Evaluating Riparian Timber Harvesting Guidelines: 2005 Bridge Funding Report

A Report to the Minnesota Forest Resources Council

By

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Overview

Minnesotan's care about how timber harvesting practices may impact the terrestrial, aquatic, and wildlife components of forested riparian areas. Of the seven components of Minnesota's forest management guidelines, the riparian guidelines have been the most controversial. Research addressing the long-term effectiveness of riparian guidelines is critical to effectively resolving riparian management conflicts and sustaining Minnesota's forest resources. The Minnesota Forest Resources Council (MFRC) and Legislative Commission on Minnesota Resources (LCMR) funded separate studies to enhance our understanding of the long-term effectiveness of these guidelines.

The MFRC funded a study to establish effectiveness monitoring sites along the Pokegama Creek in Itasca County, Minnesota. Harvest treatments were accomplished during late summer-fall, 1997. Pre- and post-harvest data was collected and a mail survey of forest resource managers in northern Minnesota was conducted in 2001 to better understand blowdown across a wider range of sites in northern Minnesota. The blowdown data from those efforts was not previously analyzed.

The LCMR funded Phase 1 of a study in 2001 to establish eight effectiveness monitoring sites in northern Minnesota's forested regions. The long-term project goal is to assess the impacts of various riparian management practices (varying density of residual standing trees within a standard riparian management zone) on terrestrial, aquatic, and wildlife habitat in these areas. Harvest treatments were accomplished during the winters of 2003-2004 and 2004-2005. LCMR project funds expired on June 30, 2004, with the collection of immediate post-harvest data.

The MFRC provided bridge funding to support additional data collection, processing and reporting of post-harvest data in the areas of terrestrial, aquatic, and wildlife resources through June 30, 2005. This report presents information from each study area that is organized as noted below.

Chapter 1 assesses blowdown. It summarizes the 2001 mail survey of forest resource managers in northern Minnesota and compares findings to post-harvest blowdown field data collected in 1998, 1999, and 2000 at Pokegama Creek, as reported elsewhere.

Chapter 2 provides a summary of the findings of the preharvest and first year post-harvest data collection for stream habitat and fish and invertebrate communities.

Chapter 3 presents spring 2005 post-harvest bird data. Data on breeding birds was collected during May 2005 using line-transects.

Chapter 1
Windthrow Dynamics in Northern Minnesota Riparian Management Zones

Abstract

A survey was mailed to forest managers in northern Minnesota to assess the effects of various factors on blowdown within riparian management zones (RMZs). The intent of the survey was to identify the conditions that result in windthrow in RMZs where the upland has been clearcut. Results suggest that topographic exposure, species and aspect are among the more important factors to consider when trying to mitigate windthrow in RMZs. Slope and distance of a tree to water in an RMZ are relatively unimportant. Overall, results suggest that many variables impact windthrow in RMZs, often interacting in complex ways. Recommendations are provided to assist forest resource managers make better decisions about retaining trees within RMZs.

Introduction

Windthrow can be defined as the effective removal of a tree from the forest canopy due to wind (Canham et al. 2001). Along with fire and disease, it is considered to be one of the most important factors affecting forest management (Canham et al. 2001; Mitchell 1995; Quine 1995). The meteorological events that cause windthrow are often categorized as either catastrophic or endemic. Catastrophic windthrow occurs with wind speeds above 70 miles per hour up to well over 100 miles per hour and usually has long return intervals (Canham et al. 2001; Miller 1985). The damage it causes is often devastating and unpredictable, thus management opportunities are limited. Endemic windthrow is much more common, and occurs with wind speeds between 40 and 70 miles per hour (Miller 1985; Navratil 1995). Although its wind speeds are lower, the return interval can be relatively short. As a result, damage caused by endemic winds in management settings is often high (Alexander 1967; Beese 2001; Moore 1977).

Wind moving over a closed, relatively smooth canopy is fairly stable and causes minimal disturbance (Curtis 1943; Gardiner 1994; Somerville 1980). When an area of forest is clearcut, a sudden obstruction is presented to the wind. The wind tends to be deflected up over the canopy as well as into it (Busby 1965; Raynor 1971; Somerville 1980). Wind approaching the forest edge has a higher velocity than in an intact forest because the frictional boundary which was above the canopy has now moved to ground level (Chen et al. 1993; Moore 1977). The wind can remain at an elevated velocity for several tree heights into the remaining forest (Burton 2001; Raynor 1971). The sudden boundary change at the edge of a clearcut also enhances turbulence in the canopy near the exposed edge, creating further destabilization (Matlack and Litvaitis 1999; Somerville 1980). Following clearcutting, trees that are not physiologically adapted to edge effects are now suddenly exposed, becoming vulnerable to windthrow at lower wind speeds than in an interior forest (Senecal et al. 2004).

Windthrow will occur when the resistive properties of the stem and roots are overpowered by the forces of the wind (Peltola et al. 2000; Petty and Worrell 1981).

Although windthrow is a complex phenomenon (Miller 1985; Navratil 1995), it does not occur randomly (Moore 1977). Damage from endemic windthrow along clearcut edges and in thinned stands can often be predicted based on site conditions, stand conditions and the local climate regime (Cremer et al. 1982; Mitchell 1998).

Where forests are managed for timber extraction, leave strips of intact forest are usually reserved along streams and other water bodies where the upland has been clearcut (Blinn and Kilgore 2001). Also known as riparian management zones (RMZs), these reserve areas serve to maintain the homeostatic balance of the near-stream environment. RMZs protect water quality and fish habitat, minimize sedimentation due to soil exposure, maintain bank stability, provide coarse woody debris for stream structure, serve as corridors to a host of birds and mammals and preserve habitat for rare and sensitive species (Banner and MacKenzie 1998; Belt et al. 1992; Darveau et al. 2001; Richardson et al. 2002; Robinson and Beschta 1990).

Because RMZs set aside timber that could otherwise be harvested, there is great interest in how to maximize timber production near riparian areas while still maintaining the goals of sustainable management. RMZs do not provide a broad suite of environmental benefits when extensive windthrow occurs (Grizzel and Wolff 1998; Reid and Hilton 1998; Steinblums et al. 1984). While some windthrow is to be expected wherever an intact forest has been opened up, excessive windthrow is deemed unacceptable, as it reduces the functional width of the RMZ (Reid and Hilton 1998).

Impact of Tree Species, Site, and Stand Characteristics on Windthrow

Several studies have investigated windthrow of local species in managed forests including balsam fir (*Abies balsamea* [L.] Mill.) (Burns and Honkala 1990; Ruel et al. 2001), white spruce (*Picea glauca* [Moench.] Voss) (Behre 1921; Burton 2001), black spruce (*Picea mariana* Mill. B.S.P.) (Ruel et al. 2001), northern white cedar (*Thuja occidentalis* L.) (Johnston 1977), and trembling aspen (*Populus tremuloides* Michx.) (Coates 1997; Perala 1977). These studies generally conclude that early-successional species are less windfirm than late-successional and that wood strength is an important predictor of windfirmness, as is rooting pattern, canopy architecture and susceptibility to rot and disease.

Several other stand characteristics have been investigated for their effect on windthrow in managed forests. They include diameter at breast height (dbh), with susceptibility to windthrow generally increasing with diameter (Lohmander and Helles 1987; Navratil 1995); crown class, with dominant and codominant trees more windfirm than intermediate or suppressed (Alexander 1964; Cremer et al. 1982); thinning regime, with heavy, late thinnings creating more unstable situations than early, light thinnings (Rollerson and McGourlick 2001; Ruth and Yoder 1953); and age, with windfirmness generally decreasing with age (Coates 1997; Lohmander and Helles 1987). Some studies

have also looked at height to diameter ratios and slenderness coefficients as measures of stem taper (Burton 2001; Navratil 1995). It has been found that an increase in either leads to increased mechanical instability.

Site factors that have been investigated in management settings include slope, where increasing slope may or may not play a role in wind susceptibility along clearcut edges (Moore 1977; Ruth and Yoder 1953); aspect of clearcut edge, with edges facing prevailing winds being more susceptible (Rollerson and McGourlick 2001); exposure, with exposed trees more susceptible to windthrow than protected ones (Miller 1985; Ruel et al. 2001); and hillslope position, with summit trees more vulnerable than those on protected slopes (Alexander 1964). Together, these four factors are related to what is collectively called topographic exposure (Somerville 1980). Distance from stand edge is another factor related to exposure, with windfirmness generally increasing away from the stand edge (Chen et al. 1992; Reid and Hilton 1998).

Soil properties are commonly studied in managed forests as well, with effective rooting depth and soil moisture content being more important indicators of susceptibility to windthrow than soil type, although some have suggested medium- to coarse-textured soils appear to be more windfirm than fine-textured soils (Busby 1965; D'Anjou 2002; Day 1950). Blowdown type, while not a causal agent of windthrow, is often assessed along clearcut edges. Studies vary in their findings, with uprooting usually being more common than stem breakage in conditions with low effective rooting depth and among species with shallow rooting patterns (Beese 2001; Burton 2001). Stem breakage and breakage of the major roots at the base of the stem are more likely with decay than is uprooting (Alexander 1964).

Overall, topographic exposure, species and soil conditions appear to be the most important drivers of windthrow in management settings. However, notable exceptions exist within each factor, and myriad interactions among them make generalizing difficult (e.g., Ruel et al. 2001; Somerville 1980). Additionally, since much of this research was conducted in other regions of the country or other parts of the world, its application to northern Minnesota conditions is unknown.

Northern Minnesota Case Study

A field study was conducted in northern Minnesota in 1998-2000 to investigate different factors affecting windfirmness of riparian trees in an RMZ where the upland was clearcut. It is the only known empirical study of windthrow dynamics along RMZs in Minnesota. The results of the study are detailed in Turner (2005). A summary of background and results for this study are presented here. Site description information is from Perry (2001). Results from the case study (Turner 2005) were compared to the current study.

The experimental field study took place in the Little Pokegama Creek watershed near Grand Rapids, Minnesota, in the Northern Minnesota Drift and Lake Plains Ecosystem. It was part of a larger study monitoring the effects of various harvesting treatments on

riparian areas. The study used a randomized block design, with four treatments in each of three blocks for a total of 12 treatment stands. Each stand was 12 acres in size (6 acres on each side of the stream). In nine of these stands, the uplands portions were clearcut, using either a cut-to-length (CTL) system or a tree length feller-buncher grapple skidder (FT) system. The riparian portions of six of the nine harvested stands also had their riparian areas thinned using the same system as in the upland. The target residual basal area was 25 feet^2/acre. Harvests resulted in actual residual basal areas of approximately 44 feet^2/acre. In the remaining three stands where the upland was clearcut, the riparian area was left intact. The three unharvested stands were true controls, with no cutting in the riparian area or the upland. In each stand, the fixed-width riparian management zone consisted of a 200 foot-wide strip centered on the stream (100 feet on each side). The length of stream contained in each stand ranges from 450–650 feet. RMZs range from 2.1–2.75 acres in size.

A complete enumeration of each species present at the time of harvest as well as the residual trees within the harvested RMZs was undertaken (Turner 2005). Windthrow was monitored for three years post-harvest (1998-2000), with species, dbh and distance from clearcut edge of each windthrown tree recorded in each stand. The complete control stands were not used in this study. Initial analysis of the data suggested that the different harvesting methods did not affect species windfirmness. The data from all the harvested sites was thus pooled.

Turner (2005) looked at windthrow along RMZs for red maple (*Acer rubrum* L.), sugar maple (*Acer saccharum* Marsh.), American basswood (*Tilia americana* L.), northern red oak (*Quercus rubra* L.), black ash (*Fraxinus nigra* Marsh.), paper birch (*Betula papyrifera* Marsh.), bigtooth aspen (*Populus grandidentata* Michx.), yellow birch (*Betula alleghaniensis* Britton), white pine (*Pinus strobus* L.), American elm (*Ulmus americana* L.), balsam poplar (*Populus balsamifera* L.), balsam fir, quaking aspen and northern white cedar. Susceptibility to windthrow for these species can be seen in Figure 1. In this figure, values greater than one indicate the species was windthrown in greater proportion than would be expected based on its relative abundance. A value less than one means the species was windthrown in lesser proportion than would be expected based on its relative abundance. A value equal to one indicates the species was windthrown in exact proportion with its relative abundance.

Turner's (2005) results suggest that quaking aspen, balsam poplar, and balsam fir were the most susceptible to windthrow, being impacted at about twice the rate as their relative abundance would predict (Figure 1). Paper birch, American basswood, red maple, northern white cedar, bigtooth aspen, black ash and sugar maple were moderately windfirm. Those species were windthrown in about the same proportion as their abundance in the RMZs. Northern red oak, yellow birch, white spruce, white pine and American elm were most windfirm, being windthrown at a lesser rate than their relative abundance. The latter species, however, were not as abundant as the other species in the residual stands, making conclusions less certain.

The information on dbh class was analyzed to determine if there were significant differences in diameter with respect to windfirmness (Turner 2005). Although differences in susceptibility to windthrow by dbh class were not statistically different, larger trees appeared to be less windfirm than smaller trees. Trees with a dbh greater than 12 inches were windthrown in greater numbers than expected based on their abundance. Similarly, trees in the smallest dbh classes were windthrown less frequently than would be expected based on their abundance. However, species that were abundant and occurred in numerous size classes were disproportionately influential in the analysis, making conclusions on windfirmness by dbh class somewhat dependent on the windfirmness of the major species.

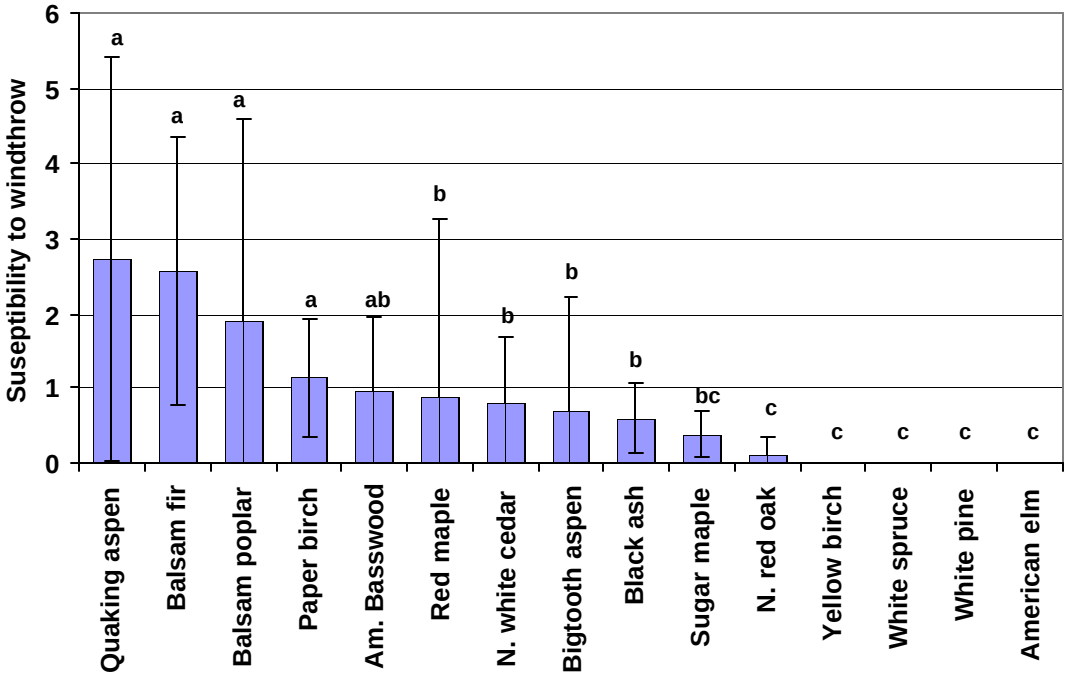

Figure 1. Mean foresters' rating of species' susceptibility to windthrow in a riparian management zone in northern Minnesota following upland clearcutting. A value greater than 1 indicates that the species was windthrown in greater proportion than would be expected by abundance alone. Error bars are 1 standard deviation of the species mean. Means with dissimilar letters are significantly different ($P < 0.05$). From Turner (2005).

The distance of each tree from the clearcut edge was analyzed by dividing each RMZ into three shelter classes based on distance to the clearcut edge (Turner 2005). The most sheltered residual trees were those 82-98 feet from the edge and 0-16 feet from the stream. Moderately sheltered trees were those 49-82 feet from the edge and 16-49 feet from the stream. The least sheltered trees were those 0-49 feet from the edge and greater than 49 feet from the stream. Data from all species within each shelter class were pooled to calculate a single index of susceptibility. Although differences in susceptibility to windthrow by shelter class were not statistically different, trees near the clearcut edge were more prone to windthrow than trees that were more sheltered near the stream.

In summary, Turner (2005) reported that statistically significant differences exist between species in their susceptibility to windthrow. Windfirmness generally decreased with increasing diameter, and also with proximity to the clearcut edge, but in neither case were resultsignificant ($p<0.05$).

Study Objectives

Because little information exists to guide managers on the role of windthrow in northern Minnesota RMZs, it is a priority to identify the major factors involved and to determine mitigation strategies. Since stand and site conditions are more readily observable to forest managers than climatic effects, they provide a convenient starting point for developing management prescriptions for windthrow mitigation in northern Minnesota RMZs.

This paper explores how a number of stand and site factors may contribute to windthrow dynamics in northern Minnesota RMZs using a survey of forest resource managers. Since forest managers often have extensive field experience across a range of site and stand conditions, they are a readily available source of institutional knowledge on windthrow in RMZs. They were thus chosen to be a first step in identifying factors that influence windthrow in this part of the country. The objectives of this study are to (1) summarize and analyze the results of the mail survey and to (2) compare those results to Turner (2005), where appropriate.

Methods

An expert opinion survey (Appendix 1) and coverletter (Appendix 2) were mailed to forest resource managers in January 2001 to assess the effects of various factors on blowdown within RMZs where the upland had been clearcut. The survey was conducted in the Laurentian Mixed Forest Region of northern Minnesota (Figure 2). This region is the location of the majority of timber harvesting in Minnesota. Forest types include conifer, mixed hardwood and conifers, and conifer bogs. Topography and soils are variable, characterized by outwash plains, lowland bogs, and mesic to xeric uplands, with soils in the orders Alfisol, Entisol and Histosol (Minnesota Department of Natural Resources 2003, 2005).

Survey Design

The survey was conducted using Dillman's (2000) Total Design Method. A literature review and series of focus groups were first conducted to determine what major factors needed to be addressed. Next, a draft survey was sent out to a limited group of foresters, with instructions to comment on how the survey questions and design could be improved. After the draft survey was modified to address reviewer comments, it was reviewed and approved by the Institutional Review Board at the University of Minnesota. The survey was mailed to 121 foresters in January 2001. A reminder post card (Appendix 3) was sent approximately two weeks later followed by a second mailing of the survey to nonrespondents along with a reminder letter (Appendix 4).

The target participants for the survey were foresters involved in field-level forest management for land management organizations. Foresters were represented from county land departments, the Minnesota Department of Natural Resources (DNR), the USDA Forest Service (USDA-FS) and private industry. Foresters were asked to specify which agency or company they worked for, what municipality they worked out of and their primary job responsibilities.

Figure 2. The three ecological provinces found in Minnesota.
Map courtesy: Minnesota DNR: http://www.dnr.state.mn.us/ecs/index.html

Section One (Question 1) of the survey consisted of one question asking foresters whether they observed windthrow in RMZs where the upland had been clearcut. The phrase "in RMZs where the upland has been clearcut" was used as a clause in each subsequent question. Section Two (Questions 2-12) contained 11 questions that addressed stand and site factors. In this section, foresters were asked to rate the levels of each factor in relation to their windfirmness, holding all other factors constant. Ratings were discrete, on a scale of one to three, with a rating of one for "least windfirm," two for "moderately windfirm" and three for "highly windfirm." The 11 factors addressed in

Section Two were: species windfirmness, dbh class, crown class, residual basal area (rba), distance of a blowndown tree to the water's edge, slope, aspect of the RMZ cut edge, amount of topographic exposure, hillslope position and soil type.

In Section Three, one question asked foresters to choose whether residual trees were younger, older or the same age as windthrown trees (Question 13). Another question asked which blowdown types were most frequently observed given the choices of uprooted, snapped, brushed (pushed by another tree) or leaning (where the tree will eventually blow down) (Question 14). Each blowdown type was to be rated as one, two, three or four, with one being least observed and four, most observed. The last question in this section asked respondents to rate the relative importance of each of the 11 factors in Section Two on a scale of one to four, with one being least important and four being most important (Question 15).

Section Four contained two open-ended questions. One asked the forester what techniques they use to minimize blowdown of residual trees in RMZs where the upland had been clearcut (Question 16). The second question asked the forester to share additional comments, suggestions or experiences concerning windfirmness in RMZs adjacent to clearcuts (Question 17).

Respondents were considered as those who returned a survey, whether or not they answered any questions. Useful surveys were defined as those that had at least one question answered, even if was only commentary. Total respondents divided by total surveys mailed out yielded the response rate. Total useful surveys divided by total surveys mailed out yielded the useful response rate.

Statistical Analysis

The statistical software program JMP (SAS Institute Inc. 2002) was used for all statistical analysis. The eleven factors addressed in Section Two (Questions 2-12) along with the second and third questions in Section Three (Questions 14 and 15) were analyzed using a One-Way ANOVA ($a = 0.05$). A Tukey Test was run on every factor in Section Two except species (Questions 3-12), as well as the second question in Section Three (Question 14) to identify significantly different degrees of windfirmness among the levels within each factor ($a = 0.05$).

Three groups were formed for the question in Section Two relating to species (Question 2). A Tukey Test was then performed to determine if the three groups were significantly different in windthrow susceptibility. Of the many groupings that yielded a significant Tukey Test, the one with the lowest sum of squares error (SSE) was chosen. Grouped averages were used in this question because there was substantial overlap in significance levels when using an ungrouped Tukey Test (as was used in the rest of Section Two [Questions 3-12] and the second and third questions of Section Three [Questions 14 and 15]). For this question it was thought that creating such groups would be more informative when viewed graphically.

For the question in Section Two relating to species (Question 2), a Kendal t (tau) rank correlation (Kendal and Gibbons 1990; Snedecor and Cochran 1980)was calculated between this data and the results from Turner (2005) to see how well the foresters' ranking of species compared to available data from northern Minnesota (a = 0.05). Regression analysis was performed on the six questions from Section Two that were factors with numeric categories (Questions 3, 5, 6, 7, 8, and 12) in order to determine the strength and shape of the relationship between the factor and foresters' rating (a = 0.05). Transformations of either the dependent or independent variable were made if it improved the fit of the model. The question from Section One (Question 1) and the first question in Section Three (Question 13) were analyzed descriptively. The open-ended commentary from Section Four (Questions 16 and 17) was integrated into appropriate Results and Discussion sections (see Appendix 5 for a complete transcription of foresters' commentary).

Results and Discussion

Of the 121 foresters who were sent the survey, 54 returned them for a response rate of 45%. Seven of the respondents did not answer any of the questions, reducing the number of useful surveys to 47 (39%). Of these, 53% were from the DNR, 17% from industry, 15% from the USDA-FS, 13% from county land departments, and 2% unknown affiliation (Table 1). Respondents were widely distributed within the Laurentian Mixed Forest Province, providing good survey coverage for the targeted geographic area. Primary work responsibilities of the foresters included timber sale preparation and layout, appraisal, road planning, timber cruising and line running, inspecting logging operations, administration of logging contracts and implementing silvicultural prescriptions. Private forest management and management of tax-forfeited land was also a responsibility for some.

Table 1: Respondent summary by organization.

Organization	Number sent a survey	Number of respondents	Percent of respondents
MN Department of Natural Resources	**53**	**27**	**51**
USDA Forest Service	**11**	**7**	**64**
Forest products company	**17**	**9**	**53**
County Land department	**38**	**9**	**24**
Unknown	**2**	**2**	**100**
Total	**121**	**54**	**45***

*Survey response rate: derived by dividing total number of respondents (54) by total number sent a survey (121).

Of those who responded to the question in Section One (Question 1), 80% observed blowdown in RMZs adjacent to clearcuts, while 20% did not. Results for the individual stand and site factors (Questions 2–12) are presented below. Appropriate responses to the open-ended questions in Section Four (Questions 16 and 17) are included for each factor. Results from published studies are also presented.

With the exception of slope ($p<0.99$) (Question 7), all ANOVA analyses for the 11 questions in Section Two (Questions 2–6 and 8–12) and the last two questions in Section

Three (Questions 14 and 15) were significant ($p<0.0001$–$p<0.0203$). Excepting slope, there are significant differences in windfirmness between the various levels for each factor ($p<0.05$), although not all levels within each factor are significantly different from each other. While low correlation coefficients resulted from high variation in the foresters' ratings for the regression analysis, most still yield strong enough relationships to make informative generalizations possible. All regression models showed a significant relationship between each factor and foresters' rating ($p<0.0001$) except for slope ($p<0.69$) (Table 2).

Table 2. Summary of regression analyses for ordinal numeric stand and site factors. All models except slope were significant ($p<0.0001$).

Factor	r^2	Best model fit	Trend
Diameter at breast height (dbh)	**0.29**	**foresters' rating = 3.202 – 0.476 ln dbh**	**Linear (descending)**
Residual basal area (rba)	**0.20**	**foresters' rating = 1.344 + 0.013 rba**	**Linear (ascending)**
Tree age	**0.43**	**foresters' rating = 3.549 – 0.222 sq rt age**	**Linear (descending)**
Distance to water's edge	**0.24**	**ln foresters' rating =-0.164 + 0.231 ln dist. to water's edge**	**Linear (ascending)**
Slope	**0**	**None**	**None**
Aspect	**0.15**	**sq rt rating = 1.747 – 0.025 sq rt aspect – 0.003 (sq rt aspect-11.287)^2**	**Quadratic (convex)**

Stand Factors

Species: Many species were similar in their vulnerability to windthrow, but noteworthy differences exist (Figure 3). With species ordered from most windfirm to least, those at either end of the scale have significant differences in windthrow susceptibility between them. The most windfirm species were sugar maple, red oak, red maple, black ash, white pine, red pine and American basswood. Paper birch, bigtooth aspen, white cedar, balsam poplar and quaking aspen had a lower level of windfirmness.Jack pine and balsam fir had the lowest windfirmness. Foresters also volunteered ratings for white and black spruce. The average windfirmness rating for these two species was 1.7 and 1.4 respectively, suggesting that they are about as vulnerable to windthrow as jack pine but more windfirm than balsam fir. The results for white and black spruce should be interpreted with caution, however, because of the low response rate ($n = 11$ for white spruce, $n = 7$ for black spruce) and possible bias in unsolicited responses. Results from the rank correlation analysis yielded a Kendal t correlation coefficient of 0.67 ($p<0.004$) (Figure 4), suggesting a moderately strong relationship between the empirical (Turner 2005) and foresters' rankings, giving further credence to the order of species' windfirmness presented in Figure 3.

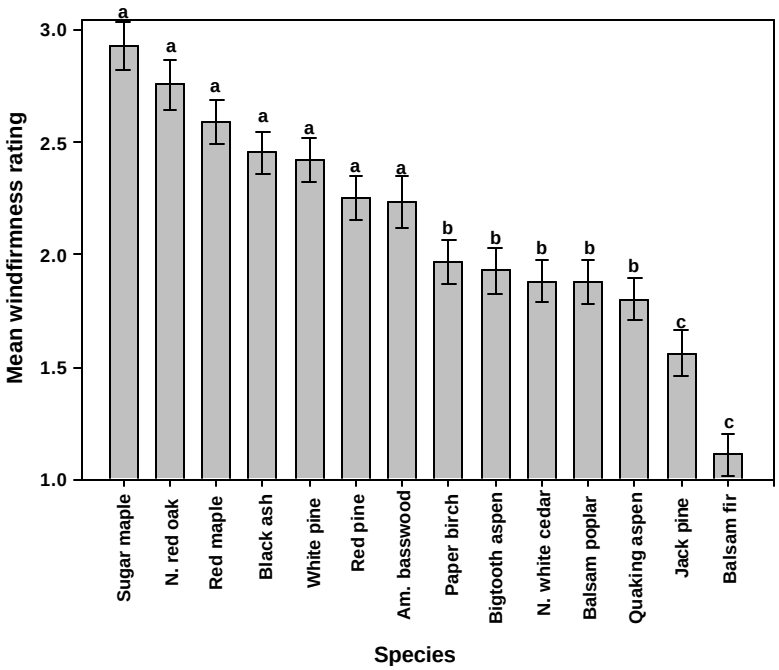

Figure 3. Mean foresters' rating of species' susceptibility to windthrow in a riparian management zone in northern Minnesota following upland clearcutting. Rating is on a scale of 1–3. A higher rating represents higher windfirmness. Error bars represent a pooled estimate of error variance. Letters above the error bars group the species into significantly different levels of windfirmness ($p<0.05$) based on pooled group averages but do not represent significantly different levels of windfirmness between individual species.

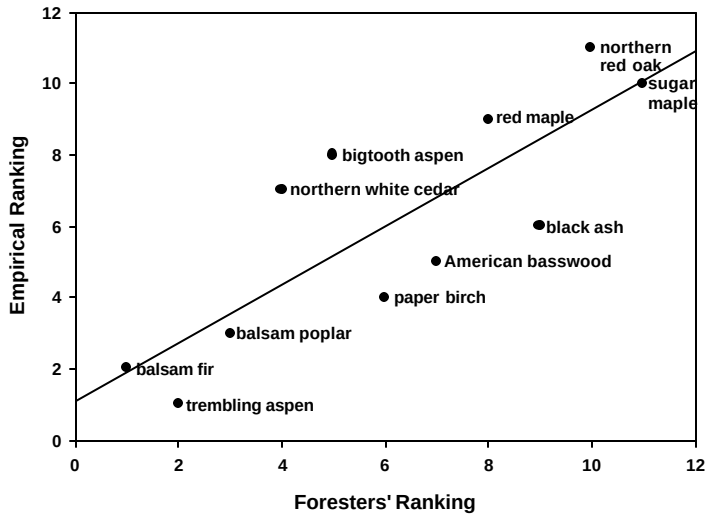

Figure 4. Empirical ranking from Turner (2005) versus foresters' ranking of eleven species susceptibility to windthrow in a riparian management zone in northern Minnesota where the upland has been clearcut. A ranking of one is the least windfirm species and eleven the most windfirm.

Table 3 compares the species windfirmness results from this study and that of Turner (2005) to Table GG-7 in Minnesota's voluntary site-level forest management guidelines (Minnesota Forest Resources Council 1999). In Table GG-7, species windfirmness is categorized as low, medium and high. Results from this study and that of Turner (2005) were similarly categorized. In the case of this study, the "a" grouping corresponds with "high," "b" with "medium" and "c" with "low." No statistical analysis was done on the comparisons, but results appear fairly consistent within species across the three studies.

Table 3. Comparison from three studies of windfirmness ratings for major tree species in northern Minnesota riparian management zones*.

Species	Turner (2005)	Steil and Blinn (2005)	Table GG-7 from MFRC (1999)
Trembling aspen	L	M	M
Balsam fir	L	L	L
BAM	L	M	L
Paper birch	M	M	L
Basswood	M	H	H
Red maple	M	H	M
Cedar	M	M	M
Bigtooth aspen	M	M	M
Black ash	M	H	H
Sugar maple	M	H	H
Red oak	H	H	H
Yellow birch	H	-	H
White spruce	H	L	M
White pine	H	H	H
American elm	H	-	H
Black spruce	-	L	L
Jack pine	-	L	L
Tamarack	-	M	M
Red pine	-	H	M

*L= low windfirmness, M= moderate windfirmness, H= high windfirmness

The most frequent open-ended comment regarding windthrow susceptibility by species was the suggestion to leave windfirm species in the RMZ and/or remove susceptible species. Species that tended to be left were dominant pines, sugar maple, oaks, and shade tolerant understory species. Susceptible species usually selected for removal were older aspen, balsam fir, and white and black spruce. Birch was considered windfirm by some respondents but not by others. One forester commented that they would selectively leave windfirm species, but would either clearcut or completely reserve susceptible species like aspen or birch. Hardwoods were usually favored for leave trees over conifers, with the exception of aspen. Trees that were prone to decay or disease were vulnerable to windthrow. Stands composed of uneven-age mixed species were most windfirm according to another forester. According to some survey respondents, species with shallow rooting habits or species that grew in areas where effective rooting depth was impeded were less windfirm than those with deeper rooting habits or that grew in soils that promote deeper rooting.

The species found to be most susceptible to windthrow in this study reflect trends found in the literature. Balsam fir, white and black spruce and aspen tend to be less windfirm than other species, with hardwoods generally more windfirm than conifers (Behre 1921; Ruel et al. 2001). Susceptibility to rot among species such as aspen or balsam fir makes them especially vulnerable (Coates 1997; Perala 1977), as does rooting habit (Frank and Bjorkbom 1973).

Diameter at breast height: A moderately strong relationship exists between mean windfirmness rating and dbh class (r^2=0.29) (Table 2). Note that survey responses for the category of trees greater than 30 inches dbh were not included in this analysis because the authors have found that such trees are not frequently encountered within managed forests in northern Minnesota. Windfirmness falls off steeply as dbh increases, but trees in the 25.1-30 inch dbh class appear to be marginally more windfirm than those in the previous two classes (Figure 5). Significant differences exist between the 0.1-5.0, 5.1-10.0, and the 15.1-20.0 and 20.1-25.0 inch diameter classes ($p<0.05$).

Foresters' open-ended comments concerning dbh echoed the trends found in Figure 5, with larger-diameter trees being susceptible to windthrow, especially if they are older and weakened by disease. Large crowns that accompany large-diameter trees tend to catch the wind and are therefore more prone to windthrow. Height in relation to diameter was cited as a major consideration by one forester, with a higher height to diameter ratio creating a less stable tree.

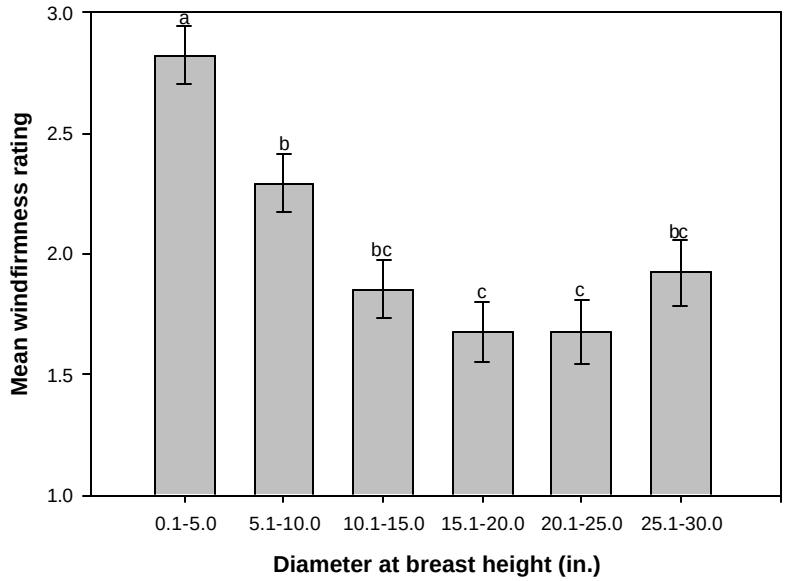

Figure 5. Mean foresters' rating of windfirmness by diameter at breast height on a scale of 1–3 in a riparian management zone in northern Minnesota where the upland has been clearcut. A higher rating represents higher windfirmness. Error bars represent a pooled estimate of error variance. Means with dissimilar letters are significantly different ($p<0.05$).

Not all foresters' comments reflected the trends in Figure 5 and Table 3, however. One forester noticed no relationship between diameter and windfirmness, while several others noted that large pines tended to be windfirm, as did large, well-anchored trees. The slight uptrend in windfirmness by dbh for the largest dbh class in Figure 5 reflects the comments regarding what are perhaps super-canopy trees that have become acclimated to wind through constant exposure (Peterson and Pickett 1991). The foresters' consensus that windthrow susceptibility increases with dbh is widely reflected in several studies (Gardiner et al. 2000; Lohmander and Helles 1987; Steinblums et al. 1984). The results of this study are also consistent with Turner (2005), who found windthrow to increase with diameter, although his results were not statistically significant.

Crown class: Codominant trees were significantly less windfirm than suppressed trees ($p<0.05$) (Figure 6), but neither were significantly different than the dominant or intermediate crown classes in windfirmness.
Many foresters noted that windfirmness by canopy position was dependent on species and root anchorage. Young trees and trees with small crowns were favored for reserving, according to one forester. While published studies differ in their conclusions as to which crown classes are most windfirm, some advise against thinning from above, which leaves intermediate and suppressed trees exposed (Cremer et al. 1982; Navratil 1995). Such studies found that high height to diameter ratios of intermediate and suppressed trees make them less stable in wind. Also, trees with asymmetric crowns can present a high windthrow hazard (Navratil 1995). It can be concluded that crown class is a poor to fair predictor of windthrow susceptibility.

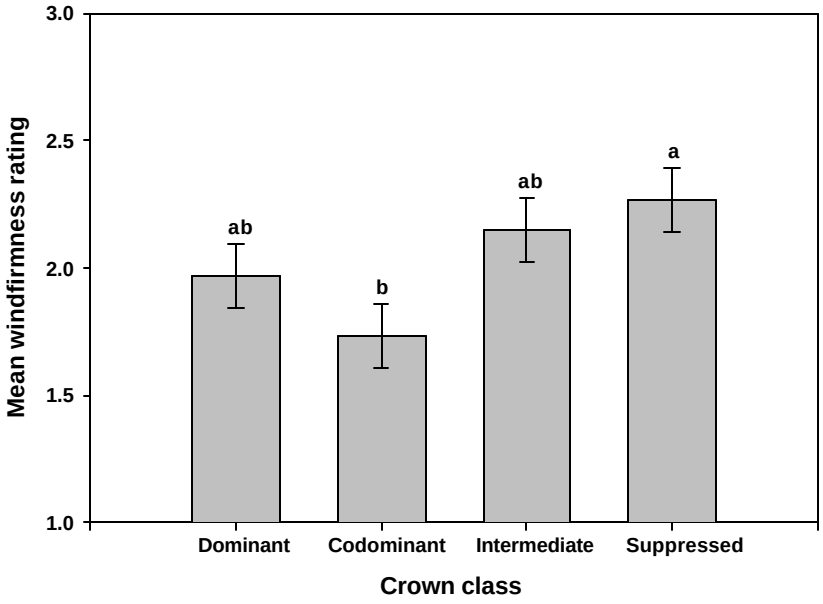

Figure 6. Mean foresters' rating of windfirmness by crown class on a scale of 1–3 in a riparian management zone in northern Minnesota where the upland has been clearcut. A higher rating represents higher windfirmness. Error bars represent a pooled estimate of error variance. Means with dissimilar letters are significantly different ($p<0.05$).

Residual basal area: A weak to moderate relationship exists between mean windfirmness rating and rba (r^2=0.2) (Table 2). Windfirmness increases steadily with increasing rba (Figure 7). The lowest four rba levels are all very similar, and are significantly less windfirm than the highest three, but not significantly different than the 41-50 feet^2/acre and 51-60 feet^2/acre rba levels ($p<0.05$).

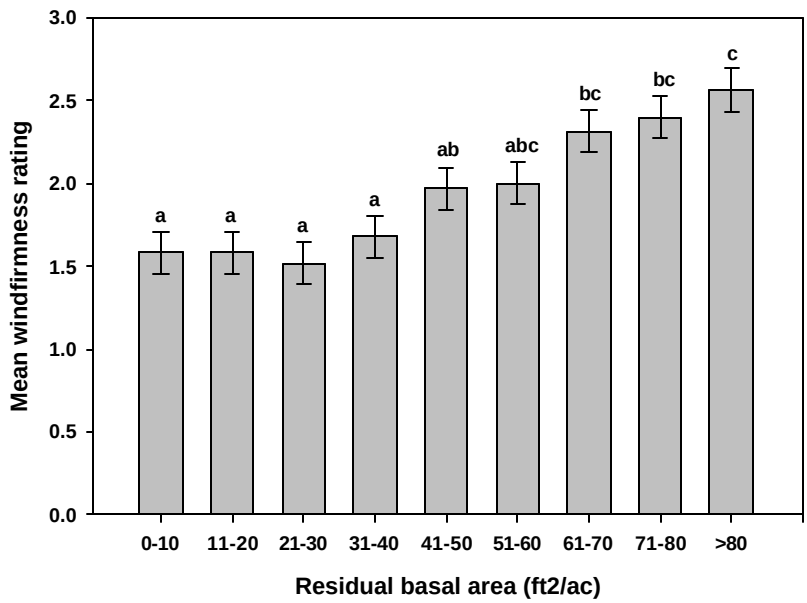

Figure 7. Mean foresters' rating of windfirmness by residual basal area on a scale of 1–3 in a riparian management zone in northern Minnesota where the upland has been clearcut. A higher rating represents higher windfirmness. Error bars represent a pooled estimate of error variance. Means with dissimilar letters are significantly different ($p<0.05$).

Foresters suggested keeping basal area high if possible, especially in high hazard areas, and removing susceptible species if necessary to promote windfirmness. Many noted that the amount of rba to leave was dependent on tree species. A lower rba could be left with windfirm hardwoods, but a higher rba would have to be left with a residual stand of aspen or birch.

Although not all studies suggest strong relationships between rba or stand volume and windthrow susceptibility, it is generally accepted that heavy or late thinnings will generally lead to greater windthrow susceptibility than early or light ones (Somerville 1980). If the rba is reduced to the point that the damping effect of a tree's neighbor is no longer present, windthrow will increase (Mayer 1989; Mitchell 1998). From a windfirmness perspective, thinning from below is better than from above (Navratil, 1995; Rollerson and McGourlick 2001), except if much of the canopy is overmature or otherwise vulnerable. One forester suggested gradually reducing rba toward the RMZ edge, a suggestion consistent with the recommendations of Palik and others (2000). Rollerson and McGourlick (2001) reported significantly less windthrow along feathered

versus straight edges, but part of this effect may have been due to removal of susceptible species.

Tree age: A moderately strong relationship exists between mean windfirmness rating and age class (r^2=0.43) (Table 2). Mean windfirmness drops substantially with age, leveling off in the last five age classes (Figure 8). The oldest five age classes are significantly less windfirm than the youngest five ($p<0.05$), with less variation in windfirmness rating in the former than the latter. When asked about the age of residual trees in an RMZ relative to those that were windthrown, 71% of respondents reported that residual trees tended to be younger than those blown down. Another 6% (2) thought that residual trees were generally older than those windthrown, while 23% (8) thought that residual trees and windthrown trees were the same age. Clearly, most foresters agree that older trees are less windfirm than their younger counterparts. Those that observed no relation between age and windthrow susceptibility may work in even-age forests where such trends cannot be ascertained. Respondents that observed more windthrow among younger trees may be performing silvicultural treatments that lead to younger trees being more vulnerable.

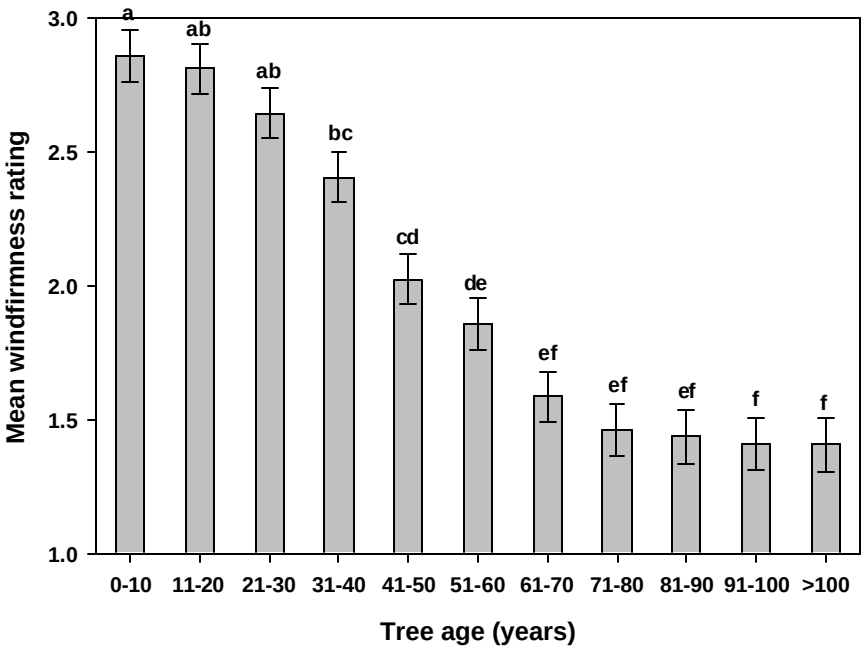

Figure 8. Mean foresters' rating of windfirmness by tree age on a scale of 1–3 in a riparian management zone in northern Minnesota where the upland has been clearcut. A higher rating represents higher windfirmness. Error bars represent a pooled estimate of error variance. Means with dissimilar letters are significantly different ($p<0.05$).

The majority of foresters' open-ended comments agree with the trends observed in Figure 8, although not all agree that age is a good predictor of windthrow susceptibility. Older trees are reported to be more vulnerable to windthrow due to rot and decay, although species plays an important role in this, with large red and white pines being more windfirm than other species of the same age. Because older, larger-crowned trees are

more vulnerable to windthrow, they are often selectively removed. This would seem to contradict the reasoning that a thin from below will be less hazardous than a thin from above. However, as one forester commented, as long as selective removal of older, weaker trees is not too heavy, it may be desirable. It may also be possible that over-mature stands leave the forester with little choice than to remove these vulnerable trees.

Most published studies agree with the finding that older trees are more vulnerable to windthrow, with weakening from decay as the major cause (Coates 1977; Lohmander and Helles 1987). Like some respondents here, however, Steinblums (1984) has suggested that age is not the major factor driving windthrow.

Site Factors

Distance from water's edge: Distance of a blowndown tree to the water's edge is weakly to moderately correlated with windthrow susceptibility (r^2=0.24) (Table 2). Mean windfirmness increases steadily as the distance from the stream increases, then levels off after about 60.1-70.0 feet (Figure 9). Trees adjacent to the stream up to 20 feet into the forest are significantly less windfirm than those more than 40.1-50.0 feet into the RMZ ($p<0.05$). Trees adjacent to the stream up to 30 feet into the RMZ are significantly less windfirm than those more than 70.1-80.0 feet away from the stream ($p<0.05$).

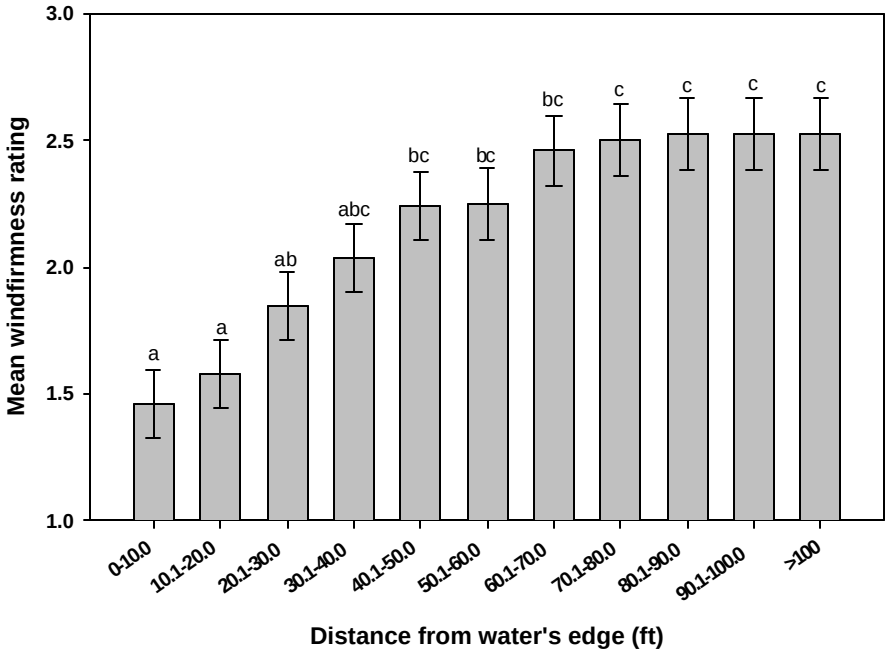

Figure 9. Mean foresters' rating of windfirmness of residual trees by distance from water's edge on a scale of 1–3 in a riparian management zone in northern Minnesota where the upland has been clearcut. A higher rating represents higher windfirmness. Error bars represent a pooled estimate of error variance. Means with dissimilar letters are significantly different ($p<0.05$).

Most foresters who provided open-ended comments said the residual tree's distance to the water's edge was not something they had measured or that it was not an important factor. Three foresters noted that trees near the water were often more vulnerable to windthrow because the streambank or floodplain created wet soil conditions, but another said that trees closest to the water are more windfirm, perhaps because they are afforded more protection than trees closer to the clearcut edge. It is possible that the trend observed in Figure 9 is due to some respondents interpreting the question as to mean the distance of the RMZ edge to the stream. If this is the case, the question becomes one of RMZ width. A narrower RMZ with the clearcut edge closer to the stream could more likely fall within a low wet area, whereas a wider RMZ would more likely have the clearcut edge on higher, drier ground, making the edge more windfirm.

No study has addressed this question as it was stated in the survey, as most have investigated windfirmness in terms of distance from the clearcut edge or width of the RMZ in relation to windthrow (Burton 2001; Chen et al. 1992). Reid and Hilton (1998) note that windthrow decreases away from the stand edge, but increases again as the water's edge is approached as a result of a high water table.

Slope: A weak relationship exists between mean foresters' rating and slope in the regression analysis (r^2=0.0006) (Table 2). Therefore, no model exists to adequately describe this relationship. Figure 10 shows no discernable trend between slope and windfirmness.

Foresters appear to widely disagree over which slope percent is more or less windfirm, or perhaps no slope percent is more or less windfirm than any another. Also, many locations within the study area are relatively flat so respondents may have had limited exposure to a broad range of slope conditions. Many foresters commented that slope was not a factor when considering windfirmness. Some suggested that flat sites are generally wet and therefore vulnerable. One respondent noted that winds tend to eddy or swirl more at the bottom of (presumably steeper) slopes, perhaps increasing the windthrow hazard in those areas.

Research on slope with respect to windfirmness is inconclusive. At least one study states that slope alone is unimportant in determining susceptibility (Ruth and Yoder 1953). Some research suggests that very steep valleys may protect trees at the bottom (Moore 1977). Others have found that steep, narrow valleys funnel and accelerate wind (Ruel et al. 2001), resulting in higher windthrow. Still others report eddying on moderately sloping leeward areas can result in wind damage to trees where steep upslope bluffs occur (James and Dier 1968). Navratil (1995) reported that wind accelerates up steep slopes, perhaps leaving upslope windward edges more vulnerable. Moore (1977) notes that flat approaches to RMZ edges create a situation with high exposure versus steep slopes where the wind would "break away" from the ground and the hillslope would be protected.

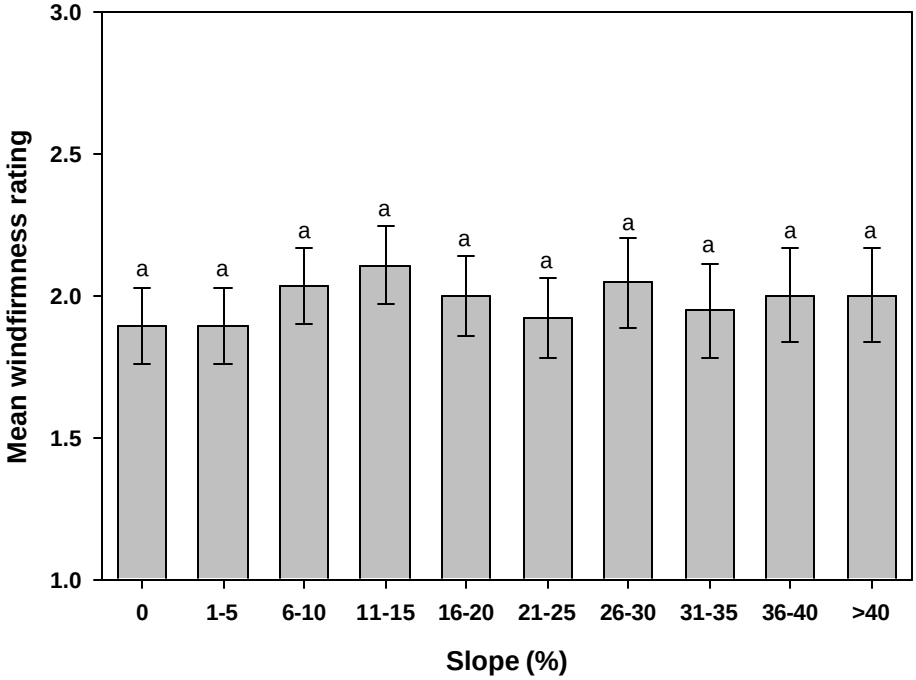

Figure 10. Mean foresters' rating of windfirmness by slope on a scale of 1–3 in a riparian management zone in northern Minnesota where the upland has been clearcut. A higher rating represents higher windfirmness. Error bars represent a pooled estimate of error variance. Means with dissimilar letters are significantly different ($p<0.05$).

Aspect: A weak relationship exists between aspect of the RMZ cut edge and windfirmness rating ($r^2=0.15$) (Table 2). This is likely due to the order of compass degrees from zero to 360 being somewhat arbitrary, as no magnitude is necessarily associated with these degrees. The quadratic form of the model relating aspect to mean foresters' rating in Table 2 and the graph in Figure 11 suggest that windfirmness increases as exposure moves from north to northeast and falls off as the northerly aspect is again approached. RMZ boundaries facing west and northwest are significantly less windfirm than those facing northeast, east and southeast ($p<0.05$). RMZ boundaries facing north, south and southwest have intermediate levels of windfirmness.

Foresters were consistent in their open-ended recommendations regarding RMZ edges and aspect. Wider RMZs are needed facing prevailing winds, and efforts should be made to avoid exposing straight edges to prevailing winds. Prevailing winds are from the west and southwest in summer, and northwest in winter. On the North Shore of Lake Superior, however, strong northeast winds may present unique hazards in the fall.

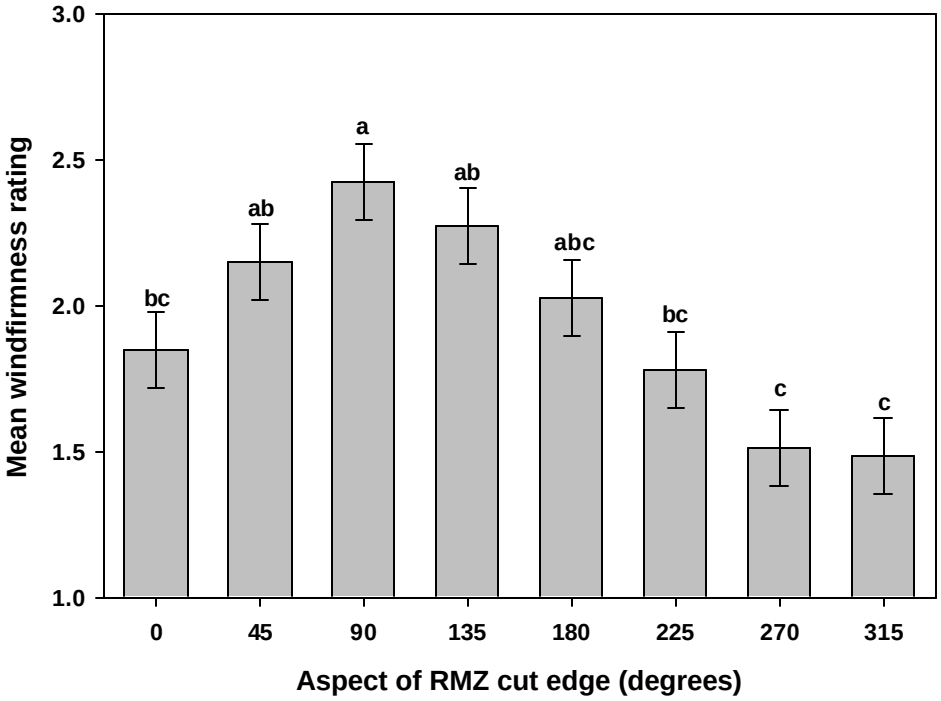

Figure 11. Mean foresters' rating of windfirmness by aspect of cut edge relative to the riparian management zone (RMZ) on a scale of 1–3 in an RMZ in northern Minnesota where the upland has been clearcut. A higher rating represents higher windfirmness. Error bars represent a pooled estimate of error variance. Means with dissimilar letters are significantly different ($p<0.05$).

Most studies agree with these results, concluding that windward aspects are most vulnerable (Ruel et al. 2001; Ruth and Yoder 1953), the only exception being where eddying creates instability on leeward slopes (Alexander 1967; Beese 2001). Recommendations are to avoid straight edges facing prevailing winds or to have long edges parallel to prevailing winds (Moore 1977). RMZs may need to be wider if effective buffer width is to be maintained along windward edges. Feathering of the RMZ cut boundary may enhance stand stability along an RMZ edge exposed to prevailing winds (Palik, 2000; Rollerson 2001).

Degree of exposure and hillslope position: Trees which are fully exposed due to topographic position are significantly less windfirm than partially exposed trees or those with limited or no exposure ($p<0.05$) (Figure 12). Partially exposed trees are in turn significantly more windfirm than those fully exposed but significantly less windfirm than trees with limited or no exposure, with neither of the latter categories significantly different in their degree of windfirmness.

Comparing windfirmness by hillslope position, trees located on the summit were significantly less windfirm than any other hillslope position, while those on a footslope or toeslope were significantly more windfirm than either the summit or shoulder position ($p<0.05$) (Figure13). Residual trees on a sideslope were not significantly different in windfirmness than those on the shoulder, footslope or toeslope.

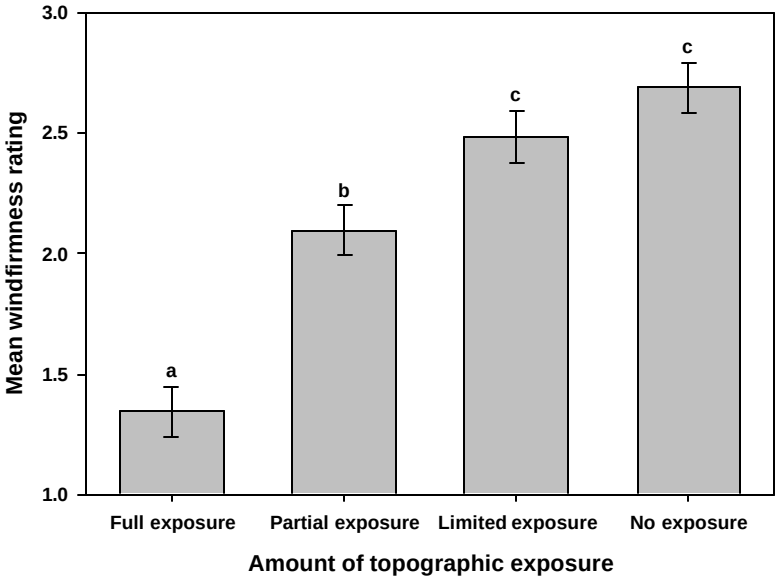

Figure 12. Mean foresters' rating of windfirmness by amount of topographic exposure on a scale of 1–3 in a riparian management zone in northern Minnesota where the upland has been clearcut. A higher rating represents higher windfirmness. Error bars represent a pooled estimate of error variance. Means with dissimilar letters are significantly different ($p<0.05$).

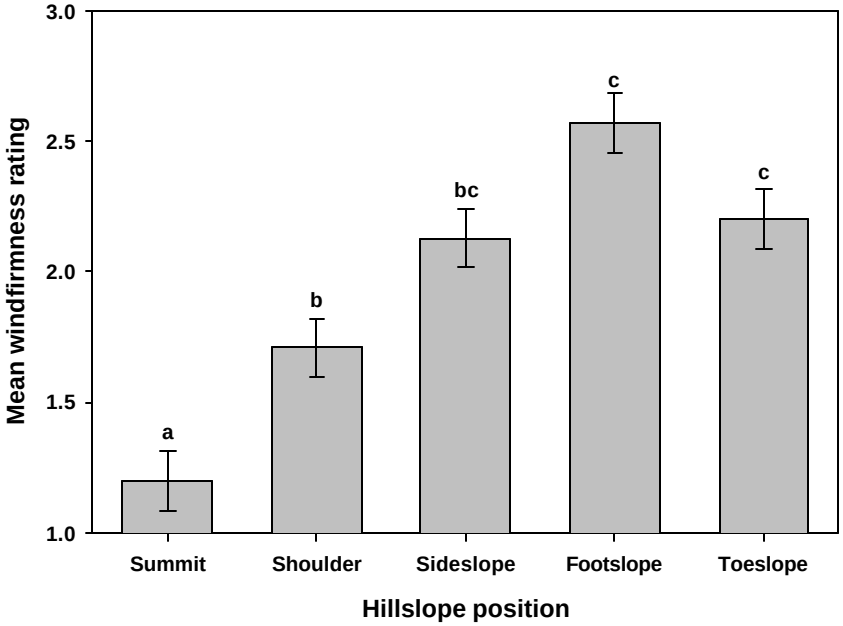

Figure 13. Mean foresters' rating of windfirmness by hillslope position on a scale of 1–3 in a riparian management zone in northern Minnesota where the upland has been clearcut. A higher rating represents higher windfirmness. Error bars represent a pooled estimate of error variance. Means with dissimilar letters are significantly different ($p<0.05$).

Foresters agreed that the more topographically exposed RMZs were, the more likely they were to experience windthrow. One respondent reported that RMZs in flat, wet areas are less windfirm than those on protected slopes.

Studies of exposure and hillslope position make it difficult to distinguish between the two, since exposure is necessarily a function of the protection afforded by hillslope position and distance from the clearcut edge. Results of other research generally agree with the findings of this study. Looking at exposure in terms of shelter afforded by distance from the clearcut edge, Turner (2005) indicated that windfirmness generally increased as the distance from the clearcut edge increases. However, it is unclear if this is because the trees closer to the stream were topographically sheltered, or because they were more protected by the trees nearer the clearcut edge. Some studies found that wide valleys leave RMZ edges exposed and vulnerable (Miller 1985; Ruel et al. 2001). Summits, especially those facing prevailing winds, are particularly vulnerable, as wind accelerates over ridgetops (Alexander 1964, 1967). Deep draws and steep leeward slopes along RMZs protect trees from wind (Moore 1977), suggesting that RMZ edges should be positioned such that canopy tops are not exposed above windward summits.

Soil type: Loamy sand was significantly more windfirm than sand and silt ($p<0.05$) (Figure 14). Clay was also significantly more windfirm than sand, but loamy sand, clay, loam, silty loam sandy loam and silt showed no significant difference in windfirmness rating, suggesting that there may be few significant differences in windfirmness among most soil types. Five survey respondents volunteered that organic soils were most windfirm, all giving this soil type a “one” for windfirmness. Two foresters also suggested rocky/gravelly soils created hazardous conditions. Because of the low response and possible bias for these soils, which were not included as an option on the survey, these results were not included in Figure 14.

Lack of significant differences among most soil types may be due to soil type being a relatively unimportant factor. Many respondents commented that soil type was not critical, but that soil moisture and other properties that determined effective rooting depth were important. Based on the consistency of comments on soil moisture across several site and stand factors, it appears that this factor may be among the most important considerations for windthrow along RMZ edges adjacent to clearcuts.

Studies of soil properties also suggest that soil type is rather unimportant in comparison to other soil properties. Saturated soils create shallow rooting patterns (Day 1950), and organic or wet soils have weak shear strength, or ability to anchor the roots (Busby 1965; D'Anjou 2002), leading to greater windthrow susceptibility. Effective rooting depth is also affected by soil depth. Areas with shallow soils overlaying bedrock or other impermeable layers will create shallow rooted species, leading to higher hazard conditions (Moore 1977).

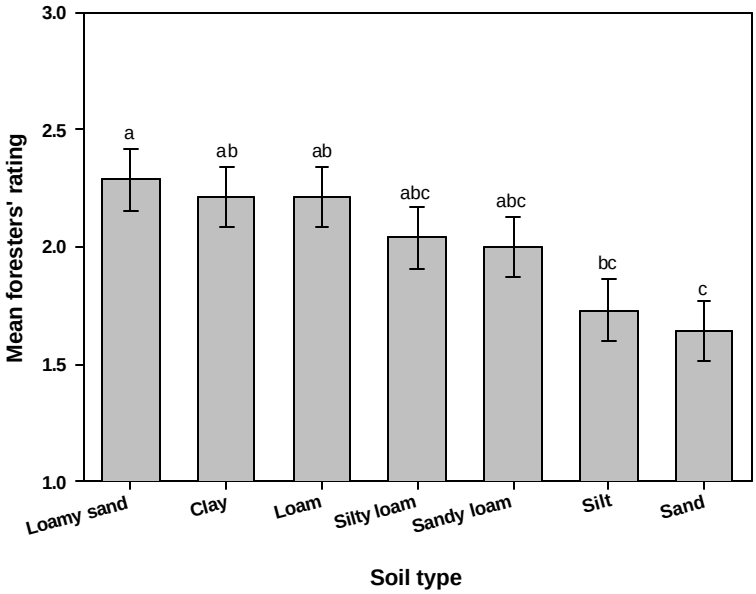

Figure 14. Mean foresters' rating of windfirmness by soil type on a scale of 1–3 in a riparian management zone in northern Minnesota where the upland has been clearcut. A higher rating represents higher windfirmness. Error bars represent a pooled estimate of error variance. Means with dissimilar letters are significantly different ($p<0.05$).

Other Factors

Blowdown type: A tree may become blowndown by being uprooted, leaning, snapped, or being brushed (pushed over) by another tree. Study results suggest that uprooting is observed at significantly higher rates than either leaning, snapped or brushed trees ($p<0.05$) (Figure 15). While uprooting is a significantly more common phenomenon than leaning trees, the latter occur at significantly higher rates than brushed trees. Snapped trees are observed at rates that are not significantly different from leaning or brushed trees.

There were few foresters' comments related to this question. One forester noted that aspen and balsam fir are most likely to be windthrown by snapping than uprooting. Another forester said that soil plays a large role, with shallow rooting depth predisposing trees to uprooting. They also suggested that codominant aspen tend to snap off.

Studies that observed blowdown type show that it is dependent on effective rooting depth, species, and disease and rot. Where soil conditions create shallow rooting patterns or where species with this rooting habit grow, uprooting will be observed more than stem breakage. Where deeper rooting patterns or stem rot occur, trees will be more prone to stem breakage (Alexander 1964; Behre 1921; Mayer 1989).

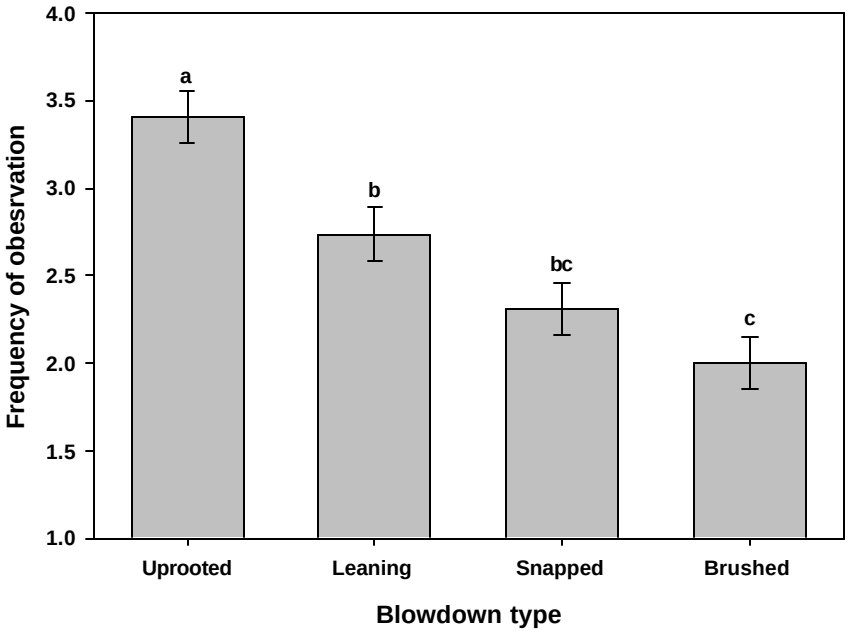

Figure 15. Mean frequency of observation of each blowdown type on a scale of 1–4 in a riparian management zone in northern Minnesota where the upland has been clearcut. A higher rating represents higher windfirmness. Error bars represent a pooled estimate of error variance. Means with dissimilar letters are significantly different ($p<0.05$).

Relative factor importance: When all factors were considered for their relative importance, species and tree exposure are significantly more important than tree dbh, topographic position, slope or distance to water's edge ($p<0.05$) (Figure 16). Distance to water's edge was the least important factor, being significantly different than every other factor except slope. Overall differences in importance between factors were small. Foresters appeared to be in disagreement about which factors were most important.

One forester said soil type and tree form were more important than rba or distance to the water's edge, while several others noted that soil type was unimportant, and that age was most important. Many thought that species was most important. The differing opinions as to which factor or factors are most important suggests that moderate discord existed among respondents despite the definite trends found in this and most previous questions. The literature tends focus on species, topographic exposure and soil moisture/effective rooting depth, while crown class, soil type and distance to the water's edge of a blown down tree receive the least attention. With some exceptions, the factors focused on in the literature are generally consistent with foresters' rating in Figure 16. Along with the emphasis on tree species, topographic exposure, and aspect of the RMZ cut edge, many of the foresters' open-ended comments noted the importance that soil moisture and rooting depth play in determining susceptibility to windthrow of RMZ trees, even though those factors were not included as separate options to evaluate in this study.

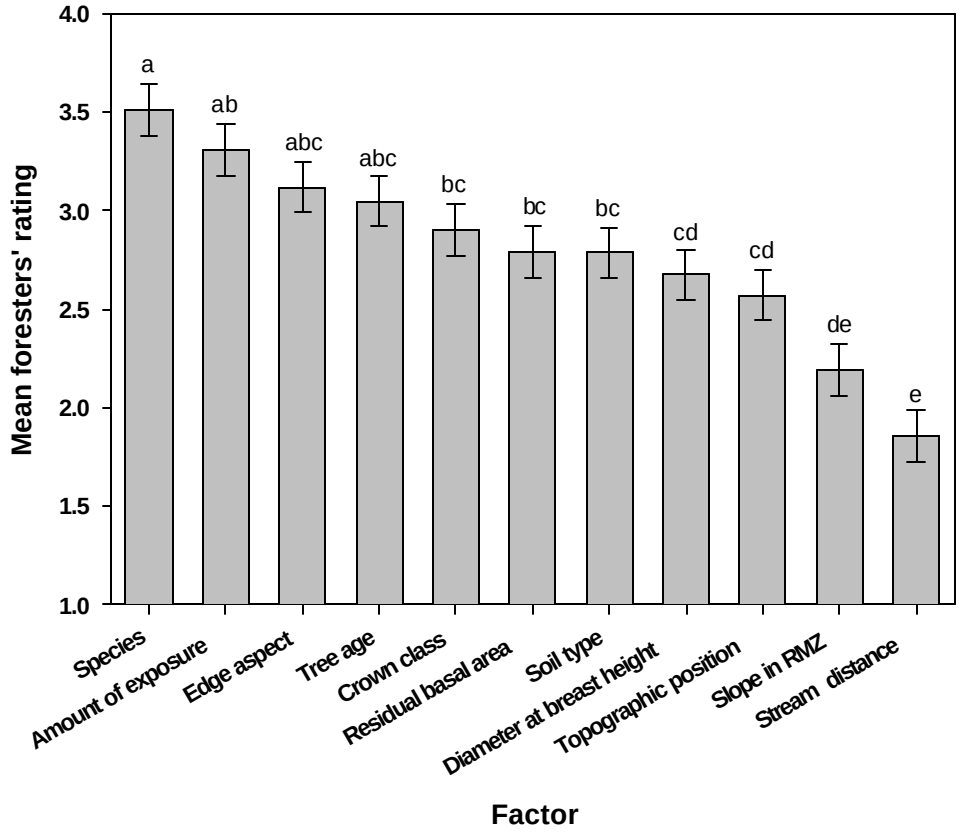

Figure 16. Mean rating of each factor's importance in influencing windthrow on a scale of 1–4 in a riparian management zone in northern Minnesota where the upland has been clearcut. A higher rating represents higher windfirmness. Error bars represent a pooled estimate of error variance. Means with dissimilar letters are significantly different ($p<0.05$).

Study Limitations

This study was of a qualitative nature. The results should therefore not be interpreted with the same approach that one would take toward an experimental study. When it is noted that certain levels within a factor are significantly different than others, this was based on respondent perspectives. While respondents did have experience performing various duties which provided opportunities to observe blowdown in RMZs, their work responsibilities did not require them to measure or record that phenomena. As such, data was provided by individuals who reported their perspective of what they had observed without ever having systematically recorded that information.

Given the above limitation, the study does represent personal observations across a broad range of stand and site conditions. Responses were consistent enough to show significant differences for most factors assessed. They also corroborated quantitative studies such as Turner (2005) and published literature.

Management Recommendations

The decision about how wide to make the RMZ and what residual trees to leave should consider management objectives as well as stand and site conditions for the area. In some instances, the options about what trees to leave are limited because of local conditions (e.g., only one species present). Based on this research and other studies, some recommendations which consider more important site and stand conditions are presented below.

- During sale setup, assess local stand and site conditions for hazard factors such as high topographic exposure, soil conditions that create weak or shallow rooting patterns, and prevailing winds.

- Leave a wider RMZ, reserve more windfirm species, and provide a gradual increase in residual basal area as you approach the water's edge (i.e., feather the cut edge) where hazards exist.

- Reserve any trees that have become acclimated to wind. Balsam fir, white spruce, black spruce, and aspen should be considered first for removal near the RMZ edge adjacent to the clearcut. Longer-lived species should be favored as reserves in RMZs, including sugar maple, red maple, red oak, black ash, white pine, and basswood.

- Large-crowned trees that show signs of decay or disease, or are known to contain heart rot at a given age should be removed first. Large-crowned or large diameter trees may be reserved if they are windfirm species that are well-anchored in the soil and relatively free of decay.

- Thinning from below is usually the recommended thinning treatment in mature forest stands that have never been thinned before. Thinning from above is recommended only if the canopy trees are not windfirm. Selectively removing vulnerable trees in each crown class may enhance stand stability, as long as the residual basal area does not drop too low.

- In flat areas and on summits, avoid exposing stand edges to west and northwest winds.

- Utilize any the slope within the RMZ to protect trees, especially in low wet areas. On lee slopes, locate the RMZ edge so as to keep the canopy below the level of the summit, or remove tall, exposed trees.

- Locate leave-tree islands closer to the exposed edge rather than farther out in the clearcut. This becomes more important if management options within the RMZ are limited due to hazardous stand or site conditions.

Summary and Conclusions

A moderately strong relationship exists between empirical (Turner 2005) and foresters' ranking of species for windfirmness. The residual tree recommendations for riparian management zones within Minnesota's voluntary site-level forest management guidelines (i.e., Table GG-7 within Minnesota Forest Resources Council 1999) are generally in agreement with this study and Turner (2005) with minor exceptions.

It should be possible to reduce windthrow in many northern Minnesota riparian management zones adjacent to clearcuts by assessing various stand and site characteristics during the preharvest, on-site reconnaissance. Shallow rooting depth will exacerbate any existing hazard, as will topographic exposure and selectively managing for species that have low windfirmness, such as balsam fir and aspen. In high hazard conditions, management strategies that maximize the windfirmness of the residual trees are the best way to minimize windthrow.

Although the management recommendations may be generally useful, they will not succeed in minimizing windthrow in every case. Wind hazard classifications and modeling windthrow at RMZ edges in northern Minnesota may further enhance our understanding of windthrow dynamics in these sensitive areas, adding to our ability to effectively minimize windthrow losses.

Acknowledgements

The authors would like to thank Marsha Mlinar for helping design and conduct the survey, survey respondents, and Clarence Turner for providing supporting materials. They would also like to thank the Minnesota Forest Resources Council and the USDA Forest Service for their financial support of this research.

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Appendix 1
Survey Mailed to Forest Resource Managers

Survey Respondent Information

Name:

Position Title:

Primary job responsibility:

Organization name:

Mailing address:

Telephone number:

FAX number:

E-mail address:

Date:

Would you like an executive summary of the results of this study? NO YES

Please return completed survey by March 30, 2001.

Marsha Mlinar
Department of Forest Resources—Box 35
University of Minnesota
1530 Cleveland Avenue North
St. Paul, MN 55108

Blowdown Questionnaire

There are several factors, which may impact blowdown within Riparian Management Zones (RMZs) that are adjacent to a clearcut. These factors include; species, tree diameter, crown class, residual basal area, tree age, distance of the residual tree from the water's edge, slope within the RMZ (percentage), direction of the clearcut with respect to the RMZ, hillslope position, and soil type. In the following questions, you will be asked to rate each of these factors independently of the others. The information we are looking for is related to blowdown that occurs due to post-harvest exposure. We are not interested in blowdown that occurs due to catastrophic wind events, such as in 1995 and 1999. Please answer to the best of your knowledge and experience, based on your current work location only.

1. As a forest manager, do you notice blowdown in Riparian Management Zones that are adjacent to clearcuts?

? Yes (please proceed to question 2)
? No (please proceed to question 12)

2. Holding all other factors constant, please rate the following **residual tree species** relative to other species that occur in your area with respect to their level of windfirmness in a Riparian Management Zone that is adjacent to a clearcut.

	Level of Windfirmness			
Residual tree species	**Low**	**Medium**	**High**	**Species not applicable**
American basswood				
Balsam fir				
Balsam poplar				
Bigtooth aspen				
Black ash				
Jack pine				
Northern white cedar				
Paper birch				
Red maple				
Red oak				
Red pine				
Sugar maple				
Trembling aspen				
White birch				
White pine				
Other (Please specify)				

3. Holding all other factors constant, please rate the following **residual tree diameters at breast height** and their relative level of windfirmness in a Riparian Management Zone that is adjacent to a clearcut.

	Level of Windfirmness			
Residual tree diameter (in.)	**Low**	**Medium**	**High**	**Tree diameter not applicable**
0.1 - 5.0				
5.1 - 10.0				
10.1 – 15.0				
15.1 – 20.0				
20.1 – 25.0				
25.1 – 30.0				
> 30				

4. Holding all other factors constant, please rate the following tree heights by crown class, **residual tree crown classes** (definitions given below) and their relative level of windfirmness in a Riparian Management Zone that is adjacent to a clearcut.

- **Dominant –** a tree whose crown extends above the general level of the canopy and receives full light from above and partial light from the sides.
- **Codominant –** a tree whose crown helps to form the general level of the canopy and receives full light from above, and relatively little light from the sides.
- **Intermediate –** a tree whose crown extends into the lower portion of the canopy, but is shorter in height than the codominants and receives little direct light from above and none from the sides.
- **Suppressed –** a tree whose crown is completely overtopped by the crowns of one or more neighboring trees.

	Level of Windfirmness			
Residual tree crown class	**Low**	**Medium**	**High**	**Crown class not applicable**
Dominant				
Codominant				
Intermediate				
Suppressed				

5. Holding all other factors constant, please rate the following **residual tree basal areas** and their relative level of windfirmness in a Riparian Management Zone adjacent to a clearcut.

	Level of Windfirmness			
Residual basal area within RMZ (ft^2/acre)	**Low**	**Medium**	**High**	**Residual basal area not applicable**
0 – 10				
11 – 20				
21 – 30				
31 – 40				
41 – 50				
51 – 60				
61 – 70				
71 – 80				
> 80				

6. Holding all other factors constant, please rate the following **distances of the residual tree to the water's edge** and their relative level of windfirmness in a Riparian Management Zone that is adjacent to a clearcut.

	Level of Windfirmness			
Distance of residual tree to water's edge (ft.)	**Low**	**Medium**	**High**	**Distance not applicable**
0 – 10.0				
10.1 – 20.0				
20.1 – 30.0				
30.1 – 40.0				
40.1 – 50.0				
50.1 – 60.0				
60.1 – 70.0				
70.1 – 80.0				
80.1 – 90.0				
90.1 – 100.0				
> 100				

7. Holding all other factors constant, please rate the following **slopes where residual trees are located within an RMZ** and their relative level of windfirmness in a Riparian Management Zone that is adjacent to a clearcut.

	Level of Windfirmness			
Slope within RMZ (%) where residual trees are located	**Low**	**Medium**	**High**	**Slope not found in my area**
0 (Level)				
1 – 5				
6 – 10				
11 – 15				
16 – 20				
21 – 25				
26 – 30				
31 – 35				
36 – 40				
> 40				

8. Holding all other factors constant, please rate the following **direction of a clearcut with respect to the residual trees within the Riparian Management Zone (RMZ)** and their relative level of windfirmness.

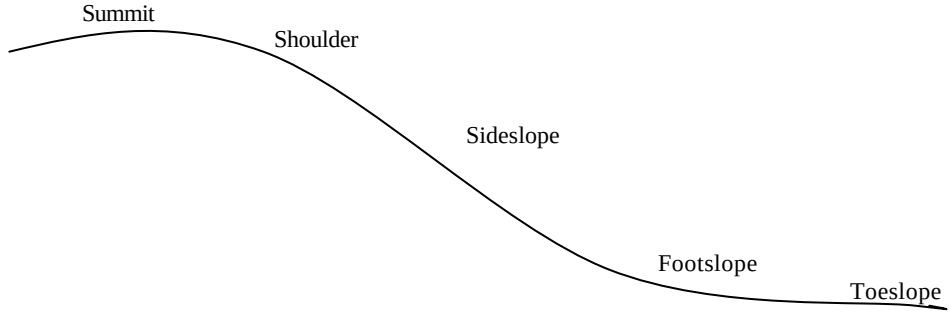
	Level of Windfirmness			
Direction of clearcut with respect to residual trees within the RMZ	**Low**	**Medium**	**High**	**Direction of clearcut not applicable**
Clearcut **N** of RMZ				
Clearcut **NE** of RMZ				
Clearcut **E** of RMZ				
Clearcut **SE** of RMZ				
Clearcut **S** of RMZ				
Clearcut **SW** of RMZ				
Clearcut **W** of RMZ				
Clearcut **NW** of RMZ				

9. Holding all other factors constant, please rate the following levels of **residual tree exposure afforded by topographic position**, and their relative level of windfirmness in a Riparian Management Zone that is adjacent to a clearcut. Please use the following definitions in answering the tale below:

- **Full exposure** - RMZ trees are at the same level as the surrounding landscape.
- **Partial exposure** - RMZ trees about ½ tree height below surrounding landscape about ½ of the trees height within the RMZ is below the surrounding landscape.
- **Limited exposure -** most of the trees height within the RMZ is below the surrounding landscape.
- **No exposure -** RMZ trees are completely below the surrounding landscape.

	Level of Windfirmness			
Tree exposure afforded to residual trees by topographic position	**Low**	**Medium**	**High**	**Tree exposure not applicable**
Full exposure				
Partial exposure				
Limited exposure				
No exposure				

10. Holding all other factors constant, please rate the following **hillslope positions for residual trees** and their relative level of windfirmness in a Riparian Management Zone that is adjacent to a clearcut. (Please use the following illustration of hillslope positions when answering this question).



	Level of Windfirmness			
Hillslope position of residual tree within RMZ	**Low**	**Medium**	**High**	**Hillslope position not found in my area**
Summit				
Shoulder				
Sideslope				
Footslope				
Toeslope				

11. Holding all other factors constant, please rate the following **soil types where residual trees are located** and their relative level of windfirmness in a Riparian Management Zone that is adjacent to a clearcut.

	Level of Windfirmness			
Soil type where residual trees are located	**Low**	**Medium**	**High**	**Soil type not applicable**
Sand				
Sandy loam				
Loam				
Loamy sand				
Silt				
Silty Loam				
Clay				
Other (please specify)				

12. Holding all other factors constant, please rate the following **residual tree ages**, and their relative level of windfirmness in a Riparian Management Zone that is adjacent to a clearcut.

	Level of Windfirmness			
Residual tree age (years)	**Low**	**Medium**	**High**	**Tree age not applicable**
0-10				
11-20				
21-30				
31-40				
41-50				
51-60				
61-70				
71-80				
81-90				
91-100				
<100				

13. Holding all other factors constant, please compare the following **tree age classes,** of standing residuals to blowndown trees, in a Riparian Management Zone adjacent to a clearcut. Please check the appropriate response.

? Residual trees are older than the blowndown tree.
? Residual trees are the same age as the blowndown tree.
? Residual trees are younger than the blowndown tree.

14. Based on your experience, which of the following types of blowdown occur most often in Riparian Management Zones that are adjacent to a clearcut? Rate the frequency of each type of blowdown using a scale of 1-4, with 1 being least frequently seen, and 4 being most frequently seen.

Type of blowdown	**Observation frequency**			
	Least			**Most**
Blowndown (uprooted)	1	2	3	4
Snapped (broken on the bole)	1	2	3	4
Brushed (pushed by another tree)	1	2	3	4
Leaning (partially uprooted, will eventually blow down)	1	2	3	4

15. Considering all of the factors that can affect the occurrence of blowdown within a riparian management zone that is adjacent to a clearcut, what is the relative importance of each factor? Rate each factor using a scale of 1-4 with 1 being least important (has little impact on the occurrence of blowdown) and 4 being most important (has a lot of impact on the occurrence of blowdown).

Factor	**Relative Importance**			
	Least			**Most**
Species	1	2	3	4
Tree DBH	1	2	3	4
Crown class	1	2	3	4
Residual basal area	1	2	3	4
Tree Age	1	2	3	4
Distance of residual tree to water's edge	1	2	3	4
Slope within RMZ	1	2	3	4
Direction of clearcut with respect to RMZ	1	2	3	4
Tree exposure	1	2	3	4
Hillslope position	1	2	3	4
Soil type	1	2	3	4
Other (please specify)	1	2	3	4

16. What techniques do you use to minimize blowdown of residuals in Riparian Management Zones that are adjacent to clearcuts?

17. Please share with us any further comments, suggestions or experiences concerning blowdown and windfirmness in Riparian Management Zones that are adjacent to clearcuts.

Thank you for your time and cooperation. Please return your completed survey by March 30, 2001 in the enclosed envelope to the address noted below.

Marsha Mlinar
Department of Forest Resources – Box 35
University of Minnesota
1530 Cleveland Avenue North
St. Paul, MN 55108

Appendix 2

Survey Cover Letter

Name
Address
City, State Zip

Dear:

A study is being conducted by Marsha Mlinar at the University of Minnesota to assess the effects of various factors on blowdown within riparian management zones (RMZs). The study is being conducted to provide information to resource managers who have to make decisions about residual trees within RMZs. As a separate part of the study, we revisited some of the 1991, 1992, 1993, 1995, and 1997 BMP field audit sites to collect data about factors such as species, slope, orientation of the RMZ to the clearcut, and hillslope position wherever blowdown occurred. Because our field sampling was limited, we need to learn from your experiences because they cover a much wider set of conditions than we were able to sample. Participation in this research project is voluntary.

The purpose of the enclosed survey is to help us understand how various factors relate to the occurrence of blowdown within RMZs adjacent to clearcuts. The information we are looking for is related to blowdown that occurs due to post-harvest exposure. We are not interested in blowdown that occurs due to catastrophic wind events, such as in 1995 and 1999. We would like you or someone else from your office that has current on-the-ground management responsibilities and experience with blowdown to complete and return the survey. All responses will be kept confidential. We will not identify your questionnaire by name nor will we summarize any of the data by landowner type. A self-addressed stamped envelope is enclosed to facilitate the return of your completed questionnaire.

We appreciate your participation in this survey. If you have any questions about the survey, please contact us at 612-624-1224 (Marsha Mlinar) or 612-624-3788 (Charlie Blinn).

Sincerely,

Marsha Mlinar
Graduate Research Assistant

Charlie Blinn
Professor and Extension Specialist

Enclosure

Appendix 3

Survey Reminder Postcard

Two weeks ago, we mailed you a questionnaire asking for your opinion about the effects of various factors on blowdown within riparian management zones (RMZs) in northern Minnesota. If you have already completed and returned it, please accept our sincere thanks.

If you haven't completed and mailed your questionnaire, please do so today. Only a sample of northern Minnesota foresters received the questionnaire so it is very important that your opinions are included in the study to accurately represent the opinions of these foresters. Remember, there are no right or wrong answers. We only want your opinion.

Thanks for your help.

Marsha Mlinar
Graduate Research Assistant

Charlie Blinn
Professor and Extension Specialist

Appendix 4

Survey Follow-up Letter

Name
Address
City, State Zip

Dear:

About a month ago, a questionnaire was sent to you to assess the effects of various factors relating to blowdown within riparian management zones. As of today, we have not received your completed questionnaire.

The study is being conducted to provide information to resource managers who have to make decisions about residual trees within RMZs. As a separate part of the study, we revisited some of the 1991, 1992, 1993, 1995 and 1997 BMP field audit sites to collect data about factors such as species, slope, orientation of the RMZ to the clearcut, and hillslope position wherever blowdown occurred. Because our field sampling was limited, we need to learn from your experiences because they cover a much wider set of conditions than we were able to sample. Participation in this research project is voluntary.

The purpose of the enclosed survey is to help us understand how various factors relate to the occurrence of blowdown within RMZs adjacent to clearcuts. The information we are looking for is related to blowdown that occurs due to post-harvest exposure. We are not interested in blowdown that occurs due to catastrophic wind events, such as in 1995 and 1999. We would like you or someone else from your office that has current on-the-ground management responsibilities and experience with blowdown to complete and return the survey. All responses will be kept confidential. We will not identify your questionnaire by name nor will we summarize any of the data by landowner type. A self-addressed stamped envelope is enclosed to facilitate the return of your completed questionnaire. Please return the completed survey by March 30, 2001.

We appreciate your participation in this survey. If you have any questions about the survey, please contact us at 612-624-1224 (Marsha Mlinar) or 612-624-3788 (Charlie Blinn).

Sincerely,

Marsha Mlinar
Graduate Research Assistant

Charlie Blinn
Professor and Extension Specialist

Enclosure

Appendix 5

Respondent Commentary Organized by Survey Question

Survey commentary was organized by survey question. Each question has been numbered the same as in the original survey and the question wording has been abbreviated. Each phrase that refers to each question will be presented as the full sentence in which it was found, even if that sentence contains references to other factors. The sentence may be repeated under a different question to address the other factors discussed in it. A factor may be mentioned more than once per respondent number. Response numbers represent the number of foresters who mentioned the factor in their commentary. Even if foresters made several references to the same factor, they are all included in a single response number. Commentary from questions 16 and 17 was combined with that found in other parts of the survey as it pertained to each variable addressed in the previous questions. Forester number is the number assigned to the forester.

Factor:	**Indicator words:**
1. blowdown presence	no, blowdown, RMZ
2. species	species, species name
3. diameter	diameter, large, small, class
4. crown class	crown, class, dominant, codominant, intermediate, suppressed, large, small
5. rba	RBA, BA, residual, basal area, density, high, low, crown, cover, thinning, heavily
6. stream distance	stream, distance, closer, water's, edge, approach, water, river
7. slope	slope, topography, land, landscape features
8. aspect	aspect, north, west, south, east, prevailing, wind, direction, orientation, perpendicular, parallel, facing
9. exposure	exposure, clumps, vulnerable, wind, protected
10. hillslope position	hill, position, slope, topography, land, landscape features, summit, shoulder, sideslope, footslope, toeslope
11. soil type	soil, type, sand, clay, organic, shallow, rocky
12. age	age, young, old, over-mature, mature, rotation
13. relative age	older than, younger than, same age, residuals
14. blowdown type	snap, blow over, tip up, break
15. rank of importance	
16. miscellaneous commentary	

Question 1: Is blowdown noticed in the RMZ?

Response #	Respondent #	Comment:
1	7	No clearcuts next to RMZs.
2	10	There is also blowdown in RMZs adjacent to forested areas.
3	16	I answered the first question with a "no". Not because we do not encounter blowdown in RMZs, but because I do not notice an increase in blowdown occurrence between the RMZs versus non-RMZs.
4	34	Four RMZs were visited that had one to five years of exposure to a clearcut and we found little, if any blowdown that may have resulted due to an adjacent clearcut.
5	37	I don't recognize problems with blowdown and windfirmness in RMZs to be at higher risk than in terrestrial zones that are adjacent to clearcuts.

Question 1 comment summary: Those that answered "no" to this question did so either because they did not observe windthrow in RMZs or because they did not observe more windthrow in RMZs than the upland clearcut edges.

Question 2: Species in relation to windfirmness.

Response #	Respondent #	Comment:
1	2	Remove susceptible species (e.g. old aspen) from RMZ if it does not reduce basal area too much.
2	5	Look at topography, species, and diameter for residuals.
3	6	Leave windfirm species where possible.
4	8	Use available size and species that are most likely to be windfirm. Species present generally limits options [as far as cut design]. The lack of options make the RMZ seem useless in some areas (overmature aspen with balsam fir that is deteriorating and beaver present).
5	11	Look at age, species, and density of stand left – may have to make a wider RMZ in cases.
6	12	In all riparian areas, I'll tend to reserve oaks, sugar maples, and pine as well as small advanced regeneration like balsam fir and spruce. If the riparian is birch or aspen, I'll tend to either reserve it completely or clearcut it completely (in patches). [Influence of diameter] depends on species. Pine would be high [windfirm] in dom-codom. [Windfirmness decreases with age] except for red and white pine, which would be high [windfirmness] for all age classes.

7	13	Avoid leaving species prone to windfall (balsam fir, spruce).
8	15	Harvest larger trees and concentrate on species and age. In flatter areas, we try not to expose too much of a stand to west and northwest winds – leave more windfirm birch and northern hardwoods.
9	16	Conifers with larger crowns, shallow root structure and located on peat or soft soils (wet) are the most likely to demonstrate blowdown. Deciduous trees may be just as susceptible but have a reprieve during the dormant season when the wind resistance is reduced, thereby minimizing the exposure time.
10	18	Try to leave: windfirm species, younger trees, trees with small crowns.
11	19	Choose species that have the best chance of withstanding wind. Choose dominant pine species or understory shade tolerant species. [Windfirmness by age] depends on species.
12	20	No cedar where he works. I don't' believe tree age and diameter by themselves are major factors. However, trees at or beyond rotation age for that species are typically in poorer health and therefore more likely to be blown down. Trees with fairly large wind-catching crowns coupled with shallow root systems may be due to growth habits (birch, balsam, fir) or to soil restrictions.
13	21	Select windfirm species. Most of the timber sales are aspen clearcuts. There will be blowdown in any RMZ composed of aspen.
14	22	Change width of RMZ depending mostly on species present. Also may harvest mature tree species of low windfirmness and leaving others with better firmness within the zone itself.
15	24	[Forester does not] have American basswood, Northern red oak, red maple or sugar maple, that far north where he works. Large conifers are most at risk due to winter winds and ice storms. Large white spruce especially should always be cut. It's a waste of a good resource not to. Our directives have been to especially reserve large white spruce instead. Usually in these instances, young, white spruce are found and we should instead go out of our way to reserve them.
16	25	Along clearcut edge, some select harvesting is done to remove species susceptible to windthrow.
17	26	Narrow black spruce stands seem to have little windfirmness but we sometimes cannot avoid leaving them to whatever chance they have of standing or not.

18	28	Aspen and balsam fir are most likely to be windthrown by snapping and other species less likely to be windthrown by snapping, but aspen and balsam fir are less likely to be uprooted than other species. [Blowdown type] depends greatly on species. As a timber forester, I am more likely to notice blowdown if it involves Norway pine than if it involves tamarack because of economic implications.
19	29	When I think about it, there is very little I've seen (blowdown) that has not been related to a blowdown event or insects and disease (i.e. spruce budworm). Most of my sales have been jack pine or aspen without much RMZs. When I have RMZs, they're cedar types (usually).
20	31	Selectively remove older, large-diameter trees and tree species that are not windfirm. [Windfirmness by crown class] depends on species. [Windfirmness by RBA] too dependent on species to answer.
21	32	In flatter areas, we try not to expose too much of a stand to west and northwest winds – leave more windfirm birch and northern hardwoods.
22	33	Important factors are exposure direction, age of residuals and species composition. [Windfirmness by RBA] seems to be more related to species.
23	34	We tend to favor leaving longer-lived species in the RMZ for their longevity.
24	40	[Windfirmness by crown class] really depends on species. [Windfirmness by RBA] depends on species.
25	42	Vulnerability of trees by age depends on species. 100-year-old aspen is not very windfirm, while 100-year-old white pine is very windfirm.
26	43	Hardwood areas will have less crown closure and aspen/birch areas will be left with heavier crown closure. I have not noticed much blowdown in these areas after harvest except for an occasional high risk aspen.
27	45	Reserve the most windfirm species we have to work with. One thing I see a lot of is where the beaver have removed all species from the RMZ except bur oak and they tend to be very windfirm.
28	47	Uneven-age, different species stands have the most resistance [to windthrow].

29	48	Height and diameter are a big factor for balsam fir, bigtooth aspen, and quaking aspen. Even big wolf aspen stand well in clay soil. Codominant aspen usually become whippy. They tend to snap off. [As for windfirmness by stream distance:] tree species, soil types, tree form are the number one consideration before stream distance or basal area are considered. [For windfirmness by age:] again, species form and soil impact residual tree ages differently.
30	49	[For windfirmness by age:] species and soil type play a huge role here.

Question 2 comment summary: When determining windthrow susceptibility for other variables, many of them closely depend on species. Species windfirmness can also be closely dependent on other variables. It is generally recommended to selectively remove species that are not very windfirm and reserve those that are. Hardwoods are more windfirm than conifers, especially in the winter when they are leafless.

Question 3: Windfirmness by diameter.

Response #	Respondent #	Comment:
1	5	Look at topography, species, and diameter for residuals.
2	6	[Large diameter trees are highly windfirm] for red and white pine only [for the last three diameter classes addressed].
3	8	Use available size and species that are most likely to be windfirm.
4	11	Residual diameter is a factor especially if large crowns.
5	12	[For windfirmness by diameter:] Assuming the same height for all trees. Without this assumption I don't believe you can accurately show this relationship.
6	15	Harvest larger trees and concentrate on species and age.
7	19	I also choose trees with large dbh in relation to height.
8	20	I don’t' believe tree age and diameter by themselves are major factors. However, trees at or beyond rotation age for that species are typically in poorer health and therefore more likely to be blown down.
9	23	Generally, larger trees have larger crowns to catch the wind, and tend to be older (more likely to have decay). However, large DBH trees that are sound may be more resistant to breakage.

10	24	Primarily would like to reserve the smaller younger trees and remove larger trees. Large conifers are most at risk due to winter winds and ice storms. Large white spruce especially should always be cut. It's a waste of a good resource not to. Our directives have been to especially reserve large white spruce instead. Usually in these instances, young white spruce are found and we should instead go out of our way to reserve them.
11	28	I have witnessed no relationship between diameter and windfirmness.
12	31	Selectively remove older, large-diameter trees and tree species that are not windfirm.
13	48	Soil plays a big factor [with regard to diameter and windfirmness] - well-rooted big crown trees will hold: In rocky shallow soil they seem to tip up.

Question 3 comment summary: Susceptibility to windthrow increases with dbh, according to most foresters. Large diameter trees that are still without rot may be windfirm (respondent 23). Respondent 28 noticed no relationship between windfirmness and susceptibility to windthrow.

Question 4: Windfirmness by crown class.

Response #	Respondent #	Comment:
1	6	[Windfirmness by diameter] depends on species.
2	11	Residual diameter is a factor especially if large crowns.
3	16	My personal observations indicate the greatest relationship may be with the crown size, root pattern, and soil composition. Conifers with larger crowns, shallow root structure and located on peat or soft soils (wet), are the most likely to demonstrate blowdown. Deciduous trees may be just as susceptible but have a reprieve during the dormant season when the wind resistance is reduced, thereby minimizing the exposure time.
4	18	Try to leave: windfirm species, younger trees, trees with small crowns.
5	20	Trees with fairly large wind-catching crowns coupled with shallow root systems may be due to growth habits (birch, balsam, fir) or to soil restrictions [are susceptible to windthrow).
6	23	Generally, larger trees have larger crowns to catch the wind, and tend to be older (more likely to have decay).
7	31	[Windfirmness by crown class] depends on tree species.
8	34	We harvest mature, over-mature and large-crowned trees which are vulnerable to windthrow.

9	40	[Windfirmness by crown class] really depends on tree species.
10	47	[Windfirmness by crown class] depends on tree species.
11	48	Soil plays a big factor - well-rooted big crown trees will hold: In rocky shallow soil they seem to tip up. Even big wolf aspen stand well in clay soil. Codominant aspen usually become whippy. They tend to snap off.

Question 4 comment summary: Many foresters said this factor is dependent on species. Larger crowns make a tree more susceptible to windthrow, especially if they are shallow rooted or have decay.

Question 5: Windfirmness by residual basal area (RBA).

Response #	Respondent #	Comment:
1	1	If proper basal area can be obtained from younger trees, I will remove the older trees.
2	2	Keep basal area up. Remove susceptible species (e.g. old aspen) from RMZ if it does not reduce basal area too much.
3	11	Look at age, species, and density of stand left - may have to make a wider RMZ in cases.
4	13	Avoid thinning basal area too heavily.
5	14	Have not looked into [windfirmness by RBA] with any detail like this.
6	20	May leave a higher basal area in areas of higher blowdown potential.
7	31	[Windfirmness by RBA is] too dependent on tree species to answer.
8	33	[Windfirmness by RBA] seems to be more related to species.
9	35	Removal of non-windfirm trees or gradual reduction in BA as you leave the RMZ.
10	40	[Windfirmness by RBA] depends on species.
11	43	Most of the riparian zones in timber sales are left as buffer zones around wetlands or shelterwood cut leaving a crown cover that varies from 35% to 70% depending on slope, tree species etc. Hardwood areas will have less crown closure and aspen/birch areas will be left with heavier crown closure. I have not noticed much blowdown in these areas after harvest except for an occasional high risk aspen.
12	44	Maintain greater basal area of residual within clearcut. The residual basal area in the clearcut would probably have a greater effect than the basal area in the RMZ, but I haven't taken notice of the differences you refer to.

13	48	There are many other factors that influence windfirmness by basal area: using basal area in my decision when working in RMZs would be low priority.

Question 5 comment summary: Foresters recommend leaving the rba high if possible. It may not be possible if overstory is susceptible to windthrow, in which case a wider RMZ may need to be left. Leave lower rba near clearcut, higher rba away from the clearcut. How much rba to leave is often dependent on species.

Question 6: Windfirmness by stream distance.

Response #	Respondent #	Comment:
1	1	Depends on orientation of RMZ to prevailing winds.
2	5	[Windfirmness by stream distance] unknown.
3	11	Depends on topo leading right up to river - high and dry or low and wet.
4	15	Have not measured [stream] distance close enough to intelligently answer.
5	19	[Windfirmness by stream distance not a factor] except in saturated conditions.
6	20	As one gets closer to water's edge, typically the rooting zone becomes less as the soil moisture limits root growth.
7	23	I don't think it matters unless it’s so close that water is washing out the bank under the roots.
8	44	My guess is that windthrow would be greatest near the clearcut and least near the water, but I haven't made empirical observations.
9	47	[Windfirmness by stream distance] depends on species.
10	48	Tree species, soil types, tree form, are the number one consideration before stream distance or basal area are considered.

Question 6 comment summary: Windfirmness decreases as the clearcut edge is approached. This factor also depends on aspect and degree of topographic exposure. Respondent 23 does not think it matters in most cases. Respondent 15 hadn’t taken notice. Respondents 19 and 20 suggest that windfirmness is low near the water where soils could be saturated.

Question 7: Windfirmness by slope.

Response #	Respondent #	Comment:
1	3	Will generally leave [unharvested] the slope going toward [the] river or stream or any water area.
2	5	Look at topography, species and diameter for residuals.
3	6	Utilize slopes where wind would be less of a factor (exposure).
4	11	Work with the topography of the land in laying out your sales to minimize exposure.
5	14	Slope is not a major factor.
6	15	Have not measured [slope] enough.
7	20	The last four [slope categories] are rarely found [>26% slope].
8	21	[Make sure] RMZ/cutover boundary follows topography (where possible).
9	23	Don't know [about slope].
10	28	0% slope areas are usually wet sites and more susceptible to windthrow.
11	29	Have RMZ boundaries follow landscape features when possible.
12	30	Select removal of over-mature trees susceptible to blowdown if topography permits.
13	40	Winds will tend to eddy or swirl more at the bottom of slopes.
14	41	[Windfirmness by slope] not applicable.
15	43	Most of the riparian zones in timber sales are left as buffer zones around wetlands or shelterwood cut leaving a crown cover that varies from 35% to 70% depending on slope, tree species etc.
16	49	Not enough slope in my area to measure this.

Question 7 comment summary: Flat areas may be wet and not windfirm. Sloping ground may be used to protect trees (something to consider during the cut layout). Most foresters either hadn't measured slope or did not think it was a major factor.

Question 8: Windfirmness by aspect.

Response #	Respondent #	Comment:
1	1	Use wider RMZ if prevailing winds are a factor and the trees have no particular windfirmness. Depends on orientation of RMZ to prevailing winds. Generally, the trees closest to the water are more windfirm, regardless of orientation.
2	2	Make RMZs a little wider on north side of RMZ.

3	15	Aspect and position on slope seems to be less important. Have not measured [aspect] enough.
4	29	Try to avoid sale boundaries which are very straight and perpendicular to prevailing winds.
5	32	In flatter areas, we try not to expose too much of a stand to west and northwest winds - leave more windfirm birch and northern hardwoods.
6	33	Exposure direction, age of residuals, species composition.
7	42	Create wider RMZs on SE side of clearcuts and NE sides of clearcuts. Most storms have winds that blow from the SW in summer and NW in winter. Hardwoods in RMZs are more vulnerable in summer depending on orientation. Conifers are always more vulnerable regardless of orientation. RMZs that are perpendicular to storm wind's most common direction are most vulnerable and need to be wider than the minimum. RMZs oriented parallel to common storm wind directions can be kept to minimum requirements.

Question 8 comment summary: RMZ may need to be widened if it is facing prevailing winds, especially in flat areas. Prevailing winds are from the southwest in summer and northwest in winter according to respondent 42. Respondent 1 said trees closest to the water are more windfirm regardless of species. Respondent 15 had not measured this factor enough to be informed.

Question 9: Windthrow by exposure.

Response #	Respondent #	Comment:
1	6	Leave clumps versus individual trees. Utilize slopes where wind would be less of a factor (exposure).
2	11	Work with the topography of the land in laying out your sales to minimize exposure. Open up a stand in a wet riparian area and you will get blowdown.
3	16	Deciduous trees. . . have a reprieve during the dormant season when the wind resistance is reduced, thereby minimizing the exposure time.
4	23	As above, assuming the exposure and wind direction are from the summit side, more exposure equals more blowdown. I am opposed to the leaving of reserve strips in most cases, because of the obvious fact that the exposed residuals are often likely to blow down. It doesn't matter if it's a riparian, roadside or other situation. Trees that have grown in the shelter of a larger stand are more vulnerable when that protection is removed. Obviously, any strip of wood is more subject to wind damage when left exposed, but usually a combination of factors is involved.

5	32	In flatter areas, we try not to expose too much of a stand to west and northwest winds - leave more windfirm birch and northern hardwoods.
6	33	Exposure direction, age of residuals, species composition.
7	41	Luck-If it is a situation where exposure seems a problem, may have a wider RMZ. A small amount of the forest types I manage involve riparian areas that subject trees to exposed areas. If there is any RMZ it is likely to border swamp forest types that offer some wind protection.
8	42	Increase width of RMZ if trees have high exposure. Leave-tree islands should be placed closer to most vulnerable exposure of clearcut edge.
9	49	Not enough slope in my area to measure this.

Question 9 comment summary: Leave wider RMZ in topographically exposed areas or areas exposed to prevailing winds. Flat areas may be considered topographically exposed (respondents 11, 32). Leave tree islands (respondents 1, 42) should be placed near the clearcut edge. Respondent 49 said that there is not enough slope on their area to measure this. Respondent 23 said that they don't usually leave reserve strips because any exposed forest is vulnerable to windthrow, regardless if it is an RMZ or not.

Question 10: Windfirmness by hillslope position.*

Response #	Respondent #	Comment:
1	15	Aspect and position on slope seem to be less important. Most ends up on ground. Have not noticed much difference in slope position.
2	23	Assuming the exposure and wind direction are from the summit side, more exposure equals more blowdown.
3	32	Wet areas are at the toe of slopes and protected from winds.
4	40	Soil moisture increases the further down the slope you go.
5	41	Generally pretty level area.
6	42	Assuming clearcut is at top of summit.

*Most of the comments from Question 7 could be roughly applied here.

Question 10 comment summary: Summits and toeslopes are least windfirm for different reasons (respondents 23, 32 and 42), the former due to exposure and the latter due to soil moisture, although exposure plays a role here too. Respondent 1 doesn't notice any difference in windfirmness by hillslope position.

Question 11: Windfirmness by soil type (including soil moisture).

Response #	Respondent #	Comment:
1	6	Soil moisture content [is an important factor].
2	9	Soil moisture will determine blowdown potential.
3	11	If wet, mostly has to do with soil moisture near riparian area.
4	13	Soil moisture - saturated soils most susceptible.
5	14	Do not know [influence of soil].
6	15	Soil . . . seems to have little effect on windfirmness in my observations.
7	16	My personal observations indicate the greatest relationship may be with the crown size, root pattern, and soil composition. Conifers with larger crowns, shallow root structure and located on peat or soft soils (wet), are the most likely to demonstrate blowdown.
8	20	Trees with fairly large wind-catching crowns coupled with shallow root systems may be due to growth habits (birch, balsam, fir) or to soil restrictions. As one gets closer to water's edge, typically the rooting zone becomes less as the soil moisture limits root growth.
9	26	Soil types don't seem to fit for me.
10	38	Organic or saturated soils are the biggest problem for windfirmness (wet soil is weaker).
11	40	Soil moisture increases the further down the slope you go. Trees near the bottom can blow down more easily when soils are saturated.
12	43	I have not noticed much blowdown in [RMZs] after harvest except for an occasional high risk aspen. These areas are also treated as filter strips which means no more than 10% soil disturbance is allowed them during harvest, which is also another factor why there is little post-harvest wind damage.
13	47	Extreme variability in the species type and soil type or lack of.
14	48	Soil plays a big factor - well-rooted big crown trees will hold: In rocky shallow soil they seem to tip up. Even big wolf aspen stand well in clay soil. Tree species, soil types, tree form, are the number one consideration before stream distance or basal area are considered. Rock with shallow duff and soil [are the most important soil considerations]. [Regarding age:] Again, species form and soil impact residual tree ages differently.
15	49	[Soil type] not observed.

Question 11 comment summary: A few foresters said soil types were not a consideration when ascertaining windfirmness. Most however, said soil moisture was an important consideration for tree stability in wind. Soil types were less important than soil moisture. Rocky shallow soil was seen as not windfirm by respondent 49.

Question 12: Windfirmness by age.

Response #	Respondent #	Comment:
1	1	If proper basal area can be obtained from younger trees, I will remove the older trees.
2	2	Remove susceptible species (e.g. old aspen) from RMZ if it does not reduce basal area too much.
3	6	Red and white pine would [have high windfirmness] for all age classes.
4	8	The lack of options make the RMZ seem useless in some areas (over-mature aspen with balsam fir that is deteriorating and beaver present).
5	10	Age of the trees is the most predominant figure that affects blowdown.
6	11	Look at age, species, and density of stand left - may have to make a wider RMZ in cases. The older the [trees] are the less windfirm they tend to be, especially if [they] develop big crowns in wetter areas - others in a tight stand fairly windfirm.
7	15	Harvest larger trees and concentrate on species and age. In the long run when managing even age species, a riparian area is better managed by harvesting enough to ensure reproduction. Uneven age [riparian forests] can be effectively managed by select harvest.
8	16	Question 12 was left blank. We typically would not obtain an age on blowdown trees. To guess would not be valid for and empirical research project.
9	18	Try to leave: windfirm species, younger trees, trees with small crowns.
10	19	[Age] depends on species!
11	20	I don't' believe tree age and diameter by themselves are major factors. However, trees at or beyond rotation age for that species are typically in poorer health and therefore more likely to be blown down.
12	22	Also may harvest mature tree species of low wind firmness and leaving others with better firmness within the zone itself.
13	23	Older trees are more likely to be weakened by decay and be large enough to catch more wind.

14	24	Primarily would like to reserve the smaller younger trees and remove larger trees. But I am directed to do otherwise, so I do - then over the months, years, I watch the blowdown occur. Our directives have been to especially reserve large white spruce. Usually in these instances, young white spruce are found and we should instead go out of our way to reserve them.
15	30	Select removal of over-mature trees susceptible to blowdown if topography permits.
16	31	Selectively remove older large diameter and tree species that are not windfirm. My rule is old trees blow down, young trees don't. This holds true across all landscapes.
17	33	[The most important factors are] exposure direction, age of residuals, species composition.
18	34	We harvest mature, over-mature and large crowned trees which are vulnerable to windthrow. We tend to favor [leaving?] longer-lived species in and RMZ for their longevity.
19	38	A lot of trees are old trees along RMZs and have plenty of defects so they are more apt to be damaged by wind.
20	41	Generally, don't count on trees standing long since much of harvest is over-mature types that I don't expect to stand up to very long.
21	42	Leave smaller, more windfirm trees while maintaining residual BA. Vulnerability of trees by age depends on species. 100-year-old aspen is not very windfirm, while 100-year-old white pine is very windfirm.
22	47	Uneven age, different species stands have most resistance.
23	48	Species form and soil impact residual tree ages differently.

Question 12 comment summary: Older trees are more susceptible to windthrow if they are overmature, and therefore should be removed in favor of younger trees in the stand. Red and white pine are highly windfirm for all age classes according to respondent 6. Respondent 10 thought that age was the most important factor when assessing windthrow, while respondent 20 didn't think age (and species) by itself was a major factor.

Question 13: Windfirmness by relative age of standing residuals compared to windthrown trees.*

Response #	Respondent #	Comment:
1	11	The older the [trees] are the less windfirm they tend to be, especially if [they] develop big crowns in wetter areas – others in a tight stand fairly windfirm.

2	20	However, trees at or beyond rotation age for that species are typically in poorer health and therefore more likely to be blown down.
3	23	Older trees are more likely to be weakened by decay and be large enough to catch more wind.
4	31	My rule is old trees blow down, young trees don't.
5	49	Species and soil type play a huge role here.

*All comments here are found in Question 12 as well.

Question 13 comment summary: According to respondent 31, older trees blow down, younger trees do not. This position is generally supported by other foresters.

Question 14: Frequency of blowdown type.

Response #	Respondent #	Comment:
1	28	Aspen and balsam fir are most likely to be windthrown by snapping and other species less likely to be windthrown by snapping, but aspen and balsam fir are less likely to be uprooted than other species.
2	48	Soil plays a big factor - well-rooted big crown trees will hold: In rocky shallow soil they seem to tip up. Codominant aspen usually become whippy. They tend to snap off.

Question 14 comment summary: Soil and species tend to play dominant roles in determining whether a tree is uprooted or snapped.

Question 15: Relative importance of each factor.

Refer to comments and comment frequency in each question to establish which factors were most important.

Miscellaneous commentary: Respondent # may be repeated for foresters who provided more than one comment in response to this question.

Response #	Respondent #	Comment:
1	3	I normally leave the entire RMZ; I do not cut inside it.
2	6	Leave clumps versus individual trees.
3	10	We attempt to harvest trees through selective harvesting and carefully following the DNR forest management guidelines for riparian areas.

4	14	Avoid blunt edges by reserving some trees (non-merchantable) within the cut-over.
5	16	No special [management?] considerations.
6	20	May vary the width of "leave strip" - make it wider in areas of higher blowdown potential.
7	21	Have RMZ/cutover boundary follow topography (where possible).
8	26	Follow the ELT edge.
9	28	I wish I could say that we apply techniques to minimize blowdown in riparian areas, but in reality we don't. Generally, the RMZ is determined by appropriate guidelines, and although limited harvest is permissible under current guidelines, most are treated as hands off areas with essentially no management done to them.
10	29	Have RMZ boundaries follow landscape features when possible.
11	32	A lot of management is in glacial moraine areas (not suitable to farm). The potholes are inhabited by beavers and there is only hazel or conifers 100yd out from riparian zone. In some cases, we just more or less write residual trees off and hope they don't make too much of a mess.
12	34	Where appropriate, we would expand the width of an RMZ to minimize the potential blowdown of residuals along with other concerns that may warrant a wider RMZ.
13	36	We typically reserve all items within the RMZ, regardless of size of species.
14	37	Cut out trees considered to be at risk.
15	38	Widen the leave zone slightly so the edge trees are more apt to stand the wind.
16	40	Leave "buffer strips" of uncut timber adjacent to the RMZ.
17	44	I have not been aware of a "need" to minimize blowdown in RMZs.
18	45	Occasionally leave a buffer to the RMZ depending on the situation.
19	47	Keep the edge of a clearcut uneven with fingers etc. Do not want a straight edge. This appears to lower blowdown. Also, monoculture versus a diverse stand makes a difference. Fire origin monoculture stand appears to have low resistance to blowdown. Uneven age, different species stands have most resistance.
20	49	Vary the width based on the entire set of conditions along RMZ as the buffer is established.
21	1	There isn't a standard prescription for RMZ width management. As question 15 indicates, there are many factors that come into play. The land manager is in the best position to make these decisions on a case-by-case basis.

22	5	Some instances 'forcing' wind at selected trees will, in time, blow trees over providing large woody debris in stream.
23	7	[Forester] has no clearcuts next to RMZs.
24	10	My concern is that this information is going to be misinterpreted to assume that there is always blowdown in riparian areas following clearcuts, when in all reality blowdown occurs whether the stand adjoins a clearcut or not.
25	11	If it’s a real bad wind, it won't make any difference what's done - it’s cooked. Techniques only work for average storms and still lose some.
26	12	I can't think of any area that has stood completely windfirm upon exposure. There always seems to be some blowdown or breakage of residual trees.
27	13	A combination of the seasonally strong winds in October-November, following heavy rain, usually is the main cause of blowdown in our area.
28	15	This survey was hard to fill out without actually measuring (i.e. distance and % slope) in small incremental changes. In the long run when managing even age species, a riparian area is better managed by harvesting enough to ensure reproduction. Uneven age [riparian forests] can be effectively managed by select harvest.
29	16	I answered the first question with a “no”. Not because we do not encounter blowdown in RMZs, but because I do not notice an increase in blowdown occurrence between the RMZs versus non-RMZs.
30	18	Why are you only concerned with blowdown in RMZs adjacent to clearcuts? There is blowdown in a selective cut also.
31	19	Most of these factors depend upon more than one characteristic. I don't believe it is possible to relate some of these factors accurately without presenting their relationships with other factors.
32	22	All these factors will influence what I may do in a particular situation, and will change my way of looking at a particular area if factors are present or absent.
33	23	I am opposed to the leaving of reserve strips in most cases, because of the obvious fact that the exposed residuals are often likely to blow down. It doesn't matter if it's a riparian, roadside or other situation. Trees that have grown in the shelter of a larger stand are more vulnerable when that protection is removed.

34	28	My work area involves about 150,000 acres of state land intermixed with forests of other ownerships, primarily county and federal. In my 23 years as a field forester I have observed a lot of blowdown but I believe only a very small portion was in RMZs adjacent to clearcuts. In addition, I have actually never observed blowdown of any scale while the blowdown event is occurring and consequently the blowdown areas I have encountered can only be estimated with respect to when the blowdown occurred. With that said, it is my belief that the vast majority of blowdown occurs in the relatively rare wind events which occur about 1 per year in my work area like the thunderstorms in '95 and '99. My main concern about the survey is with respect to conclusions the survey draws and what the survey is used for. If the survey is used to fine-tune future research, I think it is a good thing. However, if the research is used to publish "characteristics of riparian blowdown," I think it is misguided. All of my responses and I would guess that of most of the people who responded are based on recollections of casual observations and because of that subject to bias. The bottom line is that my responses are based on absolutely no measured data but rather recollections of casual observations.
35	29	This was a difficult survey for this area. When I think about it, there is very little I've seen (blowdown) that has not been related to a blowdown event or insect and disease (i.e. spruce budworm).
36	31	Leaving the wrong trees in a RMZ can be worse than cutting. Removed by harvest is far better than letting Mother Nature blow them into the water.
37	34	Four RMZs were visited that had one to five years of exposure to a clearcut and we found little, if any blowdown that may have resulted due to an adjacent clearcut.
38	36	Given the time available to allow for this survey, snow conditions, and inability to contact private landowners to cross their land, only a few RMZs were visited. The most common reason, by far, for blowdown within an RMZ, was cutting by beavers. This cutting also extended into non-RMZ areas.
39	41	I really have not paid close enough attention to most of the factors in these questions to put much validity in my answers.
40	43	These [RMZ] areas are also treated as filter strips which means no more than 10% soil disturbance is allowed them during harvest, which is also another factor why there is little post-harvest wind damage.

41	44	I haven't spent much time looking for blowdown in RMZs - regarding them as areas to be mostly left alone. Our staffing levels do not permit much uneven-aged management in small areas such as in RMZs. We may mark a few trees to be selectively removed while setting up a timber sale on the adjacent acreage, but such areas are not too likely to receive much follow-up attention.
42	45	One thing I see a lot of is where the beaver have removed all species from the RMZ except bur oak and they tend to be very windfirm. My thoughts more than my observations are as near every acre of my work area has been hit by major wind storms.
43	16	In closing, I would like to "think out loud" for a moment. While the research on this topic may be interesting and of some value, I hesitate to endorse conclusions from research undertaken with questionnaires – especially when looking at the multitude and complexity of variables found in dealing with biological entities. Too often with surveys, conclusions are projected which may not correctly portray the subject. Once conclusions are published, right or wrong, they become building blocks and are cited in additional research of they become a "weapon" of special interest groups who may take the results out of context (or intentionally distort the findings) to support their goals. Therefore, I would rather see substantiated "on the ground" research before having results published.

Miscellaneous comment summary: Many of these comments relate to the layout of the clearcut with respect to the RMZ, such as using topography to shelter residual trees and feathering the RMZ cut edge. Respondent 36 typically reserves all trees within the RMZ. A few respondents (32, 11, 12) felt that there was little that could be done to minimize windthrow in RMZs. Respondent 44 hadn't been aware of a "need" to minimize blowdown in RMZs, and respondent 16 gave them no special considerations with respect to windthrow. Respondent 19 noted that most of the factors mentioned in the survey were so interrelated that it is difficult to discuss their influence on windthrow individually. A few respondents (41, 44) hadn't spent much time looking at the factors in this survey as they relate to windthrow in RMZs. Beaver activity was mentioned as a major cause of blowdown in RMZs by respondent 36. Survey respondent 18 wondered why the survey only concerned blowdown in RMZs. Respondents 28 and 16 were concerned how the results of this study would be used.

Chapter 2
Effects of Riparian Forest Harvest on Instream Habitat, and Fish and Invertebrate Communities

Executive Summary

Stream riparian zones are critical to the health of stream fish and invertebrate communities. Forest harvest within the riparian zone may thus impact stream fish and macroinvertebrate communities and the determination of the level of acceptable harvest within the riparian zone is important to balance forestry needs with stream biotic integrity. This report provides a summary of the findings of the preharvest and first year post-harvest data collection of an ongoing manipulative experiment focused on determining the effects of no, low and high levels of riparian harvest on stream habitat and fish and invertebrate communities. Total number of fish species sampled was similar for 2003 and 2004. Although the total number of individuals was higher in 2004, this is a reflection of large increases in a few streams rather than a general trend. Index of Biological Integrity (IBI) scores were comparable in 2003 and 2004. Macroinvertebrate community indices indicate within-site and between-site variability, but none were significantly different ($p>0.05$). The qualitative habitat evaluation index (QHEI) scores exhibited variability between reaches and between treatments, but none were significantly different ($p>0.05$). Dissolved oxygen and pH exhibited similar trends in both pre- and first year post-harvest data. In contrast nitrate, alkalinity and conductivity showed considerable variability in 2004 in comparison to 2003 at all sites. These year-to-year differences between sites and between treatments indicate the need to continue monitoring for a longer time to define the effects of riparian forest harvest.

Introduction

Forest products are an important natural resource in the upper Midwest. In Minnesota, timber harvest has been increasing and will continue to increase in the near future (Anonymous 2001). Timber harvest activities have the potential to degrade water quality and aquatic resources and for this reason best management practices (BMPs) or site-level forest management guidelines have been adopted to protect riparian and aquatic resources in Minnesota (MFRC 1999, Anonymous 2001). Although BMPs are based on the best available scientific information and implementation monitoring is being conducted (Anonymous 2001), BMPs have not been evaluated for effectiveness at protecting aquatic resources. Most research on the effects of forest harvest on streams and the effectiveness of forest harvest BMPs has been conducted in more mountainous regions such as Tasmania (Davies and Nelson 1994), the Sierra Nevada, the Pacific Northwest and Appalachia (e.g., Meehan 1991, Castelle and Johnson 2000). Results from these areas may not be directly applicable to the Midwest (Perry et al. 1992).

Riparian zones provide many protective services to streams (Gregory et al. 1991, Castelle et al. 1994, Castelle and Johnson 2000). Determination of the necessary width of riparian buffers (e.g., Castelle and Johnson 2000) or the permissible level of harvest within a buffer is essential to adequately protect stream resources without removing a large

portion of the basin from harvest. Most studies on the effectiveness of riparian buffers at protecting streams from upslope harvest have focused on the width of the buffer and have not considered harvest within the buffer zone (e.g., Barton et al. 1985, Castelle and Johnson 2000). Current Minnesota BMPs allow varying degrees of harvest within the riparian management zone (RMZ). Harvest within the RMZ may be used to promote regeneration of shade intolerant species. Thus, it is important to know the level of harvest that reduces the effectiveness of the RMZ in maintaining stream quality.

The objective of this project was to experimentally determine the effectiveness of various levels of riparian forest harvest on in-stream resources. We examine site-based effects associated with high, low and no riparian harvest (30m Riparian Management Zone, upland clearcuts) on aquatic habitat, macroinvertebrates and fish. Specifically, we evaluate effects on fish and invertebrate habitat (temperature, sediment composition, embeddedness, depth, width, cover, bank stability, canopy coverage, and woody debris, etc.), and benthic macroinvertebrate and fish communities.

Methods

The eight study sites range across northern Minnesota and are located in Beltrami, Carlton, Cook, Lake, and St. Louis counties (Table 1). Pairs of treatment sites (streams) were located and harvest plots marked in 2003. Within each stream, a riparian control (no riparian harvest with upland clearcut) and one riparian management treatment (low or high residual basal area with upland clearcut) were established to compare the effects of different residual basal area levels (e.g., 4 high basal area and 4 low basal area replicates). We were also able to establish a nonharvested control (both upland and riparian zone not harvested) at seven of the eight streams (beaver activity preclude a nonharvested control plot at one site). Target treatments in winter 2004 were high residual (11.9 m^2 basal area/ha remaining) or low residual (6.3 m^2 basal area/ha) riparian harvest. During harvesting, the target residual basal area was not always met and actual values varied by ± 0.9 m^2 basal area/ha. Here, we compare the effects of different residual basal area levels (i.e., 4 high basal area and 4 low basal area replicates) on study variables.

All sites were sampled for habitat, fish and invertebrates in summer 2003 (preharvest) and 2004 (post-harvest). This includes a high residual basal area plot (Reservation River Tributary) that was not harvested in winter 2003-2004. Harvesting on this plot was completed in winter 2004-2005.

At each stream, sampling reaches were established in the no-harvest control, riparian control and riparian harvest plots. Within each plot, we sampled 100-meter reaches above the plot (upstream), within the plot (downstream most 100m) and below the plot (100m downstream of plot)—this design provides internal upstream controls and allows for assessment of downstream effects. Ideally, at a given site, we would sample nine 100-m reaches; up-, within, and below at the nonharvested control, the riparian control and the harvest treatment. Due to spatial and habitat constraints, up and below reaches were not always feasible for some plots.

Table 1. Summary description of the study streams.

County / Stream number	Stream Information				RMZ preharvest basal area (m^2/ha)	RMZ post-harvest basal area (m^2/ha)
	Owner	**Name**	**Width (m)**	**Protection**		
Beltrami (1)	DNR	Shotley Brook	4	None	28.7	20.4
Carlton (2)	DNR	Nemadji State Forest	1.6	None	25.9	10.3
Cook (3)	DNR	Reservation River Tributary	3.5	Trout	20.7	N/A
Lake (4)	DNR	West Split Rock River	6.4	Trout	13.8	5.3
Lake (5)	DNR	East Branch Beaver River	8.9	Trout	17.2	15.4
Lake (6)	County	East Baptism River	8.5	Trout	23.0	13.1
St. Louis (7)	County	Cloquet River Tributary	2.6	None	23.0	6.4
St. Louis (8)	County	St. Louis River Tributary	1	None	28.7	8.0

Forest harvest effects on response variables (outlined below) were analyzed by subtracting the upstream (internal control) value from the within or downstream value for each reach (control-control, riparian control, low riparian harvest, high riparian harvest). These differences were then analyzed with an ANOVA for treatment effects by year.

Temperature monitoring: Temperature loggers (Optic StowAway®, Onset Computer, Pocasset, MA) were placed in all reaches at each site in May 2003 and 2004. Temperature was recorded at 30 min intervals until removal in October or November.

Water quality: Water quality was recorded in the within reaches at each site in spring and fall. Conductivity, dissolved oxygen, and pH were recorded with a Quanta Water Quality Monitoring System® (Hydrolab Corporation), and orthophosphate was determined by the PhosVer 3 (Ascorbic Acid) method with a Hach model DR/2000 spectrophotometer in the field. Alkalinity (methyl orange; mg $CaCO_3$/L) was determined by titration and nitrate was determined spectrophotometrically (APHA 1989) on samples preserved in HCL with a Spectronic 1201 Dual Beam spectrophotometer in the laboratory.

Instream habitat: In July, each 100-m reach was sampled for habitat characteristics following the methods of Merten (1999) with modifications of methods given by Bailey et al. (1993). Variables measured included visual estimates of bank cover, channel stability, cover, woody debris, percent riffles, runs and pools, and aquatic plant coverage. Canopy coverage was determined in each reach with a spherical densiometer. Streambed sediment and substrate type and size (e.g., percent silt, sand, gravel, cobble) and percent embeddedness were characterized along 14 transects placed at regular intervals in each reach with a maximum total of 56 measurements per reach. Mean depth, velocity and discharge were measured at the fourteen transects within each reach. A qualitative habitat evaluation index (QHEI) was calculated from these data. Blow-down trees were also recorded in each reach.

Fish assemblages: Fish assemblages were sampled in August. Sampling was conducted in the up- (internal control), within- and downstream reaches at each treatment plot (including the control sites) with pulsed DC electrofishing (Wisconsin AbP-3 backpack

shocker) following the protocol of Simonson and Lyons (1995). Fish were identified to species, measured (total length), weighed and returned to the stream. Cold-water Index of Biotic Integrity (IBI) values were calculated according to Mundahl and Simon (1998), and warm-water IBI values according to Karr et al. (1986) and Lyons (1992) to assess the environmental health of the stream fish communities. Species richness, species abundances and IBI scores (normalized to 100) were analyzed to determine the effects of harvest treatment.

Benthic macroinvertebrates: Benthic macroinvertebrates were assessed in July following the family-level, composited, multihabitat rapid bioassessment protocol (Barbour et al. 1999) in each of the upstream (internal control) and within-plot reaches for the control, riparian control and riparian harvest plots. Two composited samples of 20 kicks/net (each sample representing 50 m) were collected with a D-net in each 100-m reach. Samples were sorted and macroinvertebrates identified to family in the laboratory.

Results

Data were collected and analyzed for 2003 and 2004 and initial data analysis has been completed for comparison of harvest effects from 2003 to 2004.

Instream habitat: There was substantial variation in habitat characteristics between sites. Water temperatures varied among sites. Overall, temperatures in 2004 were lower in August and higher in September compared with 2003. However, the trout streams (Reservation River Tributary, West Split Rock river, East Branch Beaver River, and East Baptism River) maintained temperatures = 19°C throughout the summer (range from 12-19°C), whereas other streams had summer maxima up to 25°C.

In spring 2004, conductivity and alkalinity ranged from 32 µS/cm and 20 mg $CaCO_3$/L, respectively at the Cloquet River Tributary to 228 µS/cm and 127 mg $CaCO_3$/L at Shotley Brook. The Cloquet River Tributary had the lowest conductivity and alkalinity in fall 2004 (40 µS/cm and 15.5 mg $CaCO_3$/L) and Shotley Brook the highest conductivity and alkalinity (260 µS/cm and 146 mg $CaCO_3$/L). These results were similar to the results obtained in 2003. Dissolved oxygen was higher in fall 2004 (8.9-12.6 mg/L) at all sites compared to spring 2004 (7.5-10 mg/L). The pH was generally similar in both seasons and was > 7.5 at all sites, except the Cloquet River Tributary which had a value of 7.2. Orthophosphate ranged from 10 µg-P/L to 170 µg-P/L in spring and 5 µg-P/L to 114 µg-P/L in fall. However, during both seasons, most sites had less than 50 µg-P/L. Spring nitrate concentrations were comparable to 2003 and ranged from 0.36 mg-N/L to 0.97 mg-N/L. However, nitrate concentrations in fall 2004 were higher and ranged from 0.95 mg-N/L to 1.80 mg-N/L. Nitrate was positively correlated with alkalinity and conductivity, but no significant correlation was found with phosphorus.

Qualitative habitat evaluation index (QHEI) scores normalized to 100 ranged from 39-86 in 2003 and 45-81 in 2004. After testing for a harvest effect by subtracting the upstream (internal control) value from the within or downstream value for each reach (Figure 1), there were no significant differences in QHEI between years, and between sites and

treatments (P<0.05). However, in general the smaller intermittent flowing streams had lower QHEI scores compared to the larger perennial streams.

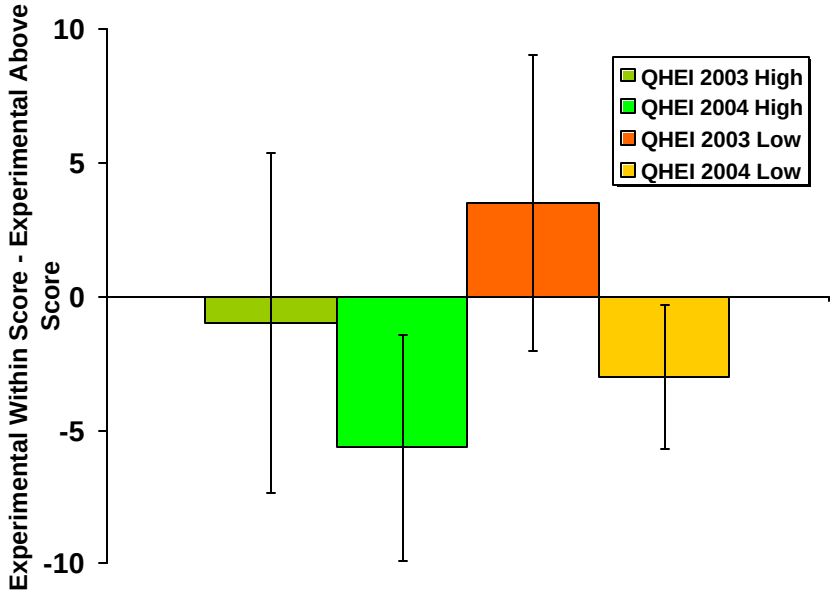


Figure 1. High and low RBA QHEI response variable between experimental and riparian control scores (error bars = 1 SE).

Fish assemblages: Seventeen species of fish were found among more than 2,600 fish collected. Total number of individuals was higher in 2004, but reflected large increases in a few streams (Reservation River Tributary and East Branch Beaver River) rather than a general trend. We observed a reduction in the percentage of brook trout sampled in 2004 in West Split Rock River and East Branch Beaver River.

Streams were grouped into three types based on the dominant fish communities. Four sites were trout streams, containing brook trout (*Salvelinus fontinalis*) and typically also blacknose (*Rhinicthys atratulus)* and longnose dace (*R.cataractae*). The exception in 2004 was the Reservation River Tributary that contained primarily rainbow trout (*Oncorhynchus mykiss*). In 2003, there were only 2 species of fish with a total of 2 individuals in the Reservation River Tributary, but the number increased to 4 species with a total of 598 individuals (590 of these were rainbow trout) in 2004. The other trout streams contained 8-12 species and a comparable number of individuals, except East Branch of Beaver River where the total increased to 1,181 individuals representing 12 species in 2004, as opposed to 190 individuals representing 10 species in 2003. Total number of species and individuals in Shotley Brook, a lake-outlet stream containing a diverse array of warm and coolwater species, decreased in 2004 in comparison to 2003, from 302 individuals representing 10 species to 47 individuals representing 5 species. The change in Shotley Brook could be attributed to high stream flow in 2004 that made electroshocking less effective. The remaining sites are classified as small minnow streams with low diversity dominated by mudminows (*Umbra limi*) and may indicate poor winter or summer oxygen conditions.

Index of biotic integrity (IBI) scores were computed using the appropriate warm or coldwater IBIs and scores were normalized to 100 for comparison purposes. Based on Lyon's (1992) IBI in mudminnow dominated warmwater streams, the normalized IBI scores ranged from 10-45 in 2003 and 22-45 in 2004. Normalized Red Lake IBI (Niemela et al. 1998) scores ranged from 47-60 in 2003 and 63-67 in 2004 for Shotley Brook. In trout streams, Mundahl and Simon (1998) normalized IBI scores ranged from 21-83 in 2003 and 13-79 in 2004. Both within-site and between-site differences were observed but none were significantly different ($p<0.05$). There were no significant differences in IBI scores between sites and treatments ($P<0.05$) (Figure 2) and between years at most sites, however, the IBI score decreased significantly ($p<0.05$) between 2003 and 2004 at East Branch Beaver River.

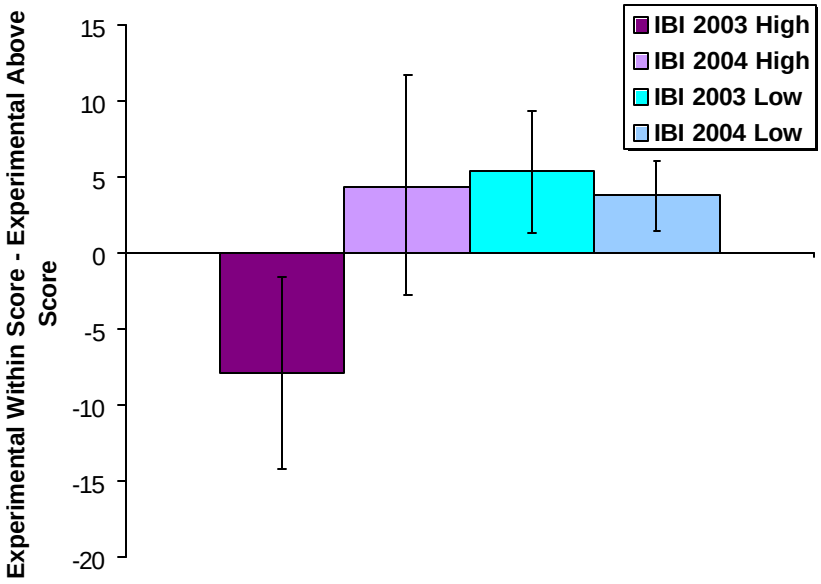


Figure 2. High and low RBA fish IBI response variable between the experimental within score and experimental above score (error bars =1 SE).

Macroinvertebrate communities: Macroinvertebrate indices indicated both within-site and between-site variations. Most indices in 2004 were comparable to those obtained in 2003 at the reach level. In the low RBA sites, mean number of individuals per net varied from a minimum of 298 to a maximum of 1,598, species richness was 6-21 families, percent EPT taxa ranged from 0-25%, whereas percent Chironomidae varied from 10-60%. In the high RBA sites, mean number of individuals per net varied from 356-2,164, species richness was 14-20 families, percent EPT taxa ranged from 16-44%, and percent Chironomidae had a range of 34-75%. No significant differences ($P<0.05$) in macroinvertebrate indices due to riparian harvest treatment were found (Figure 3).

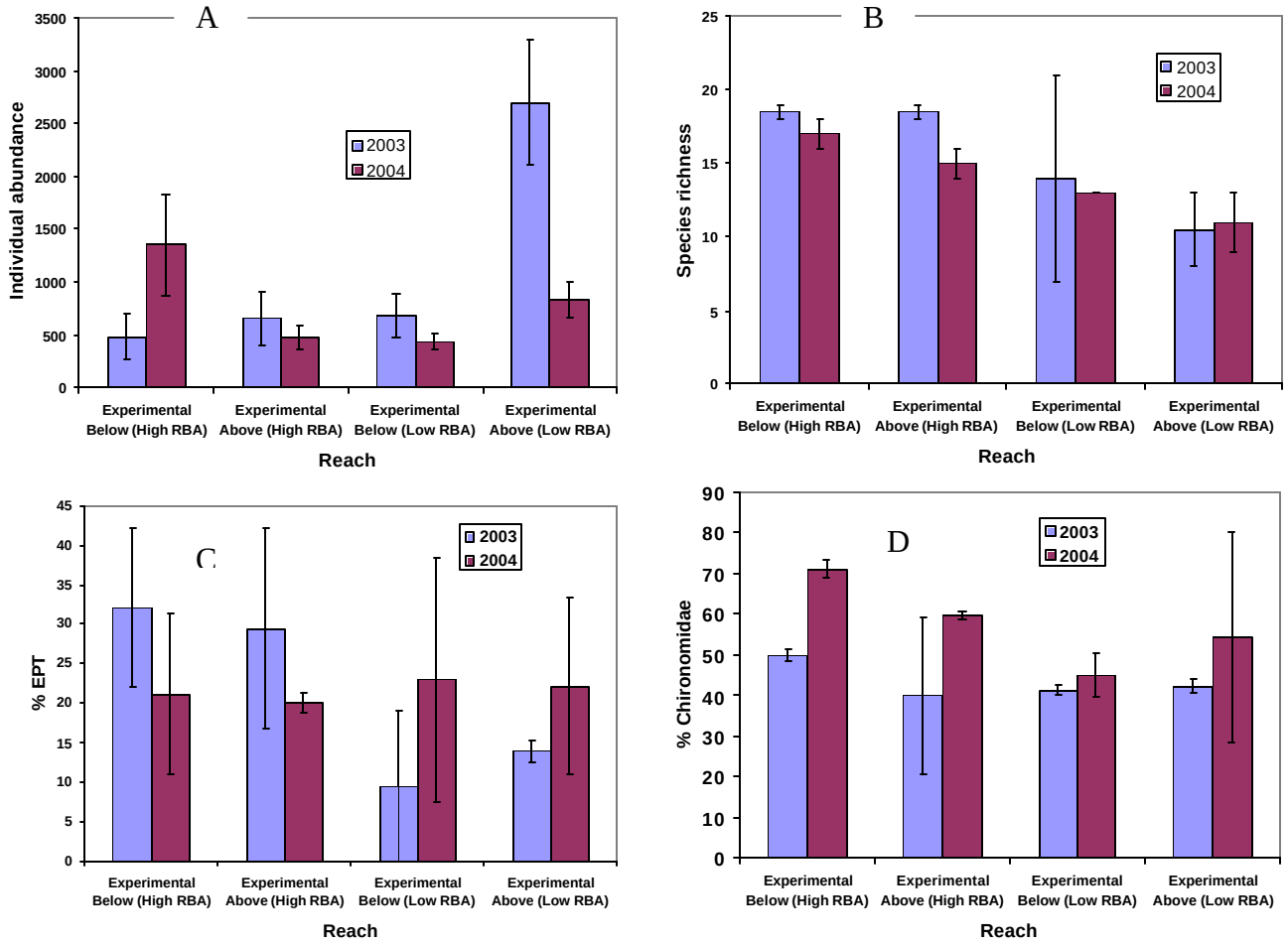


Figure 3. 2003 and 2004 mean macroinvertebrate community indices for high and low RBA experimental below and experimental above reaches (error bars = 1 SE). (A = abundance; B = species richness; C = %EPT; D = %Chironomidae)

Summary of Findings

Significant variability was observed in the number of individuals and species of fish and macroinvertebrates between 2003 and 2004, but there was no obvious trend that could be discerned in relation to harvest. QHEI and IBI scores between years were not significantly different although year-to-year variation was observed. Water quality attributes such as temperature, conductivity, alkalinity, phosphorus and nitrates also indicate seasonal and annual variability. No significant effects due to riparian harvest were found for habitat, macroinvertebrates or fish. This may indicate that the current guidelines are adequate to protect stream fauna and habitats; however, the considerable variability among streams may require a more sophisticated analysis to detect effects.

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Seminar or poster presentations resulting from the project

Effects of riparian forest harvest on instream habitat, water quality and macroinvertebrate communities in northern Minnesota. **D. M. Atuke, R. M. Newman, B. Vondracek, and N. J. Schlesser.** Annual Meeting of the Minnesota Chapter of the American Fisheries Society. 15 March 2005, Grand Rapids, Minnesota.

Effects of riparian forest harvest on instream habitat and fish assemblages in northern Minnesota. **N. J. Schlesser , R. M. Newman, B. Vondracek, and D. M. Atuke**. Annual Meeting of the Minnesota Chapter of the American Fisheries Society. 15 March 2005, Grand Rapids, Minnesota.

Yearly variation in stream habitat and fish assemblages in northern Minnesota. **N. J. Schlesser, D. M. Atuke, R. M. Newman, and B. Vondracek**. Annual Meeting of the Minnesota Chapter of the American Fisheries Society. 15 March 2005, Grand Rapids, Minnesota.

Variability in Response of Instream Habitat, and Fish and Macroinvertebrate Assemblages, to Riparian Forest Harvest in Northern Minnesota. **Atuke, D. M., Schlesser, N. J. Vondracek, B., and Newman, R. M.** The North American Benthological Society, 53rd Annual Meeting. 25 May 2005, New Orleans, LA. [***Eos Transactions AGU, 86*(18), Joint Assembly Supplement, Abstract NB33M-01.]**

Chapter 3
Breeding Bird Survey: Preliminary Data

Month	Date	Site	Transect	Abbrev	Location	Key to Codes
May	5/10/2005	7	C	GCKI	W	**Site**
May	5/10/2005	7	C	GCKI	W	1-8= site numbers used by research team
May	5/10/2005	7	T	WTSP	C	
May	5/10/2005	7	T	WTSP	C	**Transect Codes**
May	5/10/2005	7	T	WTSP	C	C=Buffer control
May	5/10/2005	7	T	BCCH	RT	T=Treatment
May	5/10/2005	7	T	BCCH	RT	X=Control
May	5/10/2005	7	T	WTSP	C	Y=Control
May	5/10/2005	7	X	WTSP	W	
May	5/10/2005	7	Y	OVEN	W	**Abbrev**
May	5/10/2005	7	Y	BRCR	W	Standard AOU Bird identification code
May	5/10/2005	7	Y	BRCR	W	GCKI=golden-crowned kinglet
May	5/10/2005	7	Y	BLJA	W	WTSP=white-throated sparrow
May	5/10/2005	7	Y	HETH	W	BCCH=black-capped chickadee
May	5/10/2005	7	Y	HETH	W	OVEN=ovenbird
May	5/9/2005	2	C	NAWA	W	BRCR=brown creeper
May	5/9/2005	2	C	NAWA	W	BLJA=blue jay
May	5/9/2005	2	C	BLJA	W	HETH=hermit thrush
May	5/9/2005	2	C	NAWA	W	NAWA=Nashville warbler
May	5/9/2005	2	C	BCCH	W	MAWA=magnolia warbler
May	5/9/2005	2	C	BCCH	W	WPWA=western palm warbler
May	5/9/2005	2	C	MAWA	W	RCKI=ruby-crowned kinglet
May	5/9/2005	2	T	WPWA	RT	BHCO=brown-headed cowbird
May	5/9/2005	2	T	RCKI	RT	NOPA=northern parula warbler
May	5/9/2005	2	T	RCKI	RT	GWWA=golden-winged warbler
May	5/9/2005	2	T	BHCO	RT	PUFI=purple finch
May	5/9/2005	2	T	BHCO	RT	MYWA=yellow-rumped warbler
May	5/9/2005	2	T	NOPA	RP	BAWW=black-and-white warbler
May	5/9/2005	2	T	GWWA	RP	YBSA=yellow-bellied sapsucker
May	5/9/2005	2	T	GWWA	RP	WBNU=white-breasted nuthatch
May	5/9/2005	2	X	PUFI	W	CSWA=chestnut-sided warbler
May	5/9/2005	2	X	OVEN	W	LEFL=least flycatcher
May	5/9/2005	2	X	MYWA	W	CHSP=chipping sparrow
May	5/9/2005	2	Y	OVEN	W	VEER=veery
May	5/9/2005	2	Y	OVEN	W	AMRE=American redstart
May	5/13/2005	8	C	OVEN	W	SCTA=scarlet tanager
May	5/13/2005	8	C	BHCO	W	DOWO=downy woodpecker
May	5/13/2005	8	C	BAWW	W	YTVI=yellow-throated vireo
May	5/13/2005	8	T	YBSA	RT	BTNW=black-throated green warbler
May	5/13/2005	8	T	WPWA	RT	BLBW=blackburnian warbler
May	5/13/2005	8	T	WTSP	C	WIWR=winter wren
May	5/13/2005	8	T	WBNU	RT	UPBD=unidentified passerine bird
May	5/13/2005	8	T	WTSP	C	CAWA=Canada warbler

May	5/13/2005	8	X	YBSA	W	COME=common merganser
May	5/13/2005	8	X	YBSA	W	YSFL=yellow-shafted flicker
May	5/13/2005	8	X	PUFI	W	AMRO=American robin
May	5/13/2005	8	X	WTSP	W	SOSP=song sparrow
May	5/13/2005	8	X	BHCO	W	HAWO=hairy woodpecker
May	5/13/2005	8	X	OVEN	W	
May	5/13/2005	8	Y	PUFI	W	**Location**
May	5/13/2005	8	Y	PUFI	W	W=woods
May	5/13/2005	8	Y	WTSP	W	RT=residual tree
May	5/13/2005	8	Y	YBSA	W	C=clearcut
May	5/13/2005	8	Y	OVEN	W	RP=residual patch
May	5/13/2005	8	Y	BRCR	W	
May	5/19/2005	1	C	CSWA	W	
May	5/19/2005	1	C	OVEN	W	
May	5/19/2005	1	C	WTSP	W	
May	5/19/2005	1	C	WTSP	W	
May	5/19/2005	1	C	OVEN	W	
May	5/19/2005	1	C	NOPA	W	
May	5/19/2005	1	C	WBNU	W	
May	5/19/2005	1	C	OVEN	W	
May	5/19/2005	1	T	LEFL	RT	
May	5/19/2005	1	T	CHSP	RT	
May	5/19/2005	1	T	WTSP	C	
May	5/19/2005	1	T	WTSP	C	
May	5/19/2005	1	T	CSWA	RT	
May	5/19/2005	1	T	VEER	RT	
May	5/19/2005	1	T	OVEN	RT	
May	5/19/2005	1	T	WBNU	RT	
May	5/19/2005	1	T	WBNU	RT	
May	5/19/2005	1	X	AMRE	W	
May	5/19/2005	1	X	SCTA	W	
May	5/19/2005	1	X	DOWO	W	
May	5/19/2005	1	X	OVEN	W	
May	5/19/2005	1	X	WBNU	W	
May	5/19/2005	1	X	AMRE	W	
May	5/19/2005	1	X	YBSA	W	
May	5/19/2005	1	X	CSWA	W	
May	5/19/2005	1	Y	NAWA	W	
May	5/19/2005	1	Y	LEFL	W	
May	5/19/2005	1	Y	OVEN	W	
May	5/19/2005	1	Y	AMRE	W	
May	5/19/2005	1	Y	CSWA	W	
May	5/19/2005	1	Y	YTVI	W	
May	5/20/2005	3	C	OVEN	W	
May	5/20/2005	3	C	BRCR	W	
May	5/20/2005	3	C	OVEN	W	
May	5/20/2005	3	C	BTNW	W	
May	5/20/2005	3	C	WTSP	W	

May	5/20/2005	3	T	BTNW	RT	
May	5/20/2005	3	T	WIWR	RP	
May	5/20/2005	3	X	BTNW	W	
May	5/20/2005	3	X	BAWW	W	
May	5/20/2005	3	X	OVEN	W	
May	5/20/2005	3	Y	OVEN	W	
May	5/24/2005	6	C	BTNW	W	
May	5/24/2005	6	C	NAWA	W	
May	5/24/2005	6	C	BLBW	W	
May	5/24/2005	6	C	MAWA	W	
May	5/24/2005	6	C	GCKI	W	
May	5/24/2005	6	C	OVEN	W	
May	5/24/2005	6	C	GCKI	W	
May	5/24/2005	6	T	BCCH	RP	
May	5/24/2005	6	T	BCCH	RP	
May	5/24/2005	6	T	WIWR	RP	
May	5/24/2005	6	X	CSWA	W	
May	5/24/2005	6	X	MAWA	W	
May	5/24/2005	6	X	CAWA	W	
May	5/24/2005	6	X	BAWW	W	
May	5/24/2005	6	X	UPBD	W	
May	5/24/2005	6	Y	GCKI	W	
May	5/24/2005	6	Y	BLJA	W	
May	5/24/2005	6	Y	NOWA	W	
May	5/24/2005	6	Y	MAWA	W	
May	5/24/2005	6	Y	GCKI	W	
May	5/24/2005	6	Y	OVEN	W	
May	5/24/2005	6	Y	BTNW	W	
May	5/24/2005	6	Y	MAWA	W	
May	5/24/2005	6	Y	LEFL	W	
May	5/16/2005	5	C	COME	W	
May	5/16/2005	5	C	OVEN	W	
May	5/16/2005	5	C	WTSP	W	
May	5/16/2005	5	C	WTSP	W	
May	5/16/2005	5	C	BTNW	W	
May	5/16/2005	5	T	YSFL	RT	
May	5/16/2005	5	T	GCKI	RT	
May	5/16/2005	5	T	GCKI	RT	
May	5/16/2005	5	T	WTSP	C	
May	5/16/2005	5	T	BTNW	RP	
May	5/24/2005	5	X	DOWO	W	
May	5/24/2005	5	X	AMRO	W	
May	5/24/2005	5	X	WIWR	W	
May	5/24/2005	5	X	BTNW	W	
May	5/24/2005	5	X	REVI	W	
May	5/24/2005	5	X	OVEN	W	
May	5/24/2005	5	Y	BTNW	W	
May	5/24/2005	5	Y	BAWW	W	

May	5/16/2005	4	C	WTSP	W	
May	5/16/2005	4	C	BCCH	W	
May	5/16/2005	4	C	CSWA	W	
May	5/16/2005	4	C	WTSP	W	
May	5/16/2005	4	C	SOSP	W	
May	5/16/2005	4	C	BHCO	W	
May	5/16/2005	4	C	BHCO	W	
May	5/16/2005	4	C	RCKI	W	
May	5/16/2005	4	C	WPWA	W	
May	5/16/2005	4	C	WPWA	W	
May	5/16/2005	4	C	CSWA	W	
May	5/16/2005	4	C	WTSP	W	
May	5/16/2005	4	C	BHVI	W	
May	5/16/2005	4	C	SOSP	W	
May	5/16/2005	4	T	WTSP	C	
May	5/16/2005	4	T	AMRO	RT	
May	5/16/2005	4	T	WTSP	C	
May	5/16/2005	4	T	WTSP	C	
May	5/16/2005	4	T	HAWO	RT	
May	5/16/2005	4	X	OVEN	W	
May	5/16/2005	4	X	DOWO	W	
May	5/16/2005	4	X	WTSP	W	
May	5/16/2005	4	Y	WTSP	W	
May	5/16/2005	4	Y	WTSP	W	
May	5/16/2005	4	Y	WTSP	W	
May	5/16/2005	4	Y	WTSP	W	
May	5/16/2005	4	Y	WTSP	W	