Soil-plant relationship in *Calluna* heathlands after experimental burning and nitrogen fertilization, studies from NW Spain

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Abstract. We studied changes in the relationship between soil nutrient content and plant species richness in *Calluna* heathlands after seven years of experimental burning (B) and nitrogen fertilization (NF). Our results indicate that both the treatments (B, NF, B+NF) and modification of several soil characteristics (total N, available Na, and C:N ratio) reflected in a significant increase in plant species richness.

Key words: *Calluna vulgaris*, Cantabrian heathlands, Nutrients, species richness, soil chemistry.

1. Introduction

Nitrogen (N) deposition is a major threat to biodiversity, but its effects may vary greatly among habitat types (Bobbink et al., 2010). Different studies have pointed out that N deposition causes severe declines in species richness, mainly in mountain habitats (Roth et al., 2013; Armitage et al., 2014), such as montane heathlands. N effect can be, however, altered by the interaction with fire (Britton et al., 2008) to enhance the impact of both drivers on heathland soils (Green et al., 2013).

In this study we investigated the effects of burning, N fertilization, and burning plus N fertilization on plant species richness and soil characteristics, with the aim of answering three questions: (i) how does species richness change in relation to these treatments?, (ii) does burning plus N fertilization alter the magnitude of these changes?, (iii) which soil characteristics are responsible for species richness variation?

2. Study area

Three *Calluna* heathland sites were selected in the Cantabrian Mountains (NW Spain): Riopinos I (1653 m a.s.l.), Riopinos II (1567 m) and San Isidro (1636 m). This area has a Eurosiberian climate with a mean annual precipitation of 1319.5 mm and a mean annual temperature of 5.5ºC. Soil is covered by snow five months per year. Soils are Umbrisols developed over shales and sandstones (San Isidro) and quartzite rocks (Riopinos I and Riopinos II). Vegetation is dominated by *Calluna vulgaris* (63% cover), accompanied by *Erica tetralix* (25%) and *Vaccinium myrtillus* (5%).

3. Materials and Methods

A randomised block design was used to investigate the influence of two driving variables (burning and N fertilization) on plant species richness and soils. Four permanent plots (20 x 20 m) were placed in each heathland site. One plot per site was subjected to N addition (NF) (56 kg N ha^{-1} yr^{-1}) from 2005 until 2014, the second plot to burning (B) in June 2005, the third plot to burning plus N addi-

tion (B+NF), and the fourth one was used as a control (C). The fertilization level was chosen to be equivalent to twice the estimated current background pollution levels in this area. In each plot, ten permanent sampling units (1 x 1 m) were established. Seven years after the treatments, all the plant species present in each unit were recorded and soil samples from all units were taken at a depth of 5 cm. Afterwards, they were analysed for pH, organic carbon, total N, C:N ratio, available P, Ca, K, Na and Mg. The statistical correlation of potential predictor variables (soil characteristics) with the response variable (species richness) was evaluated using a GLM. The response was assumed to follow a Poisson distribution with a log-link function. The optimal model was identified by selection of the model with the lowest AIC (Akaike's Information Criterion). All statistical analyses were implemented in R (R Development Core Team, 2014).

4. Results and discussion

Both burning (B) and N fertilization (NF) increased plant species richness compared to the control (Fig. 1). However, we only detected a significant increase in number of species in the B+NF treatment ($F_{3, 116}$=5.22; $P<0.05$). Seven years after B and NF deposition, there was a decrease in the values of all soil characteristics (Table 1), except in the B+NF treatment that showed an important increase in organic C, total N, available P, Ca and K. According to the results of the GLM (R^2=56%), both the experimental treatments and soil characteristics (total N, available Na, and C:N ratio) significantly ($P<0.001$) affected plant species richness.

In *Calluna* heathlands, burning and N fertilization augment plant species richness, more pronouncedly so for the combination of both treatments. Such increase in plant species richness is caused by changes on soil nutrients (mainly
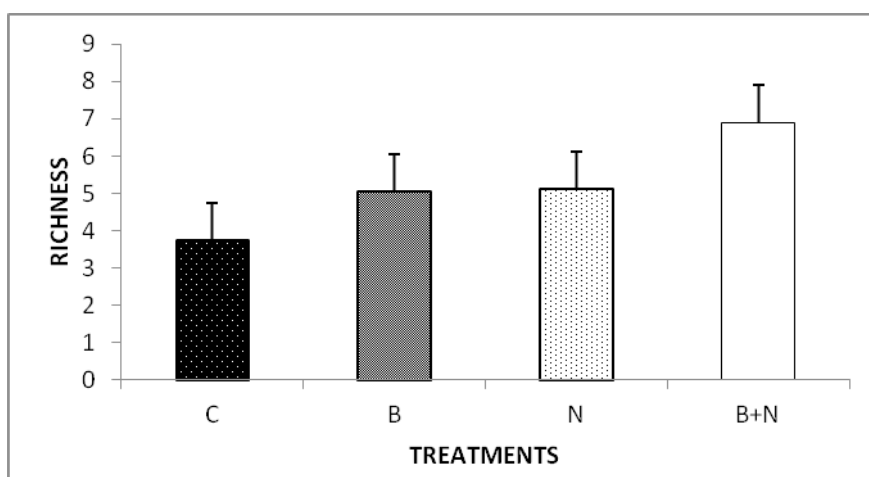

Figure 1. Mean values and standard errors (n=120) for the last sampling year of number of species for each treatment (C= control, B= burning, NF=nitrogen fertilization, B+NF=burning + nitrogen fertilization)

Table 1. Mean values and standard errors (n=120) for the last sampling year of soil characteristics for the different treatments

Treatment	pH	C (%)	N (%)	C:N	P (mg kg⁻¹)	Ca (cmol kg⁻¹)	Mg (cmol kg⁻¹)	K (cmol kg⁻¹)	Na (cmol kg⁻¹)
Control	3.85 (0.06)	8.49 (0.38)	0.41 (0.06)	21.8 (2.4)	23.34 (5.24)	1.19 (0.12)	0.39 (0.05)	0.64 (0.02)	0.04 (0.01)
N fertilization	4.05 (0.11)	7.02 (1.05)	0.39 (0.10)	19.7 (3.5)	17.11 (8.40)	1.12 (0.20)	0.25 (0.04)	0.63 (0.11)	0.03 (0.01)
Burning	3.93 (0.06)	7.29 (1.42)	0.38 (0.07)	19.9 (3.5)	22.81 (8.70)	0.85 (0.20)	0.29 (0.06)	0.46 (0.06)	0.03 (0.00)
Burning + N fertilization	4.00 (0.12)	9.56 (2.12)	0.60 (0.22)	18.0 (3.0)	30.51 (12.73)	1.54 (0.26)	0.38 (0.14)	0.83 (0.16)	0.04 (0.01)

N) and micro-environmental conditions. The highest number of species is due to the presence of native graminoids species which are the most frequent to increase after burning and N fertilization. We did not detect invasive species in the system as a consequence of the treatments. Changes on soil nutrients remained seven years after treatment, because the regeneration is very slow and the plant biomass cannot ability to sequester these additional nutrients.

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