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Ozone distribution and phytotoxic potential in mixed conifer forests of the San Bernardino Mountains, southern California

Andrzej Bytnerowicz [a,*], Michael Arbaugh [a], Susan Schilling [a], Witold Frączek [b], Diane Alexander [a]

[a] USDA Forest Service, Pacific Southwest Research Station, 4955 Canyon Crest Drive, Riverside, CA 92507, USA
[b] Environmental Systems Research Institute, Redlands, CA, USA

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Although peak ozone concentrations have greatly decreased in the San Bernardino Mountains, very high ozone phytotoxic potential remains.

Abstract

In the San Bernardino Mountains of southern California, ozone (O_3) concentrations have been elevated since the 1950s with peaks reaching 600 ppb and summer seasonal averages >100 ppb in the 1970s. During that period increased mortality of ponderosa and Jeffrey pines occurred. Between the late 1970s and late1990s, O_3 concentrations decreased with peaks ~180 ppb and ~60 ppb seasonal averages. However, since the late 1990s concentrations have not changed. Monitoring during summers of 2002–2006 showed that O_3 concentrations (2-week averages) for individual years were much higher in western sites (58–69 ppb) than eastern sites (44–50 ppb). Potential O_3 phytotoxicity measured as various exposure indices was very high, reaching SUM00 – 173.5 ppm h, SUM60 – 112.7 ppm h, W126 – 98.3 ppm h, and AOT40 – 75 ppm h, representing the highest values reported for mountain areas in North America and Europe.
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1. Introduction

In the Los Angeles Basin (LA Basin) severe episodes of photochemical smog (also known as the Los Angeles type smog) have been known since the early 1950s (Turco, 1997). In the summer season, emissions of nitrogen oxides (NO_x), carbon monoxide (CO), and volatile organic compounds (VOCs) from millions of cars, and to a smaller degree also from stationary air pollution sources, are trapped in a thermal inversion layer of air. High temperature and solar radiation promote complex photochemical reactions that produce various secondary air pollutants, among them highly toxic ozone (O_3) (Finlayson-Pitts and Pitts, 1986). Contaminated LA Basin air masses move inland with the westerly on-shore winds and are pushed against the San Bernardino Mountains (SBM). Because the marine inversion layer typically does not exceed 915 m (Bailey, 1966) and the SBM crest is about 1700–2000 m high, these mountains effectively trap contaminated air masses (Fujioka et al., 1999). As a result, very high O_3 concentrations occur in the western side of the range facing the LA Basin. In the 1970s, when the first reliable measurements of O_3 started, peak concentrations could reach 600 ppb (National Academy of Sciences, 1977), and national and state air pollution standards were exceeded during most of the photochemical smog season (http://www.arb.ca.gov/html/brochure/history/htm). During that time it was also determined that the mysterious "X" disease killing thousands of sensitive ponderosa (*Pinus ponderosa*) and Jeffrey (*Pinus jeffreyi*) pines in the SBM in the 1950s was caused by high O_3 concentrations in combination with frequent drought stress and severe bark beetle attacks (Miller et al., 1963; Taylor,

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* Corresponding author. Tel.: +1 951 680 1562; fax: +1 951 680 1501.
E-mail address: abytnerowicz@fs.fed.us (A. Bytnerowicz).

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1999). This was the first worldwide evidence of a large-scale decline of coniferous forests caused by ambient O_3 (Mackenzie and El-Ashry, 1989).

While the U.S. population has nearly doubled since 1950, it has tripled in the state of California and grown even more in southern California (U.S. Census Bureau, 2006). Historical and projected population changes for the six counties of the Southern California Association of Governments (SCAG) region indicate that growth was highest in those counties from which emissions may directly affect the air pollution status of the SBM. The highest population growth between 1960 and 2000 was recorded in Riverside County (5.05-fold increase), Orange County (4.04-fold increase), and San Bernardino County (3.4-fold increase), compared with only 1.58-fold growth in Los Angeles County (http://www.scag.ca.gov/livable/download/pdf/GV1950_2025.pdf). These demographic changes led to increased traffic in eastern parts of the LA Basin, resulting in modified distribution of air pollution throughout the LA Basin and in the adjacent areas.

At the same time, during this rapid expansion of the southern California population, numerous air pollution control initiatives were initiated by the California Air Resources Board (CARB) and implemented by the South Coast Air Quality Management District (SCAQMD). In 1975, the first two-way catalytic converters came into use as part of the CARB Motor Vehicle Emission Control Program. In 1984, the California Smog Check Program aimed at identifying vehicles in need of maintenance and ensuring the effectiveness of their emission control systems on a biennial basis. The 1992 Phase I California Cleaner Burning Gasoline (CBG) resulted in 220 tons reduction of reactive organic gases (ROG) released every day (6% reduction) and elimination of lead in gasoline. In the same year, CARB required addition of oxygenates to gasoline to cut CO emissions by 10%. In 1993, CARB enacted new standards for cleaner diesel fuels, resulting in a reduction of NO_x by 70 tons/day. In 1996, California Phase II of CBG further reduced amounts of O_3 precursors by 300 tons/day. This reduction was equivalent to taking 3.5 million cars off the road. All these measures led to significant reductions of pollutant emissions resulting in substantially lowered ambient O_3 concentrations in the LA Basin and the adjacent SBM.

In the Northern Hemisphere there is a general trend of increasing background levels of O_3 due to long-range transport of its precursors (NO_x, CO, and VOCs) to remote areas (Elvingson, 2003). This trend is influenced by long-range transport of polluted air masses: trans-Pacific from Asia to North America, trans-Atlantic from North America to Europe, and transcontinental from Europe to Asia. Rapid industrial growth without effective air pollution control and increasing number of internal combustion engine vehicles in Asia, especially in China and India, will probably be the main causes of the increasing background concentrations of tropospheric O_3 in the coming years. While it is expected that peak values of the pollutant will stay below 200 ppb, it is also predicted that the steadily increasing background O_3 concentrations in parts of Asia, North America, or Europe will cause negative changes in forests (Fowler et al., 1999).

Air pollution control measures introduced in the LA Basin resulted in reduction of O_3 concentrations in the SBM. The 1991–1993 air quality monitoring at Barton Flats (BF) showed that concentrations of O_3 rarely exceeded 200 ppb, but that the 120 ppb h national air pollution standard was still exceeded on about 20% of days (Watson et al., 1999). This significant improvement in air quality also resulted in the improvement of forest conditions in the SBM and much lower tree mortality rates (Arbaugh et al., 1998; McBride and Miller, 1999). However, measurements at the Crestline (CR) monitoring site indicated that since 1999, similarly to the Pomona site in the LA Basin, O_3 peak concentrations have generally not changed (Fig. 1).

In the early 2000s, a widespread dieback of trees in the SBM started to take place due to prolonged drought, overstocking of forests caused by long-term fire suppression, air pollution, and bark beetle infestation that eventually resulted in a death of 4.6 million trees (Christensen et al., 2007). Such enormous amounts of dead biomass caused a very serious risk to the remaining forests and to the local population. The 2003 fires in the SBM (Keeley et al., 2004) showed that a very high probability of catastrophic fires exists in southern California mountainous forests.

Long-term information on spatial and temporal O_3 distribution trends in the SBM is essential for understanding the O_3 phytotoxic potential for forests and health risks to the SBM inhabitants. Therefore, a network of passive samplers and active instruments for O_3 monitoring was established in the SBM in 2002 in order to better understand O_3 distribution and its phytotoxic potential.

2. Materials and methods

2.1. Monitoring network

Eighteen sites for air pollution and forest health monitoring were used in the SBM in 2002 (Fig. 2). These included 10 Forest Health sites previously

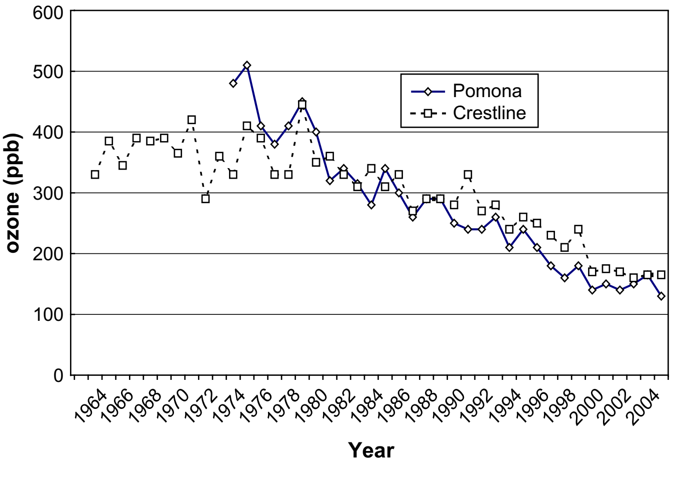

Fig. 1. Changes in maximum 1-h O_3 concentrations in the Los Angeles Basin, since 1999, in Pomona, a low elevation location in the center of the Basin and Crestline, a high elevation site on the west-exposed crest of the San Bernardino Mountains.

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