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WIND DAMAGE IN ALTERNATIVE SILVICULTURAL SYSTEMS: REVIEW AND SYNTHESIS OF PREVIOUS STUDIES

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Abstract

In the Pacific Northwest region of North America ecological and social concerns surrounding the clear-cutting of forest stands have prompted a number of studies investigating alternative silvicultural systems. These alternatives generally involve different levels and patterns of retained trees, and are often referred to as green-tree retention or variable retention systems. Wind is a major natural disturbance agent in coastal forests and the potential for increased levels of wind damage has often been seen as the one of the main limiting factors to the implementation of these more structurally complex silvicultural systems. Therefore, one of the questions of interest in all of these studies is how do the level and pattern of green-tree retention and tree-selection criteria affect the incidence of wind damage. This paper attempts to answer this question by assembling data on the incidence of wind damage from replicated studies as well as from post-hoc studies described in the literature. Tree level effects will be distinguished from stand level effects. Information from the literature describing wind patterns within different sized canopy openings and under different canopy densities will be reviewed in order to help interpret losses from wind damage.

Introduction

The four currently recognised silvicultural systems (i.e., clearcutting, seed tree, shelterwood, and selection) have primarily focussed on the regeneration and subsequent growth of commercially important tree species, often to the detriment of biodiversity and ecosystem functioning. Areas of old growth forest have declined and those remaining have become highly fragmented (Seymour and Hunter 1999). In the future, many of the forested landscapes (particularly those on public lands in the Pacific Northwest region of North America) will be managed for multiple objectives such as the maintenance of specific levels of ecosystem processes, including habitat for elements of biological diversity (Franklin et al. 1997). Provision of structural complexity in forest ecosystems is important in achieving these objectives. Proposed approaches to the creation of structurally complex managed stands include the use of long rotations, retention of structural features at the time of harvest, and silvicultural treatment of established stands to create specific structural conditions (Franklin et al. 1997). Because of the importance of structural retention coupled with the failure of current silvicultural systems definitions to adequately describe stands with differing levels of retained elements, it has even been proposed that silvicultural systems classifications be updated to include the retention system (Mitchell and Beese 2002).

Within retention systems, structural elements can either be retained in groups (often called aggregates) or dispersed across the harvested area. The relative merits of dispersed and aggregated retention patterns in achieving specific objectives (e.g., maintaining the abundance and diversity of forest-interior species) currently ranks as one of the most important research questions associated with retention systems (Franklin et al 1997). However, the potential for increased levels of wind damage is also of concern with retention systems because recently exposed isolated trees and groups of trees are generally considered more vulnerable than trees in the forest interior. Much of our knowledge about wind damage in managed forests has been gathered from pure, even-aged stands. The pool of knowledge relating to more structurally complex stands is considerably smaller.

Major silvicultural experiments to answer basic questions about the implications of different levels and patterns of retention are difficult and expensive undertakings. Despite their considerable cost, a small number of replicated scientific studies have been embarked on in the United States and Canada to test some of the theories regarding retention systems. While most of these studies are still in their infancy, they have yielded some useful data on vegetation responses including wind damage. In this paper, these studies will be briefly reviewed in order to determine whether levels of wind damage are greater in variable retention systems compared with uncut forests and traditional clearcutting, and if so, whether certain levels and spatial patterns of retention are more vulnerable than others. Additionally, the more extensive body of literature describing wind damage in shelterwood and partial cuttings will be reviewed as it relevant in assessing the potential for wind damage under dispersed retention. In both these replicated and post-hoc studies, tree characteristics associated with wind damage will be separated from stand characteristics where possible. Finally, information from the literature describing wind patterns within different sized canopy openings and under different canopy densities will be reviewed in order to help interpret losses from wind damage.

Replicated Variable Retention Studies

In the Pacific Northwest of the United States and Canada replicated variable (or green-tree) retention studies cover a wide range of forest composition and structures, geographic locations and physical environments. Arguably, the four most widely known studies are the Demonstration of Ecosystem Management Options (DEMO) study (Aubry et al. 1999, Halpern et al. 1999), Montane Alternative Silvicultural Systems (MASS) study (Arnott and Beese 1997), Date Creek silvicultural systems study (Coates et al. 1997) and the Sicamous Creek silvicultural systems research project (Vyse 1997). Across these studies, the level of dispersed retention ranged from a low of 5% of the pre-treatment basal area in the MASS study to a high of 70% of the pre-treatment volume at Date Creek (Table 1). Most of the aggregated retention treatments consisted of patch cuts ranging in size from 0.1 ha to 2.0 ha. However, in the DEMO study the 40% and 15% aggregated retention treatments consisted of circular 1-ha undisturbed patches retained within the treatment units. In the MASS study the control treatment consisted of a clearcut (although there was also a 20 ha old-growth monitoring reserve), while in the other three studies the control treatment consisted of an uncut stand.

Levels of wind damage in these studies were determined from surveys conducted between two and six years after the treatments were applied (Table 1). Information on wind damage in the MASS, Date Creek and Sicamous Creek studies was obtained from published accounts (Arnott and Beese 1997, Coates 1997, Huggard et al. 1999, Beese 2001, Huggard et al 2001) while information for the DEMO study was obtained from unpublished data. In all studies, wind damage was assessed in terms of number of trees per hectare damaged and in some cases basal area (BA) per hectare damaged. Where possible, damage has also been reported as a percentage of the residual stand density (i.e., as a percentage of the residual trees per hectare). With the exception of the two dispersed retention treatments at the MASS study, damage has been relatively minor and not significantly different from that ob served in control treatments. (Interestingly, the level of damage in the harvested units at Sicamous Creek was significantly higher than that in the uncut control after 2.7 years, but not after 4.7 years following treatment (Huggard et al 1999, 2001)). The two dispersed retention treatments in the MASS study had relatively low levels of retention (5% BA and 25% BA retained) and suffered damage to 29.4% and 10.3% of residual trees, respectively. These levels are similar to the 10% to 20% reported by Coates (1997) as warranting management intervention or leading to the treatment being classed as a failure. While the MASS site was not considered to have a high windthrow risk (Beese 2001), trees at the MASS site were considerably older than those in the other studies. Levels of damage were considerably higher than those observed in the 15% dispersed retention treatment in the DEMO study (C. Halpern unpublished data). In the DEMO study, overall mortality (i.e., all causes of tree death) in the 40% and 15% retention treatments was significantly influenced by both the level and spatial pattern of retention. Mortality increased with increasing levels of tree removal and was higher in dispersed retention treatments than in aggregated. The proportion of dead trees that were snapped did not depend on the level or pattern of retention. However, the proportion of uprooted trees depended on the spatial pattern of retained trees, but not the level. Overall, the greatest proportion of wind damaged trees (uprooted and snapped) was in the 15% dispersed retention treatment. As well as the potential for initially higher wind damage losses in low levels of dispersed retention, these treatments also incurred a significantly higher level of logging damage (Moore et al 2002). Decay associated with this wounding could make these trees vulnerable to wind damage in the future.

Across the four studies, no characteristics were found that consistently appeared to predispose individual trees to damage. Beese (2001) compared characteristics of damaged and undamaged trees in the 5% and 25% dispersed retention treatments and found that western redcedar (*Thuja plicata*) appeared to be more windfirm than either Pacific silver fir (*Abies amabilis*) or western hemlock (*Tsuga heterophylla*). Within the 5% dispersed retention treatment, wind damage was fairly evenly distributed across diameter classes with the exception of the smallest (< 17.5 cm) and largest (> 87.5 to 105 cm) classes, which appeared to have less damage. Trees less than 15 m tall suffered less damage than trees in other height classes. A similar result was found for subalpine fir (*Abies lasiocarpa*) at Sicamous Creek with proportionately less wind damage occurring in the smallest and largest DBH classes (Huggard et al 1999). Average height:DBH ratios of wind damaged subalpine fir trees were lower than those of undamaged trees, however this seemingly counterintuitive result was attributed to greater damage in areas that produced shorter trees such as wet areas and exposed knolls (Huggard et al 1999). At Date Creek, Pacific silver fir, trembling aspen (*Populus tremuloides*) and subalpine fir were found to be the most susceptible species to wind damage (Coates 1997). At this site, only wind damaged western hemlock trees had significantly smaller diameters, lower heights and greater height:DBH ratios than the general population of sampled trees (Coates 1997).

Table. 1: Descriptions of the four replicated variable retention studies conducted in the Pacific Northwest of the United States and Canada.

Study	Biogeoclimatic zone[1]	Dominant tree species[2]	Overstory tree age (years)	Treatment			Wind Damage		
				Level of retention (% BA or % Vol)	Spatial pattern	Aggregate/patch size (ha)	Time since treatment (years)	Trees/ha	Percent of residual stand
Date Creek	ICHmc	TSHE	140-300+	100% Vol			2	5.9	1.12
				70% Vol	dispersed			8.1	1.7
				40% Vol	aggregated	0.5-1.0 ha patch cuts		6.05	2.72
MASS	CHWmm2	TSHE, ABAM	200-800	25% BA	dispersed		6	20.9	10.3
				5% BA	dispersed			8.2	29.4
				50% BA	aggregated	1.5-2.0 ha patch cuts		6.2	-
				0%	clearcut	69 ha		9.1	-
Sicamous Creek	ESSFwc2	ABLA, PIEN	up to 350	100% Vol			4.7		3.3
				66% Vol	aggregated	10 ha patch cut			3.1
				66% Vol	aggregated	1 ha patch cuts			3.1
				66% Vol	aggregated	0.1 ha patch cuts			1.95
				66% Vol	dispersed				2.75
DEMO	-	PSME, TSHE	60-170	100% BA			2-3		0.6
				75% BA	aggregated	1 ha patch cuts			-
				40% BA	aggregated	1 ha retention patches			0.9
				40% BA	dispersed				1.8
				15% BA	aggregated	1 ha retention patches			2.1
				15% BA	dispersed				5.8

[1] ICHmc – moist cold subzone of the Interior Cedar-Hemlock biogeoclimatic zone; CWHmm2 – montane moist maritime subzone of the Coastal Western Hemlock biogeoclimatic zone; ESSFwc2 – wet cold subzone of the Engelmann spruce – subalpine fir biogeoclimatic zone (Pojar et al. 1987)

[2] ABAM – *Abies amabilis*; ABLA – *Abies lasiocarpa*; PIEN – *Picea engelmannii*; PSME – *Pseudotsuga menziesii*; TSHE – *Tsuga heterophylla*

Non-Replicated Studies

The low levels of wind damage observed in the majority of treatment units in the replicated studies is encouraging. In fact, low levels of wind damage may even be considered desirable for the recruitment of down woody debris and for the habitat provided by upturned root plates. Unfortunately, these replicated studies have only been in place for a short period of time and their low levels of wind damage may simply reflect their low level of exposure to damaging winds. Variable retention harvests differ from other silvicultural systems such as the seed-tree and shelterwood in that retained trees are intended to provide enduring biological legacies rather than simply a source of seed for the regenerating stand. Therefore, it is necessary to determine whether retained trees will survive beyond five to ten years. Continued long-term monitoring of the replicated studies described above will be necessary to answer this question. However, partial cutting has been practised for many decades in North America with some published accounts of partial cuts dating back to the late 1800's. While these partial cuts were often not part of any designed (replicated) study, they do cover a wide range of geographic locations and vegetation types and can offer some insight into longer term patterns of wind damage. A number of studies relevant to variable retention harvests in Pacific Northwest forest types are briefly reviewed in this section.

Wind damage in partially cut ponderosa pine (*Pinus ponderosa*) stands in the Blue Mountains region of eastern Oregon was studied by Weidman (1920). Stands covered a range of exposures from sheltered to severely exposed, removal levels ranged from 8% to 40% by volume and time since harvest ranged from 15 to 27 years. Damage was heaviest in the most severely exposed stands (22-24% of residual volume) with nearly two-thirds of the damage occurring in the first five or six years following harvest. Because of the unreplicated nature of this study, the effects of retention level could not be separated from wind exposure. In the same general area, Smith and Weitknecht (1915) observed that 17.5% by volume of reserved trees larger than 30 cm DBH were damaged in a partially cut stand within two years following harvest. These authors found that tall, large diameter trees with dense crowns were more vulnerable to wind damage and that overall levels of damage in partially cut stands were five times those recorded in neighbouring uncut stands. Conversely, in an old-growth redwood (*Sequoia sempervirens*) forest, Boe (1965) observed that the smallest and largest diameter trees were the most windfirm. Damage was lower in the shelterwood treatment (75% volume removed) compared to the selection cutting (50% volume removed). This was partly due to the manner in which retained trees were selected. In the shelterwood harvest vigorous, sound codominant or dominant trees were retained, while in the selection harvest trees of all sizes were retained. Stathers et al (1994) emphasise the need to preferentially retain windfirm trees, which in dispersed retention treatments is achieved through removing trees from the lower portion of the diameter distribution. Jull (2001) found that height:DBH ratio of leave trees was a useful indicator of the post-treatment windfirmness of interior Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) leave trees, while tree height and percent live crown were poor indicators.

Wind damage in aggregated retention patches has been studied by Burton (2001, 2002) and DeLong et al (2001). Burton (2001, 2002) found that the size of retention patches was the single most important factor in determining the amount of wind damage in the forests he studied. In analysing a larger dataset that included data from Burton (2001, 2002), DeLong (2001) found that maximum levels of wind damage decreased from 100% to 25% for reserves less than and greater than 1 ha, respectively. In retention patches smaller than 1 ha, DeLong found that wind damage decreased with increasing stand density and decreasing median DBH. Slope position and moisture regime also influenced the degree of wind dam age with the highest levels of damage recorded in patches located on mesic crests. Aggregated retention has the advantage over dispersed retention because retention patches can be located to avoid these potentially high risk sites (Stathers et al 1994). Retention patches located nearer to the upwind edge of the treatment unit appeared to suffer less damage than those further away. Patches also suffered more damage along their upwind edge and Burton (2001) suggested that patches could be made elliptical (rather than circular) with their long axis orientated in the direction of the prevailing wind.

Wind patterns in variable retention harvests

Studies of wind patterns in variable retention harvests are relatively limited in number. Because of the difficulty in making full-scale field measurements, many of these studies have been performed in wind-tunnels. Two such studies (Chen et al 1995, Novak et al 2001) have calculated the relative wind speed in forest openings as a function of distance from the upwind edge. In an opening with an infinite downwind fetch, Chen et al (1995) found that the wind speed at 22 tree heights (330 m in full-scale terms) downwind from the forest edge was still only 65% of the potential value obtained if no forest was upwind. Within 2-3 tree heights downwind from the forest edge wind speeds are less than 50% of the value they reach at 6-10 tree heights downwind (Novak et al 2001). This could explain the relationship between damage and fetch distance observed in the aggregated retention patches.

In addition to studying wind patterns in forests openings, wind measurements have also been made in stands with different tree densities. Green et al (1995) studied the effect of tree spacing on wind characteristics in Sitka spruce (*Picea sitchensis*) stands and found that as tree spacing increased, mean velocity throughout the depth of the canopy also increased. Therefore, dispersed retention patterns will result in increased wind loading on the crowns of the retained trees. In addition, the removal of adjacent trees may also reduce the ability of retained trees to dissipate energy through crown clashing (Milne 1991).

Conclusions

While there have been some documented high incidences of wind damage in variable retention harvests, overall wind does not appear to be a limiting factor to their successful implementation. However, these studies only represent a small range of sites and caution should still be exercised when attempting to implement variable retention harvests on moderate and high windthrow risk sites. While it is unlikely that potential for wind damage will be the main factor considered when deciding on the level and spatial pattern of retained trees, the studies reviewed here indicate that losses will generally be lower when trees are retained in aggregates or when the level of dispersed retention is relatively high. Regardless of the level and spatial pattern of retained trees, careful planning is required. If trees are to be retained in aggregates, these should be large (> 1 ha in size), located away from high risk topographic and soil features, but near to the upwind edge of treatment units where relative wind speeds are lower. Windfirm trees should be preferentially selected for in dispersed retention treatments. The characteristics of such trees are not universally agreed upon, but there appears to be somewhat of a consensus that retained trees should be vigorous codominant or dominant trees with low height:DBH ratios. Species believed to be more windfirm may also be preferentially retained where this is compatible with the other objectives of the harvest.

Despite most wind damage occurring within the first five to six years following harvesting, continued monitoring of wind damage in variable retention studies is necessary to determine long-term trends in wind damage. Non-replicated studies have provided some insight into long-term trends in wind damage, but it is often difficult to separate treatment effects from location effects. The use of wind-tunnels to investigate the airflow in different levels and patterns of variable retention would provide useful information about their potential for wind damage.

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