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Education Article

Assessing ozone damage to cutleaf coneflower in an ozone bioindicator garden

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Abstract

To collect data on ozone pollution and foliar damage, we established the first Philadelphia Ozone Bioindicator Garden at The Franklin Institute Science Museum. In this paper, we examine the relationship between ozone concentrations in an urban environment and changes in foliar damage in cutleaf coneflower (*Rudbeckia laciniata*) plants. Higher ozone concentrations were observed during Summer 2015 than during Summer 2014 at our site. Diurnal analysis reveals a nightly diminishment of ozone's rate of dissipation around 4am, which we attributed to intrusions of air from the residual layer (the layer of air above the boundary layer). We saw that visible foliar injury starts relatively slowly and accelerates beginning in late July for stippling and early August for chlorosis and necrosis. We found that injury ratings on ozone-damaged leaves progress faster later in the season despite lower ambient ozone concentrations; we hypothesized that this is evidence of a "latency period" in the cutleaf coneflower's foliar injury response to ozone. Cutleaf coneflowers may serve as engaging tools to alert and inform Philadelphians about air quality issues. Our results suggest that these plants are good candidates for future work in developing bioindicators of ozone where direct monitoring is not feasible.

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1. Introduction

Ozone (O_3) is an important gas that has diverse beneficial and harmful effects in our atmosphere. Ninety percent of Earth's ozone is found in the stratosphere (15–50 km from the surface), where it provides protection from UV radiation that is 200 nm to 310 nm in wavelength [9]. Ozone is also an important greenhouse gas in the mid-troposphere, comprising an increasing percentage (currently ~15%) of total anthropogenic radiative forcing [21]. Ozone and its by-product via photochemical oxidation, the hydroxyl radical (OH), "clean" the atmosphere through reactions with organic compounds, such as methane [19]. However, ozone at ground level is toxic to humans, animals, and plants as it oxidizes biological tissues [2]. In the troposphere (surface to 10–15 km), ozone has more than doubled since the industrial revolution, producing concentrations that are poisonous for living things [15]. In the United States, ozone is responsible for $500 million in reduced crop production each year [33]. Ground-level ozone has far-reaching effects on biodiversity and ecosystem services, impacting some species more than others and affecting how nutrients cycle through the ecosystem [18].

Commonly found at heightened levels in urban regions, ozone is often monitored by local and state agencies and is regulated by the U.S. Environmental Protection Agency (EPA) under the National Ambient Air Quality Standards (NAAQS). The standard for ozone is 70 parts per billion (ppb), defined as the 3-year-average of the fourth-highest 8-h-average concentration for a particular location [36]. Heightened ozone levels aggravate lung diseases such as asthma, emphysema, and chronic bronchitis in sensitive populations and induce respiratory problems, including coughing, throat or chest pain, wheezing, and shortness of breath [32]. Long-term ozone exposure is likely to be one of many causes of asthma development [32]. Children are particularly affected, given their immature respiratory systems and their time spent outdoors being physically active. In extreme cases, emergency room visits may be required and even death can result [37].

Natural sources of ozone in the troposphere include reactions involving gases produced through lightning and intrusions from the ozone layer in the stratosphere. These, in addition to pollution transported from overseas, account for northeastern US "background" ozone concentrations of around 15–25 ppb during the summertime [41]. Anthropogenic sources of ozone often push summertime concentrations in excess of 40 ppb, which is the threshold past which many plants (including crops and trees) exhibit physiological damage and yield reductions [8].

The main mechanism for ground-level ozone formation is the photolysis of nitrogen dioxide (NO_2). The main source of NO_2 in cities is the oxidation of nitric oxide (NO), which is a product of high-temperature fossil-fuel combustion. The intense heat in these combustion reactions breaks apart a small fraction of oxygen molecules. The amount of oxygen broken apart increases with temperature, and around 2700 °C, oxygen is significantly dissociated [12]. The oxygen atoms can then react with otherwise inert nitrogen (N_2) according to these reactions:

$$O_2 + \text{heat} \leftrightarrow O + O \tag{R1}$$

$$O + N_2 \leftrightarrow NO + N \tag{R2}$$

$$N + O_2 \leftrightarrow NO + O \tag{R3}$$

$$\text{Overall: } 2O_2 + N_2 + \text{heat} \leftrightarrow 2O + 2NO \tag{R4}$$

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