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Long-term impact of de-icing salts on tree health in the Lake Tahoe Basin: Environmental influences and interactions with insects and diseases

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ABSTRACT

Lake Tahoe, on the boundary of California and Nevada, is world renown for its natural beauty and is also a popular location for winter-sporting activities. De-icing compounds, such as sodium chloride (NaCl), are used to maintain safe winter driving conditions. Sodium chloride, however, can damage roadside vegetation and affect surface and ground water quality. Our objectives were to: investigate the relationship among salt damage to trees and other damage (from insects, diseases, and other biotic and abiotic factors), examine the effects of vegetation characteristics and environmental factors on salt damage to trees, and to quantify the long-term impacts of de-icing salts on roadside conifers in the Tahoe Basin. From 2006 to 2008, 442 square plots (0.1 ha) were established and surveyed throughout the Lake Tahoe Basin, including 176 control plots > 300 m from roads, and 137 plots originally established in 1990 that were used for long-term trends. Both incidence and severity of salt damage, diseases, insect pests, and other abiotic damage were recorded on all trees within plots (more than 10,000 trees). Soil and vegetation samples were collected from a subset of plots and analyzed for salt content. At least 15% of roadside trees were damaged by salt every year. Very large year-to-year variation in the incidence of salt damage was observed, but the severity of salt damage has decreased since 1990. A clear roadside effect on roadside conifers existed because symptoms of salt damage were only observed on trees in roadside plots and never in control plots, and foliage from trees in roadside plots had more sodium and chloride content than those in control plots for both salt symptomatic and asymptomatic foliage. Incidence of salt damage decreased with increasing distance from roads, was more frequent on rocky soils, and increased with downhill slope steepness and tree density. Pines (*Pinus* spp.) were more frequently and severely damaged by salt than firs (*Abies* spp.). Trees were more likely to be damaged by something other than salt, and the relationship among salt damage and other damages was antagonistic rather than synergistic. The results from this study have important implications for the ecology and management of conifer forests in relation to salinity and road maintenance.

1. Introduction

Each day, thousands of people visit Lake Tahoe, world renown for its natural beauty and crystalline waters (Fig. 1). It is a challenge to both maintain healthy forests and watersheds and to provide safe winter driving conditions for visitors and residents. During the winter months of 1990–2008, the California and Nevada Departments of Transportation used sodium chloride (NaCl) alone, in brine solution, or in combination with sand to keep roads clear of snow and ice. Sodium chloride (NaCl) is readily available, effective and inexpensive, and it is the de-icing compound most commonly used by highway departments (Barker et al., 2003). In the winter season of 1989–1990, the Nevada Department of Transportation also applied some calcium magnesium acetate (CMA) to roads in the Tahoe Basin to test its effectiveness. Salt and de-icing compounds potentially have a negative effect on forest health. Forests in the Lake Tahoe Basin are comprised of conifers that are more susceptible to damage from salt spray compared to hardwood species because they retain their foliage through the winter months when salt is applied to roads. Tip dieback and leaf scorch are the typical symptoms associated with salt damage on conifers. As the tips die, there is a sharp contrast between the brown dead tips and the remaining green foliage (Scharpf and Srago, 1974). In addition to the loss of aesthetic value of trees due to salt damage, loss of canopy cover could result in increased erosion of unprotected soils (RCI, 1990). Soil erosion is a concern in Lake Tahoe where excellent water clarity is desired.

Salt ions cause osmotic and ionic stress to plants (Tester and Davenport, 2003; Munns and Tester, 2008). Soil salinity interferes with both water and nutrient uptake by roots (Tester and Davenport, 2003). Sodium and chloride ions in the soil are absorbed

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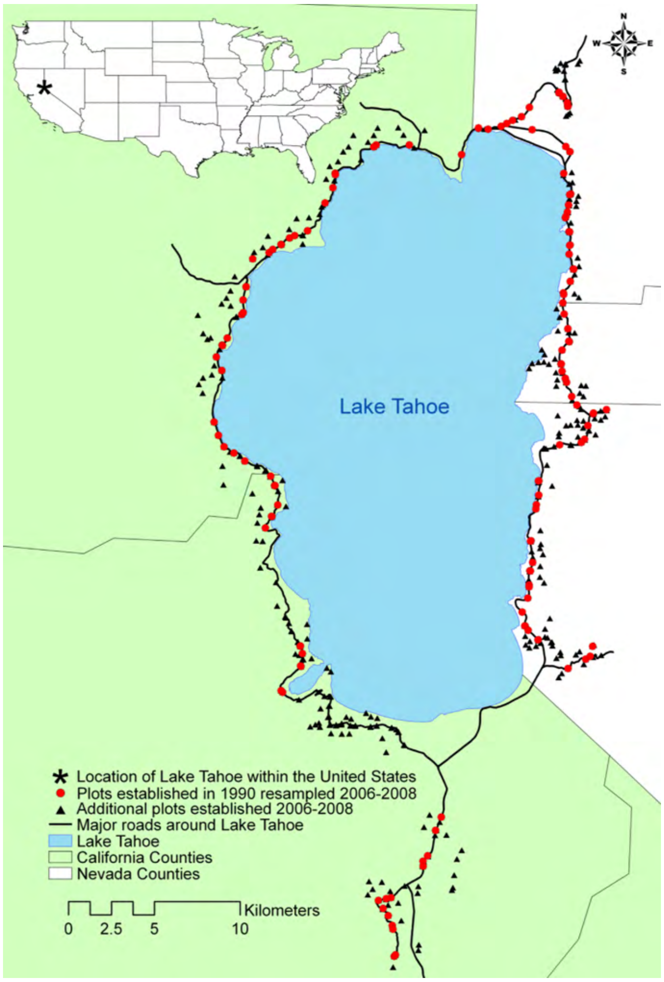

Fig. 1. Map of Lake Tahoe and study plot locations.

by roots and transported to leaves in the transpiration stream. There is little evidence that salt ions return to the roots via the phloem; therefore, salt ions accumulate at greater concentrations in leaves than in roots (Tester and Davenport, 2003). In addition, salt ions from aerial deposition or salt spray enter leaves directly via the cuticle (Franke, 1964; Benes et al., 1996). At excessive levels, ions cause toxicity in leaves, but the exact mechanisms are unknown. Possible toxicity mechanisms include: dehydration of cells, inhibition of enzymes involved with carbohydrate metabolism, or impairment of photosynthesis (Munns and Tester, 2008). In addition to the direct effects of toxicity, accumulation of salt ions in plant tissues also reduces frost hardiness (Sucoff et al., 1976) and drought tolerance (Maas, 1985).

The effects of de-icing compounds to roadside trees have been studied broadly in cold regions such as: northern Europe (Buschbom, 1980; Viskari and Kärenlampi, 2000; Pedersen et al., 2000; Czerniawska-Kusza et al., 2004), Canada (Hofstra and Hall, 1971; Lumis et al., 1973; Foster and Maun, 1978; Hofstra and Smith, 1984), Japan (Kayama et al., 2003), and the U.S.A. (Holmes, 1961; Shortle and Rich, 1970; Sucoff et al., 1975; Barrick et al., 1979). The effects of salt application to roadside trees have also been investigated in the Lake Tahoe Basin (Scharpf and Srago, 1974; Massoth, 1978; Marshall, 1984; Kliejunas et al., 1989; RCI, 1990), and of these, the study by RCI (1990) was the most extensive prior to our study. Although these studies provide ample evidence to support the hypothesis that application of NaCl to roads causes damage to roadside vegetation, particularly to conifers, prior studies from the Lake Tahoe Basin typically lack control plots at suitable distances from roads. For example, only nine control plots were established by RCI (1990) and no control plots were established for the four other studies (Scharpf and Srago, 1974; Marshall, 1984; Massoth, 1978; Kliejunas et al., 1989). Furthermore, several biotic and abiotic agents such as drought, winter injury, pine needle miner (*Coleotechnites* sp.), and the pathogen *Elytroderma deformans* (Weir) Darker) cause symptoms that could be mistaken by the casual observer for those caused by salt damage. Therefore, it is important to establish control plots and detailed sampling protocols in order to quantify the damage caused by other abiotic and biotic agents from the damage caused by de-icing compounds to roadside trees and to quantify synergistic relationships among the different types of damage. Compared to the study by RCI (1990), the current study established more roadside plots, approximately equal numbers of roadside and control plots, and data were collected during three consecutive years.

The incidence and severity of salt damage to trees varies from year-to-year (Viskari and Kärenlampi, 2000). Accordingly, it is important to collect data for more than one year because damage could be especially severe some years or not obvious in others. In addition, the study by RCI (1990) was conducted 18 years ago. Since then, the Lake Tahoe Basin has been increasingly urbanized and management practices to clear snow and ice from roads have changed. For example, the annual amount of salt applied has decreased since the late 1980s partly due to new practices such as using weather information systems to determine when to pre-treat roads before storms. To meet the stringent water quality standards in the Tahoe Basin, several agencies collaborate to manage storm water runoff using best management practices such as detention basins, infiltration trenches, revegetation efforts, and constructed wetlands (TIRRS, 2001). In spite of these best management practices, salt could be accumulating in soils, and hence past use may continue to have adverse effects on existing vegetation. The design of the plots established by RCI (1990) and in the current study is very similar and, consequently, results from the two studies can be readily compared to make inferences about the long-term effects of road salt application and increasing urbanization in the Lake Tahoe Basin.

Our objectives were to: (i) assess both incidence and severity of damage caused by salt (NaCl), biotic, and other abiotic agents to trees in roadside plots compared to trees in control plots; (ii) investigate the influence of vegetation and the environment on the incidence of salt damage; (iii) investigate the relationship among salt damage and tree health; (iv) to establish a link between damage observed in roadside trees and salt content on foliage and soil samples; and (v) assess the long-term impacts of de-icing salts on roadside conifers.

2. Materials and methods

2.1. Study area

Lake Tahoe, with a surface area of 495 km^2 and at an average elevation of 1897 m at its surface (39°N, 120°W), is one of the largest high elevation lakes in the world (USGS, 2008). Lake Tahoe is surrounded by steep mountains (up to 3320 m elevation) that comprise a basin of 1363 km^2 (USDA NRCS, 2007). The Tahoe Basin is in the Sierra Nevada and lies on the border of California and Nevada. Except for soils in the northern shore of the lake that are of volcanic origin, most soils around the lake are of granitic origin (Rogers, 1974).

Climate in the Tahoe Basin is characterized by dry summers and wet winters. Mean daily temperatures at lake elevation are 16 °C and −2 °C for July and December respectively. Annual cumulative