, drivers and future research
714 agenda. *Global Change Biology* 27: 2279–2297.
- 715 De Luis, M., M. J. Baeza, J. Raventós, and J. C. González-Hidalgo. 2004. Fuel characteristics and
716 fire behaviour in mature Mediterranean gorse shrublands. *International Journal of Wildland*
717 *Fire* 13: 79–87.
- 718 DeBano, L. F. 1981. Water repellent soils: a state-of-the-art. US Department of Agriculture, Forest
719 Service, Pacific Southwest Forest and
- 720 Doerr, S. H., R. A. Shakesby, and Rpd. Walsh. 2000. Soil water repellency: its causes,
721 characteristics and hydro-geomorphological significance. *Earth-Science Reviews* 51: 33–65.
- 722 Eivazi, F., and M. A. Tabatabai. 1977. Phosphatases in soils. *Soil Biology and Biochemistry* 9: 167–
723 172.
- 724 Elliott, K. J., J. D. Knoepp, J. M. Vose, and W. A. Jackson. 2013. Interacting effects of wildfire
725 severity and liming on nutrient cycling in a southern Appalachian wilderness area. *Plant and*
726 *Soil* 366: 165–183.
- 727 Enríquez-de-Salamanca, Á. 2023. Dynamics of mediterranean pine forests reforested after fires.
728 *Journal of Forestry Research* 34: 345–354.

- 729 Entry, J. A., and W. H. Emmingham. 1998. Influence of forest age on forms of carbon in Douglas-
730 fir soils in the Oregon Coast Range. *Canadian Journal of Forest Research* 28: 390–395.
- 731 Fernández-García, V., J. Miesel, M. J. Baeza, E. Marcos, and L. Calvo. 2019. Wildfire effects on
732 soil properties in fire-prone pine ecosystems: Indicators of burn severity legacy over the
733 medium term after fire. *Applied Soil Ecology* 135: 147–156.
- 734 Fournier, T., J. Fèvre, F. Carcaillet, and C. Carcaillet. 2020. For a few years more: reductions in
735 plant diversity 70 years after the last fire in Mediterranean forests. *Plant Ecology* 221: 559–
736 576.
- 737 Fournier, T. P., G. Battipaglia, B. Brossier, and C. Carcaillet. 2013. Fire-scars and polymodal age-
738 structure provide evidence of fire-events in an Aleppo pine population in southern France.
739 *Dendrochronologia* 31: 159–164.
- 740 Francos, M., P. Pereira, M. Alcañiz, and X. Úbeda. 2018. Post-wildfire management effects on
741 short-term evolution of soil properties (Catalonia, Spain, SW-Europe). *Science of The Total*
742 *Environment* 633: 285–292.
- 743 Garcia, C., T. Hernandez, and F. Costa. 1997. Potential use of dehydrogenase activity as an index of
744 microbial activity in degraded soils. *Communications in Soil Science and Plant Analysis* 28:
745 123–134.
- 746 Garrido-Ruiz, C., M. Sandoval, N. Stolpe, and J. C. Sanchez-Hernandez. 2022. Fire impacts on soil
747 and post fire emergency stabilization treatments in Mediterranean-climate regions. *Chilean*
748 *journal of agricultural research* 82: 335–347.
- 749 Gómez-Sánchez, M. E., M. Navidi, R. Ortega, R. Soria, I. Miralles, M. Dolores Carmona-Yáñez, P.
750 Garrido-Gallego, et al. 2023. Medium-term associations of soil properties and plant diversity
751 in a semi-arid pine forest after post-wildfire management. *Forest Ecology and Management*
752 545: 121163.
- 753 Gouveia, C., C. C. DaCamara, and R. M. Trigo. 2010. Post-fire vegetation recovery in Portugal
754 based on spot/vegetation data. *Natural Hazards and Earth System Sciences* 10: 673–684.
- 755 Granged, A. J., L. M. Zavala, A. Jordán, and G. Bárcenas-Moreno. 2011. Post-fire evolution of soil
756 properties and vegetation cover in a Mediterranean heathland after experimental burning: A
757 3-year study. *Geoderma* 164: 85–94.
- 758 He, T., B. B. Lamont, and J. G. Pausas. 2019. Fire as a key driver of Earth’s biodiversity. *Biological*
759 *Reviews* 94: 1983–2010.
- 760 Hedo, J., M. E. Lucas-Borja, C. Wic, M. Andrés-Abellán, and J. de Las Heras. 2015. Soil
761 microbiological properties and enzymatic activities of long-term post-fire recovery in dry
762 and semiarid Aleppo pine (*Pinus halepensis* M.) forest stands. *Solid Earth* 6: 243–252.
- 763 de Jonge, L. W., O. H. Jacobsen, and P. Moldrup. 1999. Soil Water Repellency: Effects of Water
764 Content, Temperature, and Particle Size. *Soil Science Society of America Journal* 63: 437–
765 442.
- 766 Kandeler, E., and H. Gerber. 1988. Short-term assay of soil urease activity using colorimetric
767 determination of ammonium. *Biology and fertility of Soils* 6: 68–72.

- 768 Kottek, M., J. Grieser, C. Beck, B. Rudolf, and F. Rubel. 2006. World map of the Köppen-Geiger
769 climate classification updated.
- 770 Lucas-Borja, M. E. 2021. Efficiency of postfire hillslope management strategies: Gaps of
771 knowledge. *Current Opinion in Environmental Science & Health* 21: 100247.
- 772 Lucas-Borja, M. E., D. Candel-Pérez, T. Onkelinx, P. Z. Fule, D. Moya, R. Gómez, and J. De Las
773 Heras. 2017. Early Mediterranean pine recruitment in burned and unburned *Pinus nigra* Arn.
774 ssp. *salzmannii* stands of central Spain: Influence of species identity, provenances and post-
775 dispersal predation. *Forest ecology and management* 390: 203–211.
- 776 Lucas-Borja, M. E., and M. Delgado-Baquerizo. 2019. Plant diversity and soil stoichiometry
777 regulates the changes in multifunctionality during pine temperate forest secondary
778 succession. *Science of The Total Environment* 697: 134204.
- 779 Lucas-Borja, M. E., M. Delgado-Baquerizo, M. Muñoz-Rojas, P. A. Plaza-Álvarez, M. E. Gómez-
780 Sanchez, J. González-Romero, E. Peña-Molina, et al. 2021. Changes in ecosystem properties
781 after post-fire management strategies in wildfire-affected Mediterranean forests. *Journal of*
782 *Applied Ecology* 58: 836–846.
- 783 Lucas-Borja, M. E., J. Hedro, A. Cerdá, D. Candel-Pérez, and B. Viñepla. 2016. Unravelling the
784 importance of forest age stand and forest structure driving microbiological soil properties,
785 enzymatic activities and soil nutrients content in Mediterranean Spanish black pine (*Pinus*
786 *nigra* Ar. ssp. *salzmannii*) Forest. *Science of the Total Environment* 562: 145–154.
- 787 Lucas-Borja, M. E., D. A. Zema, C. Fernández, R. Soria, I. Miralles, V. M. Santana, J. Pérez-
788 Romero, et al. 2022. Limited contribution of post-fire eco-engineering techniques to support
789 post-fire plant diversity. *Science of The Total Environment* 815: 152894.
- 790 Mataix-Solera, J., I. Gómez, J. Navarro-Pedreño, C. Guerrero, and R. Moral. 2002. Soil organic
791 matter and aggregates affected by wildfire in a *Pinus halepensis* forest in a Mediterranean
792 environment. *International Journal of Wildland Fire* 11: 107–114.
- 793 Mataix-Solera, J., C. Guerrero, F. García-Orenes, G. M. Bárcenas, and M. P. Torres. 2009. Forest
794 fire effects on soil microbiology. Fire effects on soils and restoration strategies, 149–192.
795 CRC press.
- 796 McLachlan, J. S., J. J. Hellmann, and M. W. Schwartz. 2007. A framework for debate of assisted
797 migration in an era of climate change. *Conservation biology* 21: 297–302.
- 798 Méndez, J., G. Morales, L. de Nascimento, R. Otto, A. Gallardo, and J. M. Fernández-Palacios.
799 2015. Understanding long-term post-fire regeneration of a fire-resistant pine species. *Annals*
800 *of Forest Science* 72: 609–619.
- 801 Michalet, R., C. Carcaillet, F. Delerue, J. Domec, and J. Lenoir. 2023. Assisted migration in a
802 warmer and drier climate: less climate buffering capacity, less facilitation and more fires at
803 temperate latitudes? *Oikos*: e10248.
- 804 Miller, J. E. D., and H. D. Safford. 2020. Are plant community responses to wildfire contingent
805 upon historical disturbance regimes? B. Poulter [ed.], *Global Ecology and Biogeography*
806 29: 1621–1633.

- 807 Mingorance, M. D., E. Barahona, and J. Fernández-Gálvez. 2007. Guidelines for improving organic
808 carbon recovery by the wet oxidation method. *Chemosphere* 68: 409–413.
- 809 Mirzaei, J., M. Heydari, R. Omidipour, N. Jafarian, and C. Carcaillet. 2023. Decrease in Soil
810 Functionalities and Herbs' Diversity, but Not That of Arbuscular Mycorrhizal Fungi, Linked
811 to Short Fire Interval in Semi-Arid Oak Forest Ecosystem, West Iran. *Plants* 12: 1112.
- 812 Moody, J. A., R. A. Shakesby, P. R. Robichaud, S. H. Cannon, and D. A. Martin. 2013. Current
813 research issues related to post-wildfire runoff and erosion processes. *Earth-Science Reviews*
814 122: 10–37.
- 815 Nachtergaele, F. 2001. Soil taxonomy—a basic system of soil classification for making and
816 interpreting soil surveys. *Geoderma* 99: 336–337.
- 817 Ne'eman, G., S. Goubitz, and R. Nathan. 2004. Reproductive traits of *Pinus halepensis* in the light
818 of fire—a critical review. *Plant Ecology* 171: 69–79.
- 819 Nelson, A. R., A. B. Narrowe, C. C. Rhoades, T. S. Feghel, R. A. Daly, H. K. Roth, R. K. Chu, et al.
820 2022. Wildfire-dependent changes in soil microbiome diversity and function. *Nature*
821 *microbiology*: 1–12.
- 822 Nolan, R. H., L. Collins, A. Leigh, M. K. Ooi, T. J. Curran, T. A. Fairman, V. R. de Dios, and R.
823 Bradstock. 2021. Limits to post-fire vegetation recovery under climate change. *Plant, Cell &*
824 *Environment*.
- 825 Osem, Y., H. Yavlovich, N. Zecharia, N. Atzmon, Y. Moshe, and G. Schiller. 2013. Fire-free
826 natural regeneration in water limited *Pinus halepensis* forests: a silvicultural approach.
827 *European journal of forest research* 132: 679–690.
- 828 Parson, A., P. R. Robichaud, S. A. Lewis, C. Napper, and J. T. Clark. 2010. Field guide for
829 mapping post-fire soil burn severity. *Gen. Tech. Rep. RMRS-GTR-243. Fort Collins, CO:*
830 *US Department of Agriculture, Forest Service, Rocky Mountain Research Station. 49 p. 243.*
- 831 Pausas, J. G., and B. Moreira. 2012. Flammability as a biological concept. *New Phytologist* 194:
832 610–613.
- 833 Pereira, P., M. Francos, E. C. Brevik, X. Ubeda, and I. Bogunovic. 2018. Post-fire soil management.
834 *Current Opinion in Environmental Science & Health* 5: 26–32.
- 835 Pigliucci, M. 2001. Phenotypic plasticity: beyond nature and nurture. JHU Press.
- 836 Prats, S. A., J. R. C. de B. Abrantes, C. de O. A. Coelho, J. J. Keizer, and J. L. M. P. de Lima. 2018.
837 Comparing topsoil charcoal, ash, and stone cover effects on the postfire hydrologic and
838 erosive response under laboratory conditions. *Land Degradation & Development* 29: 2102–
839 2111.
- 840 Reilly, M. J., M. C. Wimberly, and C. L. Newell. 2006. Wildfire effects on β -diversity and species
841 turnover in a forested landscape. *Journal of Vegetation Science* 17: 447–454.
- 842 Resco de Dios, V., C. Fischer, and C. Colinas. 2007. Climate change effects on Mediterranean
843 forests and preventive measures. *New forests* 33: 29–40.

- 844 Retana, J., J. Maria Espelta, A. Habrouk, J. Luis OrdoÑEZ, and F. De Solà-Morales. 2002.
845 Regeneration patterns of three Mediterranean pines and forest changes after a large wildfire
846 in northeastern Spain. *Écoscience* 9: 89–97.
- 847 Richards, L. A. 1947. Pressure-membrane apparatus, construction and use. *Agric. Eng* 28: 451–454.
- 848 Rodrigues, M., J. de la Riva, D. Domingo, T. Lamelas, P. Ibarra, R. Hoffrén, and A. García-Martín.
849 2024. An empirical assessment of the potential of post-fire recovery of tree-forest
850 communities in Mediterranean environments. *Forest Ecology and Management* 552: 121587.
- 851 Rodríguez, J., J. A. González-Pérez, A. Turmero, M. Hernández, A. S. Ball, F. J. González-Vila,
852 and M. E. Arias. 2017. Wildfire effects on the microbial activity and diversity in a
853 Mediterranean forest soil. *Catena* 158: 82–88.
- 854 Saatkamp, A., L. Affre, T. Dutoit, and P. Poschlod. 2009. The seed bank longevity index revisited:
855 limited reliability evident from a burial experiment and database analyses. *Annals of Botany*
856 104: 715–724.
- 857 Santana, V. M., M. J. Baeza, and F. T. Maestre. 2012. Seedling establishment along post-fire
858 succession in Mediterranean shrublands dominated by obligate seeders. *Acta Oecologica* 39:
859 51–60.
- 860 Shakesby, R. A. 2011. Post-wildfire soil erosion in the Mediterranean: review and future research
861 directions. *Earth-Science Reviews* 105: 71–100.
- 862 Shannon, C. E. 1948. A mathematical theory of communication Bell. Syst. Tech. J., 27: 379-423.
- 863 Soil Survey Staff, U. D. of A. 2014. Keys to Soil Taxonomy. Government Printing Office.
- 864 Spanos, I., Y. Raftoyannis, G. Goudelis, E. Xanthopoulou, T. Samara, and A. Tsiontsis. 2005.
865 Effects of Postfire Logging on Soil and Vegetation Recovery in a *Pinus halepensis* Mill.
866 Forest of Greece. *Plant and Soil* 278: 171–179.
- 867 Stavi, I. 2019. Wildfires in Grasslands and Shrublands: A Review of Impacts on Vegetation, Soil,
868 Hydrology, and Geomorphology. *Water* 11: 1042.
- 869 Stinca, A., M. Ravo, R. Marzaioli, G. Marchese, A. Cordella, F. A. Rutigliano, and A. Esposito.
870 2020. Changes in multi-level biodiversity and soil features in a burned beech forest in the
871 southern Italian coastal mountain. *Forests* 11: 983.
- 872 Su, X., M. Wang, Z. Huang, S. Fu, and H. Y. Chen. 2019. Forest understorey vegetation:
873 Colonization and the availability and heterogeneity of resources. *Forests* 10: 944.
- 874 Tabatabai, M. A., and J. M. Bremner. 1969. Use of p-nitrophenyl phosphate for assay of soil
875 phosphatase activity. *Soil Biology and Biochemistry* 1: 301–307.
- 876 Thanos, C. A., E. N. Daskalakou, and S. Nikolaidou. 1996. Early post-fire regeneration of a *Pinus*
877 *halepensis* forest on Mount Párnis, Greece. *Journal of Vegetation Science* 7: 273–280.
- 878 Vega, J. A., T. Fontúrbel, A. Merino, C. Fernández, A. Ferreiro, and E. Jiménez. 2013. Testing the
879 ability of visual indicators of soil burn severity to reflect changes in soil chemical and
880 microbial properties in pine forests and shrubland. *Plant and Soil* 369: 73–91.

- 881 Walkiewicz, A., A. Bieganski, A. Rafalska, M. I. Khalil, and B. Osborne. 2021. Contrasting
882 effects of forest type and stand age on soil microbial activities: An analysis of local scale
883 variability. *Biology* 10: 850.
- 884 Walkley, A., and I. A. Black. 1934. An examination of the Degtjareff method for determining soil
885 organic matter, and a proposed modification of the chromic acid titration method. *Soil*
886 *science* 37: 29–38.
- 887 Xu, W., and C. E. Prescott. 2024. Can assisted migration mitigate climate-change impacts on
888 forests? *Forest Ecology and Management* 556: 121738.
- 889 Zavala, L. M., A. Jordán, J. Gil, N. Bellinfante, and C. Pain. 2009. Intact ash and charred litter
890 reduces susceptibility to rain splash erosion post-wildfire. *Earth Surface Processes and*
891 *Landforms* 34: 1522–1532.
- 892 Zavala, L. M. M., R. de Celis Silvia, and A. J. López. 2014. How wildfires affect soil properties. A
893 brief review. *Cuadernos de investigación geográfica/Geographical Research Letters*: 311–
894 331.
- 895 Zema, D. A. 2021. Postfire management impacts on soil hydrology. *Current Opinion in*
896 *Environmental Science & Health* 21: 100252.
- 897 Zituni, R., L. Wittenberg, and D. Malkinson. 2019. The effects of post-fire forest management on
898 soil erosion rates 3 and 4 years after a wildfire, demonstrated on the 2010 Mount Carmel fire.
899 *International Journal of Wildland Fire* 28: 377.
- 900

901 **SUPPLEMENTARY INFORMATION**

902

903 Table 1.SI - Results of PERMANOVA analysis according to the regeneration strategy of plant
 904 species surveyed in the burned forest (Vall d'Ebo, Comunidad Valenciana, Spain). Significant
 905 values ($p < 0.05$) are marked in bold.

906

Factor	df	SS	MS	Pseudo-F	P(perm)
Resprouters					
Age	2	7267	3633	1.282	0.146
Aspect	1	2913	2913	1.028	0.431
Age (soil condition)	3	4943	1648	0.581	0.989
Age x Aspect	2	7374	3687	1.301	0.121
Age (soil condition) x Aspect	3	9708	3236	1.142	0.237
Residues	24	68026	2834		
Total	35	100230			
Seeders					
Age	2	4950	2475	1.158	0.297
Aspect	1	2843	2843	1.33	0.22
Age (soil condition)	3	8988	2996	1.402	0.115
Age x Aspect	2	7536	3768	1.763	0.05
Age (soil condition) x Aspect	3	6299	2070	0.982	0.471
Residues	24	51305	2138		
Total	35	81920			

907 Notes: df = degrees of freedom; SS = sum of squares; MS = mean sum of squares; Pseudo-F = F value by permutation;
 908 P(perm) = permutation test. Bold characters indicate statistical significance ($P < 0.05$).

909

910 Table 2.SI - Similarity within/among groups (“Aspect” as factor with levels “North” and “South”) according to the regeneration strategy of plant
 911 species surveyed in the burned forest (Vall d’Ebo, Comunidad Valenciana, Spain). The significant values ($p < 0.059$ are marked in red). Significant
 912 values are marked in bold.
 913

Resprouters								
Group	North plots				South plots			
		t	P(perm)			t	P(perm)	
Mature vs. Middle		1.133	0.252			1.332	0.069	
Mature vs. Young		0.991	0.434			1.024	0.461	
Middle vs. Young		0.800	0.748			1.517	0.040	
<i>Average similarity between/within groups</i>								
		Mature	Middle	Young		Mature	Middle	Young
	Mature	23.688			Mature	22.817		
	Middle	26.239	32.551		Middle	29.139	46.593	
	Young	23.460	29.546	23.858	Young	18.839	22.544	15.013
Seeders								
Group	North plots				South plots			
		t	P(perm)			t	P(perm)	
Mature vs. Middle		0.913	0.514			1.586	0.049	
Mature vs. Young		1.144	0.222			1.351	0.037	
Middle vs. Young		1.073	0.356			1.063	0.337	
<i>Average similarity between/within groups</i>								

		Mature	Middle	Young		Mature	Middle	Young
	Mature	23.026			Mature	42.906		
	Middle	37.351	51.416		Middle	23.328	16.83	
	Young	33.725	50.749	49.978	Young	36.203	26.525	36.894

914 Notes: t = test result; P(permutation) = permutation test. Bold characters indicate statistical significance ($P < 0.05$).

915

916 Table 3.SI - Results of PERMANOVA analysis according to the life form of plant species surveyed
 917 in the burned forest (Vall d'Ebo, Comunidad Valenciana, Spain).
 918

Factor	df	SS	MS	Pseudo-F	P(perm)
Therophytes					
Age	2	4.011	2.005	1.128	0.314
Aspect	1	1.906	1.906	1.072	0.377
Age (soil condition)	3	4.411	1.471	0.827	0.745
Age x Aspect	2	4.483	2.241	1.261	0.195
Age (soil condition) x Aspect	3	4.010	1.337	0.752	0.83
Residues	24	42.667	1.778		
Total	35	61.487			
Hemicryptophytes					
Age	2	5.300	2.650	1.101	0.342
Aspect	1	2.135	2.135	0.887	0.536
Age (soil condition)	3	5.156	1.719	0.714	0.865
Age x Aspect	2	3.356	1.678	0.697	0.863
Age (soil condition) x Aspect	3	8.801	2.934	1.219	0.202
Residues	24	57.771	2.407		
Total	35	82.519			
Geophytes					
Age	2	1.122	0.561	2.373	0.04
Aspect	1	0.125	0.125	0.530	0.63
Age (soil condition)	3	0.908	0.303	1.280	0.273
Age x Aspect	2	0.943	0.471	1.994	0.081
Age (soil condition) x Aspect	3	0.908	0.303	1.280	0.286
Residues	24	5.674	0.236		
Total	35	9.6798			
Phanerophytes					
Age	2	3.626	1.813	1.157	0.267
Aspect	1	2.728	2.728	1.741	0.054
Age (soil condition)	3	6.748	2.250	1.435	0.062

Age x Aspect	2	5.129	2.565	1.636	0.046
Age (soil condition) x Aspect	3	6.208	2.069	1.321	0.09
Residues	24	37.612	1.567		
Total	35	62.051			
Woody Chamaephytes					
Age	2	1.2304	0.61521	0.51506	0.901
Aspect	1	0.7865	0.7865	0.65847	0.679
Age (soil condition)	3	2.803	0.93432	0.78222	0.689
Age x Aspect	2	0.96771	0.48386	0.40509	0.975
Age (soil condition) x Aspect	3	3.2256	1.0752	0.90017	0.547
Residues	24	28.667	1.1944		
Total	35	37.68			
Herbaceous Chamaephytes					
Age	2	26.573	13.287	4.045	0.031
Aspect	1	3.172	3.172	0.966	0.322
Age (soil condition)	3	1.690	0.563	0.172	0.987
Age x Aspect	2	18.326	9.163	2.79	0.073
Age (soil condition) x Aspect	3	4.841	1.614	0.491	0.766
Residues	24	78.831	3.285		
Total	35	133.43			

919 Notes: df = degrees of freedom; SS = sum of squares; MS = mean sum of squares; Pseudo-F = F value by permutation;
920 P(perm) = permutation test. Bold characters indicate statistical significance (P < 0.05).

921

922 Table 4.SI - Similarity within/among groups (“Aspect” as factor with levels “North” and “South”) according to the life form of plant species
 923 surveyed in the burned forest (Vall d’Ebo, Comunidad Valenciana, Spain). Significant values ($p < 0.059$ are marked in red). Significant values are
 924 marked in bold.
 925

Therophytes								
Group	North plots			South plots				
	t	P(perm)		t	P(perm)			
Mature vs. Middle	1.024	0.512		1.237	0.138			
Mature vs. Young	1.048	0.484		1.231	0.188			
Middle vs. Young	1.245	0.164		0.909	0.597			
	<i>Average Similarity between/within groups</i>							
		Mature	Middle	Young		Mature	Middle	Young
	Mature	2.248			Mature	1.295		
	Middle	1.721	1.168		Middle	1.583	1.782	
	Young	1.794	1.248	1.260	Young	1.893	2.008	2.326
Hemicryptophytes								
	North plots			South plots				
	t	P(perm)		t	P(perm)			
Mature vs. Middle	0.889	0.653		0.890	0.669			
Mature vs. Young	1.116	0.381		0.797	0.840			
Middle vs. Young	1.064	0.361		0.840	0.756			
	<i>Average similarity between/within groups</i>							

		Mature	Middle	Young		Mature	Middle	Young
	Mature	2.897			Mature	1.942		
	Middle	2.415	1.950		Middle	1.893	1.914	
	Young	2.390	1.834	1.660	Young	0.847	1.856	1.844
Geophytes								
	North plots				South plots			
	t		P(perm)		t		P(perm)	
Mature vs. Middle	1.414		0.211		1.527		0.128	
Mature vs. Young	1.291		0.299		1.001		0.648	
Middle vs. Young	1.291		0.314		1.607		0.108	
	<i>Average similarity between/within groups</i>							
		Mature	Middle	Young		Mature	Middle	Young
	Mature	0.369			Mature	0.435		
	Middle	0.416	0.369		Middle	0.828	1.122	
	Young	0.324	0.324	0.230	Young	0.231	0.679	0.001
Phanerophytes								
	North plots				South plots			
	t		P(perm)		t		P(perm)	
Mature vs. Middle	1.301		0.078		1.013		0.415	
Mature vs. Young	1.324		0.049		1.312		0.1	
Middle vs. Young	0.807		0.806		1.189		0.215	
	<i>Average similarity between/within groups</i>							

		Mature	Middle	Young		Mature	Middle	Young
	Mature	2.421			Mature	1.882		
	Middle	2.082	1.472		Middle	1.834	1.780	
	Young	2.196	1.502	1.674	Young	1.667	1.590	1.252
Woody Chamaephytes								
	North plots				South plots			
	t		P(perm)		t		P(perm)	
Mature vs. Middle	0.516		0.885		0.816		0.785	
Mature vs. Young	0.516		0.910		0.881		0.664	
Middle vs. Young	0.534		0.913		0.612		0.836	
	<i>Average similarity between/within groups</i>							
		Mature	Middle	Young		Mature	Middle	Young
	Mature	1.192			Mature	1.497		
	Middle	1.093	1.222		Middle	1.233	0.949	
	Young	1.135	1.153	1.292	Young	1.481	1.106	1.470
Herbaceous Chamaephytes								
	North plots				South plots			
	t		P(perm)		t		P(perm)	
Mature vs. Middle	0.484		0.808		3.980		0.006	
Mature vs. Young	0.451		0.795		0.505		0.730	
Middle vs. Young	0.558		0.662		3.156		0.020	
	<i>Average Similarity between/within groups</i>							

		Mature	Middle	Young		Mature	Middle	Young
	Mature	2.532			Mature	1.822		
	Middle	2.021	1.630		Middle	3.237	1.413	
	Young	2.188	1.837	2.206	Young	2.180	3.701	2.728

Notes: t = test result; P(permutation) = permutation test. Bold characters indicate statistical significance ($P < 0.05$).

926

927

928 Table 5.SI - Results of PERMANOVA analysis of diversity indexes of plants surveyed in the burned forest (Vall d'Ebo, Comunidad Valenciana,
 929 Spain). The significant values ($p < 0.05$) are marked in red.
 930

Factor	df	SS	MS	Pseudo-F	P(perm)
Species richness					
Age	2	360.730	180.370	1.986	0.15
Aspect	1	196.290	196.290	2.161	0.117
Age (soil condition)	3	171.920	57.307	0.631	0.6
Age x Aspect	2	238.500	119.250	1.313	0.276
Age (soil condition) x Aspect	3	555.860	185.290	2.04	0.145
Residues	24	2179.900	90.828		
Total	35	3703.200			
Shannon index					
Age	2	316.670	158.340	1.626	0.197
Aspect	1	288.190	288.190	2.959	0.073
Age (soil condition)	3	172.320	57.440	0.590	0.69
Age x Aspect	2	127.100	63.552	0.653	0.574
Age (soil condition) x Aspect	3	526.740	175.580	1.803	0.143
Residues	24	2337.600	97.400		
Total	35	3768.600			

931 Notes: df = degrees of freedom; SS = sum of squares; MS = mean sum of squares; Pseudo-F = F value by permutation; P(perm) = permutation test. Bold characters indicate
932 statistical significance ($P < 0.05$).

933

934 Table 6.SI - Similarity within/among groups (“Aspect” as factor with levels “north” and “south”) of diversity indexes of plants surveyed in the
 935 burned forest (Vall d’Ebo, Comunidad Valenciana, Spain). Significant values ($p < 0.059$ are marked in red). Significant values are marked in red.
 936

Group	North plots			South plots			
	t	P(perm)		t	P(perm)		
Mature vs. Middle	1.093	0.285		1.510	0.028		
Mature vs. Young	1.113	0.206		1.089	0.251		
Middle vs. Young	0.863	0.734		1.524	0.013		
	<i>Average similarity between/within groups</i>						
	Mature	Middle	Young	Mature	Middle	Young	
Mature	23.309			Mature	29.350		
Middle	29.407	38.920		Middle	27.603	39.019	
Young	26.381	37.080	33.449	Young	25.489	24.375	23.793

937 Notes: t = test result; P(perm) = permutation test. Bold characters indicate statistical significance ($P < 0.05$).
 938

939 Table 7.SI - Species contribution to similarity within groups of all plant species surveyed in the
 940 burned forest (Vall d'Ebo, Comunidad Valenciana, Spain). The significant values ($p < 0.059$ are
 941 marked in red). Significant values are marked in red.
 942

Species	Average abundance	Average similarity	Contribution (%)	Cumulated value (%)
Group Adult/Treated/North				
Average similarity: 21.20				
<i>Brachypodium retusum</i>	3.12	10.35	48.79	48.79
<i>Mercurialis tomentosa</i>	1.22	2.05	9.67	58.46
<i>Rhamnus alaternus</i>	0.67	1.84	8.67	67.14
<i>Scorzonera graminifolia</i>	0.67	1.84	8.67	75.81
<i>Sonchus oleraceus</i>	0.67	1.84	8.67	84.49
<i>Ulex parviflorus</i>	0.67	1.84	8.67	93.16
Group Adult/Treated/South				
Average similarity: 27.55				
<i>Brachypodium retusum</i>	2.45	10.73	38.96	38.96
<i>Cistus albidus</i>	1.38	9.03	32.78	71.74
<i>Rosmarinus officinalis</i>	0.67	2.67	9.69	81.43
<i>Ulex parviflorus</i>	0.67	2.67	9.69	91.12
Group Adult/Untreated/North				
Average similarity: 26.78				
<i>Cistus albidus</i>	1.47	5.16	19.27	19.27
<i>Brachypodium retusum</i>	2.47	5.11	19.08	38.35
<i>Ulex parviflorus</i>	1.24	4.55	16.98	55.33
<i>Erica multiflora</i>	0.91	1.7	6.35	61.68
<i>Asparagus acutifolius</i>	0.67	1.48	5.54	67.22
<i>Brachypodium phoenicoides</i>	2.52	1.48	5.54	72.76
<i>Clematis flamula</i>	0.67	1.48	5.54	78.3
<i>Daphne gnidium</i>	0.67	1.48	5.54	83.84
<i>Pistacia lentiscus</i>	0.67	1.48	5.54	89.38
<i>Rubus ulmifolius</i>	0.8	1.48	5.54	94.92
Group Adult/Untreated/South				

Average similarity: 28.84				
<i>Brachypodium retusum</i>	2.26	11.42	39.62	39.62
<i>Cistus albidus</i>	1.24	6.6	22.87	62.49
<i>Ulex parviflorus</i>	1	6.6	22.87	85.37
<i>Lotus scorpiurus</i>	0.67	2.26	7.85	93.21
Group Middle/Treated/North				
Average similarity: 23.70				
<i>Brachypodium retusum</i>	2.59	13.37	56.42	56.42
<i>Ulex parviflorus</i>	1.14	6.3	26.6	83.02
<i>Cistus albidus</i>	0.8	2.32	9.79	92.81
Group Middle/Treated/South				
Average similarity: 50.00				
<i>Brachypodium retusum</i>	5.91	29.42	58.84	58.84
<i>Avena sterilis</i>	1	5.75	11.5	70.34
<i>Crepis foetida</i>	0.67	2.01	4.02	74.36
<i>Leuzea conifera</i>	0.67	2.01	4.02	78.38
<i>Mercurialis tomentosa</i>	1.08	1.97	3.94	82.32
<i>Allium roseum</i>	1.33	1.77	3.54	85.86
<i>Asphodelus cerasiferus</i>	0.67	1.77	3.54	89.39
<i>Eryngium campestre</i>	0.67	1.77	3.54	92.93
Group Middle/Untreated/North				
Average similarity: 46.10				
<i>Brachypodium retusum</i>	3.31	18.39	39.88	39.88
<i>Cistus albidus</i>	1.61	11.56	25.09	64.97
<i>Ulex parviflorus</i>	1.14	8.18	17.74	82.71
<i>Scorzonera graminifolia</i>	0.8	3.06	6.65	89.35
<i>Euphorbia isatidifolia</i>	0.67	2.45	5.32	94.68
Group Middle/Untreated/South				
Average similarity: 32.83				
<i>Brachypodium retusum</i>	5.02	26.84	81.76	81.76
<i>Cistus albidus</i>	1	2	6.08	87.84
<i>Rhamnus alaternus</i>	0.67	2	6.08	93.92
Group Young/Treated/North				

Average similarity: 28.83				
<i>Brachypodium retusum</i>	3.01	12.88	44.68	44.68
<i>Ulex parviflorus</i>	1.24	6.21	21.55	66.23
<i>Cistus albidus</i>	1.05	2.49	8.63	74.86
<i>Pinus halepensis</i>	0.67	1.97	6.83	81.69
<i>Eryngium campestre</i>	0.67	1.76	6.1	87.79
<i>Silene mellifera</i>	0.67	1.76	6.1	93.9
Group Young/Treated/South				
Average similarity: 19.58				
<i>Ulex parviflorus</i>	1	10.49	53.6	53.6
<i>Daphne gnidium</i>	0.67	5	25.54	79.14
<i>Brachypodium retusum</i>	1.76	4.08	20.86	100
Group Young/Untreated/North				
Average similarity: 33.53				
<i>Cistus albidus</i>	1.52	11.67	34.8	34.8
<i>Ulex parviflorus</i>	1.14	8.25	24.61	59.41
<i>Brachypodium retusum</i>	1.95	5.39	16.08	75.49
<i>Pinus halepensis</i>	0.67	3.11	9.28	84.78
<i>Conyza bonariensis</i>	0.67	2.55	7.61	92.39
Group Young/Untreated/South				
Average similarity: 27.35				
<i>Ulex parviflorus</i>	1.28	7.86	28.75	28.75
<i>Cistus albidus</i>	1	6.56	23.99	52.74
<i>Brachypodium retusum</i>	2.41	3.36	12.29	65.02
<i>Thapsia villosa</i>	0.67	3.14	11.49	76.51
<i>Euphorbia segetalis</i>	0.8	1.92	7	83.52
<i>Convolvulus althaeoides</i>	0.67	1.5	5.49	89.01
<i>Euphorbia isatidifolia</i>	0.67	1.5	5.49	94.51

944 Table 8.SI - Results of PERMANOVA applied to the main physico-chemical properties of soils
 945 sampled in forests with different stand age (mature, middle, young), soil condition (with or without
 946 treatment) and aspect (south or north) in the study area (Vall d'Ebo, Comunidad Valenciana, Spain).
 947

Factor	df	SS	MS	Pseudo-F	P(perm)
All variables					
Age	2	19.515	9.758	1.367	0.198
Aspect	1	3.314	3.314	0.464	0.785
Age (soil condition)	3	7.480	2.493	0.349	0.980
Age x Aspect	2	9.753	4.876	0.683	0.714
Age (soil condition) x Aspect	3	33.662	11.221	1.572	0.114
Residues	24	171.280	7.137		
Total	35	245.000			
TOC					
Age	2	12.007	6.004	0.568	0.602
Aspect	1	1.003	1.003	0.095	0.767
Age (soil condition)	3	26.355	8.785	0.831	0.469
Age x Aspect	2	49.114	24.557	2.323	0.120
Age (soil condition) x Aspect	3	26.913	8.971	0.849	0.510
Residues	24	253.680	10.570		
Total	35	369.070			
pH					
Age	2	0.198	0.099	4.316	0.034
Aspect	1	0.005	0.005	0.204	0.671
Age (soil condition)	3	0.002	0.001	0.036	0.996
Age x Aspect	2	0.007	0.003	0.149	0.870
Age (soil condition) x Aspect	3	0.113	0.038	1.647	0.215
Residues	24	0.549	0.023		
Total	35	0.874			
Available Water					
Age	2	284.880	142.440	0.968	0.380
Aspect	1	15.029	15.029	0.102	0.761
Age (soil condition)	3	87.475	29.158	0.198	0.893

Age x Aspect	2	276.480	138.240	0.939	0.418
Age (soil condition) x Aspect	3	666.250	222.080	1.509	0.236
Residues	24	3532.700	147.200		
Total	35	4862.800			
Wilting Point					
Age	2	197.530	98.765	0.861	0.440
Aspect	1	73.302	73.302	0.639	0.458
Age (soil condition)	3	37.910	12.637	0.110	0.947
Age x Aspect	2	1.660	0.830	0.007	0.996
Age (soil condition) x Aspect	3	124.200	41.402	0.361	0.786
Residues	24	2752.900	114.710		
Total	35	3187.500			
Field Capacity					
Age	2	52.122	26.061	0.152	0.860
Aspect	1	17.153	17.153	0.100	0.754
Age (soil condition)	3	85.412	28.471	0.166	0.922
Age x Aspect	2	303.650	151.820	0.888	0.415
Age (soil condition) x Aspect	3	362.040	120.680	0.706	0.553
Residues	24	4105.300	171.050		
Total	35	4925.700			
Soil Water Content					
Age	2	0.732	0.366	0.139	0.870
Aspect	1	4.681	4.681	1.778	0.200
Age (soil condition)	3	3.560	1.187	0.451	0.712
Age x Aspect	2	0.914	0.457	0.174	0.837
Age (soil condition) x Aspect	3	0.345	0.115	0.044	0.987
Residues	24	63.176	2.632		
Total	35	73.408			
Electrical Conductivity					
Age	2	1222.900	611.450	5.055	0.138
Aspect	1	4.681	4.681	1.778	0.200
Age (soil condition)	3	362.900	120.970	0.115	0.979
Age x Aspect	2	0.914	0.457	0.174	0.837

Age (soil condition) x Aspect	6	6320.700	1053.500	2.206	0.063
Residues	24	11462.000	477.590		
Total	35	19369.000			

948 Notes: df = degrees of freedom; SS = sum of squares; MS = mean sum of squares; Pseudo-F = F value by permutation;

949 P(permutation) = permutation test. Bold characters indicate statistical significance ($P < 0.05$).

950

951 Table 9.SI - Results of PERMANOVA applied to the main biochemical properties of soils sampled
 952 in forests with different stand age (mature, middle, young), soil condition (with or without
 953 treatment) and aspect (South or North) in the study area (Vall d'Ebo, Comunidad Valenciana,
 954 Spain). Significant values are marked in bold.
 955

Factor	df	SS	MS	Pseudo-F	P(perm)
All parameters					
Age	2	31.146	15.573	1.359	0.191
Aspect	1	8.321	8.321	0.726	0.556
Age (soil condition)	3	14.945	4.982	0.435	0.950
Age x Aspect	2	10.478	5.239	0.457	0.915
Age (soil condition) x Aspect	3	45.020	15.007	1.309	0.231
Residues	24	275.090	11.462		
Total	35	385.000			
Dehydrogenase Activity					
Age	2	2.757	1.379	0.720	0.522
Aspect	1	0.679	0.679	0.354	0.589
Age (soil condition)	3	4.650	1.550	0.809	0.555
Age x Aspect	2	0.673	0.336	0.176	0.883
Age (soil condition) x Aspect	3	1.363	0.454	0.237	0.903
Residues	24	45.970	1.915		
Total	35	56.092			
Beta Glucosidase Activity					
Age	2	23.281	11.641	3.434	0.030
Aspect	1	1.336	1.336	0.394	0.549
Age (soil condition)	3	1.709	0.570	0.168	0.944
Age x Aspect	2	0.250	0.125	0.037	0.962
Age (soil condition) x Aspect	3	11.463	3.821	1.127	0.390
Residues	24	81.353	3.390		
Total	35	119.390			
Phosphatase Activity					
Age	2	6.537	3.269	0.513	0.629
Aspect	1	13.684	13.684	2.150	0.139

Age (soil condition)	3	7.354	2.451	0.385	0.794
Age x Aspect	2	3.209	1.604	0.252	0.791
Age (soil condition) x Aspect	3	16.810	5.603	0.880	0.492
Residues	24	152.790	6.366		
Total	35	200.380			
Urease Activity					
Age	2	0.724	0.362	0.301	0.826
Aspect	1	0.086	0.086	0.071	0.804
Age (soil condition)	3	3.404	1.135	0.942	0.444
Age x Aspect	2	3.120	1.560	1.296	0.329
Age (soil condition) x Aspect	3	1.640	0.547	0.454	0.796
Residues	24	28.892	1.204		
Total	35	37.865			
Daily Basal Soil Respiration					
Age	2	1906.400	953.220	1.032	0.408
Aspect	1	1533.600	1533.600	1.661	0.196
Age (soil condition)	3	1584.900	528.290	0.572	0.647
Age x Aspect	2	73.864	36.932	0.040	0.972
Age (soil condition) x Aspect	3	4218.600	1406.200	1.523	0.228
Residues	24	22165.000	923.540		
Total	35	31482.000			
Cumulative Basal Soil Respiration					
Age	2	1952200	976100	1.032	0.403
Aspect	1	1570400	1570400	1.661	0.226
Age (soil condition)	3	1622900	540970	0.572	0.666
Age x Aspect	2	75637	37819	0.040	0.978
Age (soil condition) x Aspect	3	4319800	1439900	1.523	0.237
Residues	24	22697000	945700		
Total	35	32238000			

956 Notes: df = degrees of freedom; SS = sum of squares; MS = mean sum of squares; Pseudo-F = F value by permutation;
957 P(permutation) = permutation test. Bold characters indicate statistical significance (P < 0.05).

958