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Changes in soil properties after a wildfire in Fragas do Eume Natural Park (Galicia, NW Spain)

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ABSTRACT

The impact of a wildfire on some selected physicochemical, chemical (water retention, pH, electrical conductivity, free Fe and Al oxides, total C, extractable C), biochemical (microbial C, soil respiration, bacterial activity, β-glucosidase, urease and phosphatase activities) and microbiological properties (analysis of phospholipid fatty acids, PLFA pattern) was evaluated in Fragas do Eume Natural Park (NW Spain). Soil samples were collected three months after the wildfire from the A horizon (0–2.5 and 2.55 cm) of the unburnt and burnt soil under climax vegetation (*Quercus*) and non-autochthonous vegetation (*Eucalyptus*). The results indicated that, independent of the vegetation considered, the wildfire induced short-term modifications of most soil properties analysed, more accentuated changes being those related to labile fractions of the soil organic matter (extractable C and microbial biomass C, negative effects) as well as those in pH and bacterial growth values (positive effects). The fire effect was often more noticeable in the 0–2.5 cm layer than in the 2.5–5 cm layer. The results of a principal component analysis performed with the matrix of the physicochemical and biochemical data showed that vegetation was the most important factor controlling the overall quality of these soils and that wildfire is also an important source of variation in soil quality. This is in agreement with the PLFA pattern, differentiating clearly the *Quercus* soil samples from the *Eucalyptus* ones and, to a lesser extent, the burnt soil samples from the corresponding unburnt ones. Medium- and long-term consequences of these microbial changes in the functioning of the plant–soil system should be investigated in order to preserve the biodiversity of the Natural Park.

1. Introduction

The frequency and extent of wildfires increased dramatically in the European Mediterranean region from the 1960s, aided by a general warming and drying trend, but driven primarily by socio-economic changes, including rural depopulation, land abandonment and afforestation with flammable species (Shakesby, 2011). Wildfire effects on the soil environment are highly variable; however, in general, fires cause partial or complete combustion of organic matter, deterioration of soil structure, depletion of nutrients through volatilization and leaching, altered aggregate stability and water repellency, together with marked quantitative and qualitative alterations of soil microbial communities (Almendros and González-Vila, 2012; Carballas et al., 2009; Certini, 2005; Díaz-Raviña et al., 2010; Fernández et al., 2001; Holden and Treseder, 2013; Neary et al., 1999). Furthermore, fires cause vegetation destruction, which favors erosion processes that can produce enormous irreversible losses of soil (Díaz-Fierros et al., 1987; Shakesby, 2011; Vega et al., 2013a). The impact of wildfires on the environment (direct effects on the plant–soil system and indirect effects such as post-fire erosion) is commonly considered to be especially harmful causing very serious ecological, economic and social problems. The extent of fire effects can be highly variable due to the large amount of controlling factors such as fire regime (severity, duration and recurrence) as well as local conditions such as type of soil, vegetation composition, topography or regional climate (Neary et al., 1999). Thus, the impact of fire on soils from a temperate humid forest is very different compared to its impact on soils in an arid or Mediterranean ecosystem (Almendros and González-Vila, 2012; Carballas et al., 2009). Studies on fire impacts focused on Mediterranean areas are fairly abundant; however, information on the effect of wildfires in Atlantic ecosystems is still scarce (Santín et al., 2008).

Galicia (NW Spain) and the north of Portugal are the European areas most affected by forest wildfires, and worldwide they are among the areas with the greatest number of fires per hectare and inhabitant (Carballas et al., 2009). Galicia is a very mountainous region with 2,000,000 ha of forestland with scrub and tree stands (69% of the surface), developed on a complex mosaic of soil types and parent materials, most soils being acid and sandy. *Quercus robur* forest is the climax vegetation, but nowadays the majority of the territory is covered by

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Pinus and *Eucalyptus* stands. Approximately half of the wildfires in Spain occur in this region that represents less than 6% of the national territory; during the last ten years the number of fires was around 9000 per year on average, and the burnt area was about 40,000 ha. Thus, since forest fires are common events in Galicia causing the destruction of vegetation and soil degradation as well as enormous losses of soil and nutrients due to runoff and erosion processes (Carballas et al., 2009; Díaz-Fierros et al., 1987; Vega et al., 2013a), there is a need to determine their effects on terrestrial ecosystems, particularly when fires occur in environmentally sensitive areas, natural areas and areas set aside for wildfire protection.

Soil quality has been defined as the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation (Karlen et al., 1997). Several parameters have been proposed for the assessment of soil quality. The indication given by individual properties is often limited and subjected to seasonal and spatial variations: an integration of basic physical, chemical and biological indicators is required for the evaluation of climate and management effects on soil function. Several parameters have been measured for the evaluation of the status of burnt soils (Cerda and Jordán, 2010). Main physical and chemical properties are often included in these investigations but microbiological characterization is one of the aspects that has received less attention (Certini, 2005; Díaz-Raviña et al., 2010; Mataix-Solera et al., 2009; Neary et al., 1999); on top of that, integrative studies combining basic physical, chemical and biological properties by means of multivariate statistical techniques are even more uncommon. In addition, vegetation is not considered in most studies concerning wildfire impacts on soil quality. The aim of the present study was to evaluate the short-term impact of a wildfire that occurred in 2012 in the Fragas do Eume Natural Park (Galicia, NW Spain) on soil quality using several physicochemical, chemical and biological properties (biomass, activity and community structure measurements [PLFA pattern] as well as enzyme activities connected to the C, N and P-cycles) aggregated by means of a principal component analysis.

2. Material and methods

2.1. Experimental site

The study was performed in one of the six natural parks in Galicia, Fragas do Eume Natural Park (A Coruña, NW Spain), which extends along the valley of the Eume river within the Ferrolterra municipalities of Pontedeume, Cabanas, A Capela, Monfero, Pontedeume and As Pontes de García Rodríguez. The area was declared a natural park (a level of protection lower than national park) in 1997 and it is an example of a temperate rainforest recognized by the European Union as a Site of Community Importance in which climax vegetation is dominated by "Fragas", natural woodland with a mixture of species such as *Q. robur*, *Corylus avellana*, *Castanea sativa*, *Betula alba*, *Laurus nobilis*, *Ulmus glabra*, *Salix atrocinerea*, *Fraxinus excelsior*, *Fraxinus angustifolia* and *Alnus glutinosa*. However, the protected area also included vegetation dominated by non-autochthonous species such as *Eucalyptus globulus* and, to a lesser extent, *Pinus radiata*. On March 2012 a wildfire destroyed for 3 days the heart of the park and approximately 1000 ha of the Natural Park was affected, 750 ha dominated by non-autochthonous vegetation, mainly *E. globulus*, and 350 ha dominated by climax vegetation, mainly *Q. robur*. The extent of fire can be partly explained by the different susceptibilities of the two tree species to combustion. The level of combustion of the organic layer and the deposition of ash from the aboveground combustion of the biomass suggested that fire severity had been moderate to high (Vega et al., 2013b).

In order to evaluate the impact of this wildfire, plots with different species compositions named according the dominating species and representatives of these two types of vegetation affected by the wildfire (*Quercus*, climax vegetation; *Eucalyptus*, non-autochthonous vegetation) both in the unburnt and burnt areas were selected at different locations throughout the park. Thus, a total of 16 plots (4 unburnt *Quercus*, 4 burnt *Quercus*, 4 unburnt *Eucalyptus*, 4 burnt *Eucalyptus*), each plot covering a surface area of about 1000 m^2, were established for the field experimental design. The soil is developed over granite and the slope of the plots is 30–70%. Soil sampling was performed 3 months after the wildfire and several physicochemical, biochemical and microbiological properties were analyzed. From each plot, after removing the litter in the case of unburnt plots, multiple soil subsamples were taken from the 0 to 5 cm (0–2.5 cm, 2.5–5 cm) of the A horizon top layer; they were mixed to form one representative composite soil sample per depth and per plot and refrigerated (4 °C) until processing in the laboratory.

2.2. Methods

The following soil properties were monitored in the <2 mm fraction: moisture content and water retention capacity, pH (in water and KCl), electrical conductivity, free Fe and Al oxides, total C, extractable C, microbial biomass, soil respiration, bacterial activity and soil enzymes related to the C, N and P cycles, and phospholipid fatty acid analysis (PLFA pattern). Previous studies performed with soils from the same region with similar characteristics (coarse texture, high organic matter content, acid pH) showed that soil physical properties such as texture, aggregate stability and water repellence were unaffected or slightly affected by wildfire (Díaz-Raviña et al., 2012) and therefore these parameters were excluded from this study.

The methods described by Guitián-Ojea and Carballas (1976) were utilized to determine the following physical and chemical properties: moisture content by oven-drying soil samples at 105 °C for 6–7 h; water retention capacity using Richard's pressure plate apparatus ($pF = 2$); pH in H_2O and KCl in a soil:solution ratio of 1:2.5 and electrical conductivity in a soil/water extract of 1:5; the organic C content was determined by combustion in a Carmhograph 12 (Wosthoff OHG, Bochum, Germany) and free Fe and Al oxides by extraction with a mixture of Tamm's reagent and sodium dithionite.

2.3. Microbial biomass

The microbial biomass C was determined using the fumigation extraction method with some modifications (Díaz-Raviña et al., 1992). After soil fumigation with $CHCl_3$ for 24 h, the organic C was extracted from the unfumigated and fumigated samples with 0.05 M K_2SO_4 using a 1:4 soil:extract ratio. The microbial biomass C values were calculated from the equation: biomass $C = 2.64EC$, where EC is the extractable C flush (difference between the extractable organic C from the fumigated and unfumigated samples). Extractable C from the unfumigated samples was used as a measurement of available C (soil solution).

2.4. Microbial activity

The soil respiration, an overall index of activity of heterotrophic microorganisms, and the measurement of three specific enzyme activities related to the C (β-glucosidase), N (urease) and P (phosphatase) cycles were used as indicators of soil microbial activity. The soil respiration was determined by the incubation of fresh soil samples (75% of field capacity) at 22 °C during a 10 day period measuring the CO_2 trapped in a NaOH solution, which was then titrated with HCl (Díaz-Raviña et al., 1993b).

The β-glucosidase activity was measured following the procedure of Eivazi and Tabatabai (1988), which determines the released p-nitrophenol after the incubation of the soil with a p-nitrophenyl glucosidase solution for 2 h at 37 °C. The urease activity was estimated by incubating the soil samples with an aqueous urea solution and extracting the NH_4^+ with 1 M KCl and 0.01 M HCl followed by the