APPROVAL PAGE

ABSTRACT

A major current threat to the persistence of forest birds in Canada is forest fragmentation caused by industrial timber harvesting. The traditional silvicultural method of clearcutting creates forest fragments delineated by sharp boundaries. Conversely, selective logging techniques strive to mimic natural disturbance patterns and to produce smoother boundaries. Forest boundaries influence the ecological behaviour of forest birds in a species-specific manner. To assess the effect of forest fragmentation on bird occurrence and to derive management guidelines, I investigate the spatial association between boundaries of six bird species and forest features in a moderately harvested landscape (MHL) and an intensively harvested landscape (IHL) in New Brunswick. The focal bird species were used as indicator species for the effects of forest fragmentation. These analyses were carried out at both stand and landscape scales. I hypothesized that 1) the association of birds with forest variables would be i) species-specific and ii) stronger in the IHL than in the MHL; 2) that birds would have more common boundaries in the in the IHL than in the MHL; 3) that both scales would yield complementary results, whereby the stand scale would refine coarse-scale ecological relatiosoe1-0.027f8527f8527nMosnnosl

A mis papás por su inmenso amor y constante apoyo en cualquier camino que decida yo tomar

A mis hermanos y sobrinines por existir

A mi Noni por su gran cariño

Y a mis amigos en México también.

...and while she was tossing sea stars back into the ocean, he came and said: - " nonsense! You will never finish rescuing all these sea stars, the shore is full of them and the sea keeps bringing more and more". She responded: -"I may not be able to rescue them all" - and tossing one sea star into the sea she said...-"but for this one I made the difference!"

MR

ACKNOWLEDGEMENTS

I want to express my gratitude to all the people who contribute to the completion of my master's project. I am highly grateful to:

Dr. Marc-André Villard, researcher at the University of Moncton, for sharing with me his field data and for his feedback on my written report. Gracias.

Dr. Marie-Joseé Fortin, my supervisor, for her strong support throughout the development of my master's project. I feel fortunate for having had her supervision and guiding my interest in wildlife management. Gracias.

Dr. Jamie Smith, professor at the faculty of Zoology, University of British Columbia, for his valuable feedback on my project and his willingness to take part in my master's committee. Gracias.

LE Lab, particularly to Geraldine Bergmans and Mathieu Philibert for their special 'spatial' and moral support. Gracias.

The Government of Canada and The International Council for Canadian Studies for providing me with the scholarship to pursue my graduate studies.

Cheryl Mackintosh, for her admirable performance as my thesis defense chair and for sharing my stress throughout the program and adding moments of great fun and good laughter. Gracias.

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INTRODUCTION

The presence and abundances of forest birds depend on vegetation composition, forest cover, and the spatial configuration of landscapes. Many studies have investigated the role of such forest features aiming to identify and quantify factors that affect the presence of various bird species (e.g., McGarigal and McComb, 1995; Thompson *et al.*, 1995; Mazzerolle and Villard, 1999). For instance, Robichaud and Villard (1999) found that black-throated green warblers (*Dendroica virens*) select territories based on conifer distribution in boreal mixed-wood forests of Northern Alberta. Variation in bird responses depends on the species life history and area requirements (Villard *et al.*, 1995). Hoover *et al.* (1995) reported that nesting success of Wood Thrush (*Hylocichla mustelina*) in sites with low forest cover (<42%) was birds that rely on such elements to survive. Consequently, forest birds may fail to breed or

OBJECTIVES AND HYPOTHESES

In this study, I investigate the spatial association of five songbirds and one woodpecker to

BACKGROUND

Ecological boundaries

Boundaries are defined as areas of environmental transition that separate two homogenous stands, communities, regions, or ecosystems. Boundaries may be caused by clearcuts, forest fires, treefall gaps, insect epidemics, or by gradual or drastic changes in microclimate (Fortin *et al*., 1996). While sharp boundaries (edges) are common in landscapes modified by human activity, smoother boundaries (ecotones) occur in undisturbed forests as a result of the continuous variation in forest components (Lent and Capen, 1995).

Boundaries are of scientific interest because their locations can reflect underlying physical and/or biological processes (Maruca and Jacquez, 1997). Abiotic and biotic factors at boundaries do not appear to act independently from each other. Instead, these factors combine to affect the occurrence and distribution of bird species. For example, microclimate near forest edges changes considerably relative to the forest interior (Chen, 1994). Climatic factors often limit bird distribution due to physiological constraints on metabolic rates, the timing of breeding, and reproductive success (McCollin, 1998). Also, forest edges influence the availability of prey for insectivorous birds making these predators, in turn, available to their predators (McCollin, 1998; Desrochers and Fortin, 2000). Desrochers and Fortin (2000) have shown that edges influence the behaviour of forest birds. They suggested that black-capped chickadees (*Poecile atricapillus*) use forest boundaries as movement conduits rather than as foraging sites. Hawrot and Niemi (1996) assumed that boundaries can also enhance population size by providing a higher diversity of microhabitat conditions and resources to forest birds. This hypothesis, however, is dependent on the type of edge: whether it is abrupt or gradual, or whether it occurs between habitat fragments or in the forest interior. Logically, a boundary roughly defined from the scale of human observation can be irrelevant to a forest

Response of birds to land changes

Given the high rate of forest fragmentation worldwide and extirpation of bird species from fragmented landscapes, studies aimed at evaluating the effect of habitat change on birds have

shelterwood methods regenerate even-aged stands, yet retain various canopy components to promote tree reproduction, and shelter seedlings, saplings, and other vegetation components. Conversely, group and single tree selection maintain stands with three or more age or size

METHODS

Study area and experimental design

My research is based on data gathered in 1996 and 1997 under the supervision of Dr. Marc-André Villard (see Villard, 1999). The study sites were located in a managed forest landscape in northwestern New Brunswick, north of the village of Plaster Rock (47°11'N, 67°13'W) (Figure 1). A mix of deciduous and coniferous trees characterizes the forest, which occurs within land managed by Fraser Paper Incorporation. This logging company used three main silvicultural practices: clearcutting in mixed and coniferous stands, variable retention in hardwood stands, and plantation of conifers in clearcuts (Fraser Papers Inc. 1995, Villard *et al*., 1999). The woodland is characterized by a mix of shade-tolerant hardwoods dominated by sugar maple (*Acer saccharum),* American beech (*Fagus grandifolia)*, and yellow birch *(Betula alleghaniensis)* on well drained sites, and coniferous stands along streams and rivers and on poor drained sites (Villard 1999).

Systematic square grids of 64 points were established in an intensively harvested forest (IHL) and in a moderately harvested forest (MHL). The MHL retained 70 percent of forest cover, while the IHL retained only 45 percent of forest cover. The square grids consisted of one macro grid (49km^2; landscape scale) within which two meso grids (6.25km^2; stand scale) were nested (Figure 2). Thus, meso grids were similar in stand composition and silvicultural treatment to the macro grids. Yet, both sets of plots differed from each other in year of harvest and in the main silvicultural techniques performed (Table 1). Survey stations were 1 km apart for the macro grid and 250 m apart for the meso grids, approximately. Some points of both the macro and meso grids overlapped resulting in a total of 182 points surveyed in the moderately harvested landscape and 185 points in the intensively harvested landscape.

Fig.1. **Study area location in New Brunswick** (Villard, 1999).

Table 1. Landscape management features. Information for the intensively-harvested landscape (IHL) and the moderately-harvested landscape (MHL) is given for the macro grids and nested meso grids nested within such (Villard, 1999).

Landscape	**Percent forest cover**	**Logging technique**	**Cut block size (ha)**	**Harvesting years**
IHL	45%	clearcutting	>200	1983 - 1995
		selective logging	>400	1991 - 1994
MHL	70%	clearcutting	< 50	1982 - 1989
		selective logging	<100	1993 - 1995

Data collection

Bird Data

My research used point count data on bird species occurrence (i.e., presence/ absence). These data were collected at all stations (367 point counts overall) between 1996 and 1997. The

Table 2. Bird species included in the study. Abundance is shown as absolute number of individuals for each of the study plots (IHL, intensively harvested landscape; MHL, moderately harvested landscape; B and C meso grids within each landscape).

Bird Code*	**Abundance IHL, B, C MHL,B,C**	**Name**	**Forest habitat preference**
AMRE	24, 11, 26 23, 34, 34	American Redstart (*Setophaga ruticilla*)	Open mature stands with deciduous saplings and shrubs; Forages from ground to canopy; Hardwood trees for breeding.
BLWA	23, 21, 30 27, 34, 25	Blackburnian Warbler (*Dendroica fusca*)	Mixed wood mature stands with trees > 18m height; Forages from ground to canopy; conifers for breeding.
BTBW	33, 10, 31, 33, 39, 24	Black-throated blue Warbler (*Dendroica caerulescens*)	Mixedwood stands with dense understory below forest; canopy, understory forager; Mixedwood/ deciduous stands for breeding.
OVEN	41, 42, 44 33, 37, 47	Ovenbird (*Seiurus aurocapillus*)	Mature deciduous, contiguous stands, closed canopy Ground forager Undisturbed forests for breeding.
LEFL	56, 33, 55 32, 57, 48	Least Flycatcher (*Empidonax minimus*)	Semi-open/closed mature, deciduous stands; Deciduous trees for breeding.
YBSA	43, 45, 45 26, 41, 51	Yellow-bellied Sapsucker (*Sphyrapicus varius*)	Mature deciduous/ mixedwood stands, semi-open habitats; Live trees for nesting.

* See Appendix 1 for the meaning of bird codes.

Vegetation Data

Data on forest composition and vegetation layering were collected at each count point. Three 10 m x 20 m plots were sampled: one centered on the station and two 65 meters either to the north, southeast, or southwest (randomly selected direction). Data on forest composition include a count of all the deciduous and coniferous trees, as well as a tally of

Data Analysis

Boundary delineation

species separately. Small minimum distances between boundary locations characterize boundaries that overlap each other. The O_H statistic allows for slight spatial lag between boundaries and implies a certain degree of causality of one variable over another one. Here, I hypothesized that the spatial location of vegetation boundaries influences the distribution of

RESULTS

Boundary analysis

The main interest of my study lies in examining how bird boundaries relate spatially to particular characteristics of their habitat. The degree of spatial relation is proportional to the distance to the nearest forest boundary location. In other words, spatial proximity between boundaries of vegetation and bird species indicates that vegetation components influence the spatial distribution of birds. Boundary associations were determined between boundary locations in forest structure and composition and bird occurrence as well as between boundaries of pairs of bird species boundaries (see Methods). In analyzing whether forest features influence the occurrence of bird species, an effect of forest features exists on birds when ecologicat.w6(f)-2335(e)33.2(t)27.3(o)s variables in the IHL that were most significantly (positively) related to bird boundary location were canopy, shrub and ground cover height, as well as shrub and ground cover percentage.

approximately 80 percent and 60 percent of the environmental factors were significantly positively associated with the occurrence of BLWA and AMRE respectively (Table 4). In general, vegetation boundaries that significantly positively influenced the presence of most bird species were height and percent cover of the shrub and ground layer, the 2-4 meter and 4-6 meter tall subcanopy layers, and basal area of American beech and conifers. As on the IHL macro-grid, percent shrub cover was the only variable that significantly affected the occurrence of YBSA since the shrub-YBSA boundaries were close to each other (Appendix 4).

Table 4. Spatial relationship (O_H

b) Boundary association among bird species

Based on the overlap analysis (Os), there was a boundary association on the IHL-B plot between AMRE and BLWA, BTBW and both LEFL and YBSA, OVEN and YBSA (Table 5). In the IHL-C plot, however, only YBSA had boundaries that spatially overlapped with those of BTBW and LEFL. In contrast to the MHL-B plot, where boundaries of all the pairs of species except BTBW with AMRE and YBSA had significant direct overlap, the only species that show boundary overlap between each other in the MHL-C plot were BTBW with

MHL-A						
AMRE	40**	41	52	39*	41	3
BLWA		48	52	46	35	
BTBW			54	52	44	
LEFL				61	42**	
OVEN					37	
MHL-B						
AMRE	32**	36	34**	30*	31*	13
BLWA		36**	46**	29**	42**	
BTBW			38**	29**	42	
LEFL				31**	46**	
OVEN					29*	
RC						
AMRE	48	40	47	39	50	1
BLWA		44	51	44	51	
BTBW			43*	46	43	
LEFL				42	51	
OVEN					43	

[+] Appendix 1 explains the codes.

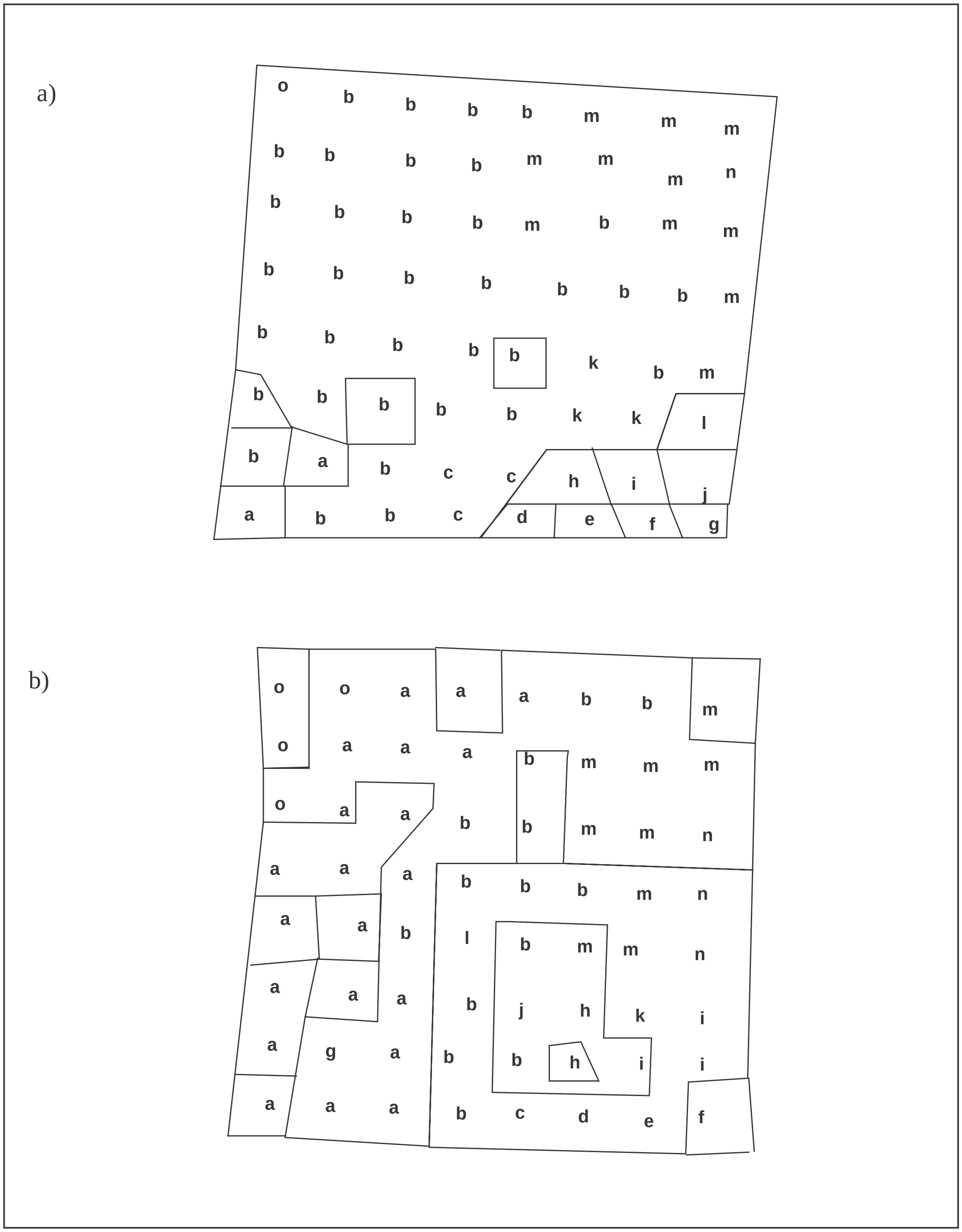

Fig.3**. Ecological boundary overlap at the landscape-scale**. Letters represent bird clusters, polygons refer to forest feature clusters, both resulted from the agglomerative cluster overlap yielding the top 15 groups with the highest occurrence turnover rate. a) cluster overlap (OH=245.34*) between the occurrence of black-throated blue warbler and subcanopy cover height within the intensively harvested landscape (IHL macro-grid); b) cluster overlap (OH=337.07*) between the occurrence of ovenbirds and overall subcanopy height within the moderately harvested landscape (MHL). (* = $p<0.05$, **= $p<0.01$).

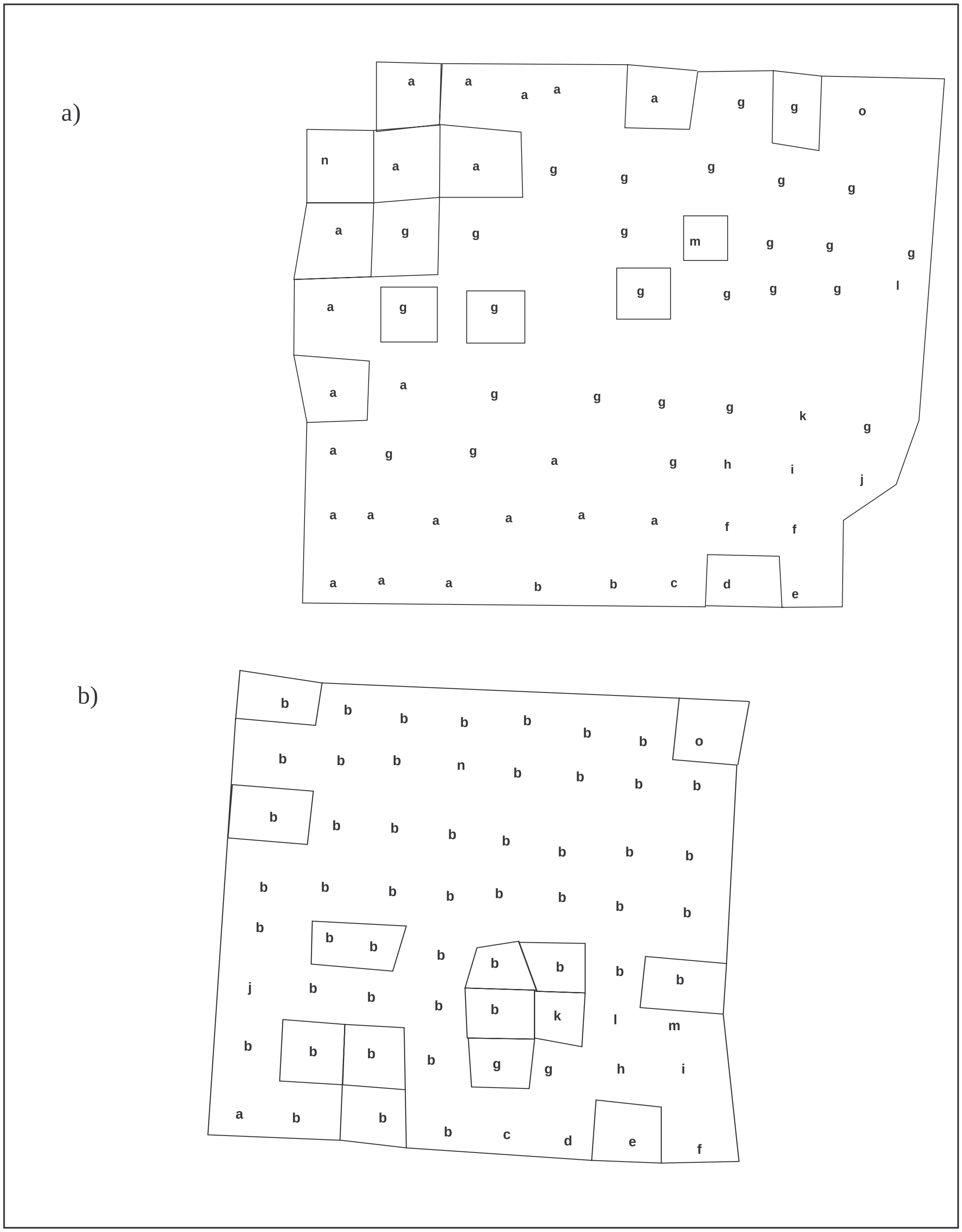

Fig.4.**Ecological boundary overlap at the stand-scale**. Letters represent bird clusters, polygons refer to forest feature clusters, both resulted from the agglomerative cluster overlap yielding the top 15 groups with the highest occurrence turnover rate. a) cluster overlap (O_H=103.81*) between the occurrence of least flycatchers and beech within an intensively harvested stand (IHL-C plot); b) cluster overlap (O_H=233.46**) between the occurrence of ovenbirds and subcanopy cover (class 4-6 m high) within an moderately harvested stand (MHL-B plot). (* = p<0.05, **= p<0.01).

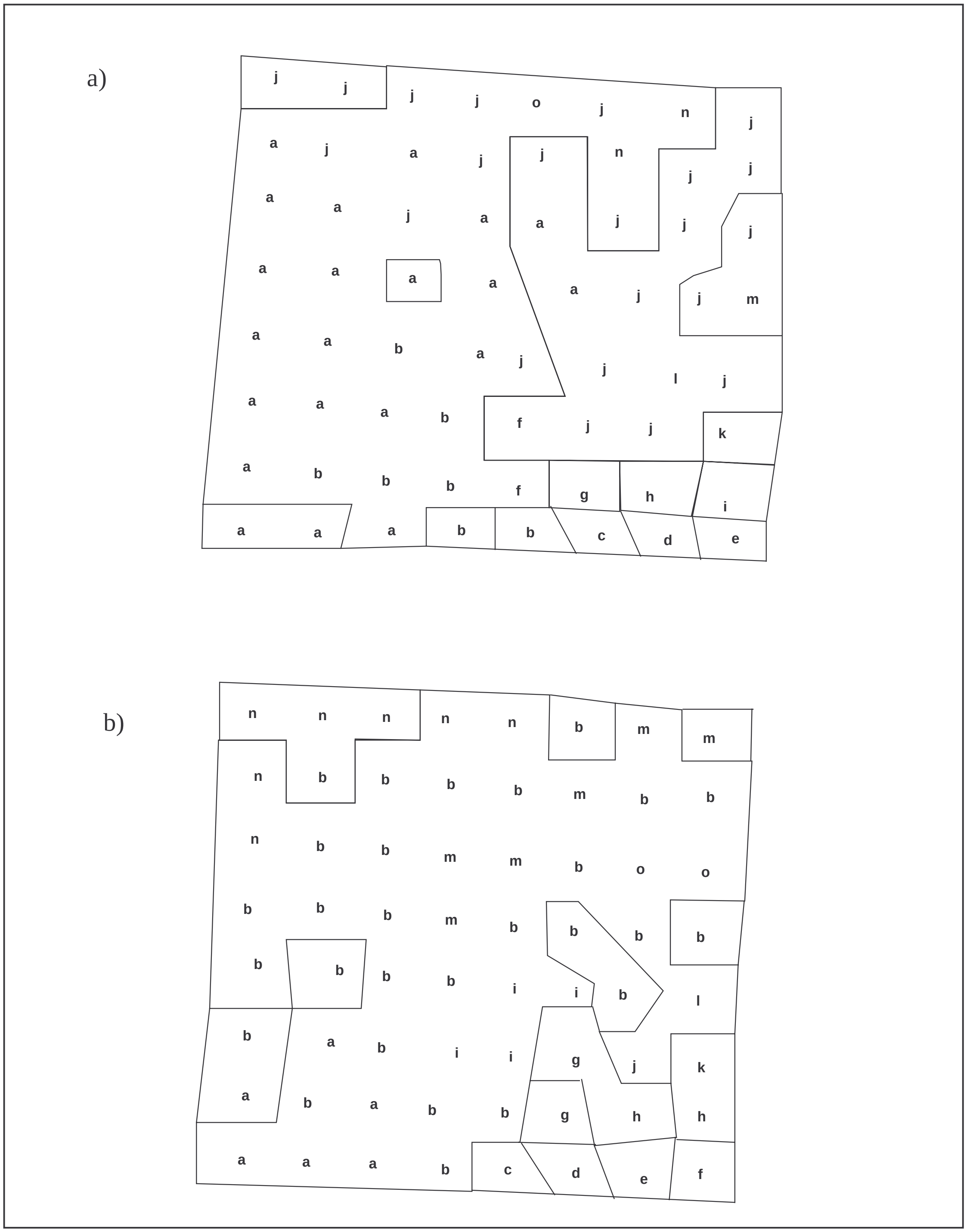

Fig.5. **Bird-bird boundary overlap at the landscape-scale**. Bird clusters resulted from the agglomerative clustering analyses yielding the top 15 bird groups with the highest occurrence turnover rate. a) direct cluster overlap (O_S=46**) between the occurrence of yellow-bellied sapsucker (letters) and American redstarts (polygons) within an intensively harvested landscape (IHL); b) direct cluster overlap (O_S=42**) between the occurrence of least flycatchers (letters) and yellow-belllied sapsuckers (polygons) within an moderately harvested landscape (MHL). (* = *p*<0.05, **= *p*<0.01).

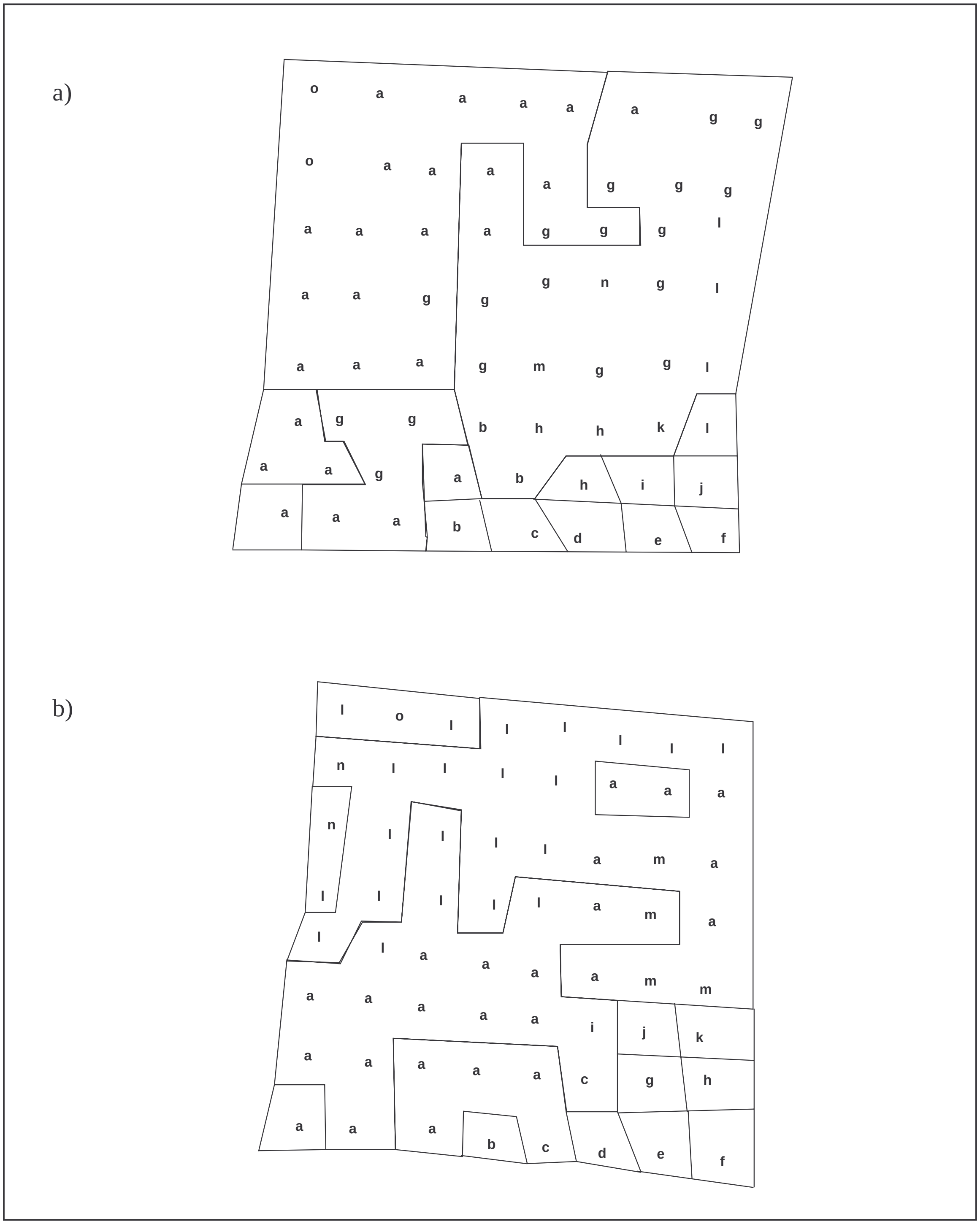

Fig.6. **Bird to bird boundary overlap at the stand-scale**. Clusters of birds resulted from the agglomerative clustering analyses yielding the top 15 bird groups with the highest occurrence turnover rate. a) direct cluster overlap (OS=39**) between the occurrence of least flycatchers (letters) and black-throated blue warbler (polygons) within an intensively harvested stand (IHL-B plot); b) direct cluster overlap (OS=46**) between the occurrence of blackburnian warblers (letters) and least flycatchers (polygons) within an moderately harvested stand (MHL-B plot). (* = p<0.05,

DISCUSSION

Birds have distinctive habitat requirements and many species select specific habitats (Whitcomb *et al*, 1981; Litwin and Smith, 1989; Reed, 1989; Freemark and Collins, 1992; Villard, 1998). Moreover, in evaluating associations between bird communities and disturbed habitats as ecological indicators of forest conditions, Canterbury *et al.* (2000) remarked that disaggregating a whole community into guilds could be a useful proxy for evaluating the collective responses of multiple species with a similar ecological behaviour before habitat changes. Hence, the six species that my study included, which I selected from the original avian community, provided reliable information that could be applied to a larger bird species assemblage.

The grouping of birds into common, intermediate and rare species arises from the weak reliability of classifying species along a scale from forest-interior to edge specialists species (Villard, 1998). In a study done to review the empirical evidence for edge avoidance among species currently considered to be forest-interior specialists, Villa33.7(r)-.2(f)-12-270.5(w)d32 10.0.5(w)32.7(5()V ecology of this species (Holmes and Robinson, 1981; Holmes, 1994; Gauthier and Aubry, 1996). Black-throated blue warblers typically inhabit shrubby sites or forest stands with relatively dense deciduous understory and forage mainly in the lower to mid canopy (Holmes and Robinson, 1981; Holmes, 1994).

American redstarts, on the other hand, have a more flexible association with their habitat. Here, this species responded equally strongly to vertical forest strata in both managed landscapes. Holmes and Robinson (1981) noted that American redstarts and least flycatchers have less tree species preference than other birds such as blackburnian warblers. In these regards, tree species preferences of some birds may be linked to species-specific foraging abilities (Holmes and Robinson, 1981, Robichaud and Villard, 1999). Particularly, American redstarts forage either on the ground or on the upper canopy and occupy a wide variety of open-wooded habitats (Robinson and Holmes, 1984).

Blackburnian warblers and ovenbirds responded similarly to both managed landscapes. Boundaries in ground cover influenced the occurrence of these species. The importance of ground cover boundaries may also be related to these species' foraging behaviour. Blackburnian warblers search for food from near the ground, although they may also feed on the upper canopy of coniferous and/or deciduous forests. Despite findings that blackburnian warblers occupy both high and low canopy (Poole and Gill, 1994), I found that this species exhibited a stronger association with the understory than the upper canopy. Although Holmes and Robinson (1981) reported strong avoidance of sugar maple trees by blackburnian warblers in a northern hardwood forest of New Hampshire, I did not find this pattern at my study sites. The minimum distances (O_H) between the boundaries of blackburnian warbler and sugar maple trees were similar to the distances to beech or conifer trees (Table 4; Appendix 4).

Ovenbirds occur where canopy heights are 16-22 meters, and percent canopy closure ranges from 60-90 percent (VanHorn and Donovan, 1994). In agreement with this, ovenbirds were strongly associated with percent canopy in the intensively harvested landscape. This relationship was stronger in the intensively harvested landscape than in the moderately harvested one (see "Harvest intensity" below). The intermediate frequency of occurrence of most of the six birds in my study, as well as their significant association with the forest understory, can be explained by two additional, interrelated factors. First, these bird species require a solid shrub layer of either deciduous or mixed coniferous/deciduous trees to build their nests (e.g., black throated blue warblers usually nest within 1-1.5 m of the ground; Holmes, 1994). Secondly, bird data collection was carried out during the breeding season, in which these species regularly occupies lower forest strata (Poole and Gill, 1994).

Overall, the strong association of forest cover strata with bird occurrence is consistent with various studies, which have demonstrated that forest cover and forest configuration are good predictors of bird species presence (Villard *et al.*, 1999; McGarigal and McComb, 1995).

Stand scale

Bird to bird boundary associations

inclusion of more parameters in the stand-scale boundary analysis, results at both scales were generally consistent and complementary. Nevertheless, there were unique boundary associations on each plot in both managed forests at the stand scale.

The optimal sca

than the intensively harvested forest. Consequently, birds might have been confined to more limited spaces in the intensively harvested landscape as found by Desrochers and Fortin (2000). Thus, the bird association with forest features could be delineated more precisely by the boundary analysis. Schmiegelow *et al*. (1997) refer to the spatial confinement of species as a “crowding effect”. They found that neotropical migrant birds exhibited a stronger crowding efe

Ecological boundary associations

Within fragmented landscapes, boundaries influence the occurrence of bird species (Kroodsma, 1984; Restrepo and Gómez, 1998; St. Louis, 2000). Forest birds are highly sensitive to the width of forest edges (Hawrot and Niemi, 1996; Desrochers and Fortin, 2000; St. Louis, 2000), to the distance from forest interior, and edge age (Restrepo and Gómez, 1998). Despite the hypothesized declines in avian community richness stemming from an increase in brood parasitism and predation rates at the forest boundaries (Villard *et al* 1993; Kneeshaw *et al*., 2000), both gradual and sharp edges have been linked to higher abundance and diversity of birds (Hawrot and Niemi, 1996). Drapeau *et al*. (2000) noted that boreal forest birds are sensitive to parasitism and predation within 100 meters of fragment edges. In addition, Hawrot and Niemi (1996) argued that breeding birds are sensitive to edge width, amount of suitable habitat, or both. They concluded that bird species diversity was higher at moderately abrupt edges than at sharp or subtle ones.

According to my findings, bird occurrence is influenced not only by boundaries in the vertical structure of the forest, but also by boundaries of various forest components. The space constraint that birds experienced in the intensively harvested plots of my study suggests that forest transition zones and their spatial configuration affect bird presence (see Mazzerolle and Villard, 1999).

SCOPE, LIMITATIONS, AND RECOMMENDATIONS FOR FUTURE RESEARCH

In my research, I explored some analytical tools to determine bird spatial associations with forest boundaries. However, the nature of my data and other limitations of this study limit my conclusions. I now discuss such and consider improvements that could be made in future investigations.

- **Presence-Absence data.** In my study, bird occurrence records were used to investigate associations of birds with habitat features through boundary analysis. Although measures of presence-absence may not necessarily reflect habitat suitability (Hutto, 1998), a first step in evaluating bird habitat involves assessing where species occur to understand their ecology, especially in changing environments. A full understanding of avian community ecology requires additional demographic parameters such as abundance, density, reproductive success and survival, and species diversity. In addition, territory mapping could improve the resolution of distribution patterns (Thompson *et al.*, 1995).

- **Scale of analysis and time frame**. One of the strengths of my study is the use of two scales of analysis. This allowed me to study the response of birds to different forest features. I found that different scales generate different results that provide a baseline for future analyses. Some habitat features may be relevant for birds at one scale but less significant at another (e.g., a tree-fall gap vs. a large clearcut). A multi-scale approach is particularly advantageous in ecological studies of forest birds because many species, like my focal species, have large (see Bélisle *et al.*, 2000; Desrochers and Fortin, 2000; Walters, 1998). Such studies could also help to explain differential sensitivities of birds to land fragmentation.

♦ **Field experimental design**. In any scientific research, controls provide reference points against which experimental variations may be assessed, and on which management decisions can be based. My findings on spatial boundary associations were different for the 45 percent and 70 percent cover retention. However, the differences were small and more analyses are needed to prescribe a specific harvesting system. Although my objectives were to evaluate how these two specific intensities of harvesting affected the occurrence of birds, a broader range of treatments and uncut controls would have been useful. Future investigations should embrace control and "experimental" variables (see McCollin, 1998) and some replication at all spatial scales studied.

♦ **Ranges of variables included at the stand and landscape level.** Another limitation of this analysis was the uneven information at both scales. The landscape-scale analysis allowed me to examine spatial boundaries of forest structural variables only. At the stand scale, I was able to include boundaries of forest components in my analysis. Ideally, investigations should homogenize the variables that are to be assessed for each study unit. However, I would recommend including variables expressed in different ways (e.g., density/ abundance/ occurrence) in all and each study unit to enhance the scope of analysis.

♦ **Temporal scales.** Long-term studies in avian ecology studies are required because of annual fluctuations in the occurrence and abundance of forest birds (Thompson *et al.*, 1995; Schieck *et al.*, 2000). It is also reasonable to consider that factors extrinsic to the silvicultural treer2h k1.1()-242(i)k2b259.7292.3(Tf0yn2b259c[(o)34.6(c)0.0.3((e)-2c(m)29.5(i)-24.br)-274(1 0)-13(t)-.1()-lvi

MANAGEMENT IMPLICATIONS

Generally, the presence of several bird species in both managed landscapes indicates that clearcutting (Drapeau *et al*., 2000). The inherent flexibility of selective forestry makes it more feasible for management objectives to be met.

Studies on conservation ecology have assessed the impact of alternative logging techniques on forest birds (Annand and Thompson, 1997; Darveau *et al*., 1997; Baker and Lacki, 1997; Costello *et al*., 2000; Schieck *et al*., 2000). Annand and Thompson (1997) suggested that a mix of even-aged and uneven-aged silviculture practices creates suitable, heterogeneous habitats for forest birds. Because the ultimate goal in avian conservation is to preserve viable populations of bird species in high quality habitats, I suggest the following management strategies:

- **Conduct monitoring of indicator species.** Monitoring is an assessment process of key environmental factors, such as the six indicator bird species of my study, wu-T43.3(,)-2.7(m)18.is wu-0.7(i)-4. Tf demographic indices (i.e., declines in population size, reproduction, and overall fitness) of indicator species allow assessing the status of forest habitat quality. The use indicator species may also be effective because: i) large number of species can be monitored simultaneously with a single survey method (see Hutto, 1998); ii) being some of them insectivorous, they play a key role in maintaining the balance of the environment's functions (delaying pest outbreaks) and; iii) their ecological response is possibly representative of other species within the same habitat or community (Niemi *et al*., 1998; Canterburry *et al.*, 2000; Kneeshaw *et al*., 2000).

Despite the need to move from a single-species approach to a multi-species one by using a group of indicator species, caution should be taken in the selection and interpretation of the

"To couple good science to management, it is important to develop goals, models, and hypotheses that allow us to systematically learn as we manage. Goals and models guide the development and implementation of management practices. The need to evaluate models and test hypotheses mandates monitoring, which feeds into a continuous cycle of goal and model reformulation" (Haney and Power, 1996)

- **Strive to recreate and maintain the complexity and variability of natural ecosystems in timberlands.** This objective can be reached through alternative silvicultural methods. Bergeron *et al*. (1999) provided a concise framework for selecting the logging technique that best resembles the natural dynamics of the target landscape. Their decision framework is based on the similarities between naturally disturbed forests (e.g. fires, insect outbreaks) and alternative silviculture systems. In mixed-wood forests, as the ones I studied, I recommend to combine various silvicultural treatments and rotate the treatment applied on different stands through time (i.e., "shifting landscape mosaic"; Bergeron and Harvey, 1997; Schieck *et al*.

dominated the forest, conifers also determined the presence of birds. Thus understanding the complexity and natural variability of the forest is essential for ecosystem management.

- **Ensure a sufficient amount of suitable forested habitat in fragmented landscapes**. As forestry practices continue, management strategies should be aware of the amount of suitable habitat within forest fragments. An intrinsic property of naturally shaped landscapes and selectively cut forests is the presence of ecotones or edges of various types (e.g., widths). Ecotones often display higher biodiversity due to the presence of variety of forest components. As shown here, birds respond distinctively to forest boundaries and can benefit from the resources that are available at boundaries. Desrochers and Fortin (2000) showed that chickadees use vegetation boundaries primarily as movement conduits travelling parallel to them. As a second alternative, birds visit edges to forage since food resources (e.g., arthropods) are more abundant near edges (McCollin, 1998; Desrochers and Fortin, 2000).

If selective logging is widely used, smoother boundaries will become more common. However, the suitability of ecotones as habitats likely has a strong dependence on the amount of forest interior area (“core area”). Indeed, forest fragments with narrow boundaries and large core areas (i.e., high perimeter-area ratio) are more likely to support stable bird populations. Thus, the influence of forest edges and ecotones on birds is positive as long as the forest interior area is large enough to compensate for the negative effect of edges (e.g. predation; Yahner, 1981).

- **Evaluate the appropriate scale of management.** To date, avian researchers hr.9(t)4275.1(en)44.4(r)-2(d)]T *al*., 1995). Moreover, migratory birds are subject to landscape changes along their migratory routes and at their overwintering sites (Cooke, 2000 pers comm.). Since ecological and habitat boundaries are not spatially coincident with geopolitical ones, I consider it essential that researchers and managers establish international decision-making networks. Such networks would improve management strategies by joining efforts and creating conservation partnerships.

CONCLUSIONS

I found clear boundary associations between forest features and six bird species in both the moderately harvested and the intensively harvested landscapes. Spatial boundary

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APPENDIX 1

Meaning of acronyms for birds and forest trees

Acronyms	**Scientific name**	**Common name**
<u>Bird species</u>		
AMRE	*Setophaga ruticilla*	American redstart
BLWA	*Dendroica fusca*	Blackburnian warbler
BTBW	*Dendroica caerulescens*	black-throated blue warbler
OVEN	*Seirus aurocapillus*	ovenbird
LEFL	*Epidonax minimus*	least flycatcher
YBSA	*Sphyrapicus varius*	yellow-bellied sapsucker
<u>Deciduous trees</u>		
ACPE	*Acer pensilvanicum*	stripped maple
ACRU	*Acer rubrum*,	red maple
ACSA	*Acer saccharum*	sugar maple
ACSSP	*Acer spicatum*	mountain maple
ALRU	*Alnus rugosa*	gray alder
BEAL	*Betula alleghaniensis*	yellow birch
BEPA	*Betula papyrifera*	paper birch
BEPI	*Betula populifolia*	gray birch
FAGR	*Fagus grandifolia*	American beech
LALA	*Larix laricina*	larch
POBA	*Populus balsamifera*	balsam poplar
POTR	*Populus tremuloides*	quaking aspen
PRPE	*Prunus pensylvanica*	pin cherry
SASP	*Salix sp*	willow species

Conifer trees

ABBA	*Abies balsamea*	balsam fir
PICE	*Picea abies*	Norway spruce
PIGL	*Picea glauca*	white spruce
PIMR	*Picea mariana*	black spruce
PISP	*Picea sp*	spruce species
THOC	*Thuja occidentalis*	northern white-cedar
TSCA	*Tsuga canadensis*	eastern hemlock

APPENDIX 2

Basal area conversion

$$BA = 0.000078539816 * DBH^{2}$$

where:

BA: basal area (m^2)
DBH: diameter at breast height (cm)

Overlap statistics

$$O_s = \text{card}\left(B_G \cap B_H\right)$$

Decomposition classification

Stage 1	Stage 2	Stage 3
Live	Declining	Dead

APPENDIX 3

APPENDIX 4

1_2	94.72**	207.35*	148.98**	105.40**	157.85**	94.88*
GC	71.71*	239.70**	139.87**	90.23**	109.77**	90.57**
%can	83.02*	174.00	97.15*	113.99**	94.60**	75.75
%subcan	37.60	94.74	38.51	91.47*	53.32	45.77
%shrub	101.94**	187.74*	152.25**	106.94**	147.19**	102.59**
%GC	120.71*	314.60*	2216.99**	138.70**	154.05**	142.30**
ACSA	105.29	501.58**	309.22**	118.86*	168.85**	161.67*
FAGR	135.78*	405.45**	298.03**	103.81*	187.29**	141.50*
Dtot	111.88	514.54**	325.10**	118.80	178.63**	147.40*
Ctot	108.01*	427.70*	277.86**	100.72	169.26**	151.02**
Drest	111.88	514.54*	325.10**	118.80*	178.63**	147.40*
Snags	106.40*	351.28*	238.94**	101.05*	172.25**	130.33**
RA						
canopy	525.18**	367.51	305.56	259.30	287.98	515.53*
subcan	503.30**	354.82	323.50	258.79	337.07*	503.02*
shrub	541.43**	381.74*	303.45	228.55	253.44	483.57*
GC	454.86*	377.68*	318.23	228.98	313.52*	499.70*
%can	443.54*	345.90	303.00	255.46	279.61	522.18*
%subcan	534.13**	418.81*	304.93	226.84	285.66	499.03
%shrub	408.91*	318.45	372.36	289.43	325.42*	630.61**
%GC	481.47**	290.45	332.35	274.13	296.81	535.93*
RB						
canopy	218.02	112.66**	176.48	58.18	214.18	131.10
subcan	267.35	127.71**	179.84	71.74	269.61	156.46*
2_4	257.04*	133.98**	135.72	50.53	220.82	120.58
4_6	132.76	119.32**	101.84	78.90	233.46**	156.30**
6_	229.84*	138.87**	138.75	78.94*	217.66	146.08**
shrub	325.01*	124.09	171.96	63.71	246.91	115.11
0.5_1	254.35*	90.84**	168.58	64.38	205.85	112.64
1_2	261.43*	131.92**	183.11	59.63	219.86	150.60*
GC	279.27*	125.32**	182.83	81.75	299.80	125.48
%can	276.66*	127.05**	151.20	73.28	238.44	141.76
%subcan	235.91	118.49**	160.53	72.75	238.86*	141.71*
%shrub	287.76**	124.35**	164.11	73.72	244.66	161.52**
%GC	220.14	144.38**	174.45	82.36*	237.46	167.49**
ACSA	259.11	131.06**	199.74	77.71	266.22	162.15*
FAGR	381.57**	117.98**	154.21	71.60	268.75	112.15
Dtot	269.99**	139.05**	175.68	62.71	235.09*	154.62*
Ctot	183.84	89.73*	140.02	83.00	260.31	122.16
Drest	301.78**	138.7**	183.63	85.58	288.83	169.90**
Snags	215.88	124.92**	174.62	77.06	248.74	151.71*
RC						
canopy	104.58*	84.03	140.5**	78.17	149.63**	129.17
subcan	110.98*	99.43	166.75**	78.49	171.77**	144.31
2_4	106.36*	80.27	115.83*	73.52	117.18**	110.15
4_6	120.96**	70.56	127.29**	78.46	123.84**	112.86
6_	101.36	97.47	197.50**	59.50	205.19**	128.61

shrub	108.91*	87.17	160.12**	77.36	162.90**	122.63
0.5_1	97.62	74.28	129.93*	65.44	139.99**	129.35
1_2	122.19*	98.23	159.83**	75.39	188.79**	137.98
GC	172.35*	125.78	230.60**	73.81	241.97**	159.38
%can	108.02*	82.57	137.61**	65.19	168.40**	124.29
%subcan	126.97*	109.01	173.44**	78.80	186.00**	145.22
%shrub	135.59*	98.58	179.73**	76.91	190.35**	143.39
%GC	141.31*	112.44	182.87**	68.52	200.35**	140.13
ACSA	130.88**	113.22	177.89**	70.83	184.58**	138.51
FAGR	139.06**	119.26	229.51**	63.63	232.57**	164.86