Research Reports

Cars and canyons: Understanding roadside impacts of automobile pollution in Grand Canyon National Park

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A sunset view of Grand Canyon near the main park visitor center.

EACH YEAR MILLIONS OF VISITORS FROM AROUND the world come to Grand Canyon National Park, in Arizona to witness awe-inspiring views and to observe over 60 million years of Earth's history preserved in the strata displayed in the canyon walls. Some days, visitors are disappointed to find these canyon views veiled by haze, reducing visibility to a fraction of the canyon's legendary vistas (NPS 2013). Disappointed visitors understandably ask what causes this haze and how air pollution affects the Grand Canyon. How can clean air and breathtaking views be restored at Grand Canyon?

Atmospheric haze is composed of a mixture of chemicals, including nitrogen oxides (NOx), ozone (O_3), peroxyacetyl nitrate (PAN), and sulphate (SO_4^{2-}) (Jimoda et al. 2011). Two of these components, O_3 and NOx, not only compromise Grand Canyon views, but also damage plant tissues and have impacts on ecosystem processes (Fenn et al. 2003; Bobbink et al. 2003), with potentially wide-ranging effects. Under certain weather conditions, urban air pollution and haze from Las Vegas, Phoenix, and Los Angeles, plus industrial pollution from power plants and copper smelters, accumulate in the canyon (Macias et al. 1981; Eatough et al. 1997; Eatough et al. 2001). In addition to visitors, automobiles bring air pollution to the park in the form of exhaust that may also reduce air quality at Grand Canyon. Every year, approximately one million automobiles pass through the south entrance of Grand Canyon National Park; nearly 200,000 pass through the east entrance at Desert View (NPS 2013; fig. 1).

Even though 78% of the atmosphere is composed of N_2 gas, this form of N is unavailable for plant use. Consequently plant growth in natural ecosystems is often limited by a shortage of N. Plants acquire some organic forms of N along with ammonia (NH_3^+) and nitrate (NO_3^-) from the soil. The process of transforming N_2 gas into plant-available NH_3^+ or NO_3^- requires a lot of energy, and occurs naturally through nitrogen-fixing microbes and lightning, or through industrial processes related to fertilizer production, and fossil fuel combustion for transportation and the production of electricity.

Since the industrial and agricultural revolutions, human activities have doubled the amount of bioavailable N on the planet, overloading some ecosystems (Vitousek et al. 1997). Even low levels of persistent NOx pollution may cause the buildup of excess N, which can result in the ecological equivalent of "too much of a good thing." Critical loads are defined as the amount of pollutants below which there are no adverse ecological effects (Fisher et al. 2007; Burns et al. 2008). Nitrogen inputs that surpass critical loads create undesirable effects on natural communities and ecosystems,

Abstract

Nitrogen oxides (NOx) in air pollution contribute to haze that diminishes the views at Grand Canyon National Park. NOx pollution negatively impacts vegetation and ecological communities, but these effects are not well understood. Some sources of this pollution, like regional airborne emissions from urban areas and coal-fired power plants, are beyond the direct jurisdiction of the National Park Service (NPS). However, NOx emitted from vehicular exhaust is one source of pollution that the park can potentially manage as it strives to provide alternative transportation options for the public. We sampled atmospheric NOx and foliar $\delta^{15}N$ signatures (the ratio of nitrogen isotopes ^{15}N to ^{14}N can be used to identify emission sources) along a traffic gradient at the south rim of the national park to assess the extent to which vehicles on park roads may be adding nitrogen (N) to transportation corridors. Atmospheric NOx was found to be elevated within a few meters of the roadside and at the south entrance where automobile traffic was the greatest. We also found that foliar nitrogen isotope signatures along the roadside gradient matched known signatures from vehicular emissions, indicating that cars and other vehicles are primary sources of nitrogen in the ecosystem near roadways. Haze-reducing legislation has recently been enacted to reduce emissions from regional coal-fired power plants, but the National Park Service can further reduce park pollution by encouraging nonmotorized recreation and greater public use of alternative transportation options.

Key words

automobile, Grand Canyon National Park, nitrogen, NOx, pollution

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Figure 1. Automobile traffic idles at the south entrance (top) and Desert View (bottom) entrances to Grand Canyon National Park.

including changes in soil fertility that disrupt native plants and their consumers (Galloway et al. 2003; Aber et al. 1989; Weiss 1999).

Automobile emissions in our national parks may damage sensitive roadside vegetation, such as conifers, and favor a few dominant species, including invasive grasses (Trahan and Peterson 2007; Angold 1997). For example, in Rocky Mountain National Park, Colorado, N inputs from highways and long-range transport from urban and agricultural centers contribute to plant community shifts and establishment and spread of invasive grasses (Bowman 2000; Bowman et al. 2012). Similarly, roadside N enrichment in Grand Canyon National Park may provide too much N to organisms accustomed to otherwise N-limited plant communities, changing nutrient cycling processes and altering plant community composition. Currently we do not know the effects of N enrichment on Grand Canyon ecosystems; however, we do know that increasing population and industrialization in the region continue to challenge park staff's ability to mitigate the effects of air pollution originating both in and outside of park jurisdiction. How can clean air be restored in the Grand Canyon? The first step is to determine the amount and sources of N pollution, the next step is to find out how much N is too much (critical loads), and the final step is to develop strategies to reduce these inputs. Our research is focused on the first step. To address this, we explored potential indicators of N enrichment and the origins of pollution in Grand Canyon National Park.

The relative abundance of the stable isotope ^{15}N can be used to quantify inputs of atmospheric N and its incorporation into plant tissues. Isotopes are variants of elements that differ in the number of neutrons in their nucleus, with ^{15}N having one more neutron than the more common isotope ^{14}N. Stable isotope analysis offers a way to trace pollution in the environment to its source since the ratio of N isotopes differs in predictable ways. Isotope ratios are expressed using δ (delta) notation in parts per thousand (‰). $\delta^{15}N = [(R_{sample}/R_{standard}) - 1]$ times 1000, where R is the molar ratio of the heavier to the lighter isotope ($^{15}N/^{14}N$) for the standard or sample (Evans and Ehleringer 1993). The additional neutron makes ^{15}N heavier and this slightly changes its physical and chemical behavior. Differences in $\delta^{15}N$ ratios of exhaust from

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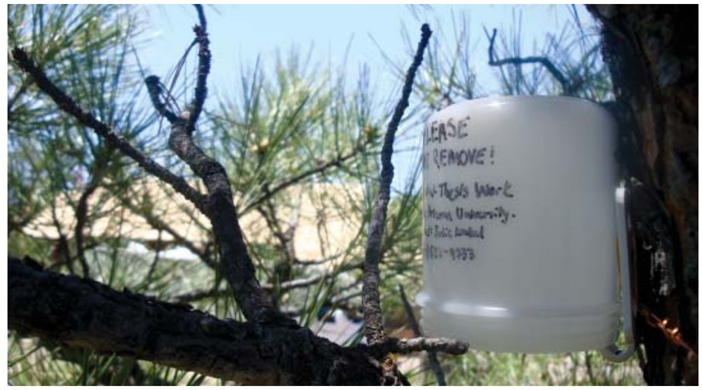

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Figure 2. We detected roadside NOx in automobile exhaust using Ogawa passive air samplers, installed 2 m high in pinyon pine trees at the roadside and 30 m from the road. Atmospheric NOx was measured at the south entrance and Desert View entrance.

power plants, vehicular emissions, and natural sources can help identify the origin of N pollution (Elliott et al. 2007). $\delta^{15}N$ ratios in NOx from automobiles with catalytic converters generally range from +3.4 to +5.7‰, compared to background atmospheric $\delta^{15}N$ signatures (Ammann et al. 1999; Pearson et al. 2000) of around 0.003‰. Plant tissue $\delta^{15}N$ signatures have been found to be 10% higher (more positive) in highly trafficked roads than in remote areas (Pearson et al. 2000). Based on these findings, we hypothesized that trees close to roadsides and high traffic areas in Grand Canyon National Park should have higher $\delta^{15}N$ ratios than trees that are farther from automobile emissions.

Research methods

We studied N inputs at different times and places in the park near (0 m) and farther away (30 m) from roadsides. We measured two indicators of N enrichment, atmospheric NOx using Ogawa air samplers (Ogawa Inc., Pompano Beach, Florida, USA; fig. 2) and $\delta^{15}N$ in needles of pinyon pine (*Pinus edulis* Engelmanii) trees near the roadside (fig. 3). We installed Ogawa passive air samplers at the south entrance and Desert View entrance. We attached the air samplers 2 m (6.6 ft) above ground level in pinyon pine trees located 0–30 m (98.4 ft) from either side of the road. We deployed two additional samplers at the south entrance to gain a finer-scale measurement of NOx concentrations at the most highly trafficked area (NPS 2013). We collected the samplers at two-week intervals, six times throughout a 12-month period (May 2011–March 2012). At collection, samplers were sealed in airtight containers and shipped to the laboratory where they were analyzed for nitrogen oxide and nitrogen dioxide concentrations using colorimetry and diazo-coupling reactions (Research Triangle Institute, North Carolina). The length of time that Ogawa samplers are exposed to air is factored into calculations of the concentration of NOx in parts per billion (ppb). Exposure times were fairly similar across sample sites and collection dates, and any variance in exposure time is accounted for by the analysis protocol (Ogawa Inc., Pompano Beach, Florida, USA).

We evaluated the $\delta^{15}N$ signature of pinyon pine needles from samples taken at 10 sites along the south rim drive of Grand Canyon National Park (fig. 4). We collected annual needle whorls from 2009 to 2011 at chest height, on the south aspect of the tree at distances of 0, 15, and 30 m (0, 49.3, 98.4 ft) from the roadside. A total of 240 samples were collected, dried, ground, and analyzed for $\delta^{15}N$ signatures using mass spectroscopy (Colorado Plateau Stable Isotope Lab, Northern Arizona University). We used the multivariate analysis of variance (MANOVA) for repeated measures to determine whether or not location in the park and distance from roads account for the variance observed in NOx concentration and foliar $\delta^{15}N$ signatures. All statistical analyses were performed using JMP 10 software (JMP 10. 2012).

Results

Across all sample dates the concentration of NOx detected by the samplers was significantly higher at the south entrance than at Desert View (fig. 5). Furthermore, at the south entrance, roadside (0 m) NOx concentrations were 52% higher than those at sites 30 m (98.4 ft) away from the road. Across all 10 sites, foliar $\delta^{15}N$ was on average about 1 part per thousand higher (less negative) at the roadside than at 15 m or 30 m (49.3, 98.4 ft) away from the road (fig. 6).

INSETS LEFT TO RIGHT: NPS, NPS/MICHAEL QUINN, NPS/NEAL HERBERT

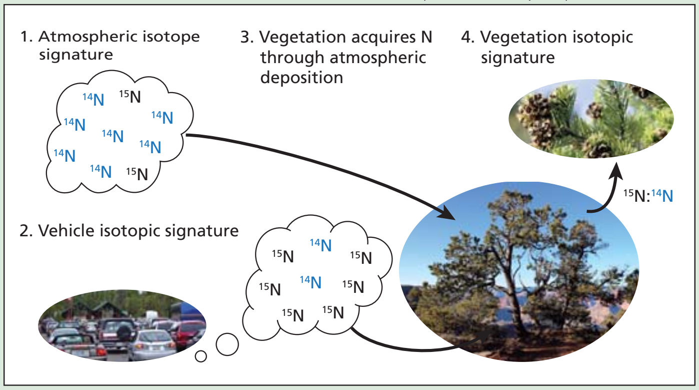


Figure 3. $\delta^{15}N$ signatures are useful in tracking human sources of N in plant tissue and air. (1) In an unpolluted environment, the isotopic signature of N is dominated by ^{14}N, and is very close to 0.00 parts per thousand (‰). (2) Automobile exhaust is relatively enriched in ^{15}N and displays a higher $\delta^{15}N$ when compared to the background atmospheric $\delta^{15}N$. (3) Vegetation acquires N via atmospheric deposition onto foliage and also through the soil, which may be influenced by vehicular sources. (4) The isotopic signature of samples of vegetative tissue can be analyzed. A stronger influence of vehicular N sources would produce greater enrichment of ^{15}N.

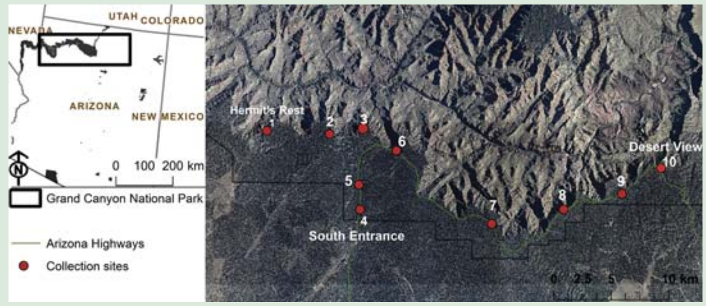
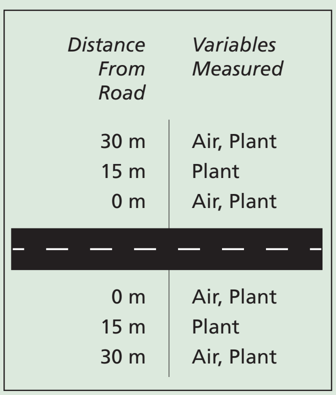


Figure 4. (Above) We measured roadside sites along the south rim drive of Grand Canyon National Park (May 2011–March 2012). (Below at left) Atmospheric NOx samples were measured at the south entrance and Desert View entrance at 0 and 30 m from the roadside; foliar samples were collected across all 10 sites along the south rim drive at 0, 15, and 30 m from the roadside.



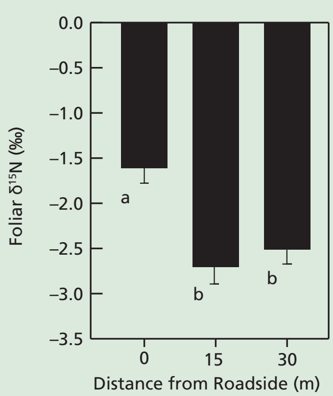


Figure 5. (Left) Ogawa passive samplers measured atmospheric NOx (ppb) along roadsides at the south entrance (0 m, n = 4; 30 m, n = 2) and at Desert View entrance (0 m, n = 2; 30 m, n = 2) sites in Grand Canyon National Park. (Right) Samples were collected for six two-week periods in May, July, August, October 2011, and January and March 2012. NOx collected at each of the sites were averaged by distance from the road (0 m and 30 m). Tukey test results denoting significant differences between NOx at each site are represented by *a* and *b*.

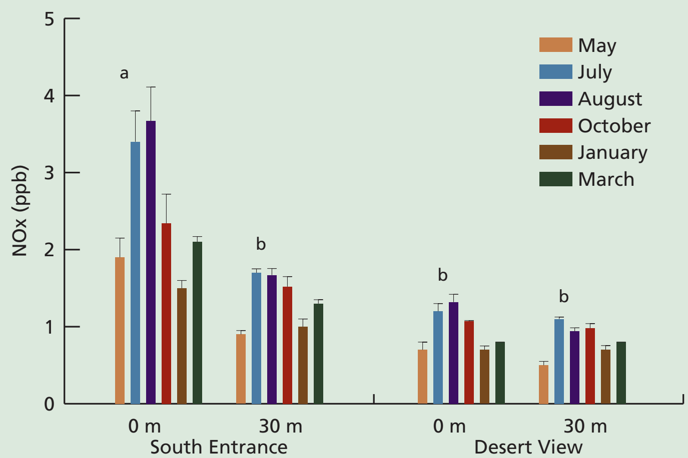


Figure 6. We measured pinyon pine $\delta^{15}N$ (‰) signatures from roadside environments along the south rim drive of Grand Canyon National Park (May 2011–January 2012). In the figure, bars represent means (n = 237) and lines represent standard errors. Different letters indicate that means are significantly different according to Tukey HSD test ($p < 0.05$).

Discussion

We discovered that air from highly trafficked areas in Grand Canyon National Park contained a higher concentration of NOx than air from areas with fewer automobiles. Although the long-range transport of pollutants from urban centers and power plants may contribute to atmospheric haze, automobile emissions affect local air quality and, over time, this chronic N fertilization is likely to affect ecological communities along adjacent roadways (Angold 1997; Fenn et al. 2003). Input of N from automobile exhaust is particularly high at the south entrance, where more than one million cars, with engines idling, line up each year for admittance to the park.

As hypothesized, we detected higher $\delta^{15}N$ ratios in pine needles collected near roadsides than in those collected 30 m (98.4 ft) away from the road. The observed plant $\delta^{15}N$ signatures were within the range expected from automobile emissions (Ammann et al. 1999; Saurer et al. 2004).

Although the NOx concentration we observed in air samples from Grand Canyon National Park is below the national air quality standards (EPA 2013), there is concern that these limits may not be low enough to protect ecological communities in semiarid ecosystems, which may be more vulnerable to human sources of N enrichment than wetter ecosystems (Burns et al. 2011; Fenn et al. 2003). Low-elevation, short-range N emissions from automobiles, especially in times of high vehicular traffic, may affect roadside ecological communities more than other, less direct sources of pollution (Forman et al. 2003). Over time, the gradual buildup of biologically available N can initiate a cascade of undesirable ecological responses (Galloway et al. 2003). Pollution from automobiles, urban areas, industry, and power plants all contributes to the larger issue of air quality in Grand Canyon National Park. The clean air and world-renowned views expected by park visitors can be restored to the canyon through policies that target haze-producing NOx emissions. The recent EPA mandate to install NOx pollution–reduction technologies at the Navajo Generating Station, a coal-fired power plant only 24 km (15 mi) northeast of the park, helped it to advance one important step toward better air quality (EPA 2013). Grand Canyon National Park is continuing to take strides toward cleaner air by targeting improvements in the air pollution source within its boundary: automobile emissions.

The National Park Service encourages people to visit their national parks and has adopted the motto "Experience Your America™". This goal increasingly involves alternative transportation options. Nonmotorized recreation and public transportation offer ways to accommodate increased park visitation without compromising the park's ability to protect natural resources. The shuttle bus system at Grand Canyon began in 1974 and continues to enhance the protection of park resources and improve the visitor experience. In 2008, the park increased its fleet of natural gas–run buses to 29 vehicles, reducing NOx emissions in the park by 176 tons/year (NPS 2013). The park's low-pollution vehicles also provide service from the gateway community of Tusayan into the park, and provide access to sensitive features of the park, like Hermit's Rest Road, which is closed to private vehicles for much of the year. Other national parks, including Acadia in Maine and Zion in Utah, have successfully adopted public transportation systems to limit traffic congestion, increase public access to the park, and conserve park natural resources. Continued development of public transportation alternatives allows visitors to enjoy their national parks and the natural resources within them. "Rerouting" the way we experience our national parks may safeguard fragile natural resources, preserve important ecosystem functions, and help to ensure their protection for "the enjoyment of future generations" (NPS Organic Act 1916).

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