Spatial distribution of the Chestnut-sided Warbler (*Setophaga pennsylvanica*) across a forested landscape

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Abstract

The Chestnut-sided Warbler (*Setophaga pennsylvanica*) is considered a species of the forest edge and shrubby meadows. An integral question remains how this species chooses a territory and how the structure of the landscape affects that choice. Fine scale habitat patches using aerial photography were collected for nine 1600m x 1600m survey plots across northern Minnesota using point counts along transects during the breeding season of 1994 and 1995. Edges between habitat patches were quantified by the degree of contrast within these large plots. A chi-square analysis was used to determine what patches and edges Chestnut-sided Warblers selected in comparison with a random distribution. I found significant ($P < 0.05$) selection for regeneration-aged forest patches on five of the nine survey plots. Chestnut-sided Warblers did not select for edges when all edges were considered; however, four plots had significant selection for abrupt edges. Chestnut-sided Warblers were strongly associated with shrubby, regenerating forest patches, but showed variable selection for edges in these forested landscapes. Current management practices are likely sufficient to provide adequate habitat for the Chestnut-sided Warbler and disturbance by clear-cutting or forest fire would be beneficial to this species.

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INTRODUCTION

Habitat destruction, degradation, and fragmentation as a result of human activities remain the largest threats to bird life worldwide (IUCN 2013). The Chestnut-sided Warbler (*Setophaga pennsylvanica*) is considered to be a species associated with forest edges and shrubby open areas (Richardson and Brauning 1995, Pfannmuller 2012). As Neotropical migrants, this species encounters many perils along its annual journeys, especially the availability of nesting habitat in northern breeding grounds. Habitat fragmentation creates more edges within a landscape; thus the more fragmented a landscape becomes the more susceptible species may be to edge-associated effects such as predation, nest predation, and brood parasitism (Brittingham and Temple 1983, Gates and Gysel 1978, Flaspohler et al 2001).

Historically, the Chestnut-sided Warbler was thought to be rare in North America; Audubon reported seeing only one in his entire career (Cassidy et al 1990). Upon the advent of western expansion and the clearing of old growth forest, the Chestnut-sided Warbler greatly expanded its range. The large areas of newly open space and forest edge provided key habitat for the Chestnut-sided Warbler. Roberts (1932) also suggests this species followed changes in habitat structure following both pre-colonial fire regimes (see Heinselman 1981), and post-colonial forest clearing. This innate affinity of the Chestnut-sided Warbler to respond to changing landscape patterns makes it an ideal candidate to study its responses to habitat patches and edges between patches. Today, the bird is relatively common across the eastern United States. Data from a long-term monitoring project suggests that most warbler species' populations are stable across the western Great Lakes region (Niemi et al 2014); however, the Breeding Bird Survey shows a slight decline in Chestnut-Sided Warbler populations, both over the Eastern region and survey-wide (Sauer et al 2011).

In Minnesota, increasing urban and ex-urban development, forest management, and many other activities have created a patchwork of habitat fragments. To what extent habitat fragmentation and edge effects influence the Chestnut-sided Warbler is unclear. Additionally, the effect of habitat edges on species in relatively undisturbed habitats remains poorly understood. Research on edge effects has primarily been completed in areas with intensive agricultural presence (Robinson 1992, Linder and Bolinger 1995, Villard et al 1999). King et al (1996), however, examined the effects of edges on Ovenbird (*Seiurus aurocapilla*) nesting success in a forested landscape. Species that are considered interior specialists or edge specialists in a relatively urbanized or agricultural landscape could potentially display a different trend in the relatively intact forests of northern Minnesota. The Chestnut-sided Warbler, which is considered an edge specialist (Richardson and Brauning 1995), would be expected to be more abundant closer to areas with greater fragmentation and respond positively to the presence of edges. Additionally, the forests of northern Minnesota are home to 6% of the global population of Chestnut-sided Warblers, nearly a quarter of the entire population in the United States (Pfannmuller 2012), making the need to understand the relationship of this species to the landscape especially important in Minnesota. If species distribute themselves across a landscape based on proximity to edges, and those patterns differ between undisturbed and disturbed landscapes, forest management practices will need to take these differences into consideration.

My objective was to determine what features in a landscape are important to the distribution of the Chestnut-sided Warbler, specifically habitat patch type and the edges between those habitat patches. Additionally, if the Chestnut-sided Warbler is responding to edges between patches, what types of edges are associated with those decisions?

METHODS

Study area. Nine 1600m x 1600m survey plots were located in northern Minnesota across the Arrowhead region (Fig. 1) (see Appendix 1 for GPS locations of survey points). Each plot was originally established by meter tape and compass because they preceded the availability of geopositioning systems (GPS). Once GPS became available, each point count location was identified by GPS. Transect surveys were conducted over this area.

Bird counts. Data were collected using five-minute point counts at 100 m intervals between late May and early July during 1994 and 1995 (Howe et al. 1998, Etterson et al. 2009). Consecutive point counts overlapped at 50m and at 100 m laterally which allowed for complete coverage of the survey plot (Fig. 2). Data were collected by trained observers, who were required to pass a song identification exam of 75 species of regional birds with greater than 85% accuracy. Individual birds' locations were estimated as accurately as possible on data sheets (Fig. 3). Special attention was made to avoid double-counting of individual singing birds both on consecutive counts and when completing adjacent transects.

Patch quantification. Habitat patch information for each site was created by a trained interpreter using aerial photographs. Habitat patch information collected on each

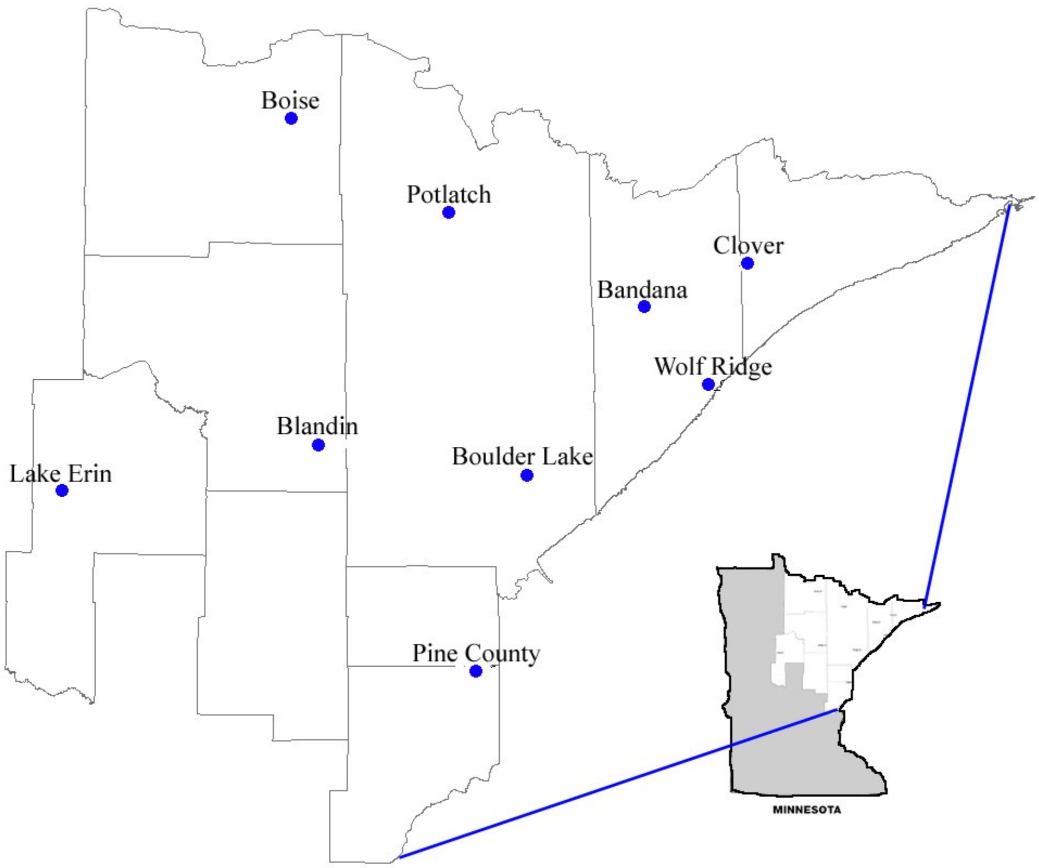

Figure 1. Survey plot locations across northeastern Minnesota that were sampled in 1994 and 1995.

plot included predominant tree species; upland or lowland distribution of the habitat; percent conifer cover; and age class of the patch from forest records. Data were digitized using ArcGIS 9 software (ESRI 2011). A total of fifteen habitat patch types were identified among the nine study plots (Table 1, Appendix B).

Edge contrasts. The high degree of detail in patch size definition allowed a refinement of the subtle, intermediate, and abrupt edge categories defined by Hawrot and Niemi (1996). The degree of edge contrast was calculated by comparing degrees of similarity between habitat patches (Fig. 4). I calculated edge contrast by adding one for

Table 1. Habitat patch information collected to determine similarity between adjacent patches. The habitat code was calculated based on tree species, upland/lowland distribution, and primarily deciduous/coniferous tree species (See Appendix A). This number could be between 0 and 3. Age class was calculated based on DBH, then converted to standard forestry terminology of regenerating (DBH < 5cm), poletimber (15cm >DBH > 5cm), and saw-timber (DBH > 15cm). Percent conifer cover was collected as 0-25%, 26-50%, 51-75%, and 76-100%, but mixed forests were defined as 26-75%. .

	Habitat Code	
Tree Species	U/L	Dec/Con
Aspen	Upland	Deciduous
Birch	Upland	Deciduous
Black Spruce, Tamarack	Lowland	Coniferous
Built Up	n/a	n/a
Cutover	n/a	n/a
Jack Pine	Upland	Coniferous
Lowland Hardwoods	Lowland	Deciduous
Non-forested Upland	Upland	n/a
Non-forested Wetland	Lowland	n/a
Northern Hardwoods	Upland	Deciduous
Oak	Upland	Deciduous
Red Pine	Upland	Coniferous
Spruce Fir	Upland	Coniferous
Water	n/a	n/a
White Pine	Upland	Coniferous

Age Class (DBH)	
Size Class	Code
Regen-Regen	0
Regen-Pole	1
Regen-Saw	2
Pole-Pole	0
Pole-Saw	1
Saw-Saw	0

Percent Conifer	
Pcon/Pcon	Code
0 - 0	0
0 -25/50	1
0 - 75	2
25/50 - 25/50	0
25/50 - 75	1
75 - 75	0

each time a difference in tree species, upland or lowland, age class, or percent conifer to deciduous tree cover was found between adjacent patches. A higher number indicates a greater degree of contrast between adjoining habitats and these contrasts range from one to seven. For example, a coniferous woodland patch of white pine (*Pinus strobus*) with >75% conifer cover in an upland area of saw-timber that borders a lowland non-forested wetland with 0-25% conifer cover, such as an alder swamp, would have a high degree of contrast. This example edge would end up being coded as seven, the highest number possible. The most common areas where there was an edge between upland and lowland

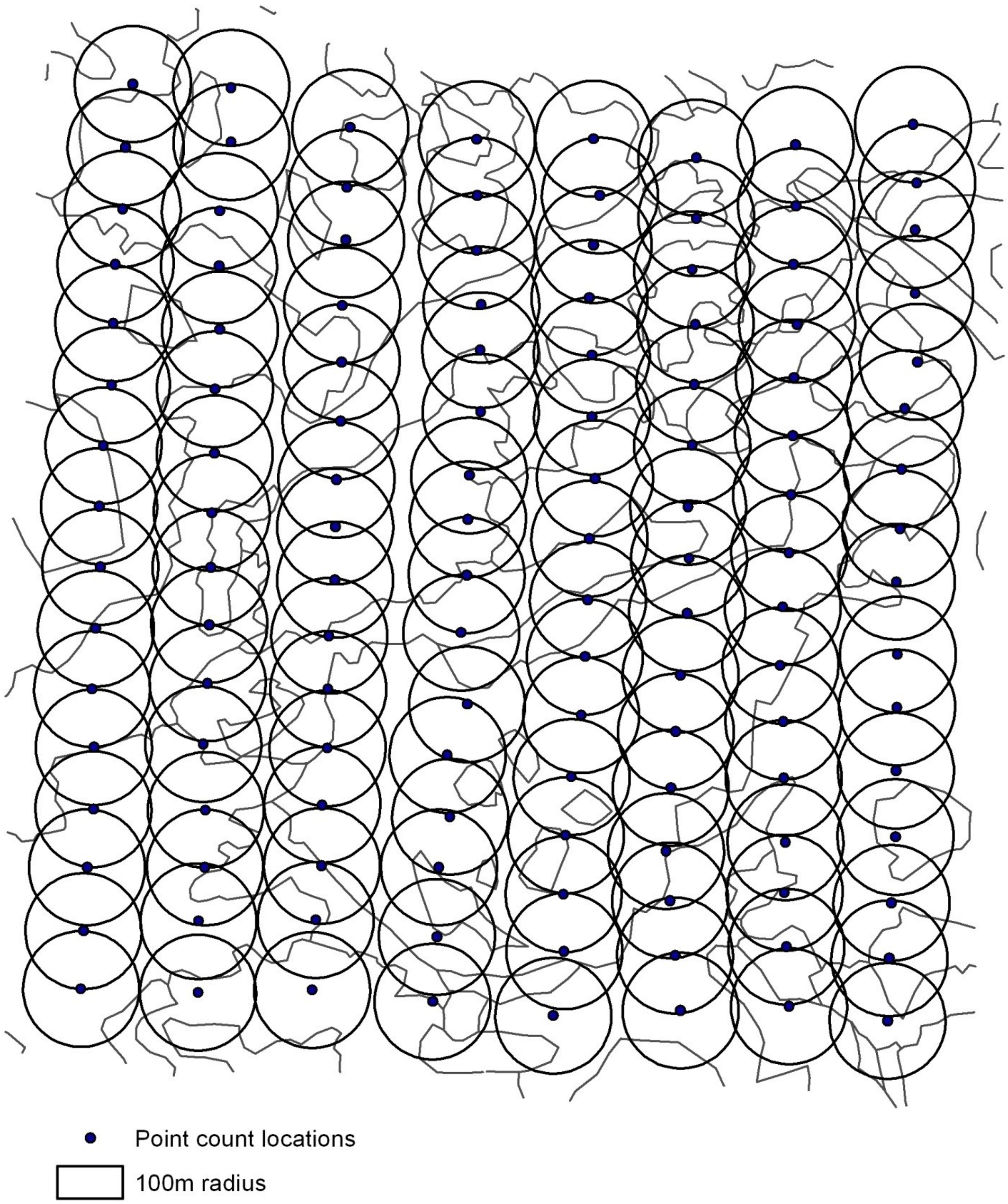

Figure 2. Point count locations on the Wolf Ridge survey plot. 100m radius circles are illustrated around each point.

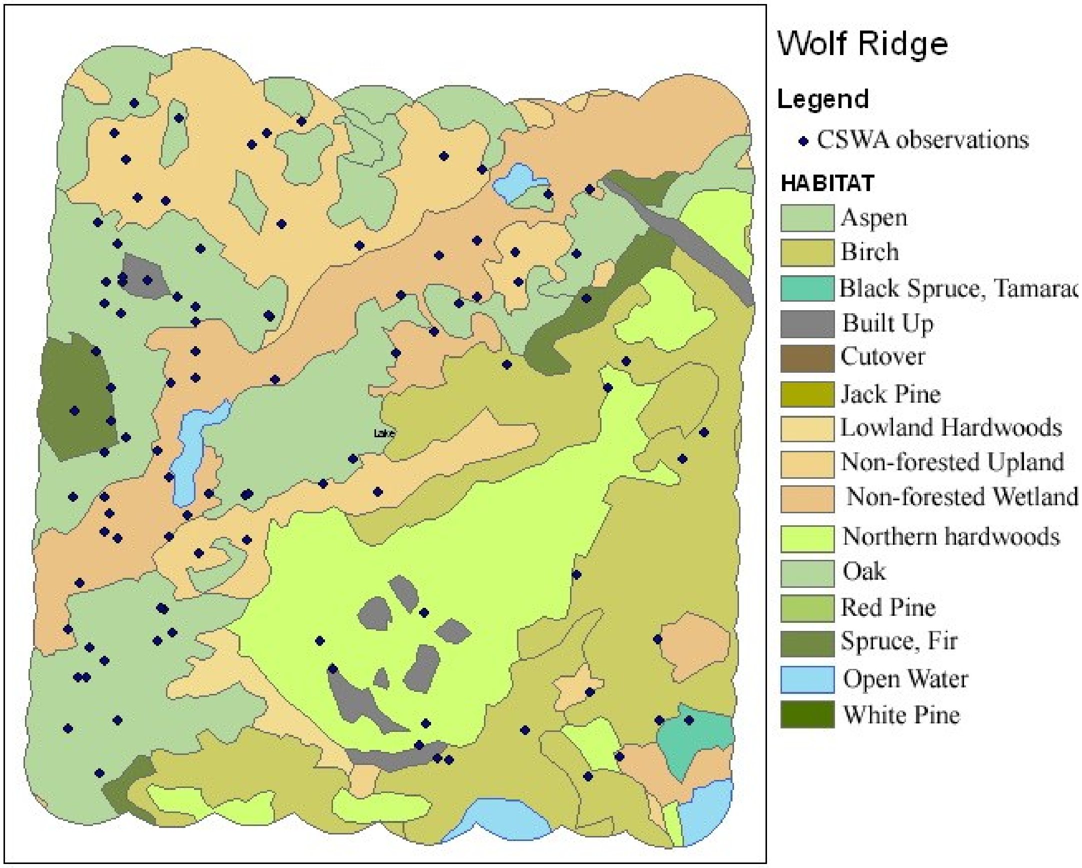

Figure 3. Habitat map and CSWA observations from 1994 and 1995. Each point represents an individual singing CSWA recorded during both sampling years. The example plot is Wolf Ridge.

patches were patches of primarily forested areas next to patches of wetland or shrubby swampland. An upland quaking aspen (*Populus tremuloides*) habitat with 0-25% conifer, that is in primary succession (DBH <5cm, regenerating) next to an upland mature aspen stand (15cm>DBH >5cm, poletimber) with 0-25% conifer would have a much lower degree of contrast and would be considered a subtle edge type. This edge would be coded as one in the database. All natural forest habitat types next to human development, and those next to open water, were put into category seven, indicating the highest degree of contrast.

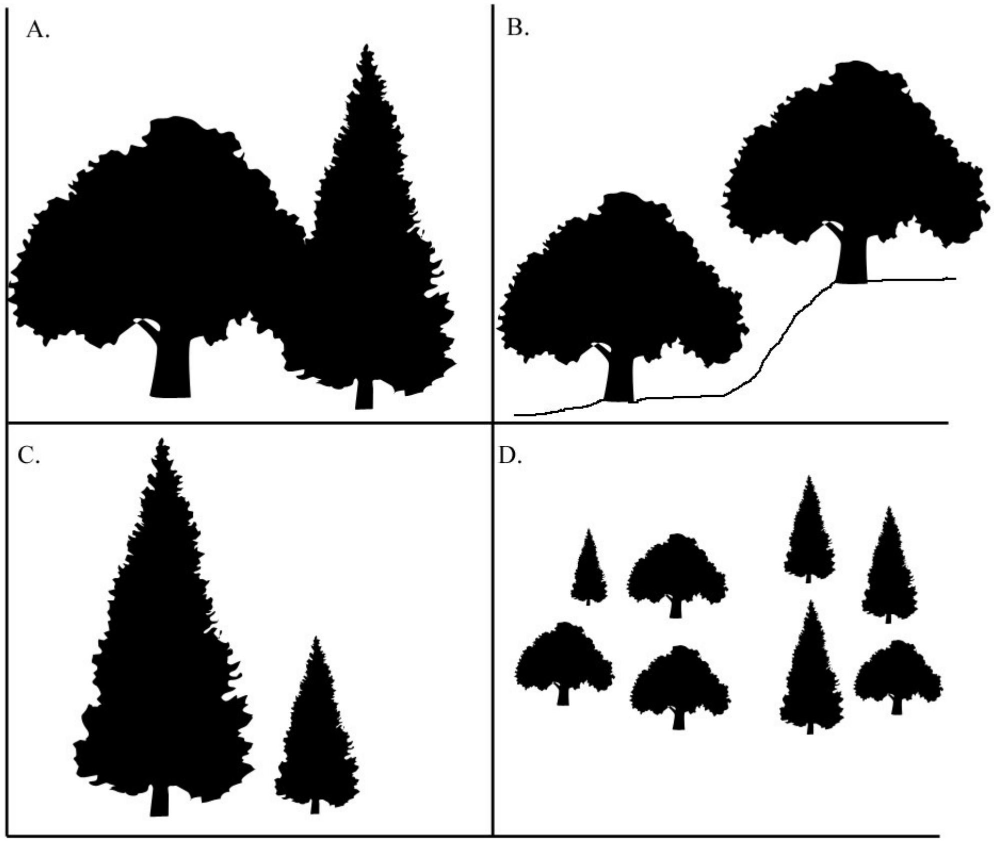

Figure 4. Habitat differences used in calculating edge codes based on similarity. The primary categories used are primary tree cover species (A.); deciduous versus coniferous (A.); upland versus lowland distribution (B.); DBH of the primary tree cover (C.); and percent conifer of the habitat patch (D.).

Habitat selection by Chestnut-sided Warblers. I first tested whether the distribution of the Chestnut-sided Warbler observations differed from a random distribution among the habitat patches on each plot using a chi-square test in Microsoft Excel (2007). The observations from both years were analyzed separately. Expected numbers of birds per habitat type were calculated by multiplying the total number of observations by the percent of the landscape each habitat type covered. This allowed comparison of available habitat versus occupied habitat by determining if there exists a significant difference in habitat selection. For this analysis, the habitats were simplified into seven categories (Table 2).

Edge contrast selection by Chestnut-sided Warbler. I used a chi-square test to determine whether edges were associated with the distribution of the Chestnut-sided Warbler. Both survey years were combined in this analysis. A distance to the nearest edge was calculated for each individual Chestnut-sided Warbler identified using ArcGIS 9. I assumed that the edge nearest to each bird had the most impact on the location of that bird in the landscape. These distances were simplified into four categories, 0-25m, 26-50m, 51-100m, and >100m (Fig. 5). This reduced the bias associated with the estimated location of individual birds in the landscape during data collection. Moreover, birds are highly mobile and observations were of territorial males that occupy territories ranging from 0.4 to 1.1ha (Collins 1982, Kendeigh 1945). This small territory size would be well within a 100m radius of an edge. If the territories are within 100m of an edge it is likely they are selecting to be closer to an edge. Edges of higher degrees of contrast would likely be contributing more to the placement of birds on a landscape. To test this assumption, a final chi-square analysis was used on a reduced edge category. This analysis lumped edge codes into two simple categories; soft edges and abrupt edges. Edges of code 5, 6 and 7 were assumed to be abrupt edges and were grouped together; all lower code edges (1-4) were assumed to be subtle edges and were removed from the analysis (Fig. 6). The Boise and Blandin plots did not contain edges of code 4 or higher, and thus were excluded from this analysis.

Table 2. Simplified habitat categories for selection analysis.

Simplified Habitat	Original Habitat
Regenerating	All forested patches of regenerating age class, except Black Spruce, Tamarack
Deciduous	Aspen; Birch
Coniferous	Red Pine; White Pine; Spruce, Fir
Lowland Deciduous	Lowland Hardwoods
Lowland Coniferous	Black Spruce, Tamarack, Cedar
Northern Hardwoods	Oak, Maple
Other	All remaining habitats*

*Open water and built up areas were excluded from this analysis.

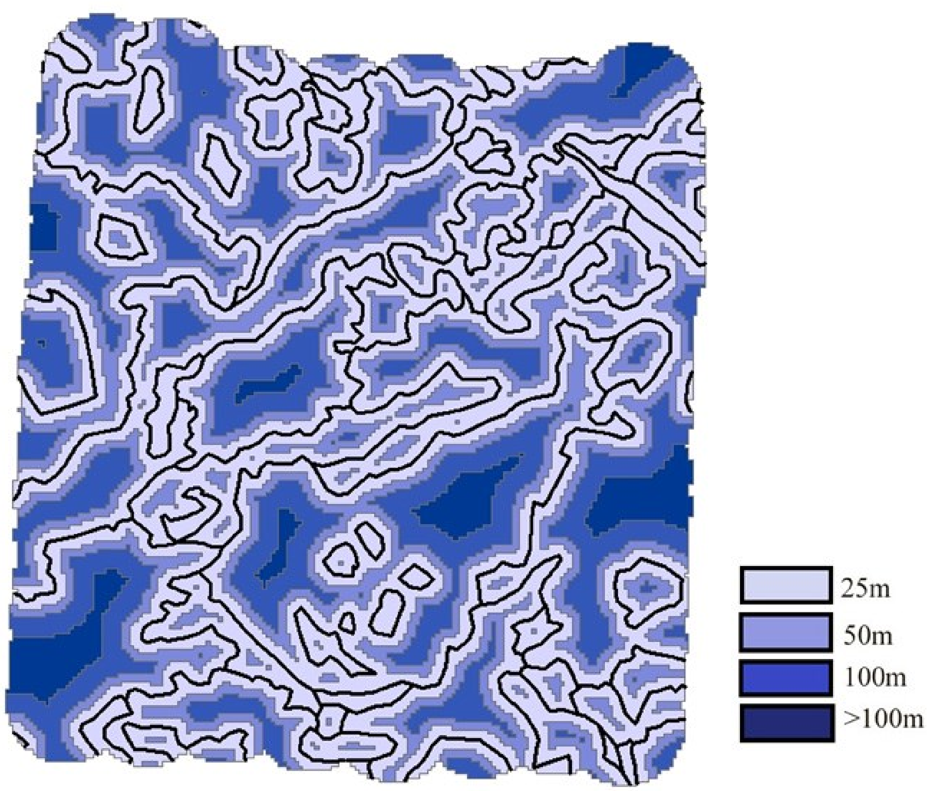

Figure 5. Landscape broken into areas based on distance to an edge. This example is the Wolf Ridge plot.

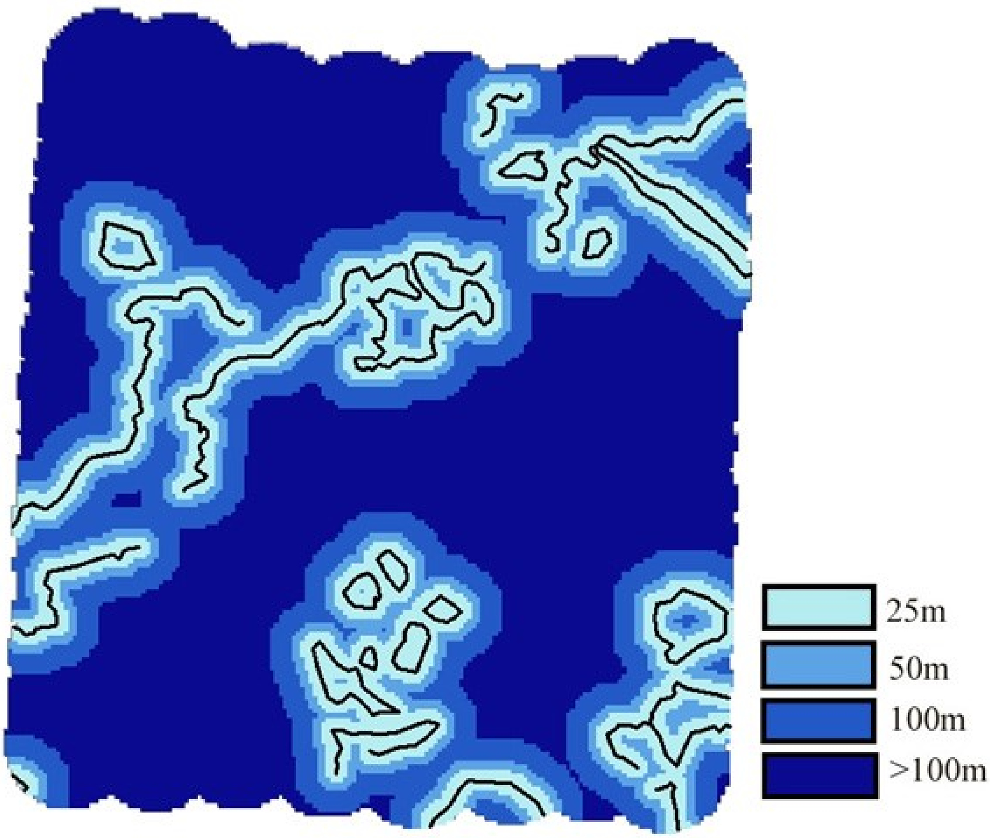

Figure 6. Reduced edge categories. All edges of code 4 or less have been removed from the landscape. This is the Wolf Ridge survey plot.

RESULTS

Habitat patch summary. There was considerable variation in the number of habitat types among the nine plots sampled (Table 3). The diversity of habitats ranged from the relatively homogenous Blandin and Boise plots with three and four habitat types to the more heterogeneous Boulder and Bandana plots with nine and eight habitat types respectively. The Boise and Blandin plots were also relatively homogenous with respect to age class; the majority of these plots included pole- and saw-timber age classes (DBH>5cm).

Table 3. Habitat patch types in each survey plot that contain Chestnut-sided Warbler observations.

	Bandana	Blandin	Boise	Boulder	Clover	Erin	Pine County	Potlatch	Wolf Ridge
Aspen	X	X	X	X	X	X	X	X	X
Birch		X		X	X	X			X
Black Spruce-Tamarack				X	X		X	X	
Built-up Areas			X						X
Jack Pine	X								
Lowland Hardwoods	X		X	X		X			
Non-forested Upland	X		X	X	X	X			X
Non-forested Wetland	X		X	X	X		X	X	X
Northern Hardwoods		X				X	X		X
Red Pine	X			X				X	
Spruce-Fir	X			X	X	X	X		
White Pine	X			X					

Density and distribution of Chestnut-sided Warbler. A total of 927 individual Chestnut-sided Warblers were counted over both years of the survey (Table 4). Chestnut-sided Warblers were recorded in thirteen out of the fifteen available habitat types (Table 4). The species was never recorded in either oak or recently cut-over habitat patches.

Habitat selection. Chestnut-sided Warbler distributions among different habitat patches were significantly different from a random distribution on five of the nine survey plots (Table 5). Selection was for areas of either regeneration-age forest patches or open, non-forested, shrubby uplands and wetlands included in the Other category (Table 2, Fig 7). Selection of regeneration-age forest patches was consistent across all plots that showed significant selection. Additional selection of the non-forested Other category was found on the Bandana plot in 1995. Blandin, Boise, Potlatch, and Wolf Ridge did not have significant selection based on habitat (e.g., see Fig. 8). Chestnut-sided Warblers were not observed in the older forested habitat types such as large areas of contiguous coniferous and deciduous forest, or the Northern Hardwoods patches. Additionally, Chestnut-sided Warblers were not found in areas of lowland coniferous habitats.

Table 4. Number of Chestnut-sided Warbler observations by habitat type per plot per year.

	Bandana	Blandin	Boise	Boulder	Clover	Erin	Pine County	Potlatch	Wolf Ridge	Total
1994	**67**	**20**	**71**	**60**	**42**	**64**	**54**	**58**	**34**	**470**
Aspen	40	6	54	7	16	28	4	16	4	175
Birch		1		1	12	2				16
Black Spruce-Tamarack				19	3		2	3		27
Built-up Areas			1				5		5	11
Cut-over										0
Jack Pine	2									2
Lowland Hardwoods			1	4		1				6
Non-forested Upland	6		11	5	5	5			12	44
Non-forested Wetland	9		4	13		26	24	25	11	112
Northern Hardwoods		10				2	18		1	31
Oak										0
Red Pine	5			1				14		20
Spruce-Fir	3			8	3		1			15
Water		3			3				1	7
White Pine	2			2						4
1995	**81**	**20**	**36**	**49**	**21**	**69**	**51**	**64**	**66**	**457**
Aspen	38	8	27	6	7	33	5	22	8	154
Birch					10				5	15
Black Spruce-Tamarack				14			3	7		24
Built-up Areas			2				2		10	14
Cut-over										0
Jack Pine	1									1
Lowland Hardwoods	1			4						5
Non-forested Upland	10		3	3	2	12			22	52
Non-forested Wetland	6		4	11	1	18	25	23	17	105
Northern Hardwoods		5			1	6	16		4	32
Oak										0
Red Pine	17							12		29
Spruce-Fir	1			8						9
Water	1	7								8
White Pine	6			3						9
Grand Total	**148**	**40**	**107**	**109**	**63**	**133**	**105**	**122**	**100**	**927**

Table 5. Chi-square analysis of habitat selection of the Chestnut-sided Warbler in northern Minnesota.

Year	Plot	X^2	Selecting	Avoiding
1994				
	Bandana	14.4*	Regenerating	Deciduous, Coniferous
	Blandin	1.9		
	Boise	7.3		
	Boulder	26.8*	Regenerating	Coniferous, Lowland Coniferous
	Clover	30.7*	Regenerating	
	Lake Erin	27.4*	Regenerating	Deciduous, Northern Hardwoods
	Pine County	25.9*	Regenerating	Lowland Coniferous
	Potlatch	9.3		
	Wolf Ridge	5.3		
1995				
	Bandana	29.2*	Regenerating, Other	Deciduous, Coniferous
	Blandin	5.6		
	Boise	1.9		
	Boulder	19.8*	Regenerating	Lowland Coniferous
	Clover	38.1*	Regenerating	
	Lake Erin	42.6*	Regenerating	Deciduous, Northern Hardwoods, Other
	Pine County	23.8*	Regenerating	Lowland Coniferous, Northern Hardwoods
	Potlatch	6.0		
	Wolf Ridge	8.2		

*Significant for $p<0.05$

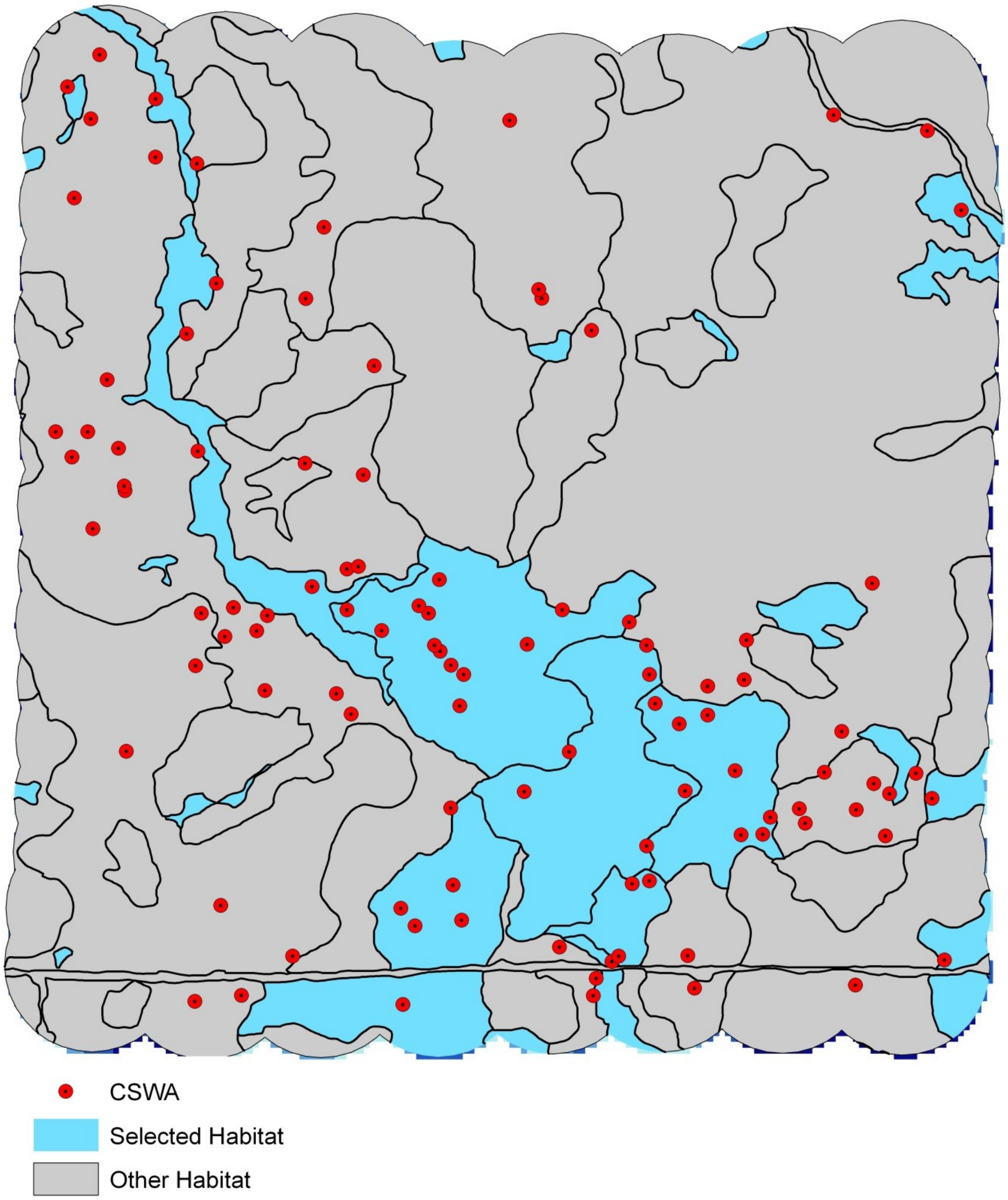

Figure 5. This plot illustrates the significant selection of the Chestnut-sided Warbler for regenerating forest stands on the Pine County study area. Both 1994 and 1995 observations are included.

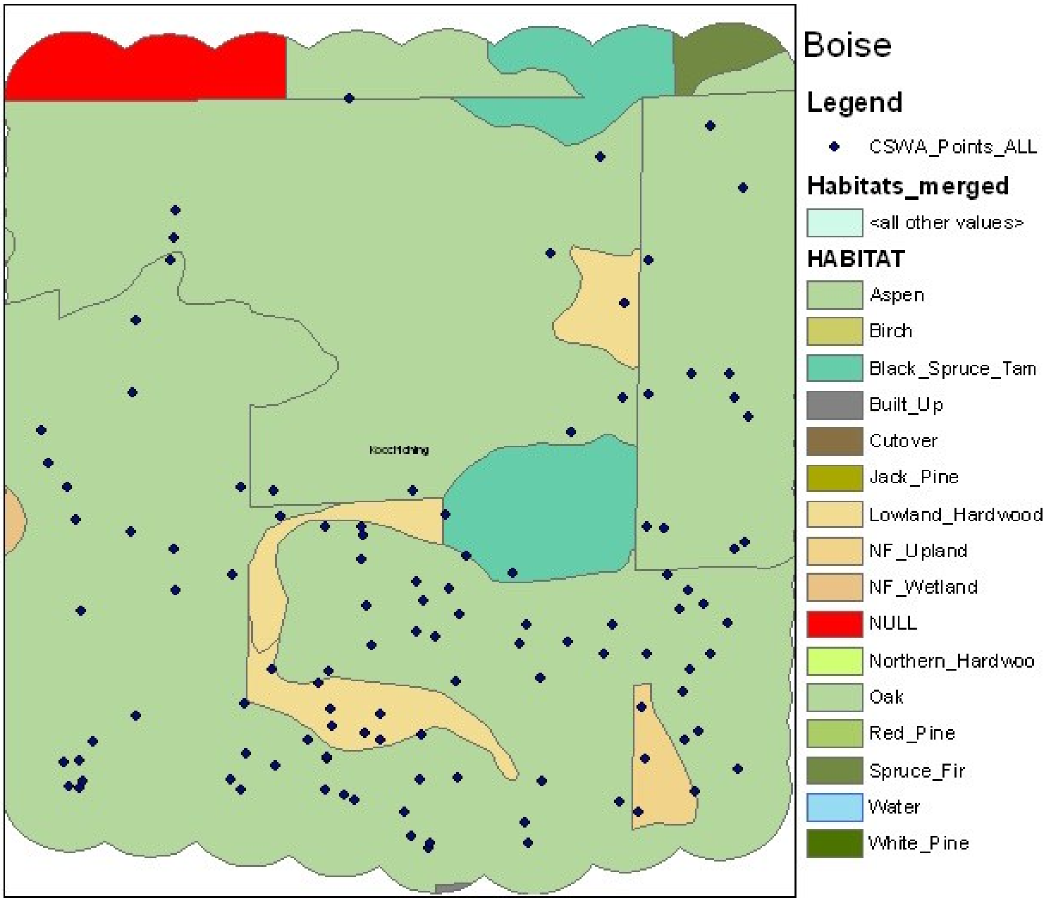

Figure 6. The Boise area did not have significant selection of habitat type by Chestnut-sided Warblers. Null indicates areas for which there was no habitat information recorded.

Edge selection. Distribution of Chestnut-sided Warblers with respect to the distance to any edge was not significant for any plot during either year of the study (Table 6).

When all soft edge codes were removed (e.g., categories 1-4), four of the remaining seven plots (Table 6) showed significant selection based on distance to edge. Bandana, Clover, and Lake Erin had significant selection only during the 1994 season. On the Bandana plot, more birds were observed within 25m of an abrupt edge and fewer were observed between 50-100m of an abrupt edge. The Clover plot had fewer birds

Table 6. Chi-square values for edge selection based on distance to nearest edge. Expected versus observed numbers of birds within each distance category are provided.

All Edges

	1994						1995					
	X^2		0-25m	25-50m	50-100m	>100m	X^2		0-25m	25-50m	50-100m	>100m
Bandana	3.98	Obs	43	18	5	1	6.11	Obs	51	23	7	0
		Exp	40	15	10	2		Exp	49	18	13	2
Blandin	4.49	Obs	6	4	5	5	0.51	Obs	3	2	5	10
		Exp	4	2	4	9		Exp	4	2	4	9
Boise	2.65	Obs	14	8	15	34	7.42	Obs	8	3	12	13
		Exp	10	7	14	40		Exp	5	3	7	20
Boulder	1.45	Obs	33	13	9	5	0.91	Obs	26	11	10	2
		Exp	30	13	13	5		Exp	24	11	10	4
Clover	0.66	Obs	29	9	4	0	0.89	Obs	13	6	2	0
		Exp	28	9	5	0		Exp	14	4	2	0
Lake Erin	1.46	Obs	40	17	6	1	7.30	Obs	35	24	10	0
		Exp	40	14	9	1		Exp	43	15	10	1
Pine County	4.37	Obs	33	12	6	3	1.72	Obs	23	13	11	4
		Exp	27	12	12	2		Exp	26	11	11	2
Potlatch	2.99	Obs	19	15	12	12	3.22	Obs	17	12	25	10
		Exp	19	11	17	11		Exp	21	12	19	12
Wolf Ridge	5.16	Obs	14	10	10	0	2.93	Obs	39	17	9	1
		Exp	18	8	7	1		Exp	36	15	13	3

Abrupt Edges, codes 5, 6, and 7

	1994						1995					
	X^2		0-25m	25-50m	50-100m	>100m	X^2		0-25m	25-50m	50-100m	>100m
Bandana	8.03*	Obs	16	5	5	41	3.07	Obs	15	7	10	49
		Exp	11	7	13	36		Exp	14	8	16	44
Boulder	5.50	Obs	19	7	13	21	0.02	Obs	10	6	11	22
		Exp	12	7	13	27		Exp	10	6	11	22
Clover	8.16*	Obs	3	9	14	16	1.10	Obs	4	1	6	10
		Exp	8	5	10	19		Exp	4	2	5	9
Lake Erin	10.60*	Obs	7	13	16	28	6.59	Obs	9	12	23	25
		Exp	17	10	17	19		Exp	18	11	19	21
Pine County	3.40	Obs	16	9	14	15	5.26	Obs	16	8	15	12
		Exp	12	7	14	21		Exp	11	7	14	19
Potlatch	0.66	Obs	7	4	10	45	3.13	Obs	8	5	7	50
		Exp	7	5	12	42		Exp	8	5	13	45
Wolf Ridge	4.79	Obs	5	7	9	13	13.70*	Obs	23	6	16	21
		Exp	6	4	7	17		Exp	13	7	13	33

*Significant for $p<0.05$

within 25m of an edge and more within 25-50m. Lake Erin had more birds observed outside of 100m and fewer within 25m. Wolf Ridge had significant selection only during the 1995 season, with more observations within 25m and fewer outside of 100m (Fig 9).

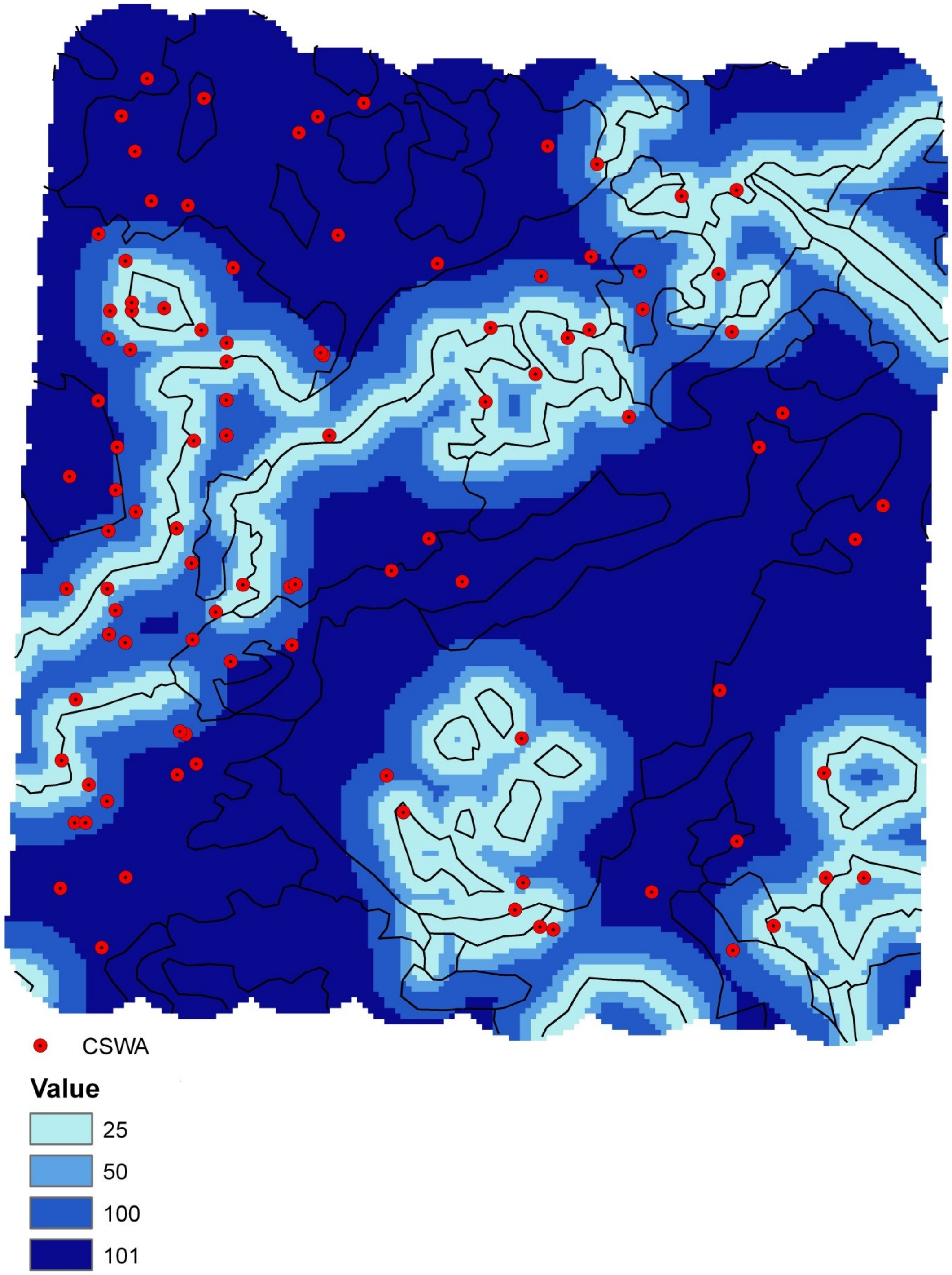

Figure 9. Significant selection (P < 0.05) of the Chestnut-sided Warbler in 1994 and 1995 based on distance-to-edge on the Wolf Ridge survey plot with only edges of codes 5, 6 and 7 included.

DISCUSSION

Habitat selection. The Chestnut-sided Warbler has been considered a bird of forest edges and shrubby open areas (Roberts 1932, Richardson and Brauning 1995), although it seems to avoid areas of intense agriculture (Robbins 1990, James 1991). Habitat selection by the Chestnut-sided Warbler was consistent across nearly every survey plot. The species chose regeneration-aged habitat patches and non-forested patches to the exclusion of the more mature forested areas (e.g., DBH>5cm) in the deciduous, coniferous, and northern hardwoods categories. The affinity for regenerating forests, open habitats, and shrubs found in this analysis supports the affinity for a habitat along a vegetation gradient between open shrubby areas and early successional forests illustrated by Collins (1982). These regenerating and shrubby open areas inherently create edges by contrast with adjacent forested patches. This confluence of dense shrub, utilized for nesting (Collins 1981), and taller trees along edges used for territorial display may explain why Chestnut-sided Warblers select these patches (Richardson and Brauning 1995). Older aged forest patches lack the shrubby understory utilized by this species for nesting. In Ontario, the Chestnut-sided Warbler showed an affinity for deciduous trees and shrubs and avoided nesting in coniferous trees (Peck and James 1987). The avoidance of coniferous habitat is supported by these results; the species significantly avoided coniferous and lowland coniferous habitats among three of the nine survey plots per year of sampling. The plots without conifer-avoidance had few, small patches of coniferous forest; primarily being covered by deciduous and non-forested habitat. The lack of larger coniferous patches likely explains the lack of a pattern in these two study plots.

Edge selection. Traditional analyses of edge effects in forested areas (e.g., Flaspohler et al 2001) have considered only abrupt edges such as clear-cuts or the borders between forests and agricultural regions; or put edges into broader categories such as subtle, intermediate, and abrupt (e.g, Hawrot and Niemi 1996). In forested landscapes, Hanski et al (1996) found no edge effect on nesting success. Average territory size of Chestnut-sided Warblers was reported as between 0.4ha and 1.1ha and, therefore, a 100m radius circle could theoretically contain between 3 and 8 territories (Richardson and Brauning 1995). With potentially small territories and edge effects extending up to 100m (Broadbent et al 2008 and citations therein) into a forest, Chestnut-sided Warblers may view most of the landscape within most of these stands as an edge. For instance, there was little core area in any of the plots that was more than 100 m away from an edge. However, the survey plots with the least amount of area more than 100m away from any edge were the plots that had significant selection based on abrupt edges.

The fine-scale differences in habitat structure quantified by this analysis appear to be less important to this species than large grain habitat structure. Indeed, it was only when subtle categories were removed that many plots showed significant selection based on distance to the nearest edge. When all edge codes were considered, the Chestnut-sided Warbler was randomly distributed across all nine survey plots.

A much simplified landscape resulted from the removal of all edges of what I identified as code four and lower. When this simplified landscape was considered, there was a pattern for the species to be closer to edges. It is interesting to note that when there was significant selection, all but one plot showed an affinity of this species for edges. The

Lake Erin plot, however, showed the opposite pattern. Chestnut-sided Warbler distribution on that plot tended to be away from edges. Again, this may have been due to greater homogeneity within this forest plot, having a greater proportion of aspen than the other plots. Where there are large areas of suitable habitat with minimal subtle edges between patches, the Chestnut-sided Warbler may simply select regeneration age patches and ignore edges. Edges might be important to this species on a micro scale, but it is possible that overall habitat type and availability are a greater influence in their territory selection. This supports the findings of Hawrot and Niemi (1996) where area effects are more important than edge effects in the distribution of the Chestnut-sided Warbler. Both the Blandin and Boise survey plots were located on lands managed for paper production. These plots were primarily covered by large aspen stands of pole or saw-timber age.

Methodology. Much of this analysis relies on the fine-scale differences between habitat patches. The broader habitat selection of the Chestnut-sided Warbler is intrinsically a coarse-grain, landscape-level issue. The focus of this analysis on the nearest edge to an observation does not consider either more subtle effects such as the next closest edge or larger scale issues such as the placement of that edge on the landscape scale. For instance, patch size might be fruitful to pursue in future analyses, especially given the different results from plots in landscapes primarily managed for paper production and plots remaining in a more natural state. These results identify habitat and edge characteristics as important to the Chestnut-sided Warbler distribution within the landscape. Further analysis using a hierarchical approach could aid in deciphering how these factors interact and the order of their importance.

The map location of each observation of this species is a powerful tool in determining environmental influences on the distribution of a species in a habitat and within its landscape context. The inherent uncertainty of field observation limits the degree of certainty allowed by such an approach. Buffering the location of each observation by a set quantity such as by average territory size could reduce this uncertainty. For the most optimal information to be collected, the use of satellite GPS technology could greatly aid our understanding of how this species utilizes both macro- and micro-environments. This technology remains cost-prohibitive on such a large scale with hundreds of observations as shown here.

Conservation and management. Harvest of forested landscapes has replaced fire as the dominant disturbance effect (Niemi and Probst 1987, World Resources Institute 2000). Given this emphasis on anthropogenic alteration of the environment, careful consideration of management practices to allow for ecological sustainability becomes paramount. Considering the overall stable population of the Chestnut-sided Warbler in the Great Lakes region (Niemi et al 2014), it seems that current forest management in northern Minnesota, where clear-cutting remains the predominant type of harvest, is providing regenerating forest and open shrubland for this species (D'Amato et al 2008). The International Union for Conservation of Nature considers this a species of Least Concern (IUCN 2013). As was the case historically, whenever new areas of open habitat are created, it seems the Chestnut-sided Warbler is there, thriving. Indeed, greater densities of this species can be found in clear-cuts with greater vegetation complexity (Niemi and Hanowski 1984). The trend in modern forest management to create more structural diversity in Minnesota's forests could benefit this species, which relies on structural heterogeneity to locate suitable habitat (Vora et al 2008, Green 1995). Partners in Flight (PFSC 2012) indicate that this species has undergone a moderate decline in population, but that there are no known significant threats to the species breeding range. This species is considered a stewardship species in Minnesota by the Audubon Society, and continued monitoring of its populations remains important.

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Appendix A. The number of edge types per survey plot based on edge code categories. Habitat data were the same for both 1995 and 1995 sample years. Each recorded habitat-to-habitat edge type per survey plot is broken down by both age-class code and percent-conifer-cover code.

		Age Code 0			Age Code 1			Age Code 2		
	Percent Conifer Code:	0	1	2	0	1	2	0	1	2
Bandana										
	Aspen / Aspen	9	69		69	127				
	Aspen / Black Spruce, Tamarack					18				
	Aspen / Jack Pine		125	62	22	20	17			
	Aspen / Lowland Hardwoods		11							
	Aspen / Red Pine	41	96	45		44	71			
	Aspen / Spruce, Fir	22				19				
	Aspen / White Pine		43				12			
	Black Spruce, Tamarack / Red Pine				35					
	Black Spruce, Tamarack / Spruce, Fir					9				
	Jack Pine / Jack Pine		13			13				
	Lowland Hardwoods / Black Spruce, Tamarack			11						
	Lowland Hardwoods / Red Pine						11			
	Non-forested Upland / Aspen				20			11	23	
	Non-forested Upland / Black Spruce, Tamarack						9			
	Non-forested Upland / Jack Pine					5				42
	Non-forested Upland / Non-forested Wetland	49								
	Non-forested Upland / Red Pine						19			33
	Non-forested Upland / Spruce, Fir								9	
	Non-forested Upland / White Pine									11
	Non-forested Wetland / Aspen				46			24	91	
	Non-forested Wetland / Black Spruce, Tamarack						34			12
	Non-forested Wetland / Jack Pine									77
	Non-forested Wetland / Lowland Hardwoods							11		
	Non-forested Wetland / Red Pine						31		19	48

Appendix A continued

	Non-forested Wetland / White Pine						11
	Red Pine / Jack Pine	82	11	41	22		
	Red Pine / Red Pine			6	11		
	Spruce, Fir / Jack Pine		13				
	Spruce, Fir / Red Pine		9		11		
	Spruce, Fir / White Pine		12				
	Water / Non-forested Wetland	2					
	White Pine / Jack Pine	23			10		
	White Pine / Red Pine		22	11			
Blandin							
	Aspen / Black Spruce, Tamarack	59					
	Aspen / Lowland Hardwoods	12					
	Birch / Aspen	11					
	Non-forested Upland / Aspen	27					
	Non-forested Upland / Black Spruce, Tamarack	13					
	Non-forested Upland / Lowland Hardwoods	11					
	Non-forested Wetland / Aspen	15					
	Non-forested Wetland / Black Spruce, Tamarack	10					
	Non-forested Wetland / Northern Hardwoods	5					
	Northern Hardwoods / Aspen	77					
	Northern Hardwoods / Birch	10					
	Northern Hardwoods / Black Spruce, Tamarack	21					
	Water / Aspen	1					
Boise							
	Aspen / NULL	11					
	Aspen / Black Spruce, Tamarack	17					
	Aspen / Lowland Hardwoods	8					
	Aspen / Spruce, Fir	11					
	Black Spruce, Tamarack / Spruce, Fir	11					

Appendix A continued

	Built-up Areas / Aspen	11								
	Lowland Hardwoods / Black Spruce, Tamarack	7								
	Non-forested Upland / Aspen	1								
	Non-forested Wetland / Aspen	11								
Boulder										
	Aspen / Black Spruce, Tamarack			11			10			13
	Aspen / Lowland Hardwoods							17		
	Aspen / Spruce, Fir								7	34
	Aspen / White Pine								20	31
	Birch / Aspen					7				
	Birch / Black Spruce, Tamarack		9			22				
	Birch / Red Pine					11				
	Birch / Spruce, Fir					15				
	Birch / White Pine				11	15				
	Black Spruce, Tamarack / Black Spruce, Tamarack		12		104	13		11		
	Black Spruce, Tamarack / Red Pine	59			22	6		10		
	Black Spruce, Tamarack / Spruce, Fir		12		20					
	Black Spruce, Tamarack / White Pine	11	11		121	46		67	63	
	Built-up Areas / Black Spruce, Tamarack									11
	Built-up Areas / Non-forested Wetland	22								
	Built-up Areas / Red Pine									12
	Lowland Hardwoods / Black Spruce, Tamarack						11			
	Lowland Hardwoods / Spruce, Fir			24						
	Lowland Hardwoods / White Pine		11							
	Non-forested Upland / White Pine									2
	Non-forested Wetland / Aspen				13					

Appendix A continued

	Non-forested Wetland / Black Spruce, Tamarack						36		13	52
	Non-forested Wetland / Lowland Hardwoods							9		
	Non-forested Wetland / Red Pine						13		11	27
	Non-forested Wetland / Spruce, Fir								46	
	Non-forested Wetland / White Pine								64	82
	Red Pine / Red Pine							10		
	Spruce, Fir / Red Pine		12		12					
	Spruce, Fir / Spruce, Fir					11				
	Spruce, Fir / White Pine	6	39		11				13	
	White Pine / Red Pine	14						13	13	
	White Pine / White Pine		22							
Clover										
	Aspen / Aspen		39			10				
	Aspen / Black Spruce, Tamarack		28	80		43	10			
	Aspen / Jack Pine	9	65	11			6			
	Aspen / Red Pine			34						
	Aspen / Spruce, Fir	23	99	59	11	54	35			
	Birch / Aspen	99	33		56	11				
	Birch / Black Spruce, Tamarack			24						
	Birch / Jack Pine		11							
	Birch / Spruce, Fir		35	64		22				
	Black Spruce, Tamarack / Black Spruce, Tamarack		9		13					
	Black Spruce, Tamarack / Jack Pine	97	46		58					
	Black Spruce, Tamarack / Red Pine	55	22		10					
	Black Spruce, Tamarack / Spruce, Fir	33	24		35					
	Jack Pine / Jack Pine		10							
	Non-forested Upland / Aspen					24				
	Non-forested Upland / Non-forested Wetland	9								
	Non-forested Upland / Spruce, Fir									11
	Non-forested Wetland / Aspen					11		35	31	

Appendix A continued

	Non-forested Wetland / Black Spruce, Tamarack						22		10	136
	Non-forested Wetland / Jack Pine									63
	Non-forested Wetland / Red Pine									21
	Non-forested Wetland / Spruce, Fir						11		10	85
	Northern Hardwoods / Aspen	34								
	Northern Hardwoods / Birch	24								
	Northern Hardwoods / Spruce, Fir						11			
	Red Pine / Jack Pine	34	11							
	Spruce, Fir / Jack Pine	20	9		23	11				
	Spruce, Fir / Spruce, Fir		22		10	13				
	Water / Aspen				10					
	Water / Birch							10		
	Water / Non-forested Wetland	33								
	Water / Spruce, Fir								11	47
Lake Erin										
	Aspen / Aspen				303			13		
	Aspen / Black Spruce, Tamarack			37			11			
	Aspen / Lowland Hardwoods	9			11					
	Aspen / Oak	12	11							
	Aspen / Red Pine					20	44			
	Aspen / Spruce, Fir			11						
	Birch / Aspen	35			37					
	Birch / Oak	11								
	Black Spruce, Tamarack / Red Pine				13					
	Lowland Hardwoods / Black Spruce, Tamarack			9						
	Lowland Hardwoods / Oak	13								
	Lowland Hardwoods / Red Pine						11			
	Non-forested Upland / Aspen				64			93		
	Non-forested Upland / Black Spruce, Tamarack									11
	Non-forested Upland / Non-forested Wetland	51								

Appendix A continued

	Non-forested Upland / Northern Hardwoods							66		
	Non-forested Upland / Red Pine						46			
	Non-forested Wetland / Aspen				217			298	11	
	Non-forested Wetland / Birch							56		
	Non-forested Wetland / Black Spruce, Tamarack						7			26
	Non-forested Wetland / Lowland Hardwoods							22		
	Non-forested Wetland / Northern Hardwoods							164	31	
	Non-forested Wetland / Oak							24		
	Non-forested Wetland / Red Pine					9	20			
	Northern Hardwoods / Aspen	165			165	10		9		
	Northern Hardwoods / Birch	21								
	Northern Hardwoods / Black Spruce, Tamarack			21						
	Northern Hardwoods / Lowland Hardwoods	26								
	Northern Hardwoods / Northern Hardwoods		35							
	Northern Hardwoods / Oak	10								
	Northern Hardwoods / Red Pine					11	79			
	Red Pine / Red Pine		10							
Pine County										
	Aspen / Aspen				22					
	Aspen / Black Spruce, Tamarack			20			44			
	Aspen / Lowland Hardwoods				9					
	Aspen / Spruce, Fir	11	24	22		11	44			
	Black Spruce, Tamarack / Black Spruce, Tamarack				9					
	Black Spruce, Tamarack / Spruce, Fir	37	42			11				
	Built-up Areas / Aspen				44			11		

Appendix A continued

	Built-up Areas / Black Spruce, Tamarack								23	
	Built-up Areas / Lowland Hardwoods							11		
	Built-up Areas / Non-forested Upland	11								
	Built-up Areas / Non-forested Wetland	24								
	Built-up Areas / Northern Hardwoods				12			93		
	Built-up Areas / Spruce, Fir								10	38
	Cutover / Aspen				10			11		
	Cutover / Spruce, Fir								9	11
	Lowland Hardwoods / Spruce, Fir			18						
	Non-forested Upland / Aspen				13					
	Non-forested Upland / Northern Hardwoods							6		
	Non-forested Upland / Spruce, Fir								7	
	Non-forested Wetland / Aspen				39				11	
	Non-forested Wetland / Black Spruce, Tamarack						9		13	68
	Non-forested Wetland / Lowland Hardwoods							24		
	Non-forested Wetland / Northern Hardwoods							48		
	Non-forested Wetland / Spruce, Fir								60	117
	Northern Hardwoods / Aspen				78			24		
	Northern Hardwoods / Black Spruce, Tamarack		17	68		11	21			
	Northern Hardwoods / Lowland Hardwoods	18								
	Northern Hardwoods / Northern Hardwoods				48					
	Northern Hardwoods / Spruce, Fir		138	60						
	Spruce, Fir / Spruce, Fir		34							
Potlatch										
	Aspen / NULL	26								
	Aspen / Aspen				22					
	Aspen / Black Spruce, Tamarack			20			24			

Appendix A continued

	Aspen / Jack Pine			92			12			
	Aspen / Red Pine			88			34			
	Black Spruce, Tamarack / Jack Pine	23			10					
	Black Spruce, Tamarack / Red Pine	38			11					
	Black Spruce, Tamarack / Spruce, Fir	13								
	Non-forested Wetland /	11								
	Non-forested Wetland / Aspen				69			29		
	Non-forested Wetland / Black Spruce, Tamarack									9
	Non-forested Wetland / Jack Pine						36			
	Non-forested Wetland / Red Pine						58			36
	Red Pine / Jack Pine	78			13					
	Spruce, Fir / Red Pine	13								
Wolf Ridge										
	Aspen / Aspen		13		34					
	Aspen / Lowland Hardwoods		10							
	Aspen / Spruce, Fir		21	50						
	Birch / Aspen	22				11				
	Birch / Birch		21		41					
	Birch / Black Spruce, Tamarack						9			
	Birch / Lowland Hardwoods				11					
	Birch / Spruce, Fir			21		10				
	Built-up Areas / Aspen							12	9	
	Built-up Areas / Birch							22		
	Built-up Areas / Lowland Hardwoods								12	
	Built-up Areas / Non-forested Upland	11								
	Built-up Areas / Non-forested Wetland	10								
	Built-up Areas / Northern Hardwoods							28		
	Built-up Areas / Spruce, Fir									22
	Non-forested Upland / Aspen							226	21	
	Non-forested Upland / Birch							55	12	

Appendix A continued

Non-forested Upland / Lowland Hardwoods								13	
Non-forested Upland / Non-forested Wetland	89								
Non-forested Upland / Northern Hardwoods							32		
Non-forested Upland / Spruce, Fir									10
Non-forested Wetland / Aspen							91	9	
Non-forested Wetland / Birch							34		
Non-forested Wetland / Black Spruce, Tamarack						9			
Non-forested Wetland / Northern Hardwoods							21		
Non-forested Wetland / Spruce, Fir									13
Northern Hardwoods / Aspen	22								
Northern Hardwoods / Birch	76	11		27	33				
Northern Hardwoods / Lowland Hardwoods		12							
Northern Hardwoods / Spruce, Fir			9						
Water / Aspen							17		
Water / Birch							11		
Water / Non-forested Wetland	28								
Water / Northern Hardwoods							9		

Appendix B. The number of habitat patches per plot of every recorded habitat type. Habitat data were the same for both sample years 1994 and 1995.

	Bandana	Blandin	Boise	Boulder	Clover	Lake Erin	Pine County	Potlatch	Wolf Ridge	Total
Aspen	28	4	6	2	24	26	15	12	18	**135**
Birch		1		1	11	3			8	**24**
Black Spruce, Tamarack	5	9	2	26	20	5	9	6	1	**83**
Built-up Areas			1	1			2		9	**13**
Cutover							2			**2**
Jack Pine	8				10			3		**21**
Lowland Hardwoods	1	2	3	1		4	2		1	**14**
Non-forested Upland	6	1	1	2	1	5	2		14	**32**
Non-forested Wetland	15	3	1	18	12	50	14	8	4	**125**
Northern Hardwoods		9			1	18	15		7	**50**
NULL		2	1					1		**4**
Oak						1				**1**
Red Pine	12			4	5	5		9		**35**
Spruce, Fir	2		1	8	19	1	17	1	4	**53**
Water	2	1			4				4	**11**
White Pine	2			5						**7**
Grand Total	**81**	**32**	**16**	**68**	**107**	**118**	**78**	**40**	**70**	**610**