Roadside Vegetation Health Condition and Magnesium Chloride (MgCl2) Dust Suppressant Use in Two Colorado, U.S. Counties

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Roadside Vegetation Health Condition and Magnesium Chloride ($MgCl_2$) Dust Suppressant Use in Two Colorado, U.S. Counties

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Abstract. Many abiotic and biotic factors affect the health of roadside vegetation, including the application of magnesium chloride ($MgCl_2$) dust suppression products. Three hundred seventy kilometers (230 mi) of forested, shrubland, meadow, rangeland, riparian, and wetland roadside habitats were surveyed along major nonpaved roads in two Colorado counties. Dominant species composition and visible damages of woody roadside vegetation were quantified. The majority (72.3% to 79.3%) of roadside vegetation surveyed was considered healthy (less than 5% damage to crown or stem), depending on slope position from the road. Severely damaged (greater than 50% damage) vegetation ranged from 6.4% to 11.4% of roadside cover, with the most severely damaged vegetation occurring downslope from the road. Percent of plants with severe or moderate damage increased with increasing $MgCl_2$ application rates for roadside aspen, Engelmann spruce, and lodgepole and ponderosa pines. Further research is needed to determine the distribution of $MgCl_2$ ions, nutrients, and interactions between $MgCl_2$ and incidence of potential biotic damage agents in roadside soils and plants.

Key Words. Aspen; lodgepole pine; magnesium chloride ($MgCl_2$); ponderosa pine; road dust control; road stabilization.

Biotic and abiotic stressors may influence the health of roadside vegetation individually or by interacting with one another. Colorado, U.S. roadside vegetation may be exposed to stresses analogous to off-road vegetation, including fungal pathogens, parasitic plants, insects, or drought (Cranshaw et al. 2000). Roadside vegetation may also be exposed to more intense abiotic factors than off-road vegetation that include pollution (Lagerwerff and Specht 1970; Monaci et al. 2000), erosion of road materials (Kahklen 2001), and road maintenance practices such as dust suppressant application and a concomitant increase in soluble salts in roadside soils and vegetation (Strong 1944; Westing 1969; Stravinskiene 2001; Hagle 2002; Piechota et al. 2004). Woody vegetation, particularly coniferous trees, is a reliable bioindicator of abiotic stress because of its perennial nature, needle retention, and large surface area and biomass per tissue weight (Monaci et al. 2000).

Magnesium chloride ($MgCl_2$)-based dust suppression products are applied to nonpaved roads during spring and summer months for dust suppression and road stabilization purposes. Chloride-based dust suppressants are used to control erosion and fugitive dust and reduce maintenance costs on nonpaved roads by stabilizing soil and drawing moisture from the atmosphere to keep road surfaces damp (Addo et al. 2004; Piechota et al. 2004). Dust from nonpaved roads can contribute significantly to atmospheric particulate matter, which has numerous environmental and human health effects (Sanders et al. 1997; Environment Canada and Health Canada 2001; Singh et al. 2003). The U.S. Environmental Protection Agency has established air quality standards for fine particulate matter (PM-10). Municipal road and bridge departments in arid climates can suppress PM-10 emissions on nonpaved roads by applied chemical dust suppression products (Singh et al. 2003).

Investigations of sodium chloride (NaCl)-based deicing salts and roadside tree health began as early as the 1950s because of concern over injured roadside trees, and thus the negative impacts of NaCl salts on roadside vegetation are well documented (French 1959; Shortle and Rich 1970; Hall et al. 1972; Hall et al. 1973; Dirr 1976; Hofstra et al. 1979; Viskari and Karenlampi 2000; Kayama et al. 2003; Czerniawska-Kusza et al. 2004). The most significant symptoms of NaCl damage to roadside trees are reduction in biomass, marginal or full leaf chlorosis and necrosis, withered leaf margins, branch dieback, or plant mortality (Westing 1969; Shortle and Rich 1970; Hofstra and Hall 1971; Hall et al. 1972, 1973; Dirr 1976; Hofstra et al. 1979; Czerniawska-Kusza et al. 2004; Trahan and Peterson 2007). Various biochemical and physical problems occur in plants growing in saline soils, attributable singly or in combination to ion toxicities and osmotic changes in the plant (Ziska et al. 1991; Munns 2002). Both sodium and chloride ions have been indicated as the causal agents of roadside tree dieback and other symptoms (Hofstra and Hall 1971; Hall et al. 1972; Lumis et al. 1973; Hofstra et al. 1979; Viskari and Karenlampi 2000; Czerniawska-Kusza et al. 2004).

Compared with available information on NaCl, there is substantially less published research that documents the impact of dust suppressant constituents such as $MgCl_2$ on roadside environments. The use of chemical dust suppressants is increasing in the United States as a result of increases in population and traffic, especially in arid regions (Piechota et al. 2004). Potential impacts of chloride-based dust suppressants to roadside soils and vegetation may vary slightly from those related to deicing salt exposure, primarily through the timing of dust suppressants, which are applied to roads when roadside trees are actively growing and transpiring; the limitation of aerial drift and spray from dust suppression products (Strong 1944; Hofstra and Hall 1971; Trahan and Peterson 2007); and the absence of snowmelt to dilute soil salts (Trahan and Peterson 2007). The detrimental effects that high concentrations of soluble salts in roadside soils cause to vegetation may be similar between both road maintenance practices. Roadside trees along nonpaved roads treated with $MgCl_2$ and calcium chloride dust suppression products have exhibited comparable symptoms to those recorded as NaCl damage such as leaf scorching, marginal necrosis, and needle tip burn (Strong 1944; Hagle 2002; Piechota et al. 2004).

A roadside survey was conducted along nonpaved roads both treated and nontreated with $MgCl_2$-based dust suppression products in Larimer and Grand Counties in northern Colorado. The specific objectives of this roadside survey were to 1) define major habitat types and dominant roadside species composition along major, nonpaved county roads both treated and nontreated with $MgCl_2$-based dust suppressants throughout both counties; 2) determine the visible health conditions of dominant roadside vegetation; and 3) determine site factors' influence on vegetation health along these roads and view the relationships between site factors and patterns of damage.

METHODS AND MATERIALS

Larimer County is located in north central Colorado (Figure 1). Elevation along study roads ranged from 1,753 to 3,210 m (5,785 to 10,593 ft) and the dominant habitat types ranged from lowland shrub and grass cover to high-elevation mixed spruce and fir forests. Grand County is located in northwestern Colorado and study roads ranged in elevation from 2,484 to 2,780 m (8,197 to 9,174 ft) (Figure 1). In 2004, Larimer County had 938 km (563 mi) of nonpaved roads and 60% of these roads were treated with $MgCl_2$-based dust suppression products (563 km [338 mi]) (D.L. Miller, Larimer County Road and Bridge Department, 2006, pers. comm.). Grand County had 1,143 km (686 mi) of nonpaved roads in 2004 and approximately 25% of these roads were treated with $MgCl_2$-based dust suppression products (292 km [175 mi]) (A. Green, Grand County Department of Road and Bridge, 2006, pers. comm.).

Two hundred sixty-seven kilometers (160 mi) of nonpaved roads were surveyed in Larimer County (n = 33 roads, 29% of total county mileage). Ninety-seven kilometers (58 mi) were surveyed along nonpaved roads in Grand County (n = 22 roads, 8% of total county mileage) in spring and summer of 2004. Roads were selected to survey using county maps and information regarding $MgCl_2$ treatment, land ownership, and occurrence of continuous roadside vegetation of county-maintained or -owned roads (D.L. Miller, Larimer County Road and Bridge Department and A. Green, Grand County Department of Road and Bridge, 2006, pers. comm.). Major county roads of interest to the researchers were those that ran through forested habitats and public, federal, or state land, so permanent vegetation health plots could be implemented in the future. Therefore, the vegetation composition along surveyed roads does not accurately extrapolate up to actual percentages of different habitats along total nonpaved road mileage in each county. Road sections were eliminated from the survey if they occurred through housing developments or other locations with extensive disturbance, removal of native vegetation, irrigation, or lack of continuous roadside habitat. Single or two-track roads were not surveyed and are not comparable to maintained roads because of the major differences between road width, vehicular use, and potential habitat disturbance, although these types of roads are included in nonpaved road mileage in both counties.

On each road, two plots, 30.5 m (100.65 ft) wide by 6 m (19.8 ft) deep, were visually estimated on both sides of the road every 0.32 km (0.19 mi). Global Position System waypoints were recorded along with site factors such as elevation, habitat, and slope position from road edge at each plot. The percent cover of the top five dominant species (adding up to 100% cover at each stop) and any disturbances were recorded at each plot (n = 2,055 treated road plots, n = 528 nontreated road plots). Visible damage and health condition were recorded for each species based on visible damage to crown, stem, or branches; percent crown defoliation or discoloration; amount of dead branches; or biotic disease symptoms obvious from the road (foliar brooms or visible fungal cankers). Severely damaged vegetation had damage to crowns or stem circumference greater than 50%, moder-

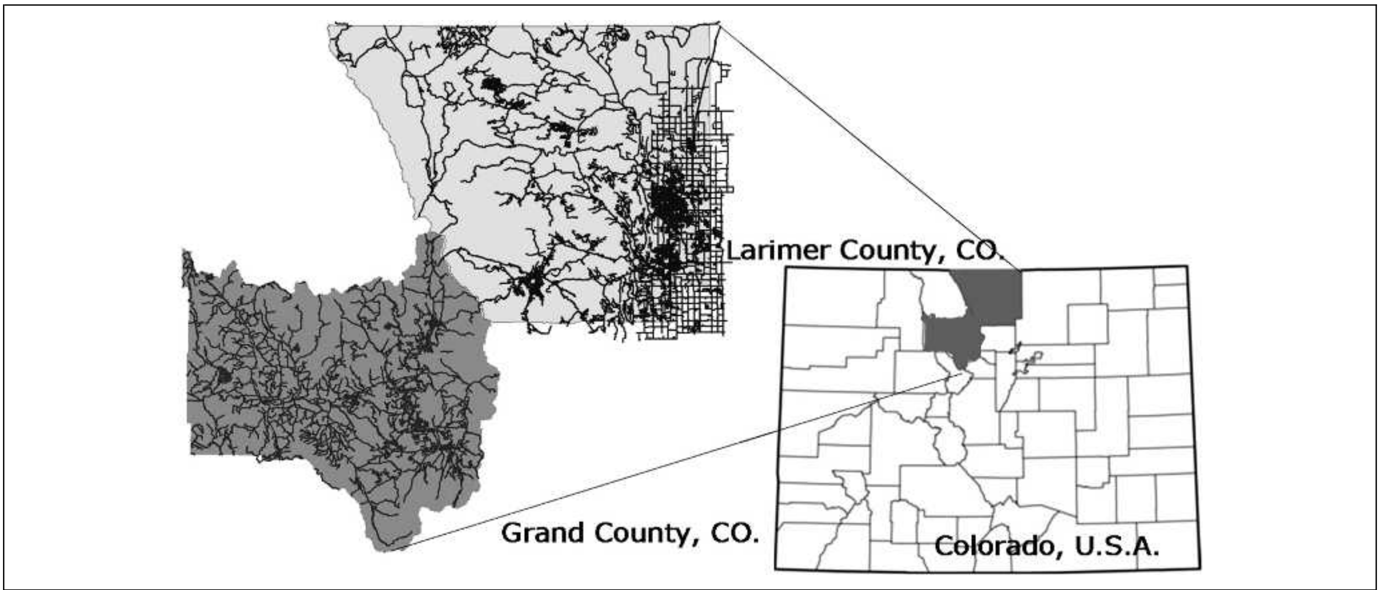

Figure 1. Borders and road networks of Grand and Larimer Counties, Colorado.

ately damaged vegetation had damage ranging from 26% to 50%, mildly damaged vegetation ranged from 5% to 25% damage, and nondamaged (healthy) vegetation had less than 5% damage.

County roads varied in maintenance procedures, years of treatment, cumulative and average amount of $MgCl_2$ applied, and chemical specificity of dust suppressants. Quantitative calculations of application procedures and rates (total and average kg/km^{æ}· of $MgCl_2$ applied calculated from gal/mi^{-1} of $MgCl_2$ solution applied, removing gallons of any other products applied such as lignosulfonates) were gathered for study roads following the survey (Larimer County Road and Bridge Department and Grand County Department of Road and Bridge, 2006, pers. comm.). Spatially gridded (800 m [2640 ft]), averaged monthly, and annual precipitation data for the climatologic period 1971 to 2000 (PRISM Group at Oregon State University 2006) were gathered at a midpoint on each study road after this survey ($n = 55$).

Statistical Analysis

Frequencies of habitat types and species composition were produced with The Frequency Procedure (SAS 9.1, Copyright 2002–2003; SAS Institute Inc., Cary, NC). Vegetation cover and health condition were analyzed by fitting random and fixed effects in The Mixed Procedure. Fixed effects included $MgCl_2$ application information (total and average kg/km^{æ}· $MgCl_2$ applied), slope position (upslope, downslope, or no slope from the road edge), county, and precipitation (summer: May to September, winter: October to April, and yearly averages). Roads were treated as random effects nested within counties. Least square means of class effects were compared and Type 3 tests of fixed effects and Fisher's least significant difference was used to determine statistical significance ($P \leq 0.05$) between each site factor and roadside species health condition (healthy, mild, moderate, or severely damaged). Multiple regression was used to compare relationships between effects, and the solution function was used to determine slopes for continuous fixed variables (application rate, slope position, and tree health status interactions), holding precipitation at a 30 year average summer constant throughout the analysis. Levels of significance are indicated as $P < 0.0001$, $P < 0.05$, or $P < 0.10$ on all tables and figures.

RESULTS

Habitat Types and Species Composition

Habitat types were based on the dominant vegetation type in the area and six major habitats were prevalent throughout surveyed roads in both counties (Table 1). The major types along surveyed roads in both counties were forested or wooded roadside areas followed by shrubland and riparian zones (Table 1). Lodgepole pine (*Pinus contorta*) and trembling aspen (*Populus tremuloides*) were principle components of roadside-forested areas along roads surveyed in both counties (Table 2). Ponderosa pine *(Pinus ponderosa*) was the dominant roadside species in Larimer County but did not occur along roadsides in Grand County. Subalpine fir (*Abies lasiocarpa*) and Engelmann spruce *(Picea engelmannii*) occurred along roadsides in both counties, although Larimer County had more mileage of both than Grand County (Table 2).

Riparian and shrubland communities were also frequent along roadsides surveyed in both counties (Table 1). Dominant shrub species throughout both counties in riparian habitats were willow (*Salix* spp.) and alder (*Alnus* spp.) species. Aspen was prevalent in riparian zones along with narrow-leaf cottonwood (*Populus angustifolia*) (Table 2). Big sagebrush (*Artemisia tridentata*) was the dominant shrub along roadsides in Grand County along with rabbitbrush species (*Chrysothamnus* spp.) (Table 2). In the foothills and eastern plains (Larimer County), some shrubland areas were dominated by shadescale or saltbush (*Atriplex confertifolia*) and rabbitbrush (Table 2). No prevalent herbaceous dominant ground cover species were identified in meadow or rangeland habitats along roads throughout the counties (Table 2). More meadow, rangeland, and shrubland kilometers were surveyed in Larimer County, accounting for the more diverse ground cover species richness in that county (Tables 1 and 2). Species occurring as more than 1% of total cover observed are

Table 1. Major habitat types, plot frequencies, and kilometers surveyed along nonpaved roads both treated and nontreated with $MgCl_2$-based dust suppression products in Grand and Larimer Counties, Colorado.

County	Habitat type	Plot frequency	Km (mi) of road cover
Grand	Forested/wooded	665	56.8 (35.3)
	Meadow	31	2.6 (1.6)
	Riparian	54	4.7 (2.9)
	Shrubland	341	29.3 (18.2)
	Wetland	34	2.9 (1.8)
	Rangeland	0	0.0 (0.0)
	Total	1125	96.2 (59.8)
Larimer	Forested/Wooded	841	157.6 (97.9)
	Meadow	39	7.4 (4.6)
	Riparian	250	46.8 (29.1)
	Shrubland	239	42.2 (26.2)
	Wetland	43	8.2 (5.1)
	Rangeland	38	7.1 (4.4)
	Total	1450	269.2 (167.3)

Table 2. Major dominant species and percent of roadside cover along nonpaved roads both treated and nontreated with $MgCl_2$-based dust suppression products surveyed in Grand and Larimer Counties, Colorado.

		Percent cover in each county	
Species	Common name	Grand	Larimer
Pinus ponderosa	Ponderosa pine	—	18.2
Populus tremuloides	Trembling aspen	18.8	17.1
Pinus contorta	Lodgepole pine	29.4	15.3
Salix spp.	Willow	11.6	7.8
Artemesia tridentata	Big sagebrush	14.8	0.3
Chrysothamnus spp.	Rabbitbrush	6.1	6.3
Picea engelmannii	Engelmann spruce	2.3	5.0
Pseudotsuga menziesii	Douglas-fir	1.2	4.9
Alnus spp.	Alder species	3.5	4.5
Juniperus scopulorum	Rocky Mt. juniper	4.0	3.4
Abies lasiocarpa	Subalpine fir	2.7	2.8
Rhus trilobata	Skunkbush	—	1.9
Amelanchier alnifolia	Serviceberry	1.6	—
Populus angustifolia	Narrowleaf cottonwood	1.2	1.8
Pinus flexilis	Limber pine	0.2	1.7
Acer glabrum	Rocky Mt. maple	0.3	1.4
Atriplex confertifolia	Saltbush	—	1.1

Table 3. Percentage of species healthy and severely damaged along nonpaved roads treated and nontreated with $MgCl_2$-based dust suppression products in Grand and Larimer Counties, Colorado.[z]

Abies lasiocarpa
Acer glabrum
Alnus
Artemesia tridentata
Chrysothamnus
Juniperus scopulorum
Pinus contorta
Pinus flexilus
Picea engelmannii
Pinus ponderosa
Populus angustifolia
Populus tremuloides
Pseudotsuga menzeisii
Salix

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Health Conditions of Dominant Roadside Vegetation

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Lodgepole Pine ( )

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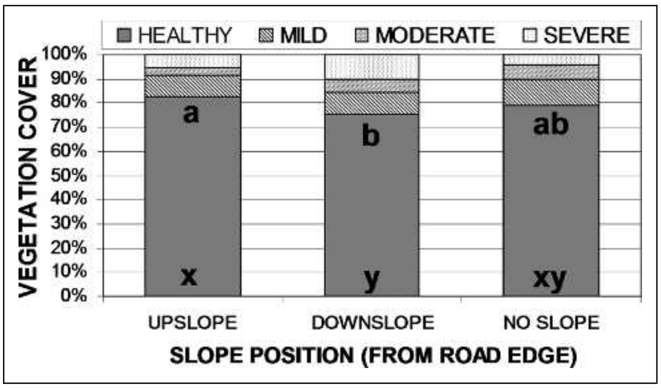

Figure 2. Roadside vegetation health condition adjusted means along nonpaved roads both treated and nontreated with $MgCl_2$-based dust suppression products in Larimer and Grand Counties by slope position from road edge (healthy = less than 5% damage, mild = 5% to 25% damage, moderate = 26% to 50% damage, severe = greater than 50% damage to crown or stem; = 2,583 plots including vegetation). Letters (a, b, ab) signify significant differences (< 0.05) between percent of severely damaged vegetation among upslope, downslope, and no slope positions. Symbols (x, y, xy) signify significant differences (< 0.05) between percent of healthy vegetation among upslope, downslope, and no slope positions.

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Ponderosa Pine ( )

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Aspen ( )

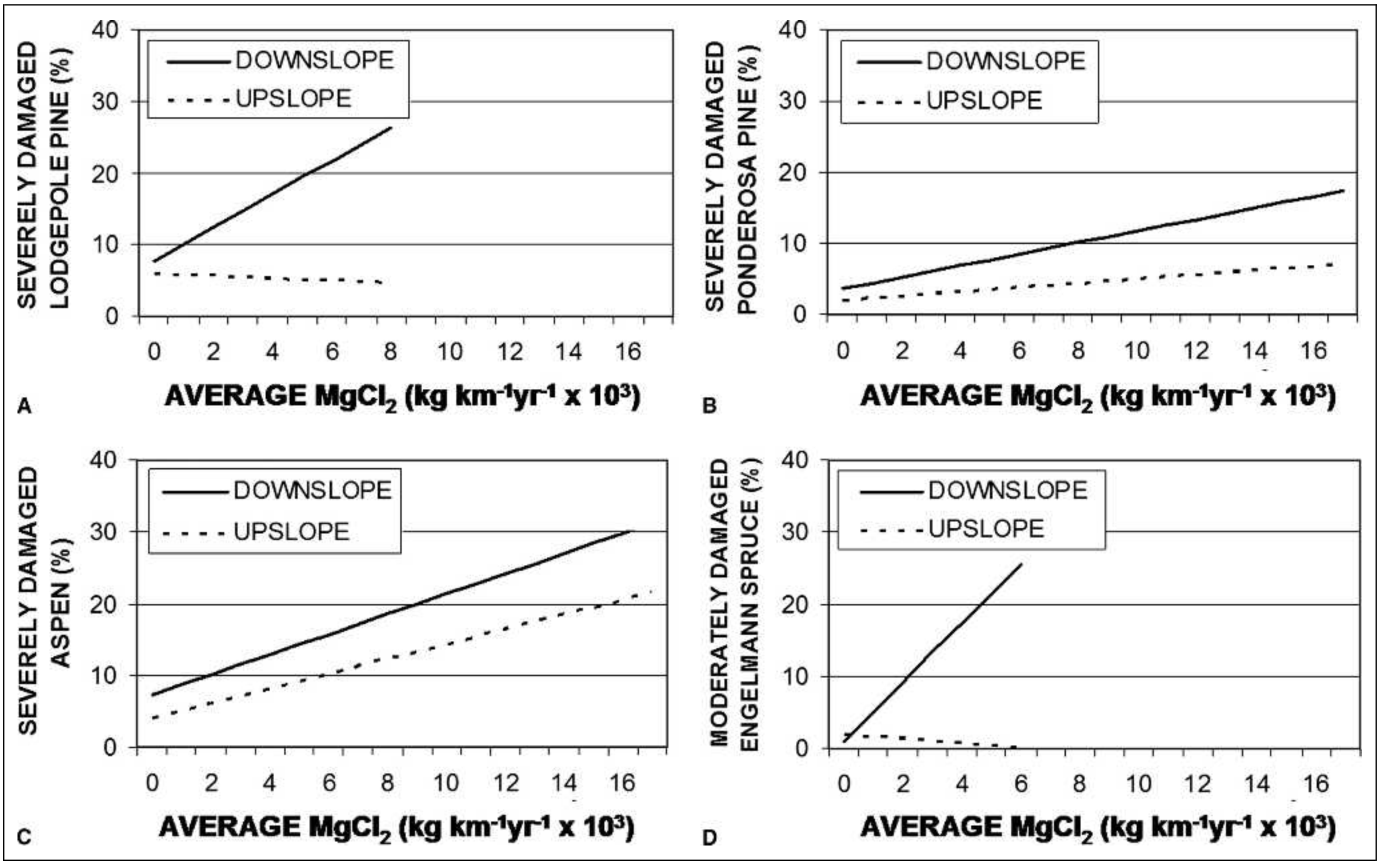

Figure 3. Modeled percent severely damaged lodgepole pine (A), ponderosa pine (B), and trembling aspen (C) and moderately damaged Engelmann spruce (D) adjusted means along nonpaved roads both treated and nontreated with $MgCl_2$-based dust suppression products in Larimer and Grand Counties by slope position and increasing amount of $MgCl_2$ applied per year (kg/km^{-1}/year^{-1}). The solution function in SAS 9.1 used to generate slopes for each species and slope position and only site factors that were significant at < 0.05 are illustrated.

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Engelmann Spruce ( )

æ – – –

$P =$

Alder (spp.) and Willow (spp.)

Big Sagebrush ( ) and Rabbitbrush (spp.)

Influence of Precipitation Rates

$P =$

$P =$
$P =$

P
P

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Salix
Juniperus scopulorum

Acknowledgments.

Betula papyrifera

Picea abies

Picea glehnii

Pinus sylvestris

Prunus salicina

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Résumé.

Zusammenfassung.

Resumen.