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Drought changes the dynamics of trace element accumulation in a Mediterranean *Quercus ilex* forest

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Drought increased biomass concentrations of As and Cd and favors exportation of some trace elements to continental waters in a Mediterranean forest.

Abstract

We conducted a field drought manipulation experiment in an evergreen oak Mediterranean forest from 1999 to 2005 to investigate the effects of the increased drought predicted for the next decades on the accumulation of trace elements that can be toxic for animals, in stand biomass, litter and soil. Drought increased concentrations of As, Cd, Ni, Pb and Cr in roots of the dominant tree species, *Quercus ilex*, and leaf Cd concentrations in *Arbutus unedo* and of *Phillyrea latifolia* codominant shrubs. The increased concentration of As and Cd can aggravate the toxic capacity of those two elements, which are already next or within the levels that have been shown to be toxic for herbivores. The study also showed a great reduction in Pb biomass content (100–135 g ha^{-1}) during the studied period (1999–2005) showing the effectiveness of the law that prohibited leaded fuel after 2001. The results also indicate that drought increases the exportation of some trace elements to continental waters.

Keywords: Arsenic; Aluminum; Cadmium; Climate change; Holm oak; Jasmine box; Lead; Mediterranean forest; *Quercus ilex*; Strawberry tree; Trace elements

1. Introduction

In Mediterranean ecosystems the most serious effects of climate change (IPCC, 2001; Peñuelas et al., 2005) are expected to be related to increased drought, since water stress is already the principal constraint in the world's Mediterranean environments (Specht, 1979; Mooney, 1989). In the Mediterranean Basin precipitation is already either exhibiting a long-term downward trend, principally in the dry season (Kutiel et al., 1996; Esteban-Parra et al., 1998), or showing no signs of significant change (Piñol et al., 1998; Peñuelas et al., 2002; Peñuelas and Boada, 2003). Nevertheless, in all cases a rise in the evapotranspiration potential has led to increased aridity (Piñol et al., 1998), because temperatures in the Mediterranean Basin have risen significantly (Kutiel and Maheras, 1998; Peñuelas et al., 2002; Peñuelas and Boada, 2003). As well, other increasingly intrusive anthropogenic disturbances are occurring in Mediterranean areas in recent decades; the number and intensity of sources of trace elements (rubbish tips, smelter stacks, fertilizers, waste incineration, vehicle exhaust, and sewage sludge) have increased, thereby increasing overall concentrations of environmental trace elements (Koch and Rotard, 2001; Peñuelas and Filella, 2002; Sardans and Peñuelas, 2005a).

Interactions between the predicted drought and trace element pollution and accumulation in Mediterranean ecosystems will have to be studied if we are to fully appreciate the real impact of climate change on ecosystems. Some experiments have shown that recent climate changes have had a strong impact on pollution pathways in Arctic ecosystems (Macdonald

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et al., 2005). Trace elements such as arsenic, cadmium, lead, and mercury have no beneficial biological effect and at certain levels are toxic to organisms such as soil microorganisms (He et al., 2005). Accumulation of trace elements in stand biomass over large areas and during long periods of time causes chronic damage to living organisms. A number of trace elements have increased their concentrations in plants in Mediterranean areas over the last few decades (Peñuelas and Filella, 2002), above all in urban and surrounding areas (Sardans and Peñuelas, 2005a). However, less is known about the effects that the predicted drought will have on trace element bioaccumulation in Mediterranean forests such as those growing in the more remote rural mountain areas.

Changes in trace element concentrations in soils and/or in plant tissues have several ecological implications and changes in the relative trace elements contents of biomass and soils will vary plant's capacities to retain trace elements in ecosystems and prevent losses to continental waters. Drier periods and consequent decreases in soil water content may reduce the rate at which plants absorb trace elements, thereby affecting the rates of loss of trace elements to continental waters, above all if the greater amounts of torrential rain predicted by GCM climate models (IPCC, 2001; Peñuelas et al., 2005) fall in the Mediterranean Basin. However, it is still uncertain whether and how drought can affect trace element dynamics in Mediterranean ecosystems; changes in water availability can affect trace element accumulation in the ecosystem via indirect processes such as plant growth and organic matter decomposition, and via direct processes such as microbial activity and bedrock meteorization. An increase in trace element accumulation in biomass or/and in soils under drier conditions could enhance the negative effects of drought on plant productivity. On the other hand, a decrease in trace element accumulation in biomass or in soil under drier conditions could increase the productive capacity of these ecosystems, thereby improving their capacity to resist drier and warmer conditions in the near future. Nevertheless, the effects of this scenario on trace element exportation from terrestrial ecosystems to run-off waters and thus to continental waters are still unknown.

We hypothesized that trace element concentrations and mineralomasses in stand biomass vary in terms of (a) trace element solubility and (b) the species-specific growth response to water stress. We aimed to see whether drought increases or decreases trace element concentrations and accumulation in stand biomass, leaf litter, and soil in a Mediterranean evergreen *Quercus ilex* forest subject to experimental drought conditions replicating the drought forecasted for the Mediterranean region by GCM and ecophysiological models such as Gotilwa (IPCC, 2001; Sabaté et al., 2002; Peñuelas et al., 2005).

2. Material and methods

2.1. Study site

The study was carried out on a south-facing slope (25%) in a natural *Q. ilex* oak forest in the Prades Mountains in southern Catalonia (NE Spain) (41°13′ N, 0°55′ E). The soil consists of a stony *Dystric Xerochrept* (Soil Taxonomy) lying on a bedrock of metamorphic sandstone and ranges in depth between 35 and 100 cm, with the depth of Horizon A ranging between 25 and 30 cm. The average annual temperature is 12 °C and average annual rainfall 658 mm. Summer drought is pronounced and usually lasts for 3 months. The vegetation consists of a dense forest dominated by *Q. ilex* L. (20.8 $m^2 ha^{-1}$ of trunk basal area at a height of 50 cm) accompanied by abundant *Phillyrea latifolia* (7.7 $m^2 ha^{-1}$ of trunk basal area at a height of 50 cm), *Arbutus unedo* L., a number of other evergreen species well-adapted to drought conditions such as *Erica arborea* L., *Juniperus oxycedrus* L., *Cistus albidus* L., and occasional individuals of deciduous trees such as *Sorbus torminalis* L. Crantz and *Acer monspessulanum* L. In winter 1999, the aboveground biomass of *Q. ilex* represented 77.1% of the total biomass, in *P. latifolia* 12.6%, and in *A. unedo* 7.8%, that is, a total of 97.6% of the whole ecosystem aboveground tree biomass. In winter 2005, the figures for the same three species were 75.6%, 13.3%, and 8.7%, respectively, representing in total 97.6% of the total aboveground biomass.

2.2. Experimental design

Eight 15 × 10 m plots were established at the same altitude (930 m a.s.l.) on a mountainside. Four of the plots received the drought treatment and four were left as control plots. The drought treatment consisted of partial rainfall exclusion achieved by suspending PVC strips at a height of 0.5–0.8 m above the soil to cover approximately 30% of the total soil surface area. Four plastic strips 14 m long and 1 m wide were placed along the drought treatment plots from top to bottom and a 0.8–1 m deep ditch was dug along the entire top edge of the upper part of the treatment plots to intercept any run-off water. The water intercepted by the strips and ditches was channeled to the bottom edge of the plots. The drought treatment began in March 1999 (Ogaya et al., 2003). Soil moisture content was measured every 2 weeks throughout the experiment by time domain reflectometry (Tektronix 1502 C, Beaverton, OR, USA, Zegelin et al., 1989). Three stainless-steel cylindrical rods, 25-cm long, were fully driven into the soil at randomly selected places in each plot. The time domain reflectometer was connected to the ends of the rods to determine the soil moisture content.

2.3. Biomass and litter determination

Just before the treatment was begun, all living stems of the three dominant species with a diameter of over 2 cm at a height of 50 cm aboveground were tagged. Circumferences were measured at 50 cm height with a metric tape. In February 2005, the circumferences of the stems were measured again to calculate the annual stem diameter increment.

Allometric relationships between aboveground tree biomass and the diameter at 50 cm (D50) were calculated for *Q. ilex* and *P. latifolia* in the studied area (outside the plots). The total aboveground biomass (AB), leaf biomass, and stem biomass were measured by weighing plant material after it had reached a constant weight in an oven at 70 °C. The allometric relationships in *Q. ilex* ($\ln AB = 4.9 + 2.277 \ln D50$, $r = 0.981$, $n = 12$, $P < 0.0001$) and in *P. latifolia* ($\ln AB = 4.251 + 2.463 \ln D50$, $r = 0.974$, $n = 13$, $P < 0.0001$) were used thereafter to estimate the aboveground standing biomass of these two species in the studied area (see Ogaya et al., 2003). To estimate the *A. unedo* biomass, we used the allometric relationship ($\ln AB = 3.830 + 2.563 \ln D50$, $r = 0.989$, $n = 10$, $P < 0.0001$) previously calculated in the same area by Lledó (1990). Leaf biomasses (LB) were calculated by the following allometric relationships: for *Q. ilex* $\ln LB = 3.48 + 1.70 \ln D50$, $r = 0.97$, $n = 12$, $P < 0.0001$; for *P. latifolia* $\ln LB = 1.43 + 2.43 \ln D50$, $P < 0.0001$; and for *A. unedo* $\ln LB = 1.887 + 2.157 \ln D50$, $r = 0.951$, $P < 0.0001$. Stem biomass was calculated by the difference between total aboveground biomass (AB) and total leaf biomass (LB).

Litterfall was collected in 20 circular baskets (27 cm diameter with 1.5 mm mesh diameter) randomly distributed on the ground of each of the eight plots. The fallen litter was collected every 2 weeks during 1999 and every 2 months during 2004. Total litterfall was estimated by the proportion of the surface area of the plots covered by the collecting baskets.