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Short communication

Evidence of widespread ozone-induced visible injury on plants in Beijing, China

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ABSTRACT

Despite the high ozone levels measured in China, and in Beijing in particular, reports of ozone-induced visible injury in vegetation are very scarce. Visible injury was investigated on July and August 2013 in the main parks, forest and agricultural areas of Beijing. Ozone injury was widespread in the area, being observed in 28 different species. Symptoms were more frequent in rural areas and mountains from northern Beijing, downwind from the city, and less frequent in city gardens. Among crops, injury to different types of beans (genera Phaseolus, Canavalia and Vigna) was common, and it was also observed in watermelon, grape vine, and in gourds. Native species such as ailanthus, several pines and ash species were also symptomatic. The black locust, the rose of Sharon and the Japanese morning glory were among the injured ornamental plants. Target species for broader bio-monitoring surveys in temperate China have been identified.

1. Introduction

Ground-level ozone is increasing at a rate of approximately 0.5–2% per year over the midlatitudes of the Northern Hemisphere due to fast industrialization and urbanization in the last three decades (IPCC, 2013). The fast economic development of China is producing serious air pollution problems, especially in Beijing. Ding et al. (2008) analysed aircraft ozone data obtained from the MOZAIC (Measurement of Ozone and Water Vapour by Airbus In-Service Aircraft) program for the 1995–2005 period and found that summertime ozone in the boundary layer near Beijing had increased by about 2% per year. The daily mean and hourly peak ozone concentrations at urban and exurban regions were 46 ppb and 67 ppb, and 181 and 209 ppb, respectively, during May to September in 2010 (Wan et al., 2013). Such high ozone concentrations are expected to induce serious damage to plants.

Tropospheric ozone is known to interact with plants causing visible injury, impair photosynthesis, produce reductions in growth and yield, and alter plant interactions with pests and diseases (Krupa et al., 2000). In the context of 'global change', it may also compromise stimulation of net primary production caused by elevated CO_2 and reduce carbon sink capacity of ecosystems (Witting et al., 2009; Ainsworth et al., 2013). Ozone sensitivity is species-specific, with plants with higher Specific Leaf Area (the ratio of leaf area to dry mass) being in general more sensitive (Bussotti, 2008; Calatayud et al., 2011; Zhang et al., 2012). Plant responses to ozone also depend on their defence capacity (Di Baccio et al., 2008) and are affected by environmental conditions: optimal water supply, leaf temperature and light conditions promoting stomatal opening and gas exchange increase ozone uptake (LRTAP Convention, 2010; Ainsworth et al., 2013).

Among the different effects of ozone on vegetation, visible injury in leaves is considered a valuable tool for the assessment of ozone impacts in the field and to detect areas of high potential risk (Schaub et al., 2010). Although it is not as biologically significant as effects on growth and yield, it is indicative of ozone stress, and its presence and extent can be used as a surrogate of biological damage to the plants (Hayes et al., 2007). For this reason, the assessment of visible injury has been incorporated in European programs as the EU/ECE International Co-operative Programmes on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests), and on Natural Vegetation and Crops (ICP Vegetation). Results from the European programmes have documented that visible injury on forest plants, crops and semi-natural vegetation occurs across

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Europe and in many species, although especially in Southern Europe where the ozone concentrations are higher (de Vries et al., 2003; Schaub and Calatayud, 2013; Hayes et al., 2007). In North America, visible injury has also been included in Forest Health monitoring programmes; it is frequently observed in several bio-indicator plants of forested ecosystems of California (Campbell et al., 2007). Besides the results of these large-scale programmes, several other studies have focused on visible injury and on identification of suitable bioindicator species at a smaller scale in different parts of the world (e.g., Skelly et al., 1999; Fumagalli et al., 2001; Manning and Godzik, 2004; Sanz et al., 2001; Bergweiler et al., 2008; Coulston et al., 2003). However, despite the important pollution problems of China, reports of visible injury to vegetation are surprisingly low (Wan et al., 2013). This is partly due to the fact that recognition of ozone injury is complex and requires training (Bussotti et al., 2003). The main objective of present paper is to enlarge the knowledge of ambient ozone impacts on vegetation in Beijing by surveying foliar visible injury on different types of plants. This information is relevant to China, an economically emergent country which is importantly contributing to the new global scenario of air pollution and climate change.

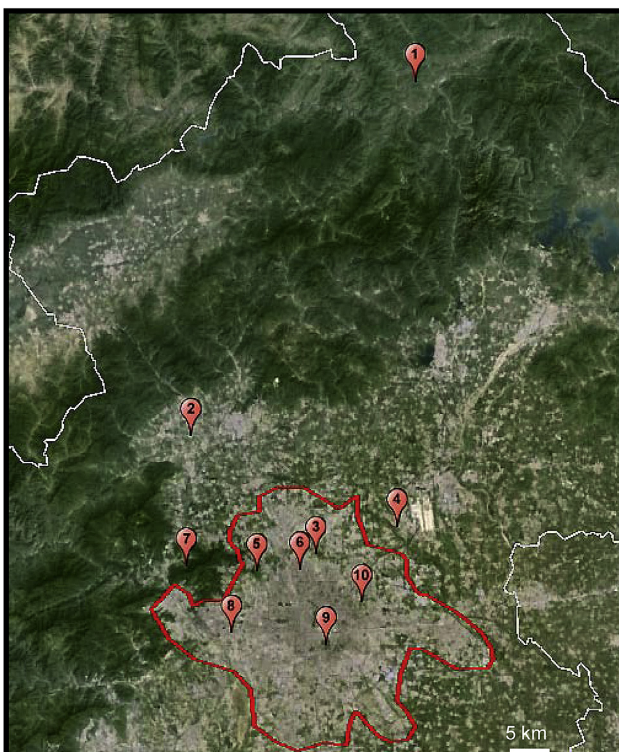
2. Methods

In Beijing area, several field surveys were conducted during July and August 2013, by walking the main parks, forest and agricultural areas (Fig. 1). The end of the summer is the most appropriate time for conducting surveys on native vegetation as the cumulative effects of ozone during the growing season may not appear until that time (Skelly et al., 1987; Schaub et al., 2010).

Ozone visible injury was identified in the plant following the procedures for ozone symptom diagnosis of the ICP-Forest Manual (Schaub et al., 2010). In broadleaf species, symptoms are typically expressed as tiny purple, yellow or black spots (described as stipple) or sometimes as a general even discolouration, reddening or bronzing; flecking is characterized by small, discrete areas of dead tissue and may be more irregular in shape. In conifers, ozone effects are typically a diffuse chlorotic mottling affecting the older whorls of needles (Sanz et al., 2001; Vollenweider et al., 2013). Photos of ozone symptoms, preferably confirmed experimentally, have been used as a reference (Table 1). Selected leaf samples were examined by microscopy (data not shown) in order to rule out mimicking symptoms caused by other biotic or abiotic factors (Vollenweider et al., 2003). Skills for correct ozone injury identification of the corresponding author have been improved through regular participation in the ozone visible injury intercalibration courses organized by the ICP-Forest in Europe since 2000 (Bussotti et al., 2003).

3. Results and discussion

Ozone levels in Beijing area were high enough to induce foliar symptoms in 28 different species (Table 1). Areas with high impacts have been identified especially in the north of Beijing, downwind from the city: in Mang Mountains, the agricultural area close to Changping, and in the Olympic Forest Park (Fig. 1). Inside the city, ozone symptoms were less frequent, which is consistent with the local scavenge of ozone due to the 'NO_x titration effect' typical of a polluted urban environment (Royal Society, 2008). Furthermore, in those sites assessed in July and in August, symptoms were more abundant in August, confirming the cumulative effect of ozone exposure (Fig. 2). In July, symptoms were observed only in Ailanthus (sites 1 and 6), in the Chinese long and common beans (site 2), in the Japanese morning glory (sites 1 and 6), and in the black locust, North China red elder and peach f. duplex (site 3).



Nr	Site	Co-ordinates	Altitude (m)	Type
1	Mang Mountains	116°35'E, 40°44'N	640	Mountain
2	Changping cropland	116°08'03"E, 40°11'40"N	65	Cropland
3	Olympic Forest Park	116°23'36"E, 40°00'06"N	86	Park
4	Capital airport sideway	116°35'04"E, 40°04'48"N	35	Cropland
5	Summer Palace Park	116°15'58"E, 40°00'14"N	60	City Park
6	Central Haidian district	116°21'07"E, 39°59'36"N	51	Streets
7	Lingguang Temple	116°10'32"E, 39°57'36"N	464	Park and Mountain
8	Central Shijingshan district	116°12'59"E, 39°53'50"N	70	Streets
9	Temple of Heaven Park	116°24'15"E, 39°52'47"N	45	City Park
10	Chaoyang Park	116°28'31"E, 39°56'40"N	40	City Park

Fig. 1. Map, co-ordinates, altitude and type of the surveyed sites in Beijing, China. The blue line represents the limits of Beijing province and the red line is the approximate limit of the urban area. Map: © Google, Mapabc.com. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)