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

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Introduction

For more than three decades, the U.S. has worked to improve 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 Acid Rain Program (ARP) in 1995, and more recently with the NO_x Budget Trading Program (2003-2008) and the Clean Air Interstate Rule (CAIR, 2009-2014).

Tropospheric, or ground-level, ozone is formed primarily from photochemical reactions between two major classes of air pollutants, volatile organic compounds (VOCs) and nitrogen oxides (NO_x). Ozone, which can cause significant cellular damage, may compromise a plant's photosynthetic capacity and eventually contribute to reduced growth and/or reproductive fitness. Ozone stress also increases the susceptibility of plants to disease, insects, fungus, and other environmental stresses. 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 commercially 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.

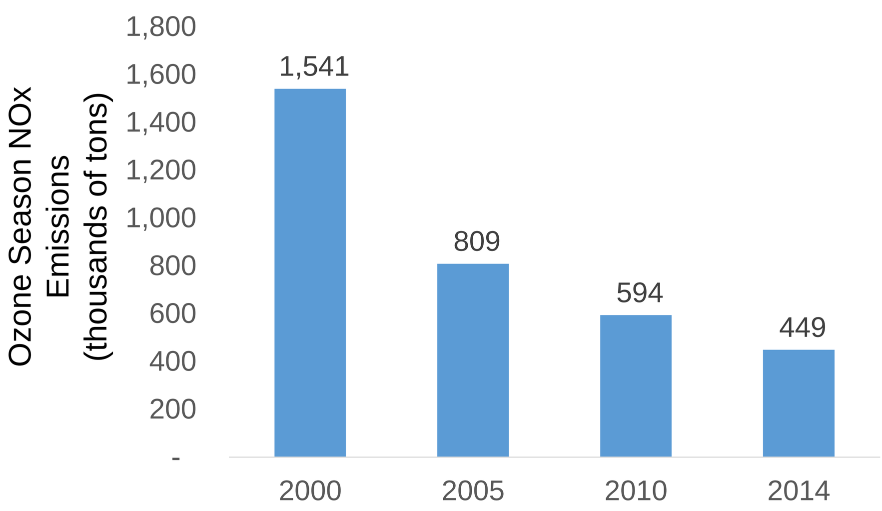


Figure 1. NO_x emissions from the NBP and CAIR ozone season program sources, 2000-2014

- In 2014, regulated sources reduced ozone season NO_x emissions by 1.0 million tons (69%) from 2000 levels.

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:

- **NOx emissions** from NBP and CAIR sources, 2000-2014, were calculated from continuous emissions monitoring (CEM) concentration and flow rate data.
- **Mean ambient nitrate** (total nitrate, NO_3+HNO_3) concentration data, 2000-2014, from the Clean Air Status and Trends Network (CASTNET) was collected weekly using a 3-stage filter pack with a controlled flow rate.
- **Ozone concentration**, 2000-2014, was calculated as the 3-year average of the fourth highest daily maximum rolling 8-hour average (DM8A) of CASTNET and Air Quality Systems (AQS) monitoring data. Hourly data was collected using a continuous ozone monitoring system operated according to 40 CFR Part 58 quality assurance criteria.

Biomass loss
Concentration-response (C-R) functions which relate ozone exposure to tree response, were determined by exposing tree seedlings to different ozone levels and measuring reductions in growth as "biomass loss." 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). 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 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 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 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 (before the NO_X Budget Trading Program) and 2012-2014.

Results

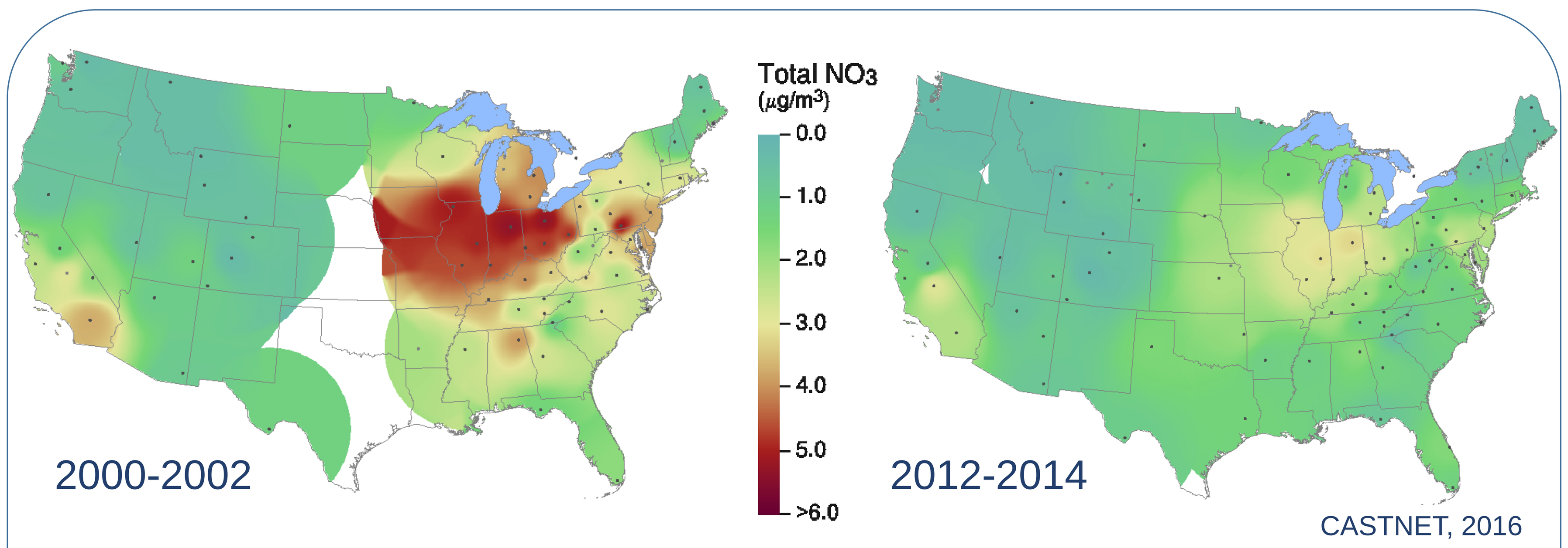


Figure 2 (above). Ambient mean annual nitrate concentration in the United States, 2000-2002 versus 2012-2014

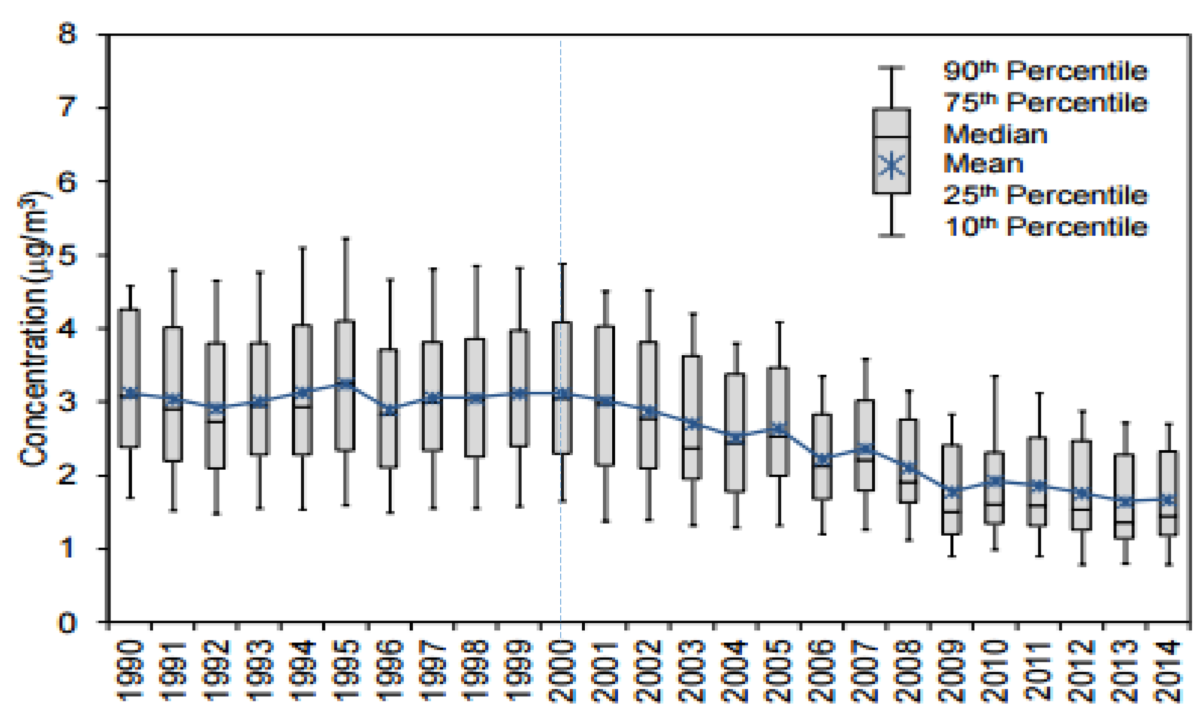


Figure 3. Trend in Total Nitrate Concentration (Eastern United States, 1990-2014

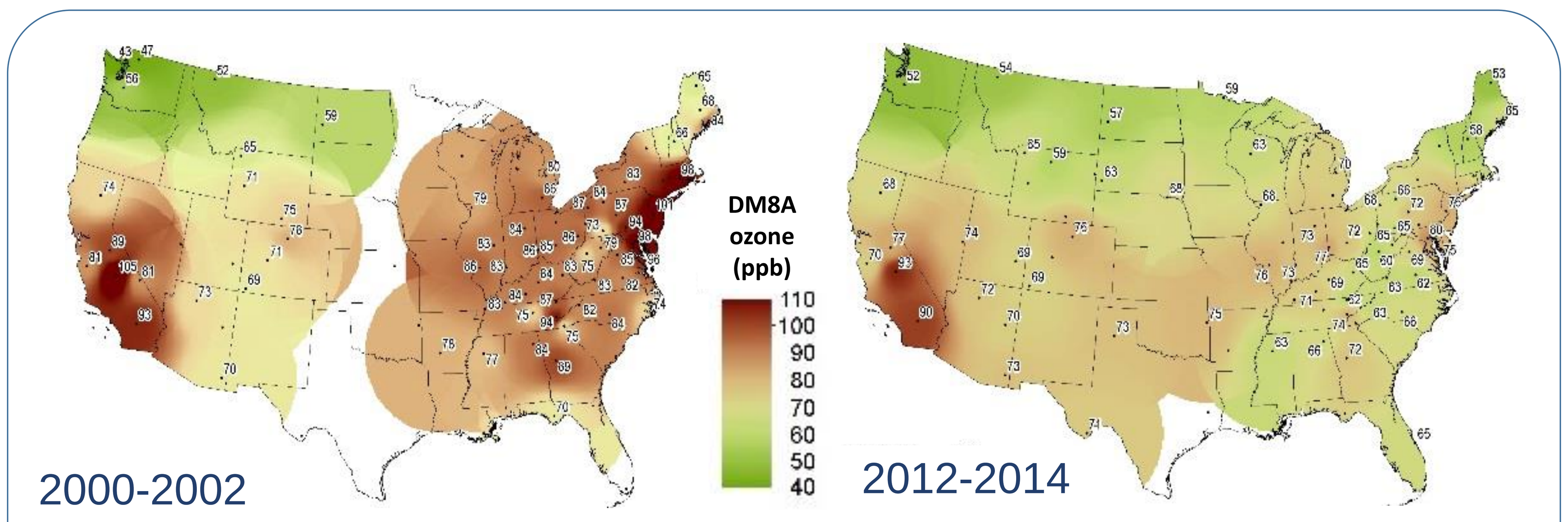


Figure 4. Three year average of fourth highest DM8A ozone concentration (ppb), 2000-2002 versus 2012-2014

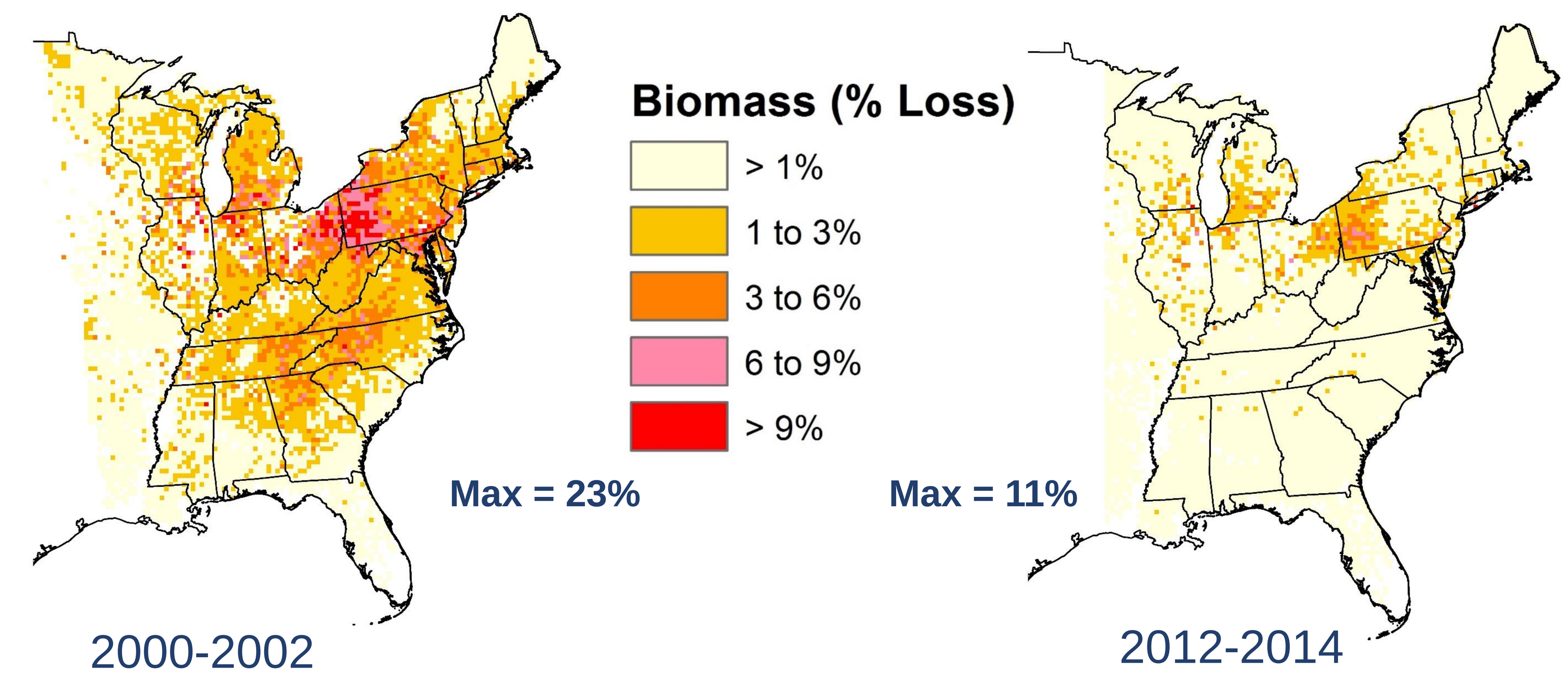
Ambient air quality and Ozone Concentrations

- Annual mean ambient total nitrate concentration declined 44% from 3.0 ppb to 1.6 ppb in the eastern U.S., 2000-2014 (Figures 2, 3)
- 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. (Figure 4)

Effects of decreased ozone pollution on forest biomass

- Areas with significant biomass loss (> 2% biomass loss (EPA 2007)) due to ozone decreased for all seven tree species across their range in the eastern United States from **33**% to **5**% from 2000-2002 to 2012-2014 (Figure 5).
- Of these, black cherry and yellow poplar are the most sensitive to ozone. Total land area in the region with significant biomass loss decreased from 15.3% to 5.1% for black cherry and by 3.1% to 0.0% for yellow poplar.
- For the period 2012-2014, significant biomass loss for the remaining five species (red maple, sugar maple, quaking aspen, Virginia pine, and eastern white pine) is zero. This is in contrast to the period 2000-2002, when 34% of range loss could be attributed to ozone exposure.

Figure 5. 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 2012-2014.



AQS & CASTNET, 2016

Conclusion

- **A 69% reduction of ozone season NOx emissions from 2000-2014 has contributed to improvements in ambient total nitrate (44%) and ozone (22%) air quality in the Eastern U.S.**
- **The large improvements in ozone air quality has led to dramatic reductions in biomass loss for the seven sensitive tree species and improved forest health in the Eastern U.S., as indicated by the biomass loss model.**
- **While this predicted improvement in forest health cannot be exclusively attributed to the NO_x Budget Trading Program and the Clean Air Interstate Rule, it is likely that NO_x emission reductions achieved under these programs – and the corresponding decreases in tropospheric ozone – contributed to this environmental improvement.**

References

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