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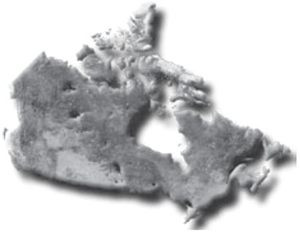

Integrating Silvicultural Control of Mountain Pine Beetle with Wildlife and Sustainable Forest Management Objectives

Ann Chan-McLeod

Mountain Pine Beetle Initiative
Working Paper 2007-05

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Abstract

The objective of this project is to generate information that would guide integrated silvicultural control of mountain pine beetle with wildlife and sustainable forest management objectives. Avian response to eight treatments was evaluated: 1) bark-beetle recovery blocks smaller than 15 ha; 2) megablocks larger than 200 ha; 3) 20% retention in primarily aggregates; 4) 20% retention in primarily dispersed stems; 5) 10% retention in primarily aggregates; 6) 10% retention in primarily dispersed stems; 7) clearcuts; and 8) beetle-infested unharvested controls. Our results indicated that mature forest-dwelling bird species were generally most abundant in controls, intermediate in partial retention treatments, and least abundant in or absent from clearcuts. The grouped retention treatments were sometimes more effective than the dispersed retention treatments in maintaining mature forest-dwelling species, whereas the 20% treatments were sometimes more effective than the 10% treatments. Cutblock size was not a major determinant of resultant bird community.

Future partial harvesting strategies must consider the risk of windthrow. Douglas-fir veterans had the lowest risk of windthrow and should be retained in dispersed treatments, whereas hybrid white spruce had the highest risk and should be retained in aggregates. Aggregate patches should be at least one hectare in size to minimize windthrow. We recommend deciduous species be retained whenever possible, as they have high wildlife value but were relatively scarce in the study area. Coarse wood debris volumes were similar in patch and dispersed retention blocks, but averaged approximately 50% lower in controls. Aspen was most susceptible to wind damage, followed by birch, Douglas-fir, spruce, lodgepole pine, and subalpine-fir.

Keywords: mountain pine beetle, integrated management, sustainable forest management, songbirds, wildlife, stand dynamics, wildlife habitat trajectories, partial harvesting, variable retention harvesting

Résumé

L’objectif de ce projet est de générer de l’information qui pourrait guider la lutte sylvicole intégrée contre le dendroctone du pin en suivant des objectifs de gestion durable des forêts et liés à la vie sauvage. On a évalué le comportement de la faune aviaire face à huit traitements : 1) coupe de récupération dans des blocs de coupe de moins de 15 ha, 2) blocs de coupe de plus de 200 ha, 3) coupe à rétention de 20 p. 100 dans des peuplements serrés, 4) coupe à rétention de 20 p. 100 dans des peuplements dispersés, 5) coupe à rétention de 10 p. 100 dans des peuplements serrés, 6) coupe à rétention de 10 p. 100 dans des peuplements dispersés, 7) coupes à blanc, et 8) peuplements témoins infestés et non coupés. Nos résultats indiquent que les espèces d’oiseaux qui nichent dans les peuplements mûrs étaient généralement plus abondantes dans les peuplements témoins, moins abondantes ou absentes dans les coupes à blanc, et entre les deux dans les zones de traitement de rétention partielle. Les traitements de rétention groupée réussissaient parfois mieux à maintenir les espèces nichant dans les peuplements mûrs que les traitements de rétention dispersés, alors que les traitements à 20 p. 100 étaient parfois plus efficaces que les traitements à 10 p. 100. La taille du bloc de coupe n’était pas déterminante en ce qui concerne la communauté aviaire résultante.

Les prochaines stratégies de coupe partielle doivent prendre en compte le risque de déracinement par le vent. Les Douglas taxifoliés âgés courent le moindre risque de déracinement par le vent et devraient être retenus pour les traitements dispersés, alors que l’épinette blanche hybride court le plus grand risque et devrait être retenue dans les peuplements serrés. Ceux-ci devraient mesurer au moins un hectare pour minimiser le risque de déracinement par le vent. Nous recommandons de retenir les espèces à feuilles caduques lorsque c’est possible parce qu’elles ont de la valeur pour la vie sauvage et qu’elles étaient relativement rares dans la zone d’étude. Les volumes de débris de bois grossiers étaient semblables dans les blocs de coupe de rétention dispersés et serrés, mais étaient en moyenne moitié moins présents dans les blocs témoins. Le tremble était le plus vulnérable aux dégâts par le vent, suivi du bouleau, du Douglas taxifolié, de l’épinette, du pin tordu et du sapin subalpin.

Mots-clés : dendroctone du pin ponderosa, gestion intégrée, gestion durable des forêts, oiseaux chanteurs, vie sauvage, dynamiques du peuplement, trajectoires des habitats fauniques, coupe partielle, coupe partielle à rétention variable

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1 Introduction

The vast scale of the current mountain pine beetle (MPB) epidemic, coupled with the silvicultural practices that must be implemented to contain its damage, have enormous implications for wildlife and wildlife habitats. Beetle control measures must be integrated with wildlife management objectives so that the detrimental impacts of a massively defoliated landscape are not magnified by harmful silvicultural practices. Silvicultural control of MPB can be integrated with wildlife and sustainable forest management objectives through various approaches. At the most fundamental level, the effects of control measures on wildlife populations and sustainable management indicators must be quantified. Additionally, a given silvicultural control may benefit some wildlife species but be detrimental to other wildlife species, because different species have widely varying and often opposing habitat requirements. For every management option exercised, there will be winners and losers among wildlife populations, and these tradeoffs must be understood and incorporated into integrated management prescriptions for silvicultural mosaics across the landscape.

Silvicultural control of MPB can also be integrated with wildlife and sustainable forest management objectives by tailoring silvicultural prescriptions to benefit wildlife and sustainable management values. For example, the spacing and harvesting prescriptions for MPB management are highly analogous to the variable-retention harvesting that is increasingly being applied in working forests in the Pacific Northwest. Recent research on variable-retention indicates that the location and dispersion pattern of residual trees and tree patches, and even slight differences in retention level, can yield significantly different impacts on wildlife populations. Finally, integration of MPB management with wildlife and sustainable management indicator objectives must incorporate long-term considerations. For example, the benefits of retaining wildlife trees or other structural attributes with high values for sustainable management are only ephemeral if these structures are immediately lost to windthrow. The stand dynamics of silvicultural options must be examined in order to project long-term implications for standing stock, habitat value, and sustainable management indicators.

1.1 Study Objectives

We had three specific study objectives. Study Objective 1 documented avian response to various silvicultural controls of MPB. Study Objective 2 quantified the abundance of 11 habitat variables according to the type of beetle control partial harvesting treatment. Study Objective 3 estimated the probabilities of windthrow and mortality status of trees according to tree, site, and neighbourhood factors.

1.1.1 Study Objective 1

Study Objective 1 measured the response of avian communities to eight treatments: 1) Bark-beetle recovery (BBR treatment) cutblocks, which are < 15 ha in size, with generally < 12 % residual tree retention. BBRs were conceived as a rapid response to small pockets of beetle infestation; 2) Very large cutblocks, often hundreds of hectares in size, with > 12% residual tree retention. These vast cutblocks (MEGA treatment), which often occurred in clusters, are the only effective measure for controlling or salvaging severe MPB infestations in the middle of epidemic areas. The slightly higher (15%) residual tree retention level was intended to offset potentially detrimental impacts of these vast cutblocks; 3) Partial harvesting that retained 20% of standing trees, primarily in groups (20% grouped treatment); 4) Partial harvesting that retained 20% of standing trees, primarily as dispersed individual stems (20% dispersed treatment) ; 5) Partial harvesting that retained 10% of standing trees, primarily in groups (10% grouped treatment); 6) Partial harvesting that retains 10% of standing trees, primarily as dispersed individual stems (10% dispersed treatment); 7) beetle-infested, old growth controls (CONT treatment); and 8) clearcut (CC treatment) controls.

1.1.2 Study Objective 2

The main research question addressed by Study Objective 2 is “Does the different type of partial harvesting treatment result in a different abundance of the stand structure elements that provide wildlife habitat and how do these treatments differ from the unharvested forest?” Study Objective 2 estimated the differences in the forest elements that provide wildlife habitat between the treatments. Since retention selection bias can significantly influence the final outcome of trees in the different treatments, Study Objective 3 cannot be considered a true measure of treatment effect. Rather, it is an indirect measure of habitat values. Habitat values were inferred by measurements of the abundance of 11 variables that represent the basic elements of wildlife habitat. Analysis of the data was accomplished by using various frequency distribution graphs and the Kruskal-Wallis non-parametric one-way analysis of variance by ranks to estimate significant differences in habitat variable abundance between the treatments.

1.1.3 Study Objective 3

The two main research questions addressed by Study Objective 3 are “Do the different partial harvesting treatments affect the probabilities of tree mortality and windthrow?” and “How do tree, neighbourhood, and site factors affect the probabilities of tree mortality and windthrow?” Study Objective 3 estimated the probabilities of tree mortality and windthrow according to tree, site and neighbourhood factors. This was accomplished through the creation of five logistic regression models estimating the significant relationships of tree mortality and windthrow. Treatment effect was inferred with the exposure variables and consideration of the varying levels of exposure between treatments. Some variables (eg., species, height, diameter at breast height (DBH)) measured in Study Objective 3 were considered important factors related to mortality and windthrow, but were more related to individual tree characteristics than treatment effect. Only the most parsimonious logistic regression models using significant relationships (alpha = 0.05) found in Study Objective 3 were kept.

2 Material and Methods

2.1 Methods for Study Objective 1

Bird surveys were conducted in the Gregg and Pelican units in the Canadian Forest Products Timber Supply Area 15, near Prince George, B.C. The study area was primarily in the SBSdw2 biogeoclimatic variant, but a few of the sampling stations were located in the SBSdw3 and SBSmw variants. Tree species consisted primarily of Douglas-fir and lodgepole pine, with minor components of subalpine-fir, trembling aspen, and hybrid spruce.

We established 181 bird sampling stations in 25 forest stands and cutblocks. With exception of the controls, three replicates were established for each treatment. Four replicates were established for the controls because of the uncertainty regarding future logging plans, and the extra control was a hedge against this possibility. One control was, in fact, harvested between 2004 and 2005, so we conducted all analyses using three replicates per treatment. Cutblocks varied in size from 40 ha to 80 ha for the partial retention treatments (10% dispersed, 10% grouped, 20% dispersed, 20% grouped). The BBR cutblocks, which were required by regulations to be < 15 ha, averaged 9.1 ha in this study. The control sites ranged from 80 ha to 600 ha.

We used stratified random sampling to lay out the bird stations within each cutblock or control stand. We recognized two strata in partial retention cutblocks: a) residual tree patches, and b) the cut-over matrix, which may or may not contain dispersed residual trees. Sampling intensity within each stratum was approximately proportional to the relative area of the stratum within the cutblock.

We used 60-m radius point count stations established at the intersection of 200-m grid lines, which allowed for 80 m between the outer circumference of adjacent stations. Bird surveys were conducted four times at each site, at approximately 2-week intervals in May and June. To control for observer bias, each station was surveyed twice by each of two observers, who were randomly rotated after each round. The sequence in which sites were surveyed was randomized in the first round; subsequent rounds followed the rotation of the first round. To standardize diurnal variation, each point count station within a site was censused in reverse order of the previous round. Censuses began at dawn and ended by 10:00 a.m. Observers waited for one minute following arrival at each count station before beginning the 8-minute survey. We did not conduct surveys on days when it was raining or windy (Beaufort Level 5). We collected data on the species and type (call, visual, song) of bird detection within the 60-m radius plot; habitat type where detection occurred in the plot, structural attribute on which bird was detected, and behaviour of the bird.

We determined whether parametric statistical methods were appropriate for the data by conducting the Shapiro-Wilks test for normality and Bartlett's test for equal variances. We found that the data often did not meet the assumptions of parametric analyses, and therefore used the Kruskal-Wallis to evaluate treatment effects. The Mann-Whitney test was used for post-hoc analyses of significant differences among treatments. We used a critical value of 0.10, to reduce the high cost of Type II errors in applied research (Smith 1995; Schmiegelow et al. 1997).

2.2 Methods for Study Objectives 2 and 3

Canfor's rationale for using the partial harvesting treatments used in this study was to meet an area-based biodiversity objective. Aggregates were selected for retention when small areas within a cutblock had certain tree characteristics such as non-pine species, immature trees, or specific wildlife values (eg., gullies, riparian areas, swampy ground). Treatments in this study that retained trees as aggregates or groups (eg., Wildlife Tree Patches) within harvested blocks will be referred to as aggregate treatments. When pre-harvest stands contained a component of large, old Douglas-fir veterans, they were often retained as individual leave trees within the cutblocks. These treatments will be referred to as dispersed treatments. Occasionally, dispersed treatments retained individual trees of species other than Douglas-fir. In order to capture a wide range of variability, cutblocks within each treatment were also grouped to include post-harvest ages from 1 to 7 years since harvest (YSH 1-7), and blocks with and without the presence of water (eg., streams, swamps, seepage or wetter ground).

The data were obtained from 35 total cutblocks comprised of 10 dispersed treatment blocks, 11 aggregate treatment blocks, and 14 blocks containing both aggregate and dispersed treatments. The sampled cutblocks ranged in size from 20-70 ha and only included stands where the main species was originally pine. Nine unharvested areas were also sampled and used as controls. The dispersed treatment blocks were further grouped into the three different relative dispersed retention levels of low, medium, and high (DispL, DispM, and DispH). The method for classification of retention levels for dispersed treatments was subjectively based on information from the silviculture prescription documents for the harvested cutblocks and from air photos where available. It was found during sampling that all but one of the dispersed treatment blocks actually contained very low stem densities. Nevertheless, representation from all three retention classes provided a range of retention values that were used in the regression analyses.

All five treatments were sampled using three circular (5.65 m radius) fixed area (1/100 ha) plots per treatment block that measured site and tree data. Each dispersed treatment block was also sampled with three additional large rectangular fixed area (40 m x 83.3 m =1/3 ha) plots in which only tree data were recorded. The circular 1/100 ha plots were too small to capture enough tree data in the low stem densities of the dispersed treatments so the larger rectangular plots were used in these three treatments to gather only tree data. The one exception was a single dispersed treatment (Block 565-1) that had a much higher stem density (407 stems per hectare (SPH)). In this block we used three mid-sized circular (12.61 m radius) fixed area (1/20 ha) plots to capture tree data.

The total number of plots in which tree data were recorded was 174 (24 dispersed blocks x 3 plots + 25 aggregate blocks x 3 plots + 9 control blocks x 3 plots = 174). An additional 72 dispersed site data plots (24 x 3 = 72) made the total number of plots measuring site and tree data 246 (174 + 72 = 246). Plots were randomly located by placing a metric dot grid (4 dots per square cm) in a North/South orientation over a 1:10000 map of the treatment cutblock and using a random number generator to identify the three dot numbers to be used for the three plot locations. During field sampling, if a portion of a plot landed outside the treatment, it was moved just sufficiently in the reverse direction of travel to allow the total plot area to remain in the treatment.

2.2.1 Variables and Hypotheses Analyzed in Study Objective 2

Variables representing various tree attributes and site features were measured at each plot. These variables included species, DBH, height, and tree status (live or dead, standing or down). These data were used to create six tree variables (StLvCon, StLvDec, StDdCon, StDdDec, DnCon, and DnDec) and the tree basal area variable (BATree). The plots also recorded the percent ground cover and average height of shrubs in the plot. The ground area of the shrub cover (dripline of foliage) was multiplied by the average height of the shrubs to produce an estimate of the 3-dimensional projected volumes of shrub cover (shrubvol). A mirror densiometer was used to measure percent canopy cover (CovA) at each plot. Line Intersect Sampling (LIS) was used to measure coarse woody debris (CWD) at each plot. The LIS method used two 25-metre lines emanating from the plot centre to a sum of 50 metres of sampling line per plot. The first 25-m line was placed in a random direction and the second 25-m line was placed at a 90 degree-angle clockwise to the first line. If a sampling line traveled outside of the treatment it was continued in the reverse direction from the opposite end to produce a total line length of 25 m. Post-harvest CWD input was estimated by calculating the volumes of trees in the 1/100ha plots that were windthrown after harvesting.

The basal area of trees was calculated from the diameter at breast height (DBH = 1.3m). The basal area of pre-harvest trees (dispersed treatments) was estimated from stump diameter classes in 5 cm increments. Since trees were cut at stump height (30 cm), the diameters of stumps were larger than they would be at.DBH. To adjust this difference, recorded stump diameters were reduced by 13%. This was the mean difference between DBH and stump height found in a sample of 13 lodgepole pine trees in a different study (Byrne 2005) from the same area. Basal area calculations using stump diameter classes instead of DBH measurements only produced an approximate pre-harvest basal area. Nevertheless, it did provide a rough estimate of what was standing before harvesting took place. Basal areas of trees in aggregate treatments and controls were measured at DBH (1.3 m) allowing relatively more accurate comparisons between these two treatments. Volumes of windthrown trees were conservatively estimated as the product of basal area times 1/3 of the height (BA x 1/3 ht). Data from variables were converted to per hectare units using the inverse of the plot size as a plot multiplier. Plot level statistical analyses were conducted after this conversion. Table 1 lists the 11 variables created for Study Objective 2.

Table 1. Habitat variables used in the analyses for Study Objective 2.

Label	Name	Unit Measurement	Description
StLvCon	Standing Live Conifers	Stems/Ha	Standing live conifer species include lodgepole pine, Douglas-fir, interior spruce, black spruce, and sub-alpine-fir.
StLvDec	Standing Live Deciduous	Stems/Ha	Standing live deciduous species include trembling aspen, paper birch, cottonwood, and alder.
StDdCon	Standing Dead Conifers	Stems/Ha	Standing dead conifer species same as standing live conifer species.
StDdDec	Standing Dead Deciduous	Stems/Ha	Standing dead deciduous species same as standing live deciduous species.
DnCon	Down Conifer	Stems/Ha	Down conifer are conifers that were left standing after harvest, but were down at time of sampling.
DnDec	Down Deciduous	Stems/Ha	Down deciduous conifers that were left standing after harvest, but were down at time of sampling.
BATree	Basal Area	m^2/Ha	Basal area per ha of live and dead trees left standing immediately after harvest.
UpBATree	Standing Basal Area	m^2/Ha	Basal area of live and dead trees standing at time of sampling.
Shrubplotvol	3-D Shrub Volume	m^3/Ha	3-dimensional projection of shrub cover.
CovA	% Canopy Cover	% Canopy	Percent canopy closure
CWD	Coarse Woody Debris	m^3/Ha	Post-Harvest CWD is coarse woody debris that was present immediately after harvesting. *CWD input is post-harvest down trees.

*CWD input is considered as trees that were left standing after harvest, but subsequently became down trees (eg., windthrow).

Study Objective 2 estimated the abundance of 11 wildlife habitat variables considered important to the species in the harvested region and tests for differences in abundance between aggregate treatments, three levels of dispersed treatments (High, Medium, and Low), and unharvested control areas. Some of the hypotheses tested in Study Objective 2 include:

*H*0: There is no difference in the abundance of habitat variables between the five treatments (Control, Aggregate, DispH, DispM, and DispL).

*H*1: The abundance of habitat variables is different in at least one of the treatments.

*H*0: There is no difference in the volume of shrub cover between the five treatments (Control, Aggregate, DispH, DispM, and DispL).

*H*1: The volume of shrub cover is different in at least one of the treatments.

Study Objective 2 also included an estimation of CWD input from post-harvest downed trees. The conversion of a standing tree to a downed tree (windthrow) contributes directly to an increase in CWD volume. The outcomes in this study were measured in cutblocks that had been harvested over the previous seven years. This timeframe is considered adequate for assessing the longer term likelihood that individual trees remain standing since many trees that are vulnerable to windthrow are likely blown down in less than seven years following harvest. For example, Burton (2001) found windthrow risk in northern British Columbia appeared to increase until about three years after harvest.

Stumps were counted and recorded for species and diameter classes in all plots sampled in the dispersed treatments. The stump counts were used to estimate pre-harvest species densities and approximate basal areas. Using pre-harvest tree densities and basal area approximations allowed the pre-harvest stand to be “reconstructed”. Relatively low SPH/basal area ratios were assumed to indicate larger mean tree sizes. The species distributions, stem densities, and basal areas from the reconstructed dispersed treatments were then compared to aggregate and control treatments to contrast pre-treatment differences.

One of the factors influencing windthrow is the ratio of the crown sail area to the DBH of the tree (Stathers et al. 1994). It seemed possible that newly exposed trees in the dispersed treatments might adapt open-grown crown forms that could affect windthrow susceptibility. In order to gain some insight into whether or not crown/DBH ratios were changed as a result of exposure in dispersed treatments, crown/DBH ratios of the six major tree species were compared between the control, aggregate, and dispersed treatments.

2.2.2 Variables and Models Analyzed in Study Objective 3

Tree locations in dispersed treatments were measured in Universal Transverse Mercator UTM coordinates using a hand-held GPS receiver (Garmin, Model: eTrex). It was not possible to receive coordinates under the canopy in aggregates and controls so aggregate plot coordinates were located from 1:5000 block maps, and control plot coordinates were located from 1:20000 maps, both supplied by Canadian Forest Products Limited (Canfor). Since all the trees sampled in the aggregates were located inside 5.65 m radius (1/100 ha fixed area) plots, for the purposes of exposure calculations all the trees in a given 1/100 ha plot were considered to be at the same UTM coordinates.

A SPOT5 satellite, pan-enhanced 2.5 m false colour image of the study site (taken in August 2004, supplied by Pacific Geomatics Ltd.), and geo-referenced block boundary polygons (supplied by Canfor) were imported into ArcView GIS 3.2. Tree and plot coordinates and image information were used to digitize the retention polygons and tree locations that were used in VRfetch and Direx30 calculations. The retention level within each polygon was estimated to the nearest 20% crown closure from the SPOT5 image. VRfetch is a fetch variable developed by Scott (2005) to include a measure of the partially obstructed distances encountered in dispersed retention treatments. Specifically, it is the segment length multiplied by the removal level (100 minus percent cover) at points located every 30 m for 300 m in each of the eight cardinal directions surrounding the plot (Scott 2005). The sum of the unobstructed line segments (>95% removal) are added to the products of the partially obstructed line segments to calculate the VRfetch value. Direx30 is a measurement that sums the number of the eight cardinal directions that have an unobstructed (>95% removal) distance of 30 meters immediately adjacent to the point of interest.

Seven tree variables and three neighbourhood variables (Table 2) were used in the five logistic regression models to estimate factors contributing to individual tree mortality status. The variables associated with site conditions (site series, soil texture, slope, and soil drainage) did not improve model fit and were, therefore, not included in any of the final models. Models 1, 2, and 3 had better fit when the three levels of dispersed retention (High, Medium, and Low) were combined into a single treatment. In these cases, the five treatment classes (DispL, DispM, DispH, aggregate, and control) were reduced to the three treatment groups of Control, Aggregate and Dispersed. Models 2 and 4 had better fit when the nine tree species were reduced to five tree species groups. Stepwise logistic regression eliminated other non-significant variables and only the most useful and parsimonious models were kept. Spearman's correlation was used to measure the strength of the linear relationship between variables. Spearman's correlation was used because the data was not normally distributed. Highly correlated variables were not used together in any of the models. Study Objective 3 used five logistic regression models to estimate the probabilities of a tree being:

1. dead from the total population of trees (includes live, dead, standing, and down trees at time of sampling),
2. dead from the population of standing trees (includes only trees standing at time of sampling),
3. down from the population of trees in aggregate and dispersed treatments (includes the trees from the aggregate and dispersed treatments, but excludes the trees from controls),
4. down from the population of trees in aggregate and dispersed treatments (population is the same as model 3, but model 4 includes exposure variable Direx 30),
5. down from the population of trees in the aggregate treatment (includes trees found only in the aggregate treatments, but model 5 includes exposure variable VRfetch).

Model 1 estimated the probability of mortality from the total population of trees. Presumably, live trees left after harvesting were intended to remain live and few if any dead trees were left in dispersed treatments. Model 1, therefore, provides a comparison of mortality status in the dispersed treatments to that in the aggregates and controls.

Model-2 estimated probabilities of an individual tree being dead from the population of standing trees. Unlike model 1, the intention of model 2 was not only to identify predictors of mortality, but also to provide some insight into the supply of standing dead snags. Model 2 indicated the likelihood of a tree dying and then remaining standing in the years following harvesting. In other words, model 2 estimated the probability of non-windthrow mortality in the stand for the residual trees. There may have been some dead trees left in the aggregate treatments, but it is unlikely there were many dead trees left after harvesting in the dispersed treatments. For the most part, model 2 provides the probability of MPB attack in the pine trees left after harvesting.

Models 3 and 4 estimated the probabilities of an individual tree being down using only the trees in dispersed and aggregate treatments. This was done because windthrown trees in the controls were not recorded as down trees. Model 4 also estimated the probability of windthrow, but focused on exposure by including the exposure variable (Direx 30) in the model.

Model 5 used the population of trees in the aggregate treatments. Model 5 included the VRfetch exposure variable and estimates the probability of windthrow in the aggregate treatments. The intention of model 5 was to provide insight into windthrow susceptibility according to aggregate size and tree proximity to edge.

Stepwise regression was used to eliminate non-significant (alpha = 0.05) variables and the five best models rated according to a combination of % concordance, c-value, and Hosmer-

Lemeshow goodness of fit p-values were kept. All five models retained at least one tree and one neighbourhood variable.

3 Results

3.1 Study Objective 1

We detected a total of 4320 birds consisting of 63 species in 2004 and 67 species in 2005 (Table 3). Dark-eyed junco, an open-habitat species, was by far the most common bird species, at approximately 20% of all bird detections in each year. Other common species included chipping sparrow, American robin, Lincoln’s sparrow, and ruby-crowned kinglet. We identified and analysed five guild types among the bird species detected in the study area. We used three criteria for defining guilds: foraging method, nest location, and primary habitat type. The identified guilds were i) cavity-nesting guild, ii) deciduous/mixed forest guild; ii) open and edge guild; iv) primarily mature forest guild i.e., occurs primarily in mature forests but will use young forests as secondary habitat; and v) shrub-nesting guild. Although many species could be categorized as habitat generalists, we did not analyse this guild because of an unlikely common response to beetle control measures. The open and edge guild had the most membership, with 19 species. This was followed by the mature/young forest guild with 14 members, the cavity-nesting guild with 10 members, and the shrub-nesting guild with 9 members. The deciduous/mixed guild had 6 bird species.

Table 2. Tree and neighbourhood variables used in logistic regression models.

Label	Name	Description
		Tree Variables
SPEC	Species	This variable classifies the tree according its species (Douglas-fir = Fd, lodgepole pine = Pl, interior spruce = Sx, black spruce = Sb, subalpine-fir =Bl, aspen = At, cottonwood = Ac, paper birch = Ep, alder = Dm).
TREESPEC	Tree species	This variable converted the nine tree species into five tree species groups (Douglas-fir = Fd, lodgepole pine= Pl, interior spruce, black spruce and subalpine-fir = SxBl, aspen = At, and birch, cottonwood and Dm = Decd).
HT	Height (m)	This variable used a hand-held laser ranging instrument (Laser Technology, Inc. Model: Impulse LTI) to measure tree heights in metres.
<u>HDR</u>	Height/dbh ratio	This variable is the ratio of height(m)/dbh(m) and is a measurement of ‘slenderness’.
DBH	Diameter at breast height	This variable is the diameter measured at DBH. Diameter units are measured in centimeters.
LIVEORDEAD	Live or dead	This variable classified a tree as live or dead. Although some downed trees (eg., uprooted) were still living they were recorded as dead. Therefore, a tree could be classed as standing and dead, but not down and live.
UPORDOWN	Up or down	This variable classified a tree as standing (up) or down. Leaning trees were considered ‘up’ trees.
		Neighbourhood Variables
TREATMENT TYPE	TREATMENT	This variable classified the five treatment types according to level of retention. DispL=dispersed with low retention, DispM=dispersed with medium retention, DispH=dispersed with high retention, Aggregate=reserve patch of trees, and Control=unharvested forest.
VRfetch	Variable retention fetch	This variable is the sum of the distances of unobstructed and partially obstructed line segments for a distance up to 300 meters in the eight cardinal directions. The VRfetch variable is a measure of the tree’s access to the sum of the obstructed and unobstructed wind.
DIREX30	Direx 30	This variable is a measure of exposure that sums the number of cardinal directions (from a possible total of eight) that have openings at minimum distances of 30 meters. For example, a tree with a direx-30 value of three means that there are a total of three cardinal directions that have openings of at least 30 meters associated to that tree.

Table 3. Bird species observed in point count surveys in Prince George study area.

# detections				
Common Name	Scientific Name	Code	2004	2005
Blackbird, Red-winged	*Agelaius phoeniceus*	RWBL	1	1
Bluebird, Mountain	*Sialia currucoides*	MOBL	20	20
Chickadee, Black-capped	*Poecile atricapilla*	BCCH	7	5
Chickadee, Mountain	*Poecile gambeli*	MOCH		2
Creeper, Brown	*Certhia americana*	BRCR	19	7
Crossbill, Red	*Loxia curvirostra*	RECR	24	63
Crossbill, White-winged	*Loxia leucoptera*	WWCR	1	
Eagle, Bald	*Haliaeetus leucocephalus*	BAEA	2	
Finch, Purple	*Carpodacus purpureus*	PUFI		1
Flicker, Northern	*Colaptes auratus*	NOFL	10	10
Flycatcher, Alder	*Empidonax alnorum*	ALFL	8	5
Flycatcher, Dusky	*Empidonax oberholseri*	DUFL	55	53
Flycatcher, Hammond's	*Empidonax hammondii*	HAFL	156	18
Flycatcher, Least	*Empidonax minimus*	LEFL	3	7
Flycatcher, Olive-sided	*Contopus cooperi*	OSFL	16	13
Goose, Canada	*Branta canadensis*	CAGO	2	
Goshawk, Northern	*Accipiter gentilis*	NOGO	1	
Grosbeak, Evening	*Coccothraustes vespertinus*	EVGR	1	3
Grouse, Ruffed	*Bonasa umbellus*	RUGR	14	5
Grouse, Sharp-tailed	*Tympanuchus phasianellus*	STGR		4
Hawk Red-tailed	*Buteo jamaicensis*	RTHA		2
Hawk, Rough-legged	*Buteo lagopus*	RLHA	1	
Hawk, Sharp-shinned	*Accipiter striatus*	SSHA		1
Hummingbird, Calliope	*Stellula calliope*	CAHU	7	
Hummingbird, Rufous	*Selasphorus rufus*	RUHU		5
Jay, Gray	*Perisorius canadensis*	GRAJ	7	7
Junco, Dark-eyed	*Junco hyemalis*	DEJU	467	365
Killdeer	*Charadrius vociferus*	KILL	5	4
Kingfisher, Belted	*Ceryle alcyon*	BEKI		1
Kinglet, Golden-crowned	*Regulus satrapa*	GCKI	105	43
Kinglet, Ruby-crowned	*Regulus calendula*	RCKI	93	49
Mallard	*Anas Platyrhynchos*	MALL		2
Merlin	*Falco columbarius*	MERL	3	
Nighthawk, Common	*Chordeiles minor*	CONI	1	1
Nuthatch, Red-breasted	*Sitta canadensis*	RBNU	35	14
Raven, Common	*Corvus corax*	CORA	6	1
Robin, American	*Turdus migratorius*	AMRO	152	92
Sandpiper, Solitary	*Tringa solitaria*	SOSA		1
Sapsucker, Red-breasted	*Ficedula parva*	RBSA	8	15
Sapsucker, Red-naped	*Saphyrapicus nuchalis*	RNSA		1
Siskin, Pine	*Carduelis pinus*	PISI	74	16
Snipe, Common	*Gallinago gallinago*	COSN	8	
Snipe, Wilson's	*Gallinago delicata*	COSN		11
Solitaire, Townsend's	*Myadestes townsendi*	TOSO	18	39
Sparrow, Chipping	*Spizella passerina*	CHSP	196	87

Sparrow, Clay-colored	*Spizella pallida*	CCSP		5
Sparrow, Lincoln's	*Melospiza lincolnii*	LISP	116	166
Sparrow, Savannah	*Passerculus sandwichensis*	SAVS	13	31
Sparrow, Song	*Melospiza melodia*	SOSP	36	9
Sparrow, Vesper	*Pooecetes gramineus*	VESP	23	32
Sparrow, White-throated	*Zonotrichia albicollis*	WTSP	2	16
Swallow, Tree	*Iridoprocne bicolor*	TRES	50	31
Swallow, Violet-green	*Tachycineta thalassina*	VGSW	2	
Swift, Black	*Cypseloides niger*	BLSW		3
Tanager, Western	*Piranga ludoviciana*	WETA	32	32
Tern, Black	*Chlidonias niger*	BLTE		2
Thrush, Hermit	*Catharus guttatus*	HETH	8	20
Thrush, Swainson's	*Catharus ustulatus*	SWTH	27	21
Thrush, Varied	*Ixoreus naevius*	VATH		3
Vireo, Cassin's	*Vireo cassinii*	CAVI	14	24
Vireo, Red-eyed	*Vireo olivaceus*	REVI	19	
Vireo, Warbling	*Vireo gilvus*	WAVI	53	40
Warbler, MacGillivray's	*Oporornis tolmiei*	MGWA	7	2
Warbler, Orange-crowned	*Vermivora celata*	OCWA	58	73
Warbler, Townsend's	*Dendroica townsendi*	TOWA	6	2
Warbler, Wilson's	*Wilsonia pusilla*	WIWA	19	8
Warbler, Yellow	*Dendrocia petechia*	YEWA		3
Warbler, Yellow-rumped	*Dendroica coronata*	YRWA	158	99
Waterthrush, Northern	*Seiurus noveboracensis*	NOWA	5	4
Waxwing, Cedar	*Bombycilla cedrorum*	CEDW	8	15
Woodpecker, Black-backed	*Picoides arcticus*	BBWO	8	
Woodpecker, Downy	*Picoides pubescens*	DOWO	2	1
Woodpecker, Hairy	*Picoides villosus*	HAWO	24	28
Woodpecker, Pileated	*Dryocopus pileatus*	PIWO	1	3
Woodpecker, Three-toed	*Picoides tridactylus*	TTWO	13	16
Wood-pewee, Western	*Contopus sordidulus*	WEWP	27	22
Wren, Winter	*Troglodytes troglodytes*	WIWR	29	15
Yellowlegs, Greater	*Perisoreus canadensis*	GRYE	2	1
Yellowthroat, Common	*Geothlypis trichas*	COYE	1	
Unknown Species				
woodpecker spp		WOOD	18	13
Dusky or Hammonds Flycatcher		DUHA		47
Flycatcher spp		FLYC		5
Kinglet or chickadee spp		KICH		8
Thrush spp		THRU		6
Warbler spp		WARB		11
Passerine spp		PASS		31
Sparrow spp.		SPAR	24	89
Other unknown		UNK	73	2
		Totals	2404	1916

When we considered individual species for which there were at least 10 detections, we found that in 2004, the brown creeper, a mature-forest obligate, was observed only in the control and in the residual tree patches of mega cutblocks. In 2005, four bird species (brown creeper, Cassin's vireo, golden-crowned kinglet, and three-toed woodpecker) were abundant in the controls but were present in only two or three of the seven harvest treatments. The harvest treatments where these species were detected varied somewhat with species, but the mega treatment was consistently favoured. Brown creeper was detected in the 10% grouped treatment, the 20% dispersed treatment, and the mega treatment. Cassin's vireo was detected in the 10% dispersed treatment, the 20% treatment, and the mega treatment. Golden-crowned kinglet was detected in the 20% grouped treatment, the BBR treatment, and the mega treatment. Three-toed woodpecker was detected in the 10% grouped treatment, the 20% grouped treatment, and the mega treatment.

We analysed on a species-specific basis 43 birds that were detected at least 10 times during the study. We found significant treatment effects for 12 species. Additionally, we found significant treatment effects for five avian guilds. Seven of the bird species with significant treatment effects (brown creeper, Cassin's vireo, golden-crowned kinglet, Hammond's flycatcher, red-breasted nuthatch, Swainson's Thrush, three-toed woodpecker) are forest-dwelling. For all seven species, the mean detection rate in control sites significantly exceeded the mean detection rate in most or all harvest treatments (Figure 1). Woodpeckers and the mature forest guild were also significantly more abundant in controls than in the seven harvest treatments.

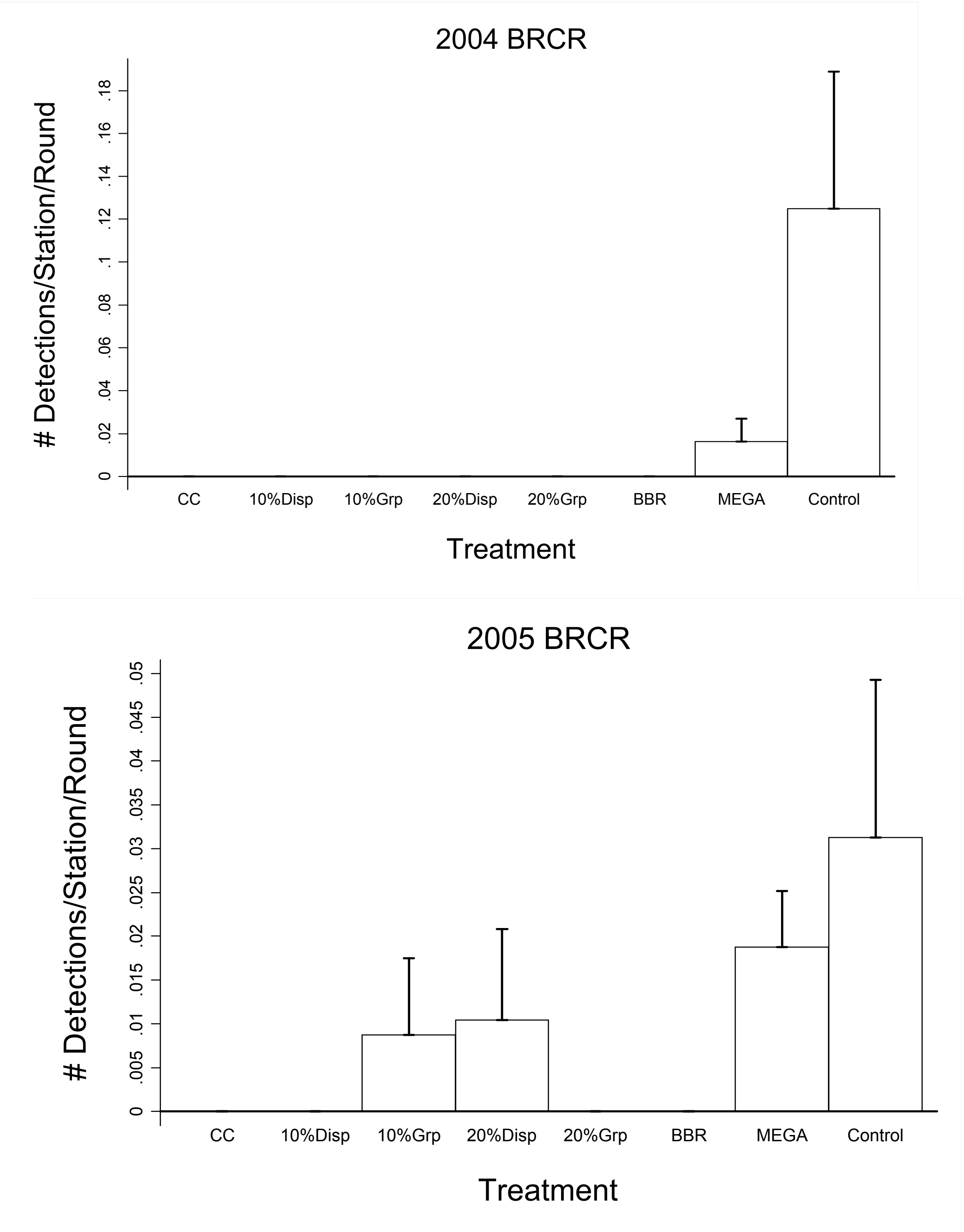

Figure 1. Brown Creeper Abundance. Brown creeper was an example of seven bird species for which mean abundance in controls significantly exceeded that in the other harvest treatments.

In 2004, brown creepers were approximately 10 times more abundant in the controls than in the mega cutblock, which represented the only harvest treatment other than the control in which this species occurred (Figure 1). In 2005, brown creepers were also detected at low densities in the 10% grouped treatment and the 20% dispersed treatment, but were absent from the clearcut, the 10% dispersed treatment, the 20% grouped treatment, and the BBR treatment. Golden-crowned kinglet was absent from the clearcut, the 10% partial retention treatments (10% grouped and 10% dispersed), and the 20% dispersed treatment in both study years. It was detected in the 20% grouped, BBR, and mega cutblocks, but were significantly less abundant in those treatments than in the control sites. Hammond's flycatcher (HAFL) was detected on all treatment types in 2004, but was again most common in controls. The relative abundance of HAFL was lowest in the clearcut and the 10% dispersed harvest, and intermediate in the other harvest treatments. Treatment effects for HAFL in 2005 could not be conducted because of an observer bias from a 2005 surveyor that prevented discrimination between this species and the similar sounding Dusky flycatcher.

Four species for which significant treatment effects were not found but which appeared to be more abundant in the control than in most or all other harvest treatments included the red-eyed vireo, western tanager, and winter wren. Lack of significance in statistical analyses was due to high variability in the data and low power. Differences between the harvest treatments were not marked, but the grouped treatment supported significantly higher abundances of three forest-dwelling bird species and the mature forest avian guild than the dispersed treatments. Golden-crowned kinglet was detected in the 20% grouped treatment in both study years, but was not detected in the 20% dispersed treatment in either year. Swainson's thrush was detected in the 10% grouped and 20% grouped treatments in both 2004 and 2005, but was not detected in either the 10% dispersed nor the 20% dispersed treatments in either year (Figure 2). Three-toed woodpecker was detected in both the 10% grouped and the 20% grouped treatments in 2004, and in the 20% grouped treatment in 2005. This species was never detected in either the 10% or the 20% dispersed treatment in either year. Densities of the mature forest guild were higher in the 10% and 20% grouped treatments, than in the 10% and 20% dispersed treatments, respectively.

The grouped treatments also had higher densities of eight other bird species than the dispersed treatments, but these differences were not statistically significant. The eight species consisted of dusky flycatcher, Hammond's flycatcher, the pooled dusky and Hammond's flycatcher when identification could not be done to species, hermit thrush, hairy woodpecker, ruby-crowned kinglet, western wood pewee, Wilson's warbler, and winter wren. The 20% partial retention treatments sometimes supported higher abundances of forest dwelling birds than the 10% partial retention treatments, but the differences were not always large nor consistent. The 20% dispersed treatment supported higher abundances of eight bird species (Cassin's vireo, Hammond's flycatcher, red-breasted nuthatch, red-eyed vireo, Townsend's solitaire, warbler species, western tanager, and yellow-rumped warbler) than the 10% dispersed treatment while the 20% grouped treatment supported higher abundances of six bird species (golden-crowned kinglet, ruby-crowned kinglet, red-eyed vireo, savannah sparrow, Swainson's thrush, warbler species) than the 10% grouped treatment. However, only the red-eyed vireo and warblers (not identifiable to the species level) were detected significantly more often in both the 20% dispersed and the 20% grouped treatments, than the respective 10% treatments. A few open-habitat species (e.g., Lincoln's sparrow, mountain bluebird, song sparrow) were detected more frequently in the 10% partial retention treatments than in the respective 20% partial retention treatments, but differences in detection rates were not statistically significant.

Cutblock size did not appear to be as important as residual tree retention in determining the occurrence and abundance of bird species. Even though the bark beetle recovery units averaged only 9.1 ha in this study, they did not support more forest dwelling birds than the other harvest treatments. In fact, three forest-dwelling species (brown creeper, Cassin's vireo, and Townsend's solitaire) were absent from the BBR treatment, even though they were present in some or all of the other harvest treatments. Similarly, many mature forest bird species occurred in the very large mega cutblocks with > 12% retention, even when absent from other harvest treatments. In some cases, detections of mature forest dwelling species (e.g., brown creeper, cassin's vireo, golden-crowned kinglet, and three-toed woodpecker, mature forest guild) were higher in the mega cutblocks than in many or all of the other harvest treatments, though these differences were not always statistically significant.

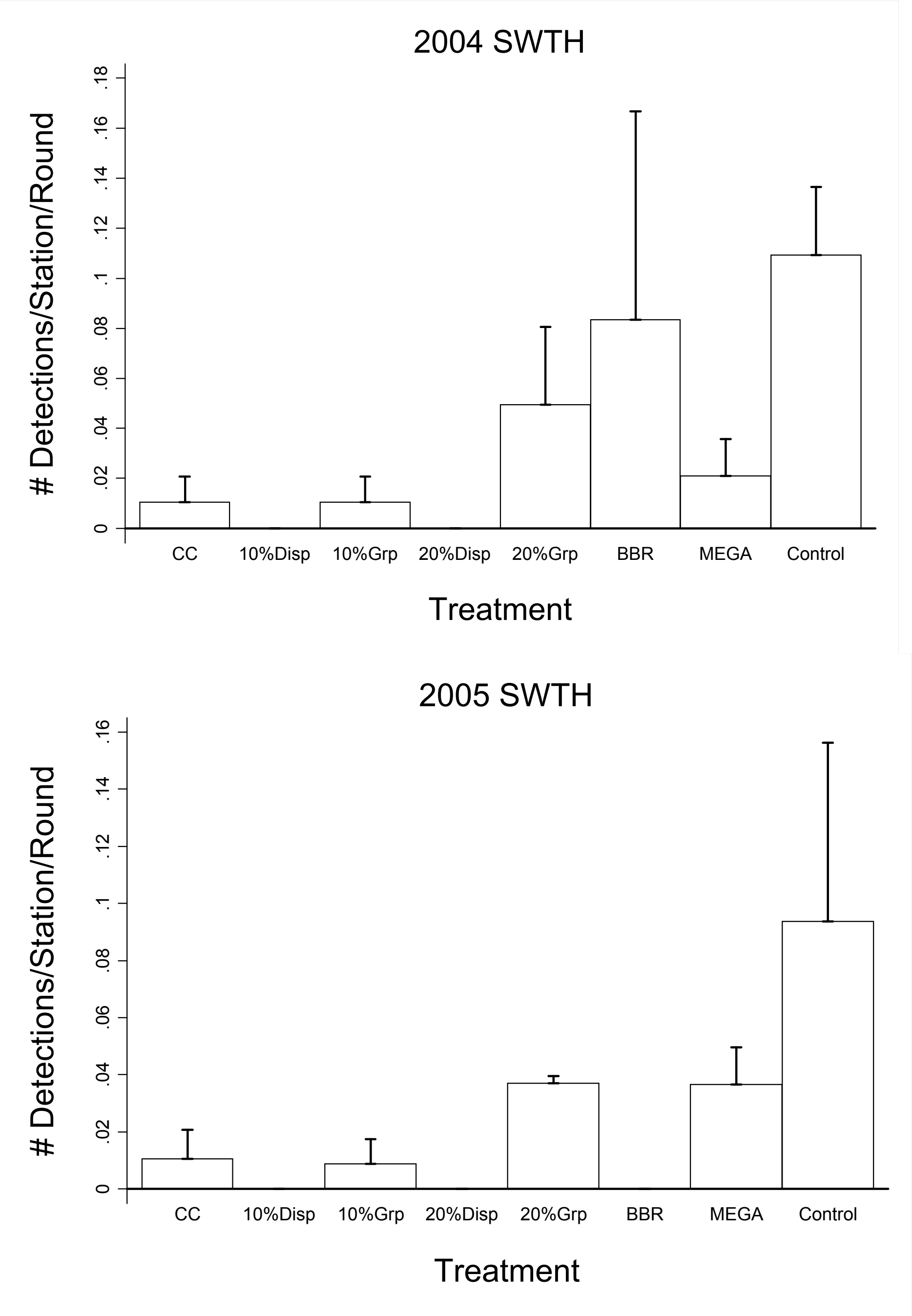

Figure 2. Swainson's Thrush Abundance. Swainson's thrush was an example of a bird species which significantly favoured grouped treatment over the dispersed treatment, for a given retention level.

3.2 Study Objective 2

Pre-harvest stem densities were generally lower in the harvested areas (dispersed treatments) than in the aggregates or controls, but basal areas were relatively higher. Trees in pre-harvest dispersed stands had larger mean DBH's than aggregates and mean DBH's were larger in aggregates than controls. There were also differences in pre-harvest species composition between treatments. The aggregate treatments contained the lowest proportion of lodgepole pine (Pl) and the highest proportions of non-pine conifers. Differences in pre-harvest stem density, basal area, and species proportions indicated a bias for harvesting larger pine in dispersed treatments and for retaining smaller pine and non-pine species in aggregate treatments. This trend is the result of focusing harvesting efforts on mature pine that was either killed by MPB or at the highest risk of future attack.

Standing live conifer (StLvCon) densities in the control and aggregate treatments did not differ from each other, but both were higher than densities in the dispersed treatment. Total standing conifer densities including both live and dead trees were higher in controls than in aggregates, but the proportion of non-pine conifers was higher in aggregates. Even though standing conifer densities were higher in controls, comparatively higher pine mortality from MPB in controls resulted in similar abundance of standing live conifers in controls and aggregates. There appeared to be variations in the abundance of standing live deciduous (StLvDec) between the control and the dispersed treatments, and between the aggregate and dispersed treatments. However, differences may not have been significant because there was high variability between aggregate and control treatments as well as a low abundance of standing live deciduous in all treatments, especially dispersed treatments. The abundance of standing dead conifers (StDdCon) was relatively high in control, moderate in aggregate, and very low in dispersed treatments. An important consideration when comparing standing dead conifers in controls and aggregates is that there are twice as many MPB-susceptible lodgepole pine in controls than in the aggregates. The densities of standing dead deciduous (StDdDec) were very low and highly variable in all treatments and significant differences could not be verified.

The aggregate treatments contained much higher densities of trees than dispersed treatments and commonly suffered extensive windthrow, especially in small aggregates and near aggregate edges. This resulted in a higher abundance of post-harvest downed conifers DnCon) in aggregates. Down trees were not recorded in the control plots because of the inability to assign a time since harvest. However, the relatively low number of firm solid logs lacking any signs of decay detected on the line transects indicated very few trees were windthrown in the control plots over the period of interest. The densities of down deciduous trees (DnDec) were low in all treatments especially in dispersed treatments and significant differences could not be verified. Down trees were not recorded in controls.

Differences in basal area (BATree) were indicated between control and dispersed treatments, and between aggregate and dispersed treatments, but not between aggregate and control treatments. Since this basal area variable is an estimate of all trees (live and dead) left standing immediately after harvesting it was expected that the dispersed treatments would contain considerably less basal area than aggregate and control treatments. There were differences in the basal area of trees standing at the time of sampling (UpBATree) between control and dispersed treatments, and between aggregate and dispersed treatments. However, there was also a difference in UpBATree between control and aggregate treatments. This difference is likely due to aggregates experiencing more windthrow than controls. Presumably, the majority of basal left after harvesting was intended to remain standing in both treatments, but more trees (more basal area) was windthrown in aggregates than dispersed treatments simply because there were more trees available to be windthrown in the aggregate treatments.

Canopy cover (CovA) was similar between control and aggregate treatments, but they were different from the dispersed treatments. These differences are simply the result of many more trees in the control and aggregate treatments compared to the scarce residual trees retained in the dispersed treatments. The overall low densities of standing trees in the three levels of dispersed treatments meant there were no significant differences in canopy cover between them.

There were differences in shrub volumes between control and dispersed treatments and between control and aggregate treatments. Even though canopy cover (CovA) was similar between controls and aggregate treatments, shrub cover was much higher in aggregate than in controls. Grass is favoured over shrubs in the highly exposed and highly disturbed dispersed treatments, whereas shrubs are favoured over grass in the undisturbed, and moderately exposed aggregate treatments. However, both grass cover and shrub volumes are low in the relatively low-light undisturbed controls. For the first two years following harvesting there are large increases in grass cover in the dispersed treatments, but grass cover increases in the aggregate treatments are less dramatic. Shrub volumes showed an increasing trend for the first three years following harvesting, but did not continue to increase with additional time.

The 'CWD' variable only recorded the CWD present immediately after harvesting and did not include any additional input from post-harvest downed trees. Coarse woody debris was lowest in the controls and highest in the high-and medium-dispersed treatments. Aggregates supplied more total trees to be windthrown than dispersed treatments and therefore produced the most new CWD input from down trees. In fact, aggregates often resulted in a high occurrence of windthrow, especially smaller aggregate sizes. However, a higher proportion of retained trees in the dispersed treatments were windthrown compared to aggregate treatments. It was expected that the proportions of windthrown trees would be similar in all dispersed treatments or have an inverse relationship to retention levels. It is unclear why the medium retention dispersed treatment had a slightly lower proportion of downed stems than the low retention dispersed treatment; it may be due to sampling error. Estimations of windthrown trees were based on both live and dead standing trees, but presumably most, if not all of the retained trees in the dispersed treatments were live immediately following harvest.

There were dramatic differences in the distribution of post-windthrow standing tree sizes between the treatments. The most obvious difference was between the dispersed treatments and the two other treatments (control and aggregate). This was expected since relatively few trees were left after harvesting in the dispersed treatments and a high proportion of those leave-trees were windthrown. Most trees selected for retention in the dispersed treatments were large Douglas-fir. This is the most appropriate choice since Douglas-fir is not at risk to MPB attack and is considered more windfirm than spruce. The stem densities for all tree sizes in dispersed treatments were quite low with the exception of one dispersed block (Block 565-1) with an unusually high density. The mean densities of very large trees were low in all treatments.

There was little difference in crown/DBH ratios of pine (Pl) between the dispersed and aggregate treatments, but ratios were relatively smaller in controls. Spruce trees (Sx) appeared to have higher crown/DBH ratios than Douglas-fir (Fd) in dispersed treatments, but lower crown/DBH ratios than Douglas-fir in the other treatments. If this trend actually exists, it may mean spruce crowns (and possibly pine crowns) are being released and becoming larger and/or Douglas-fir is developing smaller crown profiles in the newly exposed conditions in dispersed treatments. Crown/DBH ratios of aspen (At) and birch (Ep) appear to be slightly higher in aggregate treatments compared to dispersed and control treatments.

3.3 Study Objective 3

As expected, varying both tree and exposure variables produced changes in windthrow occurrence. The largest size classes had a much lower proportion of down trees in the dispersed treatments. There were no very large trees in the aggregate treatments. Generally, aggregates experienced lower proportions of windthrow in most size classes compared to dispersed treatments. The shortest and tallest height classes had the lowest proportions of windthrow. Similar to the trend for DBH classes, aggregates experienced lower proportions of windthrow in all height classes compared to dispersed treatments. There were no very tall tree height classes found in aggregate treatments. The least slender of the height/diameter (HDR) classes experienced the lowest proportion of windthrow in all dispersed treatments. The most slender of the HDR classes experienced less windthrow in DispH and aggregate compared to DispL and DispM. Aggregate treatments consistently experienced the lowest overall proportional windthrow occurrence for all HDR classes. Proportions of windthrown trees were lowest in the lowest

VRfetch exposure class. There was a general trend for proportions of windthrown trees to increase with an increase in VRfetch class.

For the logistic regression Model 1, the likelihood of being dead from all sources of mortality was much higher for lodgepole pine (Pl) than for cottonwood (Ac). For the most part, mortality in dispersed treatments was from windthrow, mortality in controls was from MPB attack, and mortality in aggregates was from both windthrow and MPB attack. A tree was more likely to be dead in the dispersed treatment group compared to the aggregate treatment, and also more likely if it was in the control treatment than in the aggregate treatment. The likelihood of tree mortality increased with increasing tree height (ht). There was also a small increase in the likelihood of tree mortality with an increase in years since harvest (YSH). The difference in mortality between the control and aggregate treatments was associated with the proportion of pine. The proportion of pine was higher in the control than the aggregate, coinciding with the relatively higher mortality from MPB in the control. Pine mortality was proportionately higher in control compared to aggregate, which also contributed to higher mortality in the control compared to the aggregate treatments. The proportions of dead or down trees did not increase with increasing years since harvest classes, but there was proportionately more mortality from windthrow (down trees) in the dispersed compared to the aggregate treatment.

Model 2 estimating non-windthrow mortality indicated Pl and aspen (At) had a greater likelihood of being dead than species group SxBl. The probability of a tree being dead was higher in the control than in the aggregate treatment, coinciding with the higher densities of lodgepole pine in controls than aggregates (Figure 2). Standing mortality was associated with abundance of pine in aggregate and control treatments. However, there were few standing pine in the dispersed treatments, yet an individual standing tree was still more likely to be dead in the dispersed compared to the aggregate treatment group.

Model 3 estimated the likelihood of being windthrown from the population of trees in the aggregate and dispersed treatments according to the variables of treatment group and species. Down trees were not recorded in controls, but occurrence of windthrow was very low. The probability of being down was greater in the dispersed compared to the aggregate treatments. However, during sampling, it was observed that trees in smaller sized aggregates and on the edges of aggregates were highly susceptible to windthrow damage. Model 3 indicated that all species had lower probabilities of being down than cottonwood (Ac), but the likelihood of Spruce (Sx) being down was the highest compared to cottonwood. Actual occurrence of cottonwood, alder, and black spruce was minor in all treatments. The type of mortality was commonly related to species. For example, pine mortality was most often from MPB and spruce mortality was most often from windthrow. The very low indicated probability of black spruce being down was not considered reliable since only nine standing black spruce trees were recorded from one plot in the bottom of a small gulley in a relatively protected area inside a large aggregate in Block 544-4. Black spruce often has shallow rooting and can be susceptible to windthrow (Burns and Honkala 1990). Similarly, most of the subalpine fir trees were located in a gulley inside a single aggregate in Block 592-1. Compared to the aggregate treatments, the dispersed treatments experienced a much higher proportion of windthrow mortality (down trees) for most species, but due to the low stem densities, a lower overall total of dead trees. Proportional windthrow to dead trees varied between treatments, but was generally greater for most species in the dispersed compared to the aggregate treatments. Proportions of standing dead species was generally low for most treatments, but the highest proportions of standing dead trees were provided by pine (Pl), and aspen (At). Down trees were not recorded in controls, but abundance of standing dead pine was much higher in controls than other treatments.

Model 4 estimated the likelihood of being windthrown from the population of trees in the aggregate and dispersed treatments, but unlike Model 3, included the neighbourhood (exposure) variable direx 30. Model 4 included the exposure variable direx 30 to infer a treatment effect resulting from increased exposure in different treatments. The likelihood of a tree being down increased with increases in the exposure variable direx30. There was also an increase in the likelihood of being down with an increase in height. These results suggest a relationship between exposure and height, and risk of windthrow. This model also indicated the likelihood of being down was higher for Douglas-fir compared to the combined spruce/fir species class (SxBl). This may be in part because the spruce/fir class includes black spruce, and as mentioned previously, the data for this species is not considered dependable. All down deciduous trees were wind damaged, but some wind damaged deciduous trees remained standing. Even though the dispersed treatments experienced more exposure, there appeared to be proportionately less wind damaged deciduous trees in the dispersed treatments. A higher proportion of wind damaged deciduous trees remained standing in the aggregate treatments than in the dispersed treatments. This means there are proportionately more wind damaged standing deciduous trees in aggregate treatments with decay wound entry points (eg., broken tops and branches); these trees will become a future source of valuable standing wildlife trees.

Model 5 estimated the likelihood of being down from the population of trees in the aggregate treatments according to the variables DBHcm and VRfetch. The probability of being windthrown increased with increases in both diameter and VRfetch. Since the VRfetch variable increases as level of exposure increases (eg., proximity to edge), Model 5 suggests the probability of being windthrown increased with an increase in proximity to the aggregate edge. Model 5 also indicated the probability of being windthrown increased slightly with increasing DBH. Graphs of down trees by size class in the dispersed treatments indicated the probability of being windthrown increased with increasing DBH up to an approximate threshold DBH of 40 cm-50 cm at which point windthrow risk decreases with further increases in DBH. There were no trees over this threshold DBH found in the aggregate treatments, but presumably this same trend exists in these relatively lower exposed treatments. The higher level of exposure in dispersed treatments resulted in higher proportions of windthrow compared to aggregate treatments, regardless of DBH.

4 Discussion

4.1 Study Objective 1

The most consistent and pronounced treatment effects were between the controls and all other harvest treatments, with significantly more mature-forest birds detected in the controls than in any of the other treatments. These results concur with the results from a study on the effects of variable-retention harvesting on avian communities in coastal BC (Chan-McLeod unpublished data). Significant differences in avian communities between the controls and the harvested treatments were probably due to low retention levels. In coastal BC, avian communities in partial retention cutblocks approximated those in undisturbed forests only when retention levels approached 70% (Chan-McLeod unpublished data).

The occurrence and abundance of mature-forest bird species were sometimes higher in the partial retention harvests than in the clearcut. Many mature forest bird species were absent from the clearcut, but were detected in at least one or more of the partial retention treatments, albeit in low densities. These results suggest that the current retention practices are at least somewhat effective in retaining some of the biodiversity that would otherwise have been lost under clearcutting scenarios. However, the lack of consistency regarding which partial treatment supported the highest densities of mature-forest bird species underscored the relative lack of distinction between the different types of harvesting treatments.

Although not consistent, the 20% partial treatments did sometimes support higher abundances of mature forest species than the 10% partial treatments. The positive correlation between retention level and the occurrence and abundance of mature-forest birds is expected, but the lack of consistency is not. There may be interactive effects between retention level and retention pattern. We found that more species responded differentially to the 10% and 20% dispersed treatment than to the 10% and 20% grouped treatments. We found evidence that the grouped retention treatment was better than the dispersed retention treatment in retaining forest-dwelling bird species. These results are consistent with previous findings from coastal BC (Chan-McLeod unpublished data), and to the characteristically more hospitable habitat in the grouped retention cutblocks, which provide a more protected microclimate as well as higher abundances of many habitat structures (see Section 3.2).

The maintenance of mature-forest species in the harvested treatments will apply only as long as the residual trees remain standing. Thus, our results do not account for the continued deterioration and eventual fall down of beetle-killed trees that were retained as part of the residual tree patches. As most of the study sites were recently harvested, our results may not be valid for situations where harvesting was conducted a long time ago.

Future research should, therefore, address how the effectiveness of beetle-killed residual pine in maintaining bird communities in cutblocks will change over time, as the beetle-killed trees deteriorate and fall down, but the surrounding matrix greens up. Research should also focus on the effectiveness of higher retention levels in maintaining biodiversity, perhaps in mixed forests where lodgepole pine constitute a relatively minor component of the stand. The differential habitat value of different types of residual trees should also be addressed. The current study focused on breeding birds in the spring; future research must be conducted to evaluate the effectiveness of the partial harvesting treatments for winter habitat of resident wildlife, as winter habitat requirements are dramatically different from summer requirements, and are not reflected in the current findings.

4.2 Study Objective 2

There were differences in the abundance of many habitat variables between treatments. However, the deciduous variables (StLvDec, StDdDec, DnDec) were not significantly different among any of the treatments. The density of standing live conifers in aggregates was similar to that in controls. The high density of lodgepole pine in the controls, coupled with mortality from MPB, contributed to high relative abundance of standing dead conifers (StDdCon) in controls. Basal area left immediately after harvesting (BATree) was not different between control and aggregate. However, the basal area of trees that remained standing at time of sampling (UpBATree) was higher in control than in aggregate because there was a higher occurrence of windthrow in aggregates. Standing dead trees were probably not retained in dispersed treatments because of safety concerns so it can be assumed that downed trees likely originated from standing live trees.

Coarse woody debris was highest in the dispersed treatments and lowest in the controls. The sum of pre-harvest CWD plus the additional post-harvest logging waste may account for the higher volumes of CWD in the dispersed treatments compared to the unharvested controls. The difference in CWD between control and aggregate may be related to site factors associated with the selection of aggregate areas that result in slightly higher volumes of CWD (eg., sites with a history of older mortality). However, new CWD input from windthrow was highest in the aggregates due to a high occurrence of windthrow along aggregate edges and in small aggregate patch sizes. The high proportional occurrence of windthrow in the dispersed treatments will provide long-term large CWD from downed trees. The canopy cover variable (CovA) is simply the result of the abundance of standing live trees. Standing live trees were abundant in control and aggregate treatments but, low stem densities in the dispersed treatments resulted in a lower CovA. Overhead canopy cover was similar for control and aggregate treatments, but light from aggregate edges increased available light in aggregate treatments.

Aggregates likely had the highest shrub volumes because of a combination of undisturbed ground and moderate light conditions. Grass response is higher than shrub response in dispersed treatments, but is not due to competition between the two. In fact, grass cover did not show any direct association to shrub cover. The increase in grass cover may simply be a response to the increased light and disturbed ground in dispersed treatments. If the exposed dispersed treatments are experiencing drier conditions, grass may be growing better than shrubs due to a difference in soil moisture requirements. Dispersed areas have higher light conditions than aggregates, but also contain highly disturbed ground. It may be the increase in ground disturbance that reduced the pre-existing understory vegetation, coupled with the highly exposed conditions of dispersed treatments, is a combination not conducive to shrub growth. On the other hand, the moderate light and undisturbed ground in aggregates may not only allow shrub growth to survive, but perhaps even to thrive. Other factors influencing the apparent higher volume of shrub cover in aggregates may be related to certain characteristics associated with aggregate selection that naturally contain higher shrub volumes (eg., non-productive brush, wet soil conditions).

Before treatment, the harvested areas (dispersed treatments) contained the highest abundance of mature pine trees, but the lowest abundance of spruce, subalpine-fir, aspen, cottonwood, and immature pine. However, the newly exposed conditions of the dispersed treatments may allow some deciduous species (eg., aspen) to establish where they were not growing in the pre-harvest stand. Regardless of treatment, mature pine trees are highly susceptible to MPB attack. There has been a strong selection bias to either pre-emptively harvest susceptible mature pine trees or salvage harvest dead or dying MPB attacked trees. As expected, there were very few mature pine trees retained in dispersed treatments. Pre-harvest proportions of pine were higher in dispersed and control treatments than in aggregate treatments. This means aggregates were selected in part because of their characteristics of beetle resistance since aggregates contained fewer pine trees than the surrounding pre-harvest stand. The implications for the interpretation of the results of this study are variables related to factors such as species abundance (eg., pine vs non-pine), windthrow (eg., standing dead pine), and tree size (mature vs immature pine) will be more affected by harvesting selection bias than by treatment effect.

The main factors influencing the abundance of the tree habitat variables are windthrow resulting from increased wind exposure, low retained tree densities in the dispersed treatments, and mortality from MPB. Beetle-killed trees lose their foliage and are therefore expected to be initially less prone to windthrow. This will result in more pine in the controls that are dead (StDdCon), but remain standing. The factors influencing shrub volumes are less clearly apparent. Varying light conditions likely play a role in shrub volume growth, but ground disturbance could also be a factor. There was a greater abundance of fireweed, a shade-intolerant pioneer species, in the dispersed treatments and more bunchberry, a more shade-tolerant species, in the aggregate and control treatments. Dispersed treatments contained the highest abundance of grass cover and moderate shrub volumes. Control areas contained the lowest shrub volumes, but also the lowest grass cover. It is likely that the lower light conditions in controls do not allow either grass or shrubs to thrive. Aggregate treatments contained the highest shrub volumes, but grass cover was almost as low as controls. This suggests the moderate light conditions and the lack of ground disturbance in aggregates are adequate for shrub growth, but not for grass growth. Grass cover increased rapidly in the dispersed treatments for the first two years following harvest. The presence of grass and shrubs are important considerations for habitat management. Grass is a valuable source of food and cover for many species (Mackinnon et al. 1999). Shrub cover provides many benefits to wildlife including providing nesting and rearing habitat for songbirds and grouse, providing cover for mammals, maintaining diversity of arthropod communities, and providing a moist stable microclimate that can promote sensitive plant species (Bunnell et al. 2003).

4.3 Study Objective 3

Models 1 and 2 indicated lodgepole pine (Pl) had a higher likelihood of being dead than other species. This is not surprising since the study site is located in a MPB infested area. The severe MPB losses also affected other results. One of the factors that made other species (eg., spruce) more prone to windthrow than pine is the lower sail area of dead pine (less foliage). The probability of mortality from all sources (Model 1) is higher compared to mortality using only standing trees (Model 2) in the dispersed treatment group. This is because mortality from windthrow is included in Model 1. Windthrow did not follow a consistent increasing trend with increases in years since harvest class. In other words, the occurrence of windthrow did not increase dramatically after the first year.

Model 1 indicated that the likelihood of mortality was higher in the control compared to the aggregate treatment. This is due to the fact that there was more pine at risk to beetle attack in the controls compared to the aggregates. The proportion of pine mortality from all sources (including windthrow) was lowest in the aggregates. The higher occurrence of pine in controls resulted in more standing dead pine in controls compared to aggregate treatments. It is possible that pine trees in aggregate conditions were also less susceptible to beetle attack due to increased light and wind (traits of beetle-proofing) compared to the relatively dense unharvested control areas

(Pacific Forestry Centre 2002). Pine trees in dispersed treatments also had increased light and wind levels, but suffered more relative mortality from windthrow.

Both models 1 and 2 indicated a higher likelihood of a tree being dead in the dispersed treatment group compared to the aggregate treatment. Most of the mortality in the dispersed treatment group was from windthrow. Harvesting damage to stems was low and most of the scarred trees were Douglas-fir veterans in the dispersed treatments. Even though some of the trees scarred during harvesting died, it is unclear whether the harvesting scars contributed significantly to the mortality of these trees. It is possible that all trees in the dispersed treatments were experiencing some level of increased exposure stress, increasing the risk of mortality from drought stress (Black and Oke 2000). However, there was little evidence of Douglas-fir bark beetle in any of the sampled trees, indicating stress was not likely a major factor affecting Douglas-fir mortality (Leslie and Bradley 2001).

Pine mortality was proportionately lowest in aggregate treatments and proportionately highest in dispersed treatments. Most pine mortality in dispersed treatments was from windthrow. It is possible that standing dead pine trees in dispersed treatments were either previously infected, but undetected at the time of harvest (green attack) or attacked very soon after harvesting. In contrast, the fact that a group of trees were selected for aggregate retention in a beetle infested area suggests pine trees in the aggregate were not infected at time of harvest. There may be certain characteristics of those selected trees that make them less susceptible to infection (eg., immature trees, increased vigour). In fact, mean DBH's were smaller in the aggregate areas than in the pre-harvest dispersed treatments, suggesting trees were likely younger and possibly more vigorous in the aggregates.

Model 3 indicated windthrow risk was much higher in dispersed treatments than in aggregate treatments and higher for spruce than for other species. These results are further supported by Model 4 that indicated trees were more susceptible to windthrow with an increase in the exposure variable direx30. A study in mature lodgepole pine forests by Whitehead and Brown (1997) found a similar trend where commercial thinning to a 50%–65% basal area reduction aggravated windthrow. Model 4 indicated the likelihood of being down was highest for Douglas-fir compared to all other species. This seems unusual since spruce has been reported as being less windfirm than Douglas-fir (Burns and Honkala 1990). Since most of the trees in the dispersed treatments were Douglas-fir, this apparent trend was likely less related to species than to the fact that all species in the dispersed treatments had a greater risk of windthrow. In fact, Douglas-fir suffered the least proportional windthrow of all species in both the dispersed and aggregate treatments.

The study results indicated deciduous species in dispersed treatments experienced more proportional windthrow compared to the aggregate treatments. Aggregates reduced windthrow occurrence, but more wind damage occurred to branches and tops. Wind damage in aggregates likely occurred through contact with other trees during high winds. The implication is that deciduous trees in aggregates will provide damaged live standing trees with natural wound entry points (eg., broken branches, broken tops). This situation will result in decay patterns desirable for primary cavity nesters (Boyland and Bunnell 2002).

Model 5 indicated windthrow risk was greater with increases in DBH and exposure. Delong et al. (2001) also found windthrow increased in reserves as the median DBH of stems increased. However, my study indicated windthrow risk increased with size up to 40 cm-50 cm, but then decreased with further increase in size. Risk of windthrow was lowest for very small and very large trees. Graphs of down trees in tree height classes indicated windthrow risk was lowest for the tallest tree heights.

The proportions of down trees in HDR classes indicated windthrow risk was lowest for the least slender class. These results support the assertion that large, dominant trees have adapted more wind-resistance (eg., lower HDR's, stronger root systems) than more slender trees that have never been exposed to wind prior to harvesting. The most slender tree class experienced less windthrow in the aggregate and DispH treatments compared to DispM and DispL, and the aggregates experienced less overall windthrow suggesting increasing exposure increases windthrow risk. Generally, there was an increasing trend of windthrow with increasing slenderness in most dispersed treatments, but windthrow in the aggregate treatments remained consistently low. This suggests windthrow is not related to slenderness in aggregate treatments.

Other factors important to keep in mind include the influence of species and level of exposure. Most of the very large, tall trees were old Douglas-fir veterans located in dispersed treatments. Dispersed treatments produce a higher exposure to wind, but due to stand history and species characteristics, large Douglas-fir veterans should be more windfirm relative to other trees. Factors related to windfirmness include tree size and rooting pattern related to species, soil conditions, and exposure history (Kimmins 1996, Smith et al. 1997). The pre-fire disturbance history and dominant positions of Douglas-fir veterans have allowed these large old trees to adapt to exposed conditions by developing more windfirm taper and stronger root systems (Smith et al. 1997). Model 5 indicated an increase in exposure in aggregates, as measured by the VRfetch variable, increased the occurrence of windthrow. This suggests increases in proximity to edge and/or decreases in the size of aggregates increased the risk of windthrow.

The mortality results provide arguments for the types of trees to retain for wildlife habitat. The relative windfirmness of Douglas-fir veterans provide the best opportunity for large live trees to remain standing in the regenerating stand. The large diameter, deeply furrowed bark, large branches, and age-related conditions of Douglas-fir provide important structural elements for wildlife. If a Douglas-fir veteran dies but remains standing it will provide a large dead snag valuable to several wildlife species. Retaining most other species in dispersed treatments will result in a much higher occurrence of windthrow. However, retaining live pine will likely result in MPB-killed trees that initially have a relatively low risk of windthrow due to reduced foliage.

5 Conclusions

5.1 Study Objective 1

In general, mature forest-dwelling bird species were most abundant in control sites and least abundant in or absent from the clearcuts. Relative abundance of mature forest avian species in the partial retention treatments were either similar to clearcuts or were intermediate to the clearcuts and the controls. Differences between the partial retention treatments were neither marked nor consistent, but mature-forest dwelling species sometimes favoured the 20% retention treatments over the 10% retention treatments. Cutblock size did not appear to be as important as residual tree retention in determining the occurrence and abundance of bird species. Thus, the megablocks were as effective as, or in some cases better than the other partial retention treatments in retaining the occurrence of mature-forest bird species despite their very large sizes. Likewise, the small bark beetle recovery cutblocks were generally not more effective, and sometimes less effective at maintaining mature forest-dwelling species, than other partial retention treatments, despite their average size of only 9.1 ha. The grouped retention treatment was somewhat more effective than the dispersed retention treatment in maintaining species. Silvicultural control of MPB can best be integrated with wildlife and sustainable forest management objectives by maximizing retention level in the cutblock, retaining trees with high mature-forest habitat values, and retaining trees in groups rather than as dispersed stems. Our results suggest that the potentially detrimental impacts of increased cutblock size may be countered at least partly by increased retention levels. Our results apply only to cutblocks that were recently harvested, and do not account for the continued deterioration and eventual fall down of beetle-killed trees that constituted some of the residual tree patches. Future research should address how the effectiveness of beetle-killed residual pine in maintaining bird communities in cutblocks, the effectiveness of higher retention levels in maintaining biodiversity, and the effectiveness of partial harvesting treatments for winter habitat values will change over time.

5.2 Study Objectives 2 and 3

The hypothesis tested in Study Objective 2 asked the question, “Does aggregate treatment result in a different abundance of wildlife structural/habitat features than dispersed treatment and how do they both differ from unharvested forest?” Results indicate aggregate treatments, dispersed treatments, and controls did differ in the abundance of the 11 sampled habitat variables. Abundance of most variables in dispersed treatments was different from aggregate and control treatments. There were also some differences between aggregates and controls, likely due to differences in exposure (eg., aggregate edge influence) and aggregate retention selection bias (eg., species, size). Differences between the levels of dispersed treatments were often less apparent. This is likely due to the relatively small range in retention between the low, medium, and high retention classes of the dispersed treatments.

The occurrence of standing dead conifers primarily resulted from the higher likelihood of mortality for lodgepole pine compared to other species. Risk of windthrow was highest in dispersed treatments, but the abundance of windthrown trees was higher in aggregate treatments simply because there were more trees available to be windthrown. Similarly, CWD input from windthrown trees was higher in aggregate compared to dispersed treatments. These results were expected since lodgepole pine is highly susceptible to MPB attack and it is logical to assume that even though increased exposure in dispersed treatments produces greater windthrow risk, the low stem densities will result in a low abundance of windthrown trees. The initial expectation was that shrub volumes would be highest in dispersed treatments due to higher light conditions. However, shrub volumes were found to be highest in aggregate treatments, moderate in dispersed treatments and lowest in control areas. Shrub volumes increased for two years in dispersed and for three years in aggregate treatments.

It is likely the different conditions created by the control, aggregate, and dispersed treatments resulted in variations in the abundance of many habitat variables. However, it is important to remember that any bias that was part of the process for selecting which individual trees or groups of trees to retain in dispersed or aggregate treatments would strongly influence what remained intact after any treatment. For example, regardless of the treatment, any individual tree or group of trees that were selected for their qualities of windfirmness (eg., species, size) would have a lower chance of experiencing windthrow than those that were randomly chosen. Also, aggregates that originally contained higher or lower abundances of other variables such as CWD or even shrub cover would likely retain those levels after an aggregate treatment has been done. Therefore, variable abundances can depend on the aggregate site selection (or individual tree selection) process as much or more as the type of treatment.

According to densities recommended by Boyland and Bunnell (2002), neither the dispersed or aggregate treatments are meeting the minimum requirement for two large snags/ha. The minimum requirements for 10-20 smaller snags are being met in the aggregate treatments because of MPB mortality of pine trees, but are not being met in dispersed treatments because of windthrow. Boyland and Bunnell (2002) considered a large snag to be 50 cm DBH (30 cm DBH in less productive forest) with preferred species being hardwoods, Ponderosae pine, Douglas-fir, and larch. There are sufficient large trees available to meet minimum large snag requirements in the dispersed treatments, but they are live trees and therefore do not qualify as large snags. However, since these large trees are old Douglas-fir veterans they provide many valuable habitat features such as deeply furrowed bark, large branches, etc. If standing dead trees are desired, management can easily employ various methods including girdling, herbicide, and fungal inoculation to create large dead snags. Also, the wildlife value of a large snag is influenced by its environment (eg., surrounding tree densities).

The mean densities of deciduous species in aggregates was half of that in controls and considerably lower in dispersed treatments. It is unlikely that deciduous presence will provide significant wildlife habitat in the dispersed treatments. Any requirements for general canopy cover in dispersed treatments will likely not be met due to very low stem densities and high windthrow occurrence. Total long-term requirements for CWD will most likely be met because of the windthrow events in both dispersed and aggregate treatments. Shrub management strategies must be linked with the specific type of partial harvesting treatment. There were more early seral shrub species found in aggregate treatments, more late seral shrub species found in dispersed treatments and more overall shrub volumes found in aggregates than in dispersed or controls.

Study Objective 3 indicated probabilities of mortality and windthrow were affected by species and type of treatment. The first question asked in Study Objective 3 was “Do the different partial harvesting methods of aggregate treatment and dispersed treatment affect probabilities of tree mortality or windthrow?” The five logistic regression models indicate different partial harvesting methods have different results. For example, the most influential treatment effect for placing a tree at risk of mortality was windthrow from increased exposure. The second question asked in Study Objective 3 was “How do tree, neighbourhood, and site factors affect the probabilities of tree mortality or windthrow?” Generally, the most influential factor affecting mortality was species. Specifically, lodgepole pine was indicated to be at the greatest risk for mortality. It was expected that the current MPB epidemic would produce this result. Model 5 indicated windthrow risk increased with increases in DBH or exposure. However, very large, tall trees had a lower risk of windthrow. Windthrow susceptibility was also influenced by species. Spruce was the most susceptible and Douglas-fir was the least susceptible. Mountain pine beetle-attacked pine also had a lower risk of windthrow. Selecting large veteran Douglas-fir leave trees would likely provide the best opportunity for retaining standing live trees in dispersed treatments and aggregate treatments are better able to provide protection for less windfirm trees.

Table 4 compares the abundance of the 11 habitat variables in the partial harvesting treatments to the unharvested control areas. Generally, there is a much lower abundance of most variables in the dispersed treatments than in the controls. However, shrub volumes and CWD were more abundant in all treatments than in controls. Down trees (DnCon, DnDec) were not recorded in controls so direct comparisons cannot be made. Nevertheless, windthrow in control areas was rare, suggesting the abundance of down trees was much higher in both dispersed and aggregate treatments than controls.

Table 4. Treatments Compared to Unharvested Control Areas. The number of plus (+) or minus (-) signs indicates the approximate proportional difference between the treatments and the unharvested control areas. The “~” sign indicates approximately equal proportions.

Variable	DispL	DispM	DispH	Aggregate
StLvCon	- - - -	- - - -	- - - -	≃
StLvDec	- - -	- - -	- - -	-
StDdCon	- - - -	- - - -	- - - -	- -
StDdDec	- -	- -	- -	+ +
DnCon	na	na	na	na
DnDec	na	na	na	na
BATree	- - - -	- - - -	- - - -	-
UpBATree	- - - -	- - - -	- - - -	- -
CovA	- - - -	- - - -	- - - -	≃
ShrubVol	+ + +	+ +	+	+ + + +
CWD	≃	+ +	+ +	+ +

Table 5 lists the main effects of the dispersed, aggregate, and control treatments and the impacts on stand structure habitat. The main effects in the different treatments are the result of the varying levels of exposure to wind and light (and possibly moisture differences). The different levels of exposure produce different impacts on stand structure. Dispersed treatments experienced the highest exposure to wind and light and produced relatively high windthrow, moderate shrub volumes, and high grass cover. Aggregate treatments experienced moderate exposure to wind and light and produced relatively moderate windthrow, high shrub volumes, low grass cover, and a lower risk of MPB attack. Control treatments experienced low exposure to wind and light and produced low windthrow, low shrub volumes, low grass cover, and a higher risk of MPB attack (Table 5). Some impacts were influenced as much or more by the leave tree criteria used in the retention selection process. For example, lowered risk of windthrow and MPB attack were likely affected by characteristics of tree size and species more than level of exposure.

Table 5. Main Effects and Impacts of Treatments

Treatment Type	Main Effects	Impacts on Stand Structure
Dispersed	high exposure to wind and light	• high windthrow • moderate shrub volumes • high grass cover
Aggregate	moderate exposure to wind and light	• moderate windthrow • high shrub volumes • low grass cover • reduced MPB risk
Control	low exposure to wind and light	• low windthrow • low shrub volumes • low grass cover • high MPB risk

There are similar trends indicated by the results of Study Objective 2 and Study Objective 3. The species type is predominantly lodgepole pine and the region is heavily infested by MPB. This situation results in high standing tree mortality rates for pine wherever they are found. Even though the controls contained more overall conifer trees, both the control and aggregate treatments had a similar abundance of standing live conifers because controls contained more beetle-killed pine. Aggregates may also have more beetle-resistance properties than controls. There is likely some increase in tree vigour created by the higher light conditions (vigorous trees are more beetle resistant) and increased wind (dispersed pheromone plumes) resulting from edge effect in aggregates.

Study Objective 2 indicated the abundance of down trees is highest in aggregate treatments, but Study Objective 3 indicated probability of being down is higher in dispersed treatments. Given the overall low stem densities, but higher proportion of down trees to leave trees in the dispersed treatments compared to the aggregate treatments, these results are in agreement. Study Objective 3 indicated windthrow risk increased with increased exposure and spruce is the most likely species to be windthrown.

The control treatment had the highest occurrence of pine and contained the highest abundance of standing dead conifers (Study Objective 2). The dispersed treatments had the lowest basal area (Study Objective 2) and highest level of exposure, and showed the highest probability of being windthrown (Study Objective 3). Dispersed treatments had a higher risk of windthrow (Study Objective 3), but aggregate treatments had a higher density of trees and therefore a higher abundance of down trees (Study Objective 2). Study Objective 3 indicated the probability of being windthrown in an aggregate increased with an increase in proximity to edge. Study Objective 3 also indicated very small trees and very large trees were less prone to windthrow than medium sized trees.

The unharvested controls contained the highest stem densities and therefore experienced the lowest light conditions. Aggregate treatments contained higher mean stem densities than pre-harvest dispersed treatments, but lower mean stem densities than controls. Controls contained the highest density of pine, but mean tree sizes were smaller than in the pre-harvest dispersed treatments. These results reflect the selection bias for salvage harvesting larger mature pine resulting from MPB attack or pre-emptive harvesting of MPB susceptible mature pine. Also, aggregates contained a higher abundance of non-pine species than pre-harvest dispersed treatments, indicating a selection bias for retaining non-pine, MPB resistant species during cutblock layout. This is likely a good harvesting strategy in this area.

Study Objective 2 addressed the question “Does aggregate treatment result in a different abundance of wildlife structural/habitat features than dispersed treatment and how do they both differ from unharvested forest?” The results indicate that different partial harvesting treatments do result in different abundances of important habitat variables. Aggregate treatments result in higher abundances of most habitat variables simply because aggregates retain more trees, and fewer of these trees are subsequently windthrown. Deciduous trees in aggregates are still wind damaged, but there is sufficient protection to allow many damaged stems to remain standing. Damaged standing deciduous trees can provide valuable wildlife habitat. The conditions in aggregates also result in the highest abundance of shrub cover. However, large veteran Douglas-fir and deciduous trees occurred infrequently in aggregates. Douglas-fir veterans can be retained in dispersed treatments where they occur throughout the stand, with moderate levels of windthrow loss. The unharvested forest (controls) provided the lowest abundance of shrub cover, but the highest abundance of snags in the form of MPB-killed trees. The difference in species composition between controls and aggregates is due to the retention selection bias used in aggregate location.

Study Objective 3 asked the two questions, “Do the different partial harvesting methods of aggregate treatment and dispersed treatment affect probabilities of tree mortality or windthrow” and “How do tree, neighbourhood, and site factors affect the probabilities of tree mortality or windthrow?” Most differences could be attributed to the different levels of exposure between the treatments, but individual tree characteristics were also important. Very large trees and very small trees experienced less windthrow than medium-sized trees. Most results indicated spruce as more susceptible to windthrow than other conifers. Most differences in non-windthrow mortality could be attributed to species (eg., MPB-killed pine). Differences in beetle mortality for pine may be influenced by a combination of factors including individual tree characteristics (eg., size, age, vigour), site factors (eg., increased wind, exposure), and stand history (eg., pre-harvest infection).

The results of this study have various implications for forest managers, biologists, and researchers. Since managers are using the partial harvesting treatments to meet biodiversity objectives that are based on conserving areas of forest, the level of windthrow is a crucial factor in determining long-term treatment success. If an area of forest is conserved during harvesting only to be blown down by wind soon after harvest, the conserved area no longer provides the habitat values associated with an intact forested area. The proportions of windthrow were high in dispersed treatments and moderate in aggregate treatments. Increasing the densities of retained stems (dispersed treatments) and the areas of retention (aggregate treatments) will increase the chances of having the desired numbers of standing trees surviving in the future stand. The results indicate Douglas-fir veterans have the best chance of remaining standing in the dispersed treatments and larger aggregates experience less proportional windthrow.

Biologists are concerned with windthrow and mortality status since the habitat value of a tree changes if it is live, dead, standing, or down. Standing Douglas-fir veterans in the dispersed treatments provide wildlife values including large branches for perching or nesting platforms, deeply furrowed bark as a foraging substrate for woodpeckers, and age related decay patterns desirable for cavity excavators. Deciduous trees were often wind-damaged, but remained standing in aggregates. Standing damaged deciduous trees can provide important wildlife values and were scarce or absent in the other treatments including the unharvested controls. Some windthrow is inevitable in dispersed and aggregate treatments and can be an important source of future large CWD. Input from windthrown trees will supply long large diameter lengths of CWD that can be used as travel corridors and cover for small mammals (eg., voles) as well as hunting opportunities for their predators (eg., marten). The branches on down trees can provide substitute escape cover for small animals until shrub cover and tree seedlings regenerate (Smith et al. 1997). As trees eventually decay they can provide moist localized conditions for salamanders and invertebrates and foraging substrates for insect-feeding animals (Kimmins 1966). Aggregate treatments resulted in higher volumes of shrub habitat than dispersed treatments and unharvested control areas. Aggregates supply islands of habitat in the form of high shrub cover volumes, and a mixture of species of standing live, dead, and dying trees.

It would be valuable for researchers to find out why lodgepole pine was less susceptible to MPB attack in the aggregates than in the unharvested control areas. We have speculated that increased wind, light, tree vigour, and higher proportions of non-pine species were affecting the rates of MPB attack. Further studies focusing on those factors are needed to confirm these assumptions. Experimental design for this type of study must include measurements before and after harvesting. This will allow an estimation of any beetle resistance resulting from the actual effects of the aggregate treatments rather than the pre-harvest (eg., species mixture, tree size, age) stand conditions. There may be threshold levels of exposure (eg., light, wind), or densities of pine that provide characteristics of beetle resistance. Aggregate size, location, and orientation may also be important factors.

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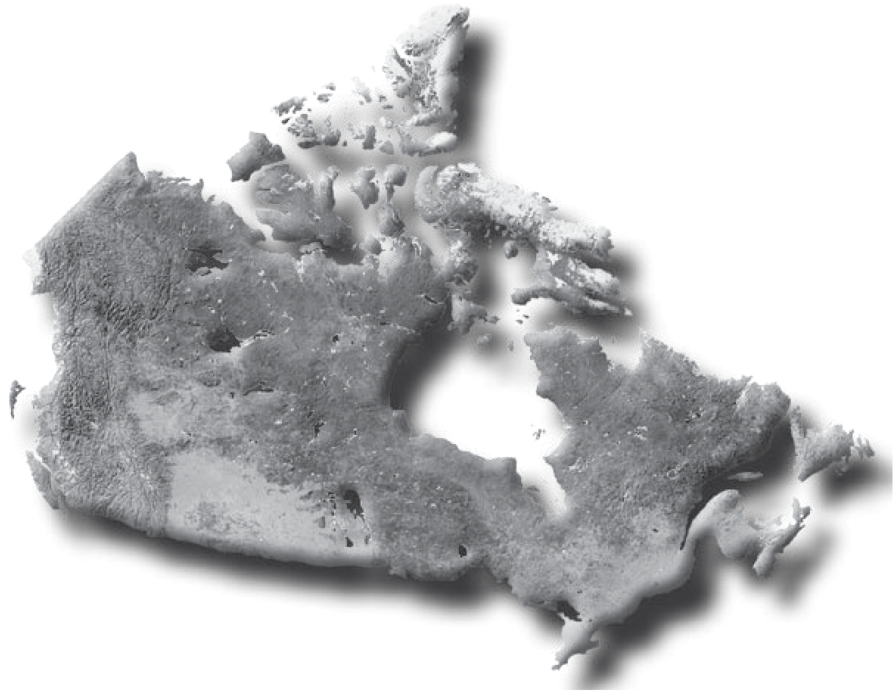

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