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Health and vitality assessment of two common pine species in the context of climate change in southern Europe

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ABSTRACT

The Mediterranean Basin is expected to be more strongly affected by ongoing climate change than most other regions of the earth. The South-eastern France can be considered as case study for assessing global change impacts on forests. Based on non-parametric statistical tests, the climatic parameters (temperature, relative humidity, rainfall, global radiation) and forest-response indicators (crown defoliation, discoloration and visible foliar ozone injury) of two pine species (*Pinus halepensis* and *Pinus cembra*) were analyzed. In the last 20 years, the trend analyses reveal a clear hotter and drier climate along the coastline and slightly rainier inland. In the current climate change context, a reduction in ground-level ozone (O_3) was found at remote sites and the visible foliar O_3 injury decreased while deterioration of the crown conditions was observed likely due to a drier and warmer climate. Clearly, if such climatic and ecological changes are now being detected when the climate, in South-eastern France, has warmed in the last 20 years (+0.46–1.08 °C), it can be expected that many more impacts on tree species will occur in response to predicted temperature changes by 2100 (+1.95–4.59 °C). Climate change is projected to reduce the benefits of O_3 precursor emissions controls leading to a higher O_3 uptake. However, the drier and warmer climate should induce a soil drought leading to a lower O_3 uptake. These two effects, acting together in an opposite way, could mitigate the harmful impacts of O_3 on forests. The development of coordinated emission abatement strategies is useful to reduce both climate change and O_3 pollution. Climate change will create additional challenges for forest management with substantial socio-economic and biological diversity impacts. However, the development of future sustainable and adaptive forest management strategies has the potential to reduce the vulnerability of forest species to climate change.

1. Introduction

The sensitivity of Europe to climate change has a distinct north–south gradient, with many studies indicating that southern Europe will be the more severely affected (EEA, 2004; Bates et al., 2008). Climate change is expected to be more pronounced in the Mediterranean Basin than in most other regions of the world (Bates et al., 2008). Indeed, in a scenario of increased temperatures worldwide (on average 1.4–5.8 °C) by 2100, the variation should be at least 3 °C in the Mediterranean Basin. Furthermore Mediterranean basin will be one of the areas subject to the most drastic reductions in precipitation (IPCC, 2007) with considerable effects on the environment (EEA, 2004).

Ozone (O_3) and climate change are interlinked (Bytnerowicz et al., 2007). Ground-level O_3 is an important atmospheric pollutant and climate forcer (Ramaswamy et al., 2001). Surface O_3 concentrations in the South-western European Mediterranean Basin are relatively high relative to human well-being and vegetation impacts (Sicard et al., 2013). Indeed, high annual mean O_3 concentrations, exceeding 40 ppb, were recorded in some regions, particularly along the coasts, because of shipping tracks, industrial development, road traffic increment, high temperature, high solar radiation and sea/land breeze recirculation (Vestreng et al., 2009; Sicard et al., 2013). Ground-level O_3 affects trees through visible leaf injury, accelerating leaf senescence, decreasing foliar chlorophyll content, photosynthesis, growth, productivity and carbon sequestration, predisposing to pests attack and a variety of other physiological effects in plants (e.g. Dalstein et al., 2002; Karnosky et al., 2007; Paoletti et al., 2009; Sicard et al., 2011). Ozone is the phytotoxic air pollutant and greenhouse gas of most concern to forests (Paoletti, 2006). The forests have important functions for economic activities, for development of rural areas and for recreational purposes, in terms of nature conservation and

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environmental protection, e.g. as carbon sinks, important in the climate change context (Kohut, 2005; Fischer and Lorenz, 2011). Climate change will alter forest ecology and will change phenology, by advancing time in flowering or rising level of pollinators, and geographical distribution of plants (Giannakopoulos et al., 2009). Disturbances created from the interaction of drought, pests, diseases, and fires are projected to have increasing impacts on forests and their future distributions (IPCC, 2007). An overview of the consequences of climate changes for trees in the Mediterranean basin is provided by Petit et al. (2005). When analyzing the future ranges of some 1400 plant species in Europe, the strongest reshuffling would take place in southern Europe, where 60–80% of the flora present in 1990 would go extinct by 2050 compared to 20–40% further north (Bakkenes et al., 2002).

Climate change, creating additional challenges for European forest, is expected to be more pronounced in the South-eastern France, particularly at the rural alpine Mediterranean area, at highest risk of O_3 injury (Dalstein et al., 2005; Sicard et al., 2011).

The main aim of this study was to establish a state-of-the-art of the health and vitality of two common pine species in South-eastern France, in a context of climate change and high ground-level O_3. For that, the study focused on two valuable bio-indicator species for O_3 stress (i.e. *Pinus halepensis* and *Pinus cembra*) at 20 experimental plots over the time period 2000–2012. Secondary aims were: (i) to detect and estimate trends for surface O_3 concentrations, climatic parameters (temperature, relative humidity, rainfall, global radiation) and visible injury, i.e., crown defoliation, crown discoloration and visible O_3 injury; and (ii) to assess the most important environmental variables that affect crown defoliation, discoloration and visible foliar O_3 injury of adult trees under field conditions.

2. Methodology

2.1. Study area and sampling sites

Experimental sites are located in South-eastern France (Fig. 1 and Table 1) into the Mercantour National Park at relatively high elevations (1700–2400 m a.s.l.) and along the coastline (French Riviera). The Mediterranean weather which rules the coastal area rapidly turns into an Alpine climate when altitude overcomes 800 m. The plots, 13 in the Mercantour National Park and 7 along the Mediterranean coastline, were selected to represent different conditions (north/south-facing side, valley and ridges) in order to consider the impact of local meteorology, topography, soil conditions, water availability on the visible injury occurrence. The study focused on two O_3-sensitive conifer tree species (Elvira et al., 1998; Ashmore, 2005; Wieser et al., 2013): Arolla pine (*P. cembra L.*) from the inland Alps, mostly distributed in high-lying sites (1700–2400 m), and Aleppo pine (*P. halepensis Mill.*), a typical *circum*-Mediterranean conifer, mostly distributed along the coastlines and generally found at low altitudes, from sea level to 600 m. Aleppo pine is very drought-resistant and thermophilic and has an important role in maintenance and reforestation due to its good regenerative potential (Scarascia-Mugnozza, 1986; Voltas et al., 2008). Ozone produces very characteristic injury on the needles of *P. halepensis* and *P. cembra* (Sanz et al., 2000; Kivimäenpää et al., 2010), therefore, are valuable bio-indicator species for O_3 stress.

2.2. Meteorological and ozone data

First, for the trend analysis of *in-situ* climatic parameters, the meteorological data (daily maximum and minimum temperatures, mean temperature, relative humidity, rainfall, global radiation) were supplied by the French national meteorological service (Météo-France) from 3 sites located in the South-eastern France: Nice [43.65°N; 7.20°E; 4 m a.s.l.] and Saint-Auban [44.06°N; 5.99°E; 461 m a.s.l.] over the time period 1973–2012 and Cannes [43.54°N; 6.95°E; 2 m a.s.l.] over the 1993–2012 period.

Secondly, for the statistical analyses, to assess the most important environmental variables that affect crown defoliation, discoloration and visible foliar O_3 injury, the hourly O_3 concentrations and meteorological data (daily temperatures, global radiation, rainfall, relative humidity, soil water content) were obtained from the MM5–CHIMERE modeling system (Bessagnet

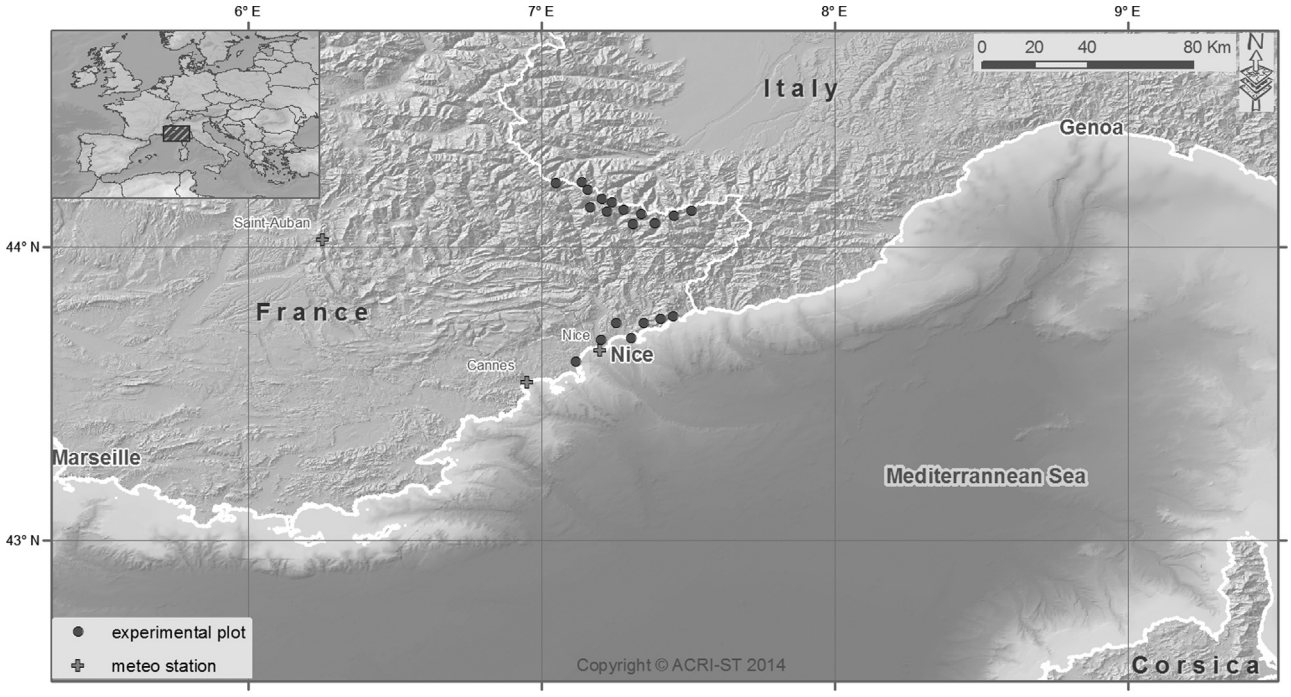

Fig. 1. Location of experimental plots in South-eastern France.