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Species, tree size, and overstory environment affect likelihood of ice storm damage to understory trees in a mature Douglas-fir forest

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ABSTRACT

Glaze events (i.e., ice storms) are a potential source of disturbance whose effects have not been heavily researched in forests in the Pacific Northwest. This study examines the effects of species, size, and overstory environment on occurrence, source, and severity of damage sustained by planted understory trees in a mature Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) forest as a result of the glaze event that struck the central Oregon Coast Range in November 2014. Understory tree species were Douglas-fir, grand fir (*Abies grandis* (Douglas ex D. Don) Lindl.), western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), and western redcedar (*Thuja plicata* Donn ex D. Don). Overall, western redcedar was damaged least frequently, and western hemlock was damaged most frequently. Redcedar was less susceptible to crown damage and more susceptible to bending damage than the other three species, while hemlock showed the opposite trend. We found significantly lower ($P < 0.001$) likelihoods of ice loading damage to understory trees from increasing overstory basal area under both conifers and hardwoods, but significantly higher ($P = 0.006$ and $P < 0.001$ respectively) likelihoods of damage from falling debris. The opposition of these trends resulted in no change in likelihood of damage occurrence with increasing overstory conifer density ($P = 0.544$), while likelihood of damage was higher under increasing hardwood density ($P < 0.001$). In examining the influence of tree size, we found that increasing diameter at breast height resulted in a significantly lower likelihood of bending ($P = 0.009$), but a significantly higher likelihood of crown loss ($P < 0.001$). Finally, we saw significantly higher likelihoods of both bending ($P < 0.001$) and crown loss ($P = 0.009$) with increasing height:diameter ratio. These results suggest that managers may want to consider overstory environment, species, and understory tree size when planning for the risk of future glaze events.

1. Introduction

The potential for natural disturbances to interact with silvicultural practices has always presented challenges for forest managers. Disturbances can variably impact stands, depending upon management objectives and event severity (Brown, 1975; Pickett and White, 1985; Fettig et al., 2007). When management objectives call for late-successional and old-growth (LSOG) structure, disturbance events may play important roles in facilitating structural development (Franklin et al., 2002). However, disturbances that kill or damage key LSOG features such as understory trees planted to promote vertical canopy layering or increase species diversity in young stands may still be undesirable. If some form of future timber production is also intended, the damage to potential merchantable timber from such disturbances may make them even more problematic (Kangur, 1973; Reukema, 1979). Thus, knowledge of the impacts of disturbance events is important so that forest managers can determine if planning or intervention is required to meet ecological or commercial objectives, or reduce the risk of catastrophic disturbance.

In the Oregon Coast Range, wildfire and windthrow are the two primary sources of natural disturbance (Spies and Cline, 1988), and their effects on stand development have been thoroughly studied (e.g., Palmer et al., 2000; Rumbaitis del Rio, 2006; Van Pelt and Franklin, 1999; Boerner, 1982; Heinselman, 1973). Major ice storms have received less attention in the Pacific Northwest (PNW), though from 1949 to 2000, there were five severe ice storms across the PNW (Changnon, 2003). By contrast, there were 59 large (> 40ha burned) timber fires across the PNW in 2014 alone (NWCC, 2015).

An ice storm, or "glaze event," is defined as an event where ice accumulations reach at least 6.35 m (NWS, 2009). Glaze events create partial canopy disturbances that modify forest structure by altering the overstory environment, as well as damaging understory trees and shrubs. Damage may result from either direct (i.e., ice loading) or indirect (i.e., falling debris) sources (Boerner et al., 1988) and can affect

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trees in several ways, with varying degrees of severity (Bragg et al., 2003; Nykänen et al., 1997). Slight bending and minor crown loss generally will not result in long-term negative effects, while trees that are bent prone, uprooted, or suffer major crown loss are at high risk of mortality, and those that survive are unlikely to recover fully (Bragg et al., 2003; Bragg and Shelton, 2010; Hopkin et al., 2003).

As with any disturbance, silvicultural treatments can impact the severity of glaze events. The effects of treatments can be difficult to predict, due to the sheer number of variables that contribute to glaze damage (Bragg et al., 2003). For instance, in eastern Ontario, Nielsen et al. (2003) found some variation in overstory damage with stand type, but no significant difference between managed and unmanaged stands; others, however, have found that recent thinning can make stands much more susceptible to glazing (McCulloch, 1943; Shepard, 1975).

Disturbance/management interactions are further complicated by the considerable number of factors that influence both individual tree and stand-level responses to glaze events. At the individual tree scale, the type and severity of ice damage sustained can be influenced by species (Boerner et al., 1988; Lafon, 2006) and differences in properties such as crown form, branch angle, and wood strength (Bragg et al., 2003; Bruederle and Stearns, 1985; Van Dyke, 1999). For instance, ice/snow interception is largely a function of crown surface area (Kangur, 1973; Lemon, 1961) and, consequently, deciduous vs. evergreen habit (Boerner et al. 1988; Lemon, 1961).

Tree size and canopy position also influence glaze damage susceptibility, independent of species. In general, smaller trees tend to be more prone to bending, while larger individuals are more likely to lose canopy (Lafon, 2006; Shepard, 1975). Damage severity tends to show a non-linear trend, where small trees receive the least severe damage, intermediate-sized trees receive the most, and large trees receive an intermediate amount (Hopkin et al., 2003; Nielsen et al., 2003). For example, trees occupying dominant/codominant positions in the canopy generally receive more damage than suppressed trees that are less exposed to ice loading (Rebertus et al., 1997). All of these factors, along with environment, topography, soil saturation, storm severity, and wind speed can influence the amount of glaze damage received by the forest canopy; in turn, the canopy environment and severity of canopy damage affect the damage to understory trees (Bragg et al., 2003).

Much of this information, however, comes from regions where ice storms are more common, such as Canada and the northeastern US. Literature describing the impacts of glaze disturbances in westside forests of the PNW is scarce, although some work has been done on snow loading, which is functionally similar (Kangur, 1973; Maguire et al., 2006; Reukema, 1979; Williams, Jr., 1966). While significant glaze events are rare west of the Cascades in the PNW, they have the potential to have long-term impacts, particularly on multi-aged stands (Abrams and Scott, 1989; Lemon, 1961; Whitney and Johnson, 1984). Little information exists, however, on how glaze disturbance impacts understory cohorts in multi-aged, westside forest ecosystems.

In November 2014, a major ice storm struck the central Oregon Coast Range, causing significant overstory damage including branch loss, top break-out, and uprooting (Withrow-Robinson, 2014). This storm provided an excellent opportunity to study the interactions between disturbance and management on the understory cohort of Douglas-fir stands managed using a multi-aged system. The Mature Forest Study (MFS) is an ongoing silvicultural study on residual overstory trees, underplanted seedlings, and stand structural diversity under a combination of variable density thinning, planting, and understory vegetation management (Brandeis et al., 2001; Newton and Cole, 2015). One of the sites for this study is located in the foothills of the central Oregon Coast Range, an area that received significant storm damage during the November 2014 glaze event. Using the MFS as a framework, the objectives of this study were to determine how: (1) frequency of damage occurrence, type, and severity differed among planted understory tree species; (2) likelihood of total, direct, and indirect damage varied with overstory density; and (3) severity of bending and crown damage varied with planted understory tree size.

2. Methods

2.1. Study site

All data for this study were collected at the McDonald Forest site within the MFS (detailed site descriptions are available in Nabel et al., 2013). McDonald Forest is located in the eastern Oregon Coast Range, 8 km north of Corvallis, OR. The area has a warm climate with a long summer dry season with low relative humidity. The McDonald Forest MFS sites were originally planted around 1940, with overstory ages of 50–53 years when the study began in 1993. At the time of thinning, the overstory at McDonald was composed mostly of planted Douglas-fir, with some naturally regenerated bigleaf maple (*Acer macrophyllum* Pursh) and grand fir (*Abies grandis* (Douglas ex D. Don) Lindl.) scattered throughout. The understory was mainly dominated by fern and shrub species. The most abundant of these were western sword fern (*Polystichum munitum* (Kaulf.) C. Presl.), western bracken fern (*Pteridium aquilinum* (L.) Kuhn), trailing blackberry (*Rubus ursinus* Cham. & Schltdl.), Himalaya blackberry (*Rubus armeniacus* Focke), Pacific poison oak (*Toxicodendron diversilobum* (Torr. & A. Gray) Greene), hazel (*Corylus cornuta* Marshall), and ocean spray (*Holodiscus discolor* (Pursh) Maxim.). Prior to the MFS, the site was thinned in 1964 and again in 1980. The ice storm occurred on November 13–14, 2014, when the overstory was approximately 70 years old and the underplantings were 21 years old.

The 2014 ice storm impacted 2760 ha of forestlands centered around Blodgett, OR, including the MFS sites on the McDonald Forest. Ice thickness generally ranged from 13 to 19 mm, with localized accumulations up to 51 mm (NOAA, 2014; Norlander and Kanaskie (2014), Withrow-Robinson, 2014). Freezing rain contributed to ice accumulations over a 15-h period (NOAA, 2014), and the ice generally melted within 24–36 h of the end of the glaze event.

2.2. Experimental design

The Mature Forest Study was designed as a randomized complete block experiment with a split-split plot arrangement of treatments (Fig. 1). Three 20-ha blocks were established by relative site quality in McDonald Forest. Each of the three blocks contained two 10-ha whole plots. Within blocks, each whole plot was randomly assigned to receive either uniform thinning or gap thinning treatments. In uniform treatments, residual trees were left evenly-spaced throughout the whole plot. In the gap treatments, twelve 0.10-ha gaps and twelve 0.06-ha gaps were cleared within a matrix of evenly spaced trees.

Each whole plot was divided into four 2.5-ha subplots. Within whole plots, each subplot was randomly assigned to be thinned to low, medium, medium-high, and high levels of overstory retention (Table 1). All subplots were thinned from below (smaller trees removed, larger trees retained) during fall 1993. The medium and medium-high treatments were all rethinned to initial post-thinning density after 8 years. Overall, basal area was equivalent at each level of thinning for uniform and gap plots.

Each of these subplots was further divided into three 0.5-ha sub-subplots, surrounded by an 18-m buffer. Understory tree sampling occurred at the level of grids of planted trees within each of the sub-subplots nested within subplots (Appendix A: Fig. A.1). Each subplot was underplanted in January 1994 in a matrix consisting of 32 columns, with 3-m × 3-m spacing. Western redcedar [C] (*Thuja plicata* Donn ex D. Don), Douglas-fir [D], grand fir [G], and western hemlock [H] (*Tsuga heterophylla* (Raf.) Sarg.) seedlings were planted in pairs of columns by species, with a repeating order for the pairs (e.g., DDGGHHCC, repeated four times) randomly generated for each subplot. Each of the sub-subplots contained a 15-row subset of this subplot-level matrix. Western redcedar seedlings were containerized seedlings