Decreased mushroom production in a holm oak forest in response to an experimental drought

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Summary

A holm oak forest located in the Prades mountains (north-east Spain) was subjected to an experimental drought, reducing soil water moisture by 15 per cent by the use of plastic strips and funnels that partially excluded rain throughfall and by ditch exclusion of water runoff. We monitored mushroom production per plot once a week during 1999 and 2000. Drought treatment did not delay mushroom appearance, but reduced mushroom production by 62 per cent on average. This suggests that in a drier environment – as predicted for Mediterranean areas in the near future – there is likely to be a decrease in mushroom production, and as a result, changes in some ecological parameters such as soil organic matter decomposition, and also a reduction in the economic and recreational value of these Mediterranean forests.

Introduction

In Mediterranean regions, reductions in water availability are expected in the near future as a result of decreased precipitation and increased temperature, and the consequent increases of evapotranspiration rates (IPCC, 2001). These reductions are predicted to occur in addition to those that have already occurred in the twentieth century (Piñol et al., 1998; Peñuelas et al., 2002). In particular, in the Mediterranean forests of Catalonia, a 15–20 per cent decrease in water soil moisture is expected during the next decades (IPCC, 2001; Gracia et al., 2002; Peñuelas et al., 2005). A decrease in water availability not only has strong effects on plant physiology and development and on ecological processes, such as soil organic matter decomposition and soil respiration rates (Hanson et al., 2003), but it also affects mushroom productivity (Píliz and Molina, 2002) since it is also strongly dependent on water availability. The heterotrophic activity of mushrooms plays a key role in soil carbon decomposition, and it is very important to take it into account when calculating ecosystem carbon budgets (Hanson et al., 2003). Moreover, edible mushrooms also have an important economic value derived from their high commercial demand (Oehnoja, 1988; Alexander et al., 2002; Píliz and Molina, 2002) and recreational interest for mushroom harvesters, even though mushroom production is by far not as much valued as timber (Oria, 1991; FAO, 1992).
There is a lack of studies of mushroom production and its variations induced by environmental changes including climate change. In some Mediterranean areas such as Catalonia, there are many harvesters and a high demand for edible mushrooms, which makes it an especially suited area to study. Our aim was to study the effects of decreased water availability on mushroom production and phenology in a Mediterranean forest to gain further knowledge on their responses to a drought such as the one predicted for next decades by global circulation models and ecophysiological models (IPCC, 2001; Gracia et al., 2002; Peñuelas et al., 2005).

Materials and methods

The study was carried out in a holm oak forest in the Prades Mountains in Southern Catalonia (north-east Spain) (41° 13' N, 0° 55' E), on a south-facing slope (25 per cent slope) at 930 m a.s.l. The soil is a stony xerochrept on a bedrock of metamorphic sandstone, and its depth ranges between 35 and 90 cm. The average annual temperature is 12°C and the annual rainfall is 658 mm with a pronounced summer drought during ~3 months (data from Riudabella meteorological station, 8 km away from the study site).

This holm oak forest is very dense (16616 trees ha⁻¹, and 115 Mg ha⁻¹ of total above-ground dry biomass) and it is dominated by Quercus ilex L. (8633 trees ha⁻¹; 89 Mg ha⁻¹), Phillyrea latifolia L. (3600 trees ha⁻¹; 14 Mg ha⁻¹) and Arbutus unedo L. (2200 trees ha⁻¹; 9 Mg ha⁻¹) with abundant presence of other evergreen species well adapted to dry conditions (Erica arborea L., Juniperus oxycedrus L., Cistus albidus L.), and occasional individuals of deciduous species (Sorbus terminalis (L.) Crantz and Acer monspessulanum L.).

Eight 15 × 10 m plots were delimited at the same altitude along the slope. The plot layout was random to assume uniformity of plot characteristics prior to the drought treatment. Four plots (chosen randomly) received the drought treatment and the other four were considered control plots. The drought treatment consisted of partial rain exclusion by suspending PVC strips and funnels at a height of 0.5–0.8 m above the soil. Strips and funnels covered ~30 per cent of the total plot surface. Moreover, a 0.8 m deep ditch was excavated along the entire top edge of the upper part of the treatment plots to intercept runoff water supply. Water intercepted by strips, funnels and ditches was conducted outside the plots, below the bottom edge of the plots.

An automatic meteorological station installed between the plots monitored temperature, photosynthetic active radiation, air humidity, and precipitation every half-hour. Soil moisture was measured every 2 weeks throughout the experiment by time domain reflectometry (Tektronix 1502C, Beaverton, OR, USA) (Zegelin et al., 1989; Gray and Spies, 1995). Three stainless steel cylindrical rods, 25 cm long, were permanently fully driven into the upper 25 cm of the soil at four randomly selected places in each plot. The time domain reflectometer was connected to the ends of the rods in each measurement.

The biomass of mushrooms in each plot was visually estimated once a week from winter 1998–1999 to winter 2000–2001, by establishing three categories: <0.5 kg of fresh weight; >0.5 kg and <1 kg of fresh weight; and >1 kg of fresh weight per plot. The estimation was conducted by a well-trained person after calibration in other plots of the study forest. Earlier calibration exercises showed that these categories could be estimated with 95 per cent accuracy.

Repeated-measures ANOVA was conducted with the maximum mushroom biomass measured seasonally as dependent variable, and drought treatment as independent factor. Data of categories of mushroom biomass were transformed to arcsin (p)½ to reach the normality assumptions of the ANOVA. For phenological analyses we used the Kaplan–Meyer non-parametric method for the computation of survival curves with the time of the start of the mushroom growing season as a survival time. Thereafter we used the log-rank test to assess treatment differences. All analyses were performed with the Statistica software package (StatSoft Inc., 2001).

Results and discussion

During these 2 years of experimental set-up, mean annual temperatures were slightly higher in 2000 (12.4°C) than in 1999 (12.2°C). Rainfall was also higher in 2000 (727 mm) than in 1999 (610 mm). However, in 2000, rainfall was concentrated in
late spring and late autumn whereas in 1999 it was concentrated in early spring and early autumn (Figure 1).

Soil moisture showed great fluctuations throughout both years but was on average 3.3 per cent higher in 2000 than in 1999 (Figure 1) in agreement with rainfall data. Minimum values (~10 per cent v/v) were reached in summer, as a consequence of summer drought, and maximum values (~30 per cent v/v) in spring and autumn, coinciding with heavy rainfall periods. Control plots had on average 16 per cent higher soil moisture than drought plots in 2000 and 13 per cent in 1999. Differences in soil moisture between control and drought plots were significant on most of the samplings throughout the two years (Figure 1).

In the study, mushrooms were present in autumn 1999, spring 2000 and autumn 2000, coinciding with well-watered conditions and relatively high temperatures, while in spring 1999 there were no mushrooms, probably because rainfall in late spring (when the temperature is more favourable for mushroom development) was lower than in spring 2000 (Figure 1). There were many mushroom species, several of them of high economic value as edible mushrooms. The most abundant edible mushrooms were *Hygrophorus russula* (Sch.:Fr.) Quél., *Macrolepiota procera* (Scop.:Fr.) Sing. and *Russula delica* Fr. for the mycorrhizal species, and *Agaricus campestris* L.: Fr. and *Lycoperdon* sp. for the non-mycorrhizal ones.

Mushroom production was high. It was similar to that reported for *Pinus sylvestris* L. forests of the Pyrenees (Martínez de Aragón et al., 1998). On average, yield in drought plots was 62 per cent lower than in control plots during the overall period studied (*P* = 0.023) (Figure 2). On the other hand, no differences were detected in the timing of mushroom appearance (data not shown). In control plots, the maximum mushroom production of the period studied was reached in autumn 1999, when heavy rainfalls took place in early autumn coinciding with high temperatures, whereas in autumn 2000 most rainfall took place in late autumn when temperatures were lower (Figure 1). In spring, there were heavy rainfalls too, but, although the temperatures were higher than in autumn, there were stronger evapotranspiration rates reducing soil water availability, especially in the upper soil layer, where mushrooms grow. Mushroom productivity was the lowest during the spring season probably because of that lower soil water availability.

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**Figure 1.** Seasonal course of soil moisture (0.25 m depth) (a), daily mean temperature (b) and precipitation (c) at the study site. Vertical bars in (a) indicate standard errors of the mean (*n* = 4 plot averages of four TDR measurements per plot). Significant differences between the two treatments: *P* ≤ 0.05; **P** ≤ 0.01. The arrow indicates the start of drought treatment.
Figure 2. Estimated fresh weight of the overall mushroom (including both edible and inedible) biomass produced in the control and drought plots of the holm oak forest of Prades (South Catalonia). See text for details. Vertical bars indicate standard error of the mean (n = 4 plots).

As this study was only conducted for 2 years, and mushroom production has a high inter-annual variation depending on climatic conditions, further studies are needed to improve our knowledge of the responses of mushrooms to climate change in the Mediterranean forests and their potential economic value. In any case, these results showed that drought treatment exerted a strong effect on mushroom production and, in consequence, on the organic matter decomposition rates (Hanson et al., 2003) and the biogeochemical cycling of this forest. Moreover, the lower above-ground biomass increment observed in drought plots than in control plots (Ogaya et al., 2003) could also produce changes in plant cover that indirectly could also affect the mushroom species distribution and production (Alexander et al., 2003).

In conclusion, the preliminary results presented here show that the decrease in water availability expected for the next decades in the Mediterranean areas (IPCC, 2001; Gracia et al., 2002; Peñuelas et al., 2004) could produce changes in mushroom production, with important economic and recreational consequences, and with possible changes in all ecological processes related to organic matter decomposition where fungi are involved. This is thus an issue that deserves further study in forestry research.

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References


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