NO_x emissions reduction programs have translated to improved ozone air quality and forest health in the Eastern United States

Jason Lynch, Clara Funk and Richard Haeuber

U.S. Environmental Protection Agency, 1200 Pennsylvania Ave. NW, Washington, DC, 20006, www.epa.gov/airmarkets, Haeuber.richard@epa.gov

Abstract

Data from several monitoring programs are examined to assess the effectiveness and environmental benefit of air pollution reduction programs in the United States (U.S.). Integrated assessment of monitoring data demonstrates that reductions of nitrogen compound emissions, such as NO_x, and byproducts like ozone lead to improved air quality and forest ecosystem health. Three important environmental monitoring programs were used to evaluate the impact of emission reductions and improved ozone concentrations on forest health. Assessing the impact of ground-level ozone on forests in the eastern U.S. involves understanding the risk to tree species from ambient ozone concentrations and accounting for the prevalence of those species within the forest. As a way to quantify the risk to particular trees, scientists have developed concentration-response (C-R) functions that relate ozone exposure to tree response. In 2014, regulated pollution sources reduced NO_x emissions by 4.7 million tons (73%) from 1990 levels. Based on regional data from CASTNET from 2000 through 2014, annual mean ambient nitrate concentration (an ambient pollutant resulting from NO_X emissions) declined 48% from 3.1 ppb to 1.6 ppb in the eastern U.S. Rural ozone concentrations, calculated as DM8A, were found to decrease from 84 ppb to 66 ppb (22%) from 2000-2002 and 2012-14 in the eastern U.S. Comparing data from the start of the NO_X Budget Trading Program (2000-2002) to 2007-2009, we found that the total land area in the Eastern U.S. with significant biomass loss decreased substantially for all sensitive tree species as NO_x emissions and concentrations of ambient nitrogen compounds have declined over this time period.

Key Words

Nitrogen Compound Emissions

Introduction

For more than three decades, the U.S. has made great strides in improving air quality, resulting in important improvements to human health and ecosystems. Air pollution control programs implemented under the Clean Air Act have delivered substantial emission reductions and air quality improvements since the first nationwide program, the Acid Rain Program (ARP), began in 1995. With the addition of the NO_x Budget Trading Program (2003-2008) and the Clean Air Interstate Rule (CAIR), which began in 2009, emissions of NO_x from power plants and industrial units have decreased further. In order to assess the effectiveness and environmental benefits of air pollution control programs, data from several monitoring programs are used to evaluate the extent to which emission of nitrogen compounds, such as NO_x, have declined and to understand the corresponding changes in air quality and ecosystem health.

When ozone is present in the environment, it can enter a plant through stomatal pores in leaves and cause significant cellular damage that may compromise the plant's photosynthetic capacity. This loss of energy resources can lead to reduced growth and/or reproduction of plants. Ozone stress also increases the susceptibility of plants to disease, insects, fungus, and other environmental stresses (e.g., harsh weather). Tropospheric, or ground-level, ozone is formed primarily from photochemical reactions between two major classes of air pollutants, volatile organic compounds (VOCs) and NO_x. Thus, reducing NO_x emissions should translate to lower ground-level ozone concentrations and improve forest health by reducing biomass loss of a variety of commercial and ecologically important forest tree species. Here we examine how NO_x emission reduction programs in the U.S. have resulted in improved air quality, decreased ozone levels, and improved forest health.

Methods

Three important environmental monitoring programs were used to evaluate the impact of emission reduction programs on ambient NO_x products, ozone, and forest health. In the U.S., continuous emissions monitoring systems (CEMS) are central to understanding how power sector NO_x emissions have declined in response to emission control programs. Data from national environmental monitoring programs, including the Clean Air Status and Trends Network (CASTNET) and Air Quality System (AQS), were used to quantify declines in NO_x, other nitrogen compounds, and ozone in the atmosphere.

The long term regional trend in ambient mean nitrate concentrations was assessed using data from the CASTNET monitoring program from 1989-2014. Measurements were collected weekly using a 3-stage filter pack with a controlled flow rate. Ozone was measured hourly at CASTNET sites starting in 2000 through 2014 using a continuous ozone monitoring system operated according to 40 CFR Part 58 quality assurance criteria. To account for daily variability in ozone concentrations and smooth atmospheric events, data was calculated as the 3-year average of the fourth highest daily maximum rolling 8-hour average (DM8A).

Ground-level ozone has been shown in numerous studies to have a strong effect on the health of many plants, including a variety of commercial and ecologically important forest tree species throughout the United States (Ollinger et al. 1997, EPA 2007). Assessing the impact of ground-level ozone on forests in the eastern U.S. involves understanding the risk to tree species from ambient ozone concentrations and accounting for the prevalence of those species within the forest. As a way to quantify the risk to particular trees, scientists have developed concentration-response (C-R) functions which relate ozone exposure to tree response. Tree seedling C-R functions are determined by exposing tree seedlings to different ozone levels and measuring reductions in growth as "biomass loss." In areas where certain species dominate the forest community, the biomass loss from ozone can be significant. In this analysis, biomass loss is used as an indicator for the effects of ozone on the forest ecosystem.

Common tree species in the eastern United States that are sensitive to ozone include black cherry (*Prunus serotina*), yellow-poplar (*Liriodendron tulipifera*), sugar maple (*Acer saccharum*), eastern white pine (*Pinus strobus*), Virginia Pine (*Pinus virginiana*), red maple (*Acer rubrum*), and quaking aspen (*populus trenuloides*) (Chappelka et al., 1998). To estimate the biomass loss for forest ecosystems across the eastern U.S., the biomass loss for each of the seven tree species was calculated using the three-month, 12-hour W126 exposure metric at each location, along with each tree's individual C-R functions. The W126 exposure metric is a cumulative (not average) exposure index that is biologically based and places a greater weight on the higher hourly ozone concentrations (Heck and Cowling 1997). The W126 exposure metric was calculated using monitored ozone data from the rural CASTNET and urban AQS networks, and averaged over a three-year period to mitigate the effect of variations in meteorological and soil moisture conditions. The biomass loss estimate for each species was then multiplied by its prevalence in the forest community using the U.S. Department of Agriculture (USDA) Forest Service IV index of tree abundance calculated from Forest Inventory and Analysis (FIA) measurements (Prasad and Iverson, 2003). This analysis compared two time periods, 2000-2002 (beginning of NO_X Budget Trading Program) and 2007-2009 (last modelling years), and demonstrates the benefit to forest ecosystems from decreasing ozone concentrations.

Results

NO_X Emissions
Substantial emission reductions and air quality improvements in the U.S. have been realized since the first nationwide program, the Acid Rain Program (ARP), began in 1995. In 2014, sources regulated under Clean Air Act emission reduction programs reduced NO_x emissions by 4.7 million tons (73%) from 1990 levels, and 3.5 million tons (67%) from 2000 levels.

Ambient air quality and Ozone Concentrations
Based on regional data from CASTNET from 1989 through 2014, annual mean ambient nitrate concentration declined 48% from 3.1 ppb to 1.6 ppb in the Eastern U.S. (Figure 2). Rural ozone concentrations, measured at CASTNET sites beginning in 2000, calculated as DM8A, were found to decrease from 84 ppb to 66 ppb (22%) from 2000-2002 and 2012-14 in the eastern U.S. (Figure 3).

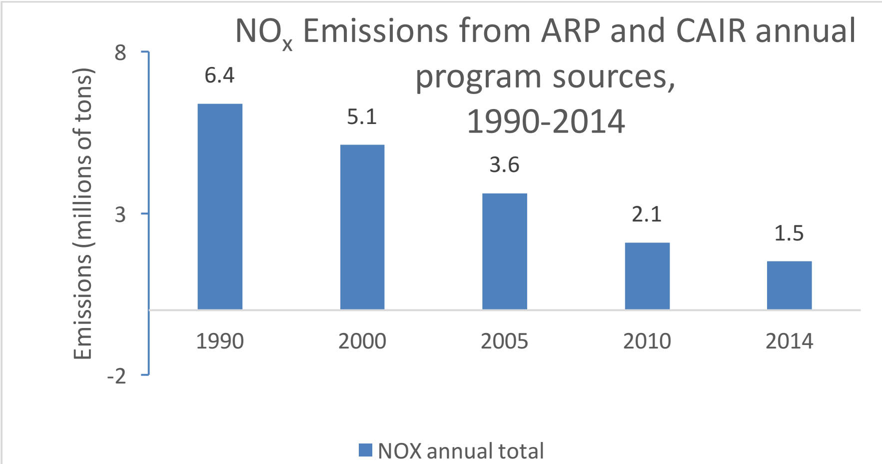

Figure 1. NO_x emissions from ARP and CAIR annual program sources, 1990-2014

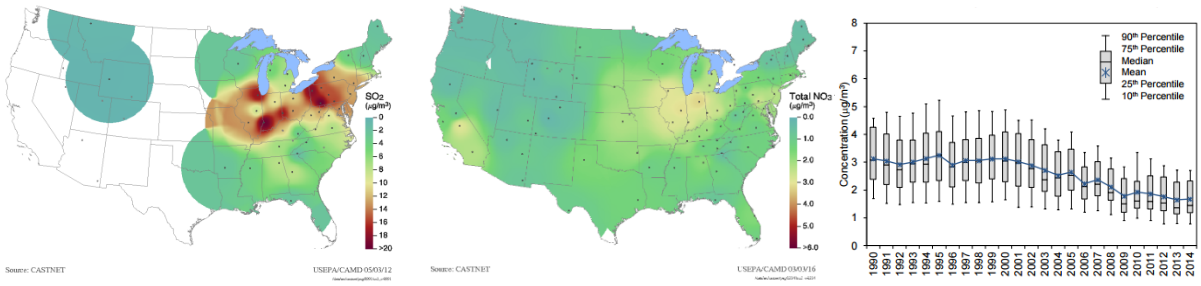

Figure 2. Ambient mean annual nitrate concentration in the United States, 1989-91 versus 2012-2014

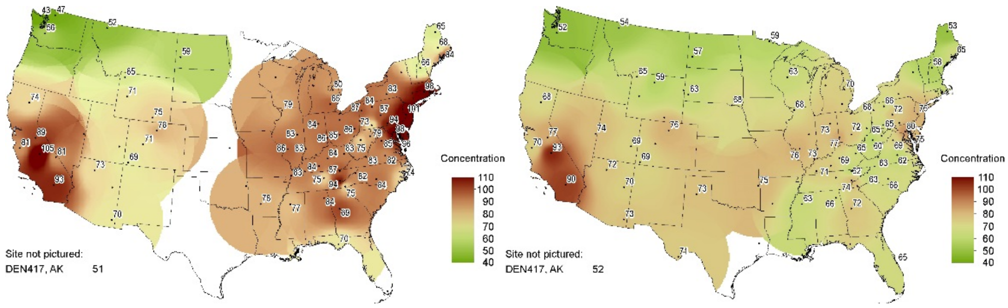

Figure 3. Three year average of fourth highest DM8A ozone concentration (ppb), 2000-2002 versus 2012-2014

Effects of decreased ozone pollution on forest biomass

Starting in 2000, the NO_X Budget Trading Program achieved significant NO_X emissions reductions. We assessed the impact of those emission reductions on forest health. The number of areas with significant biomass loss (e.g., areas with more than 2 percent biomass loss (EPA 2007)) due to ozone has decreased for all seven tree species across their range in the East United States (see Figure 4). Of these seven species, black cherry and yellow poplar are the most sensitive to ozone. Comparing data from 2000-2002 versus 2007-09, we found that the total land area in the Eastern U.S. with significant biomass loss has decreased by 5 percent for black cherry and by 4 percent for yellow poplar. In addition, areas with significant biomass loss for the remaining five species (red maple, sugar maple, quaking aspen, Virginia pine, and eastern white pine) now make up less than 1 percent of their total range. This was not the case in 2000-2002. While this change in biomass loss cannot be exclusively attributed to the implementation of the NBP, it is likely that NO_x emission reductions achieved under the NBP and the corresponding decreases in ozone concentration contributed to this environmental improvement.

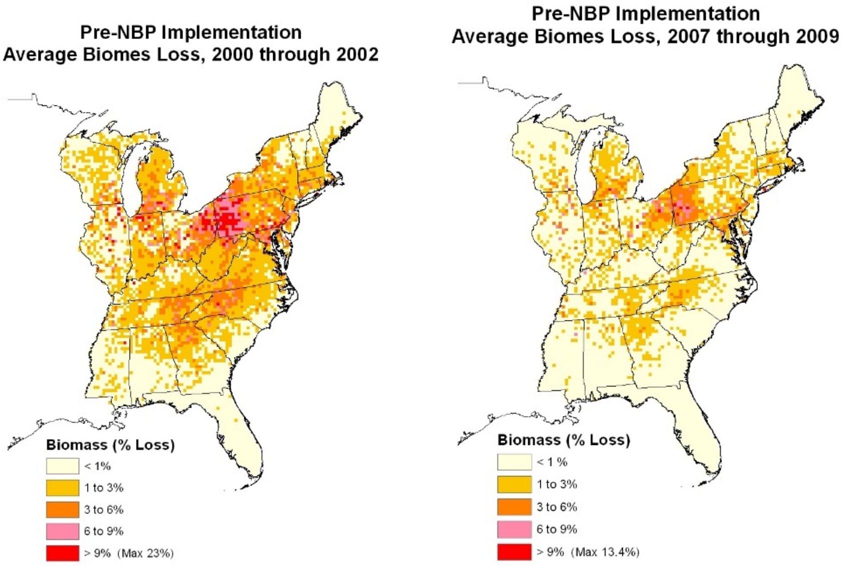

Figure 4. Estimated Black Cherry, Yellow Poplar, Sugar Maple, Eastern White Pine, Virginia Pine, Red Maple, and Quaking Aspen Biomass Loss due to Ozone Exposure, 2000-2002 versus 2007-2009

References

Chappelka AH and Samuelson LJ (1998). Ambient ozone effects on forest trees of the eastern United States: A review. New Phytologist 139, 91-108.

Heck WW and Cowling EB (1997). The need for a long term cumulative secondary ozone standard – an ecological perspective. Environmental Management, January, 23-33.

Ollinger SV, Aber JD, Reich PB. (1997). Simulating ozone effects on forest productivity: interactions, among leaf-canopy and stand-level processes. Ecological Applications 7(4), 1237–1251.

Prasad AM and Iverson LR (2003). Little's range and FIA importance value database for 135 eastern U.S. tree species. <http://www.fs.fed.us/ne/delaware/4153/global/littlefia/index.html>, Northeastern Research Station, USDA Forest Service.

Schwede DB and Lear GG. (2014). A novel hybrid approach for estimating total deposition in the United States. Atmospheric Environment, 92, 207-220.

U.S. EPA. (2007). Review of the National Ambient Air Quality Standards for Ozone, Policy Assessment of Scientific and Technical Information. OAQPS Staff Paper. EPA-452/R-07-003. This document is available in Docket EPA-HQ-OAR-2003-0190 and online at http://www.epa.gov/ttn/naaqs/standards/ozone/s_o3_cr_sp.html.