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Research article

Winter road management effects on roadside soil and vegetation along a mountain pass in the Adirondack Park, New York, USA

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ABSTRACT

In 2003–2005, we resurveyed and expanded plots surveyed in 1985 to examine the cumulative impact of road salt (sodium chloride) and sand along a two-lane highway in the Adirondack State Park in New York State (USA). Annual salt applications in the period 1985–2005 ranged from 50 tonnes per centerline-km (1985) to 140 tonnes (2005) and sand applications ranged from nearly zero tonnes (2005) to 325 tonnes (1985). Roadside soils and vegetation were significantly impacted by salt deposition compared to soils and vegetation 30 m and 150 m from the road. Roadside soil contained more sand, less organic matter, had a lower cation exchange capacity, was denser, and retained less water than soils 30 m and 150 m from the road. The concentration of sodium in roadside soils was elevated (103 vs. 44 ppm in soil 150 m from the roadside), and roadside concentrations of plant-nutritive cations were lower than 150 m from the road (roadside Mg, Ca and K concentrations were 0.2, 5, and 1 ppm respectively vs. 23,168, and 30 ppm at 150 m from the road). Along the roadside, paper birch trees (*Betula papyrifera*) and other woody vegetation present in 1980 were absent in 2004, suggesting that survival and recruitment of paper birch trees was impacted by degradation of soil fertility, deposition of road salt and aerosolization of salt from the roadway. Roadside environmental degradation caused by winter road management has worsened since 1980; revegetation with native salt-tolerant plants may provide some mitigation of the most severe effects. Overall, we conclude that the full extent of roadside environmental degradation caused by winter road management can take decades to manifest, and this may be the case more generally along cold-climate montane roadways.

1. Introduction

In the US, Canada, Europe, and Japan the quantity of sodium chloride and other chemical deicers applied to roads to improve traffic safety has increased dramatically over the last 50 years, and continues to rise (Environment Canada and Health Canada, 1999; Jackson and Jobbagy, 2005; Thunqvist, 2004). In New York State, road applications of halite result in an annual salt loading of 200 kg NaCl/ha (averaged over the entire state's surface area), as compared to 0.9 kg/ha from natural sources of atmospheric deposition (Jackson and Jobbagy, 2005). Single pass loadings in the northeastern United States and Eastern Canada range from 130 to 170 kg/km two-lane highway (Environment Canada and Health Canada, 1999), and annual loadings in this region range from 12,000 to 75,000 kg/km highway (Environment Canada and Health Canada, 1999). Long-term monitoring programs show that chloride concentrations are dramatically increasing in rivers and lakes within watersheds traversed by roads salted in winter (Godwin et al., 2003; Kaushal et al., 2005; Kelly et al., 2008; Kelting et al., 2012; Moll et al., 1992). Negative environmental impacts of halite, other chemical deicers, and sand have been noted since the 1940s (reviewed in Hanes et al., 1970, 1976; Environment Canada and Health Canada, 1999; Transportation Research Board, 1991).

Roadside soil and vegetation can be altered dramatically by use of deicing road salt and sand. Roadside soils are inherently different from native soils; they are young, derived from construction fill material, and compacted. Salt-impacted roadside soil is more unstable, infertile, and drought-prone (Blomqvist, 1998; Cain et al., 2001; Neher et al., 2013). Sodium chloride, the most widely used chemical deicer, may alter soil chemistry, soil physical structure, and soil biota (Environment Canada and Health Canada, 1999). With chronic use, Na^+ tends to accumulate in the soil over time whereas Cl^- is transported away with surface or groundwater flow (Hofstra and Smith, 1984; Howard and Beck, 1993). Na accumulation in soil contaminated by deicing road salt can result in

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losses of Ca, Mg, and K cations through cation exchange (Bryson and Barker, 2002; Löfgren, 2001; Norrström and Bergstedt, 2001). Toxic trace metals, common contaminants in roadside soils due to motor vehicle exhaust and wear, may become mobilized due to the physical and chemical changes to soil associated with road salt contamination, and can be rendered more bioavailable for uptake by plants (Amrhein et al., 1992; Bäckström et al., 2004; Buckler and Granato, 1999; Granato et al., 1993; Norrström and Jacks, 1998). Excessive Na causes breakdown of soil aggregates, soil swelling, decreased pore size, and reduced permeability of soil to air and water (Jones et al., 1992; Morin et al., 2000). Sand is often used in conjunction with road salt, and may act synergistically with salt to alter soil properties: sand accumulates near the site of deposition, and alters the bulk density and porosity of roadside soil, and sand deposition reduces the concentration of soil organic matter (SOM) and clay particles, which in turn lowers cation exchange capacity and therefore the ability of soil to retain plant nutrients (Staples et al., 2004).

Changes in soil chemistry and physical structure can degrade soil microbial and macrofaunal communities (Butler and Addison, 2000; Ke et al., 2013). Loss of soil nutrients, water-stress, and changes in soil physical structure caused by salt and sand can physiologically stress plants (Cain et al., 2001). Aerial deposition of salt and particulate matter from sand applications work in synergy with the decline in soil fertility to adversely impact the health of roadside plants (Blomqvist, 1998; Hanes et al., 1976). Vegetation loss also results in higher erosion rates, causing further degradation of soil fertility (Cain et al., 2001; Environment Canada and Health Canada, 1999).

New York State (NYS) Route 73 is a two-lane highway designated a state scenic corridor that is the principal route for visitors to access Lake Placid, New York, a major winter tourist destination in the Adirondack State Park (Route 73 Steering Committee, 1999). Fleck et al. (1988) examined the impact of deicing road salt at Cascade Pass along this highway, in response to public concerns about tree mortality blamed on excessive salt use during the 1980 Winter Olympic Games in Lake Placid. They compared soil conditions and paper birch (*Betula papyrifera*) density along the roadside to a short distance from the roadway, and documented higher mortality and lower regeneration of trees along the highway. Soil Ca, Mg, K, and SOM were lower along the roadside, whereas Na was higher. Fleck et al. (1988) concluded that changes to the physical and chemical properties of the soil resulted in declining health of roadside birch, and that the long-term prognosis of the roadside birches was poor.

In this study, we replicated and expanded the work of Fleck et al. (1988) two decades later as part of a larger research project on the long-term impact of winter road management practices on three high-altitude Adirondack lakes. We documented changes in application rates of deicing salt and sand over the last two decades along Route 73, and examined how soil chemistry and physical structure, and paper birch abundance and age-structure had changed along the roadside. Our objectives were to provide answers to a working group comprised of agencies responsible for regional environmental management (Adirondack Park Agency [APA], and New York State Departments of Transportation [NYSDOT] and Environmental Conservation [NYSDEC]) about whether roadside environmental quality had continued to decline since the mid 1980s and whether winter road management practices had caused a die-off of paper birch, as predicted by Fleck et al. (1988).

2. Methods

2.1. Study sites

The Cascade Pass (44.226° N, 75.875° W, elevation 625 m above mean sea level [amsl]) and Chapel Pond Pass (44.140° N, 73.747° W; elevation 485 m amsl) are narrow mountain passes bordered by steep slopes (e.g., 70° at Cascade Pass) composed of anorthosite and syenite that lie within the Adirondack Park of New York State (Van Diver, 1985, Fig. 1); soils are classified as leptosols with a fine sandy loam texture. NYS Route 73 is a narrow 2-lane highway with minimal shoulder perched along a steep slope adjacent to the Cascade Lakes at Cascade Pass and Chapel Pond at Chapel Pond Pass; at the time of the study the speed limit was 90 km/h and the annual (2001) mean traffic volume was 3360 vehicles/d. The Cascade Pass climate is similar but windier, colder, and snowier than the nearest weather station at Lake Placid, New York due to the higher elevation and narrow valley that is subject to frequent high winds. Lower-elevation Chapel Pond Pass has a less severe winter climate than Cascade Pass. At Lake Placid, the monthly mean low temperature is below 0 °C from November through April, and total precipitation averages 42 cm during the six winter months. The region averaged 77 ± SE 6.3 winter storm events requiring salting per year during winters 1998–99 to 2003–04. The typical 'snow season' lasts from November to April, although winter storm events can also occur in October and May (Fig. 2).

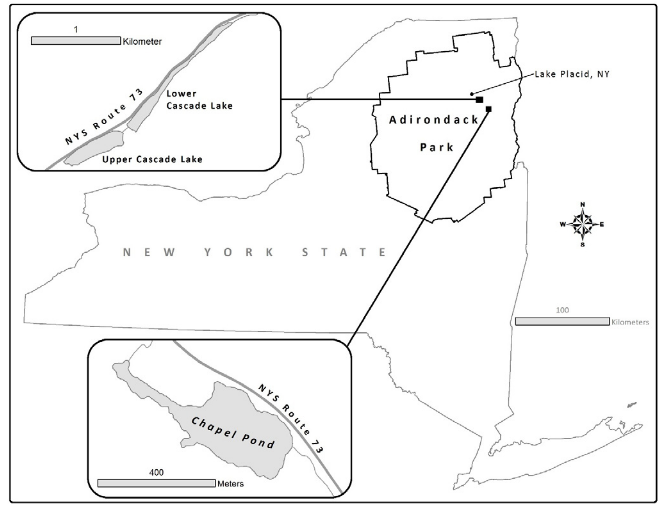

Fig. 1. Location of the two study sites along NYS Route 73 in the Adirondack Park of New York State, USA.

The plant communities in the region of the passes were red spruce – northern hardwood forest, spruce-fir forest, and boreal talus woodland (Thompson and Sorenson, 2000). At Cascade Pass, paper birch was the dominant tree species in 1985, but was largely replaced by red spruce (*Picea rubens*) and balsam fir (*Abies balsamea*) in 2005. Dating via tree rings indicated that the cohort of paper birch trees established around 1915 (Fleck et al., 1988); forest fires burned the Cascade Pass in 1903 and 1913, and birch trees became prevalent after these fires (McMartin, 1994).

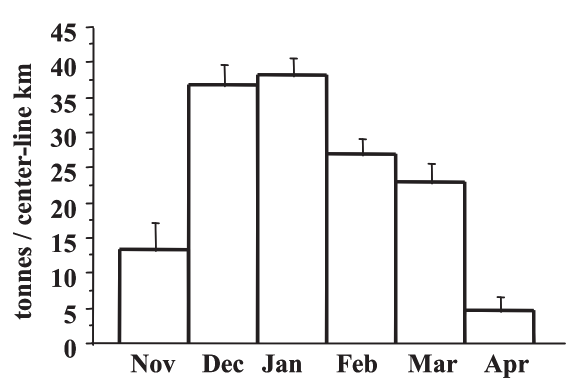

Fig. 2. Mean + SE cumulative application per month of deicing road salt per month along NYS Route 73 in the Cascade Pass region. Data are the average of five winters (2000–2001 to 2004–2005).