

BREEDING BIRD RESPONSE TO VARYING AMOUNTS OF BASAL AREA RETENTION IN RIPARIAN BUFFERS

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Abstract: We examined response of breeding bird communities to forest harvest that removed varying amounts of tree basal area from riparian buffers on a 2- to 4-m-wide stream in northern Minnesota, USA. We compared bird species and communities in 30-m-wide riparian buffers along the stream. Buffers were established within plots in which upland forests were clear-cut (basal area 2 m²/ha) according to standard local forest management practice. Buffers had 4 treatments (3 plots/treatment): (1) no harvest (riparian control); (2) reduction of basal area to an average of 7–10 m²/ha; (3) reduction of basal area to an average of 2 m²/ha (defined as a clear-cut); and (4) control (no harvest in either riparian buffer or adjacent upland). Bird surveys were conducted 1 year prior to harvest and for 4 years after harvest. Results revealed a significant response of the bird community to varying amounts of tree basal area retention in the riparian area. Univariate (analysis of variance) and multivariate (principal response curves [PRC]) analyses showed that in the first year after harvest, bird community composition in the riparian buffers changed in all 3 treatments relative to the control plots, and continued to diverge over time. More species and individuals, primarily those species associated with edge or early-successional habitats, colonized the harvested riparian buffers after treatment. In contrast, the number of birds and species that inhabit interior forests declined in the riparian buffers. Results suggest that any amount of harvest in riparian buffers next to clear-cut upland forest will affect breeding bird communities along small headwater streams. Because individual bird species are differentially affected by riparian forest harvest, management should consider the desired future condition of the forest and choose a harvest prescription to benefit the desired avifauna community.

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Forest management in riparian buffers has often been a compromise between maintaining the ecological benefits of these forest ecosystems and realizing the economic value of the timber within them. Minnesota has about 300,000 ha of forest within 30 m of lake and stream edges (Hanowski et al. 2002), and it is estimated that 12,000,000 cords of timber exists in these riparian buffers (Vasievich and Edgar 1998). In the current forest resources market, this represents over US\$70,000,000 of revenue. Due to the economic consequences of leaving uncut riparian buffers of any width across the landscape, it is important that we quantify biological responses of breeding birds and other aquatic and terrestrial organisms to varying amounts of residual basal area left standing in riparian buffers. If bird communities respond differently to partial levels of harvest in buffers, for example, certain management prescriptions might allow some level of economic

value to be realized while essential ecological functions are maintained.

Over the past decade, most riparian forest harvest studies have documented the response of breeding birds to different widths of riparian buffers left uncut during harvest (Dickson et al. 1995, Kinley and Newhouse 1997, Hagar 1999, Whittaker and Montevecchi 1999), or to harvests with various combinations of buffer width and residual basal area (Darveau et al. 1995, Parker et al. 1998). We are not aware of any replicated experiment in a northern forest that has examined breeding bird response to different levels of post-harvest tree basal area within a constant width riparian buffer. In general, few experimental and replicated riparian buffer harvest studies have been published. For a more comprehensive review of riparian literature, see Wegner (1999) and for a synopsis of historical riparian breeding bird literature, see Hanowski et al. (2002, 2003).

In our study, the objective was to determine whether the amount of residual tree basal area left in harvested riparian buffers impacted breed-

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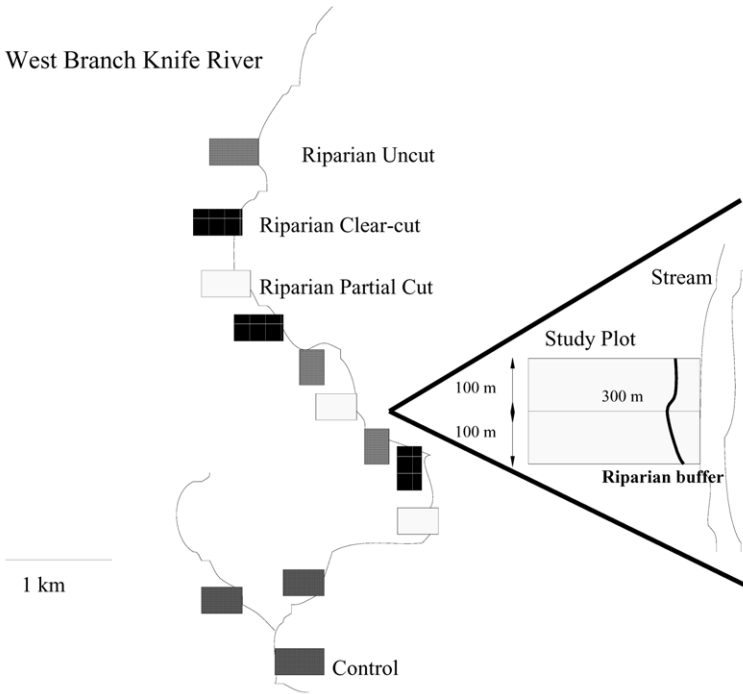


Fig. 1. Location of 12 study plots along 2 branches of the west branch Knife River in northern Minnesota, USA. See inset on right for detailed study plot set-up.

ing bird communities. We examined riparian forest buffers that were harvested but retained a gradient of residual basal area, including clear-cut (leaving 2 m²/ha), harvested with partial retention (7–10-m²/ha), and uncut. All of these buffers were adjacent to clear-cut upland forest plots, reflecting local management practice. We also established control sites in which neither the buffer areas nor the adjacent plots were harvested. We predicted that, if we detected differences in breeding bird communities within the various

Table 1. Forest harvest treatment types applied to riparian area forest and adjacent uplands within study plots where breeding bird surveys were conducted in northern Minnesota, USA, 1997–2001. Treatments were replicated 3 times.

Treatment name	Riparian treatment type	Upland treatment
control	no harvest	no harvest
uncut	no harvest within 30 m of stream edge	clear-cut harvest
partial	7–10 m ² /ha basal area left within 30 m of stream edge	clear-cut harvest
clear-cut	<2m ² /ha basal area left within 30 m of stream edge	clear-cut harvest

treatments, the clear-cut harvest would result in the largest change in breeding bird communities in riparian areas because of the greater amount of basal area removed.

STUDY AREA

We conducted our study within 1 watershed in northern Minnesota (Fig. 1). We choose this area because it had forest cover at rotation age, the stream morphology was similar along all stream reaches, and the landowners were willing to harvest stands with the designated treatments. We located 12 individual study plots within a 10-km² area along 2 reaches of the west branch of the Knife River, a 2- to 4-m-wide

designated trout stream. The dominant tree species prior to harvest were quaking aspen (*Populus tremuloides*), balsam fir (*Abies balsamea*), and white spruce (*Picea glauca*). Study plots were from 3 to 6 ha, and all contained at least 200 m of stream reach. We placed plots at least 100 m apart to ensure that bird data collected on each site was independent. Subsequent tests (Moran’s I) for independence (Sokal and Oden 1978) indicated that this assumption was met for the bird community data. We found this result in previous bird community studies in this region (Hanowski et al. 1990, 2003).

The experiment consisted of a replicated before–after control–impact (BACI) design. We applied 3 treatments, which consisted of different harvest combinations in the riparian and upland areas, and established 1 set of control plots in which no harvesting occurred (Table 1). With the exception of the control plots, treatments were assigned to all other plots randomly. All treatments were applied to the same side of the stream, and the upland areas were clear-cut in a manner consistent with typical commercial operations. All harvests were completed in the winter with a feller buncher with tree-length skidding.

METHODS

Bird Surveys

We conducted 3 bird surveys during the breeding season on each plot in each year (1997–2001). We collected before-harvest data on all plots in 1997, and we collected post-harvest data in 1998, 1999, 2000, and 2001. One survey was done in mid-May to document early breeding and permanent resident species (e.g., chickadees and woodpeckers), 1 in mid-June to capture peak singing of long-distance migrants, and 1 in early July for the later breeding species (e.g., goldfinches and waxwings). Because we were interested in documenting locations of birds relative to the stream, we conducted line-transect bird surveys that ran across the plot perpendicular to the stream edge (Hanowski et al. 1990; Fig. 1). Surveys were completed by 1 of 4 experienced observers who passed a bird identification test, a hearing test, and received training to standardize counts (Hanowski and Niemi 1995). All surveys were completed during early morning hours (within 4 hr of sunrise) and with good weather conditions (no rain and winds < 20 kph).

Data Analysis

We focused our statistical analyses on bird response to the amount of post-harvest residual basal area in the riparian buffers. In order for us to infer a causal relationship between the residual basal area in buffers and the composition of bird communities, it was necessary that treatments were randomly assigned to experimental units and that the riparian areas were typical for northeastern Minnesota (Stewart-Oaten et al. 1986, McDonald et al. 2000). Our replicated BACI design satisfied both criteria. We were not interested in developing bird/habitat relationships, and therefore no vegetation data were collected.

A sample was defined as 3 bird surveys on a transect in a year. For each sample ($n = 60$), we calculated several response variables: number of individual bird species, number of species representing different nesting guilds and habitat guilds, the total number of individuals, and species richness. Because we were primarily interested in bird response to harvest in the buffers, we used only the data for those birds observed within the designated riparian zone (30 m). For analyses involving individual species, guilds, and the total number of individuals, we used the maximum count of individuals observed on any one of the May, June, or July surveys. Species were assigned to members of guilds based on pub-

lished literature sources (Hanowski et al. 2003). For species richness, we used cumulative richness per sample. Bird community data for multivariate analyses were generated by aggregating the individual species data. From the pool of 44 species observed in the riparian buffer over the 5-year sampling period, we excluded 15 species that were present on fewer than 3 of 60 samples. This was done to minimize the number of zeroes in the ordination data set (Legendre and Gallagher 2000) and resulted in a matrix of 60 samples (rows) and 29 species (columns). Bird counts were transformed by $\ln(\text{count} + 0.2)$ to make the distributions more Gaussian. The cells of the matrix contained the \ln -transformed maximum counts for each species.

For univariate variables (number of individuals per species, total number of individuals, species richness), we used a Poisson alternative to Gaussian repeated measures ANOVA (analysis of variance) because the data were non-normally distributed. Poisson models are an appropriate alternative to traditional linear approaches when the response variable is a count (Jones et al. 2002). We used Generalized Estimating Equations (GEEs) to model bird abundance in SAS Proc GENMOD and evaluated significance using Wald statistics (SAS Institute 2000). GEEs are used to account for within-subject correlation in repeated measures designs when the normality assumption is not reasonable (SAS Institute 2000). When there was a significant treatment effect, we carried out pairwise comparisons among the treatment groups and used Bonferroni adjusted alpha levels. Tests were carried out for only the 7 most abundant bird species because many zeroes made it difficult to build models for the other species.

We used Principal Response Curves (PRC) to analyze the response of bird communities to harvest in the riparian buffers (ter Braak and Šmilauer 1998). This method was preferred (over univariate methods) because it summarized all information on bird communities simultaneously; therefore, effects of experimental manipulation at the community level could be identified (Kedwards et al. 1999*a,b*; Van den Brink and ter Braak 1999). In addition, multivariate methods can accommodate the many sequential zeroes often present in ecological community data. PRC is a recent extension of redundancy analysis (RDA) that distills the complexity of time-dependent, community-level responses into a graphic form that is easier to interpret (Van den Brink and ter Braak 1999). This method has been used as an effective graphical and

analytical tool in other ecological experiments having a similar number of experimental units (Van den Brink and ter Braak 1999, Frampton et al. 2000, Sibley et al. 2001, Hanowski et al. 2003).

We followed guidelines of Van den Brink and ter Braak (1999) and ter Braak and Šmilauer (1998) to compute the PRC. Independent variables are used in a partial RDA to explain variation in a bird species data set after first accounting for variation attributable to a third data set (covariable data). In other words, we first accounted for variation in species composition due to time, and then we attributed the remaining variation to the treatments. In our study, explanatory variables were 12 dummy variables that consisted of all combinations of the 3 treatments and 4 post-treatment times. By excluding variables that denoted control treatments or pre-treatment years, we ensured that treatment effects were expressed as deviations from the control (ter Braak and Šmilauer 1998). Covariables were denoted by dummy variables indicating sampling year. The PRCs were generated by plotting the first and second principal components of the treatment effects against time for each treatment group.

The significance of the PRCs was assessed with a Monte Carlo permutation test, by permuting whole time series in the partial RDA from which each PRC was obtained. This test used an F -type statistic based on the eigenvalue of the component (ter Braak and Šmilauer 1998). The null hypothesis was that the treatment effect was zero for all times, treatments, and species.

The interpretation of bird species responses in the PRC diagram was aided by a line graph of species weights. The line graph is similar to an ordination axis, but is vertical instead of horizontal. In our case, a positive weight for a species indicated an increase in abundance following harvest, while a negative weight for a species indicated a decline. Species with weights farther from zero have increased or decreased by greater amounts than species with weights near zero. The quotient $\exp(b_k * c_{dt})$, where b_k is the species weight and c_{dt} is the canonical coefficient at time t and treatment d , can be used to quantitatively evaluate the expected increase or decrease in abundance.

RESULTS

Univariate Tests

Species richness and total number of individuals increased ($P < 0.001$) in buffers of all harvested plots relative to buffers on control plots,

regardless of how much basal area remained in the buffer (Fig. 2). The increase in richness and individuals was primarily due to an increase in number of bird species that are associated with edge habitats. We found more ($P < 0.0001$) edge-associated birds in all buffers in the harvested plots than in the unharvested controls, regardless of basal area remaining in the buffer (Fig. 2). In contrast, although the number of forest interior bird species decreased in buffers of plots that were harvested relative to buffers of controls, the difference was not significant ($P > 0.05$; Fig. 2). Birds that nest in the shrub or sub-canopy layers also increased ($P < 0.0001$) in riparian areas of all harvested plots relative to control plots (Fig. 2). The response of canopy nesting species to harvest was not consistent: numbers were lower ($P < 0.001$) in the uncut buffers than in either the buffers that were clearcut or the control riparian areas (Fig. 2). No differences were detected in ground- or cavity-nesting birds in any of the treated plots relative to the control (Fig. 2).

We found a significant treatment effect for 5 of 7 individual bird species that were tested, but no 2 species illustrated the same pattern of response. The chestnut-sided warbler (*Dendroica pensylvanica*) increased ($P < 0.001$) in all plots that were harvested regardless of the amount of basal area remaining in the riparian buffer (Fig. 3). Nashville warbler (*Vermivora ruficapilla*) numbers were higher ($P < 0.001$) in uncut and partially harvested buffers relative to both control and clearcut buffers (Fig. 3). Veery (*Catharus guttatus*) abundance was higher ($P < 0.05$) in the clearcut riparian buffers than in the uncut buffers. Partially harvested riparian buffers had more ($P < 0.001$) red-eyed vireos (*Vireo olivaceus*) than did the control plots (Fig. 3). Although the analysis for the ovenbird (*Seiurus aurocapillus*) indicated an overall difference, no pair-wise comparison tests were significant although numbers were lower in riparian buffers in harvested plots than in the control plots (Fig. 3). The pattern exhibited by the black-throated green warbler (*Dendroica virens*) was similar to that of the ovenbird, but no significant difference was detected (Fig. 3).

Multivariate Tests

The first PRC was statistically significant ($P = 0.004$): the covariable year accounted for 6% of the variance in the species data, while the treatment accounted for 30% of the variance in the species data (Fig. 4). Bird community composition changed in all 3 treatments relative to the

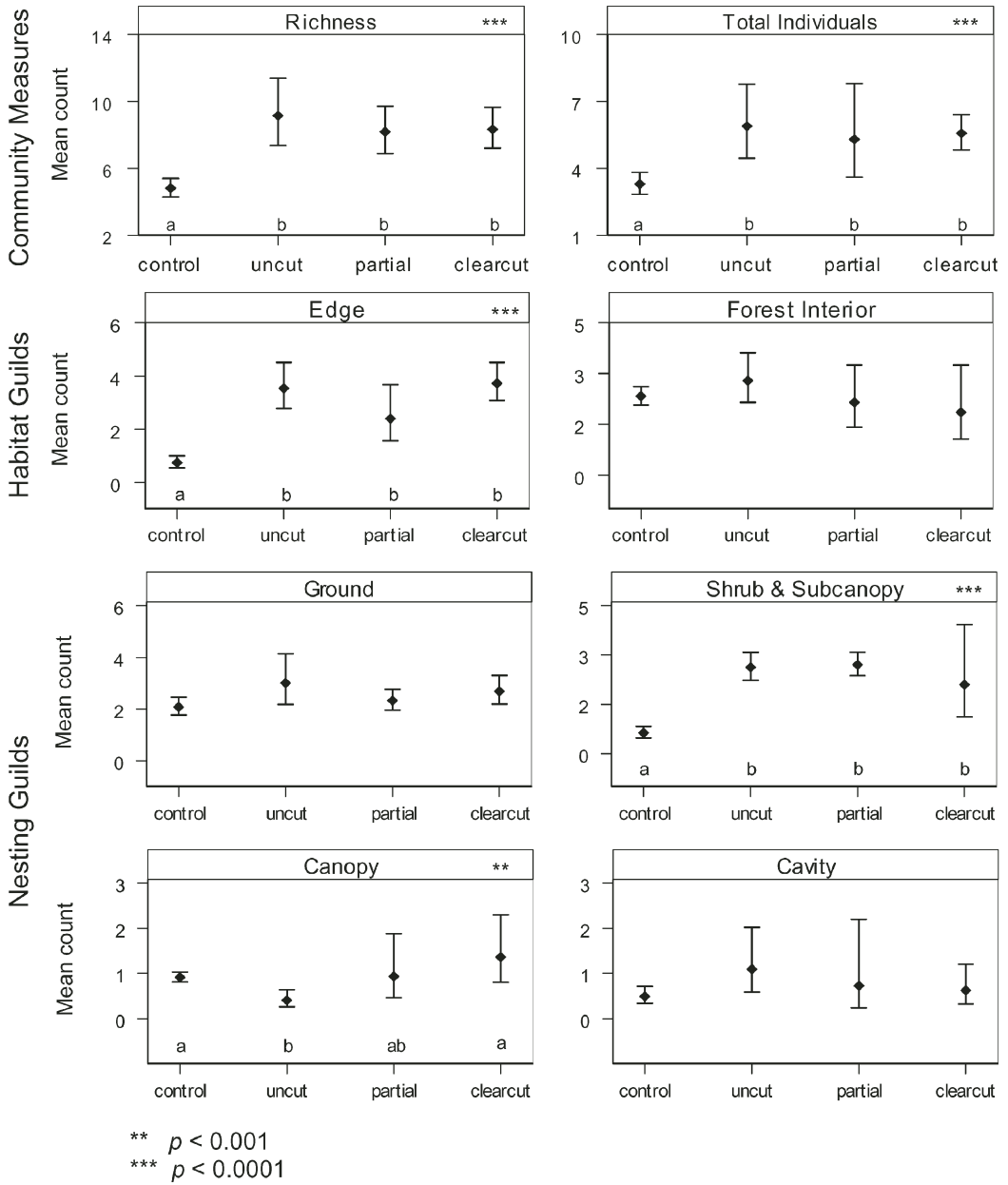


Fig. 2. Back-transformed least-squared mean number of individuals or species and 95% confidence intervals for community and guild response variables. Means which are based on after-harvest years with the same letter are not significantly different ($P > 0.05$) using Bonferroni adjusted p -values. Asterisks indicate an overall significant treatment effect.

control plots the first year after harvest and continued to diverge over time. Four years after treatment, the bird communities in the riparian clearcut treatment plots were the most different from the bird communities on controls. The bird communities in the partially harvested plots buffers (7–10m² ha residual) were most similar to those

in buffer zones on the control plots after 4 years. Bird communities in the uncut riparian buffers were more similar to those in the clear-cut buffers 4 years after harvest along the first PRC axis (Fig. 4).

Bird species locations along the first PRC illustrate individual species responses to the treat-

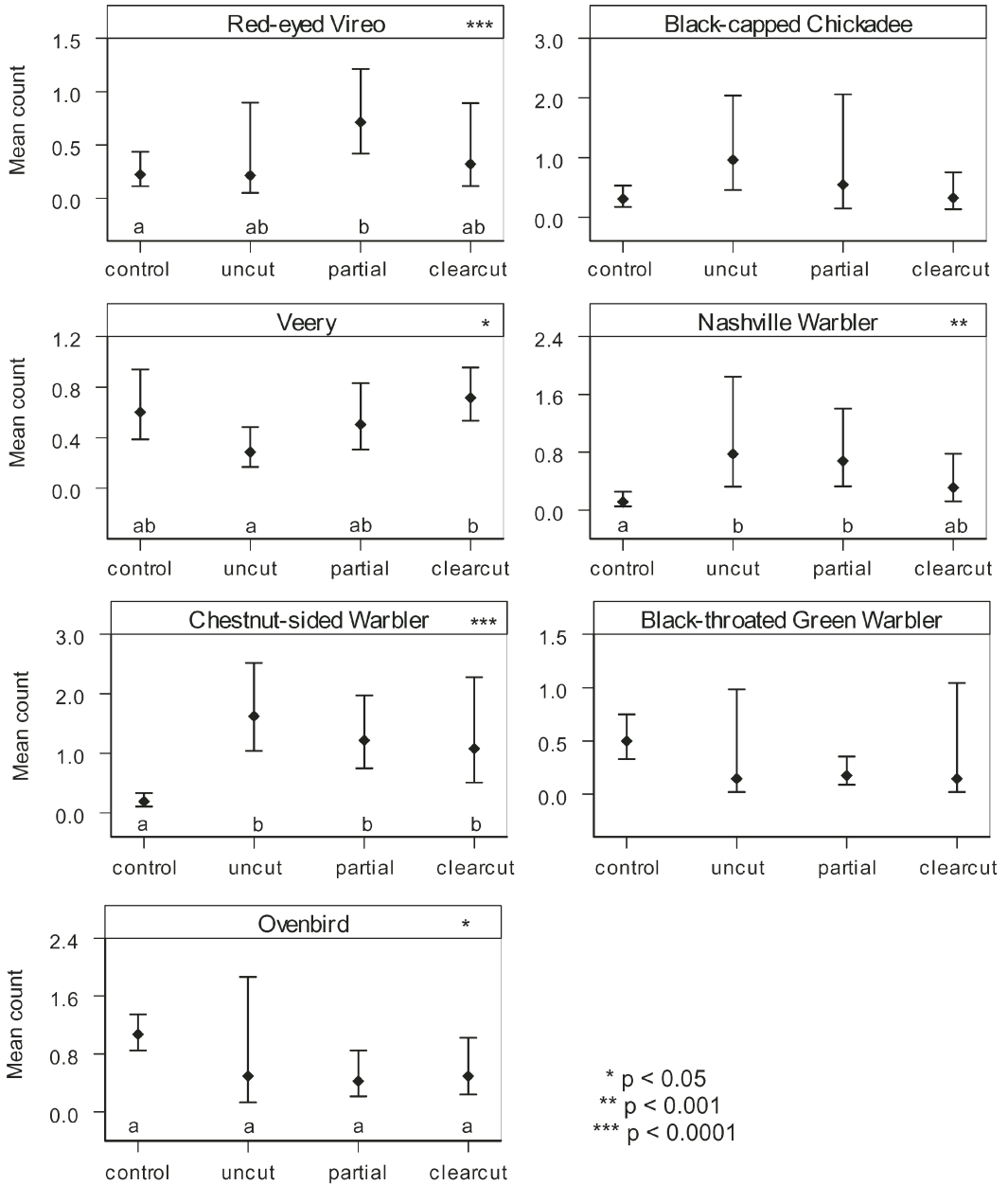


Fig. 3. Back-transformed least-squared mean number of individuals and 95% confidence intervals. Means which are based on after harvest years with the same letter are not significantly different ($P > 0.05$) using Bonferroni adjusted p -values. Asterisks indicate an overall significant treatment effect.

ments (Fig. 4). Seven species (ovenbird, black-throated green warbler, wood thrush [*Hylocichla mustelina*], blue jay [*Cyanocitta cristata*], ruffed grouse [*Bonasa umbellus*], winter wren [*Troglodytes troglodytes*], and purple finch [*Carpodacus purpureus*]) had negative species weights, indicating

that they declined in the treated buffers after the treatment, relative to controls (Fig. 4). On the other end of the axis, the chestnut-sided warbler, American redstart (*Setophaga ruticilla*), Nashville warbler, magnolia warbler (*Dendroica magnolia*), and downy woodpecker (*Picoides pubescens*) had

the most positive weights indicating that they increased in abundance in the clear-cut, partially cut, and uncut riparian buffers, relative to controls, after treatments (Fig. 4). For example, the canonical coefficient for the clearcut treatment 4 yrs post-treatment is 0.831. For chestnut-sided warbler, which has a species weight of 2.113, the change in geometric mean count is $\exp(2.113 * 0.831) = 5.79$. The PRC analysis thus predicts that, 4 yrs after harvest the chestnut-sided warbler's relative abundance in clear-cut buffers would be 5.79 of its relative abundance in control plot buffers (see Fig. 3).

Our interpretation of individual species impacts based on the PRC mirrors results from the individual species univariate tests. For example, the chestnut-sided warbler had the most positive weight on the first PRC axis and also increased ($P < 0.0001$) on all treatments relative to control plots in the univariate tests (Fig. 3). In contrast, the ovenbird had the most negative score on the first PRC axis, and its numbers decreased on all treatment plots relative to controls (Fig. 3).

Although the second PRC had a P -value that was not quite significant at alpha 0.05, ($P = 0.064$), this axis explained 22% of the variation of the species data that was due to the treatment (Fig. 5). This axis more clearly separated treatment types from each other versus the first axis that separated all treatments from the control, especially 2 years after treatments. Plots with the clear-cut riparian prescription diverged from control plots and had more early-successional bird species like the white-throated sparrow (*Zonotrichia albicollis*), mourning warbler (*Oporornis philadelphia*), and American redstart (Fig. 5). Along this axis, bird communities

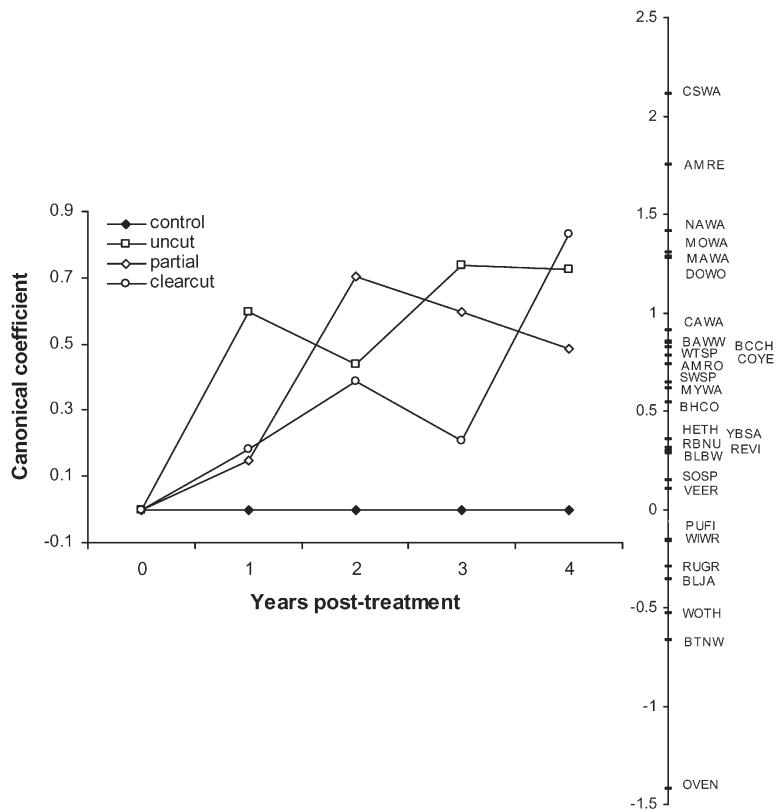


Fig. 4. First PRC with species weights for birds observed within 30 m of the stream edge in 12 study plots along the west branch Knife River in northern Minnesota, USA. Response of bird communities to harvest treatment is indicated by curves that depart from the control plots. Species with positive weights increased in abundance relative to control plots, and species with negative weights decreased. The vertical axis represents 32% of the variation in the bird community due to the treatment regime and is significant ($P = 0.004$). See Appendix 1 for species codes interpretation.

in the partially harvested buffers were more similar to bird communities in controls, especially in the third and fourth years after harvest. Bird communities in plots with uncut riparian buffers changed in composition relative to those in control plots primarily in the third and fourth years after harvest. Species associated with the uncut riparian buffers were the black-and-white warbler (*Mniotilta varia*) and magnolia warbler (Fig. 5). Again, results of the univariate species tests support this interpretation of bird community response to the treatments. For example, the univariate test for the veery indicated that the clearcut treatment plots had more individuals than the uncut riparian buffer plots (Fig. 3). The veery's positive position on the second PRC (Fig. 5) that separates bird communities in the clearcut and uncut buffers reflects the difference that we found in the univariate test for this species.

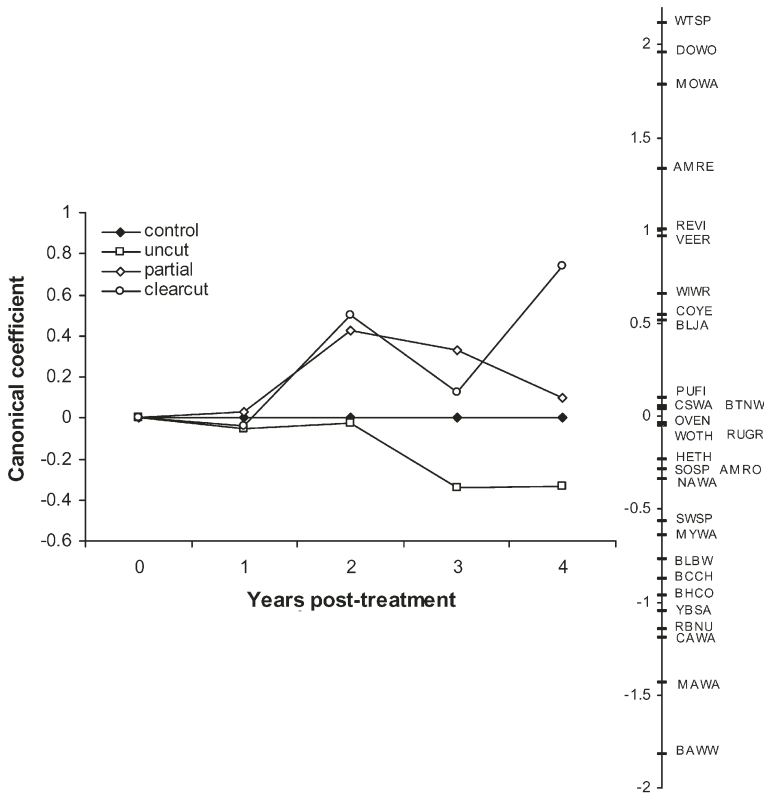


Fig. 5. Second PRC with species weights for birds observed within 30 m of the stream edge in 12 study plots along the west branch Knife River in northern Minnesota, USA. Response of bird communities to harvest treatment is indicated by curves that depart from the control plots. Species with positive weights increased in abundance relative to control plots, and species with negative weights decreased. The vertical axis represents 22% of the variation in the bird community due to the treatment regime and had a *P*-value of 0.064. See Appendix 1 for species codes interpretation.

DISCUSSION

We designed this experiment to test the opposite extremes of management prescriptions for riparian forest buffers, comparing a clear-cut buffer to an uncut buffer. We found that bird community composition changed in response to any harvest prescriptions in the buffers adjacent to 2- to 4-m-wide streams in northern Minnesota. Bird communities in the clear-cut buffer treatment changed more, relative to the control plots, than did communities in uncut buffers. As Darveau et al. (1995) and Hanowski et al. (2002) previously found, changes in species composition on treatment plots did not occur in the first year after harvest. However, 3 years after harvest, the composition of bird communities on treatment plots (especially those with the clear-cut buffers) continued to diverge from that on control plots.

We found that species associated with mature forest, like the ovenbird, black-throated green warbler and wood thrush, were negatively impacted by all types of riparian forest management prescriptions, including the uncut buffers adjacent to clear-cut land. In another region of northern Minnesota (Hanowski et al. 2003), we also found that even uncut riparian buffers 60 m wide did not provide suitable habitat for forest-associated bird species. Other investigations have documented similar impacts of harvest in riparian areas on bird species associated with the forest interior (Kinley and Newhouse 1997, Parker et al. 1998, Hagar 1999). In contrast, early-successional species like the chestnut-sided warbler, American redstart, and Nashville warbler responded positively to all treatments. This result was not unexpected due to

the significant amount of basal area removed from the treatment riparian forest plots and the small amount of residual basal area left on the site (Perry et al. 2001).

Our results also demonstrate the usefulness of multivariate bird community analysis using PRCs as a supplement to more-traditional univariate tests. In many breeding bird studies, it is difficult to conduct univariate species tests because of the low numbers of individuals observed. In addition, power of these tests were generally low (Hanowski et al. 1995) leading to type II errors. The PRC was useful in our study to identify bird community responses to riparian harvest treatments and to demonstrate which individual species were responsible for the differences that developed in the bird communities after harvest.

We found that the amount of basal area left remaining in riparian buffers adjacent to clear-cut

areas differentially impacted breeding bird communities. As predicted, the clear-cut harvest treatment resulted in the largest change in bird communities relative to control plots. However, because all treatments resulted in a change in breeding bird communities, it is difficult to say which riparian treatment would have the least impact on breeding bird communities on a regional scale. As in upland forests, some bird species increase and others decrease in abundance after harvest (Hobson and Schieck 1999). In our study, we did not find any riparian obligate bird species such as the osprey (*Pandion haliaetus*), bald eagle (*Haliaeetus leucocephalus*), or waterfowl that are associated with water bodies. These species are more commonly associated with wider streams, rivers, and lakes, rather than the narrower stream systems that we studied (see Hanowski et al. 2001). From a conservation perspective, it is most critical to provide habitat for riparian dependent species due to their requisite need for habitat features that are found in these ecosystems.

MANAGEMENT IMPLICATIONS

Several ecological factors should be considered when making management decisions for harvest in forests along streams and rivers; the response of breeding birds is but one of these. Our results suggest that any amount of overstory removal within 30 m of a stream (the total width of our buffers) will alter the bird community in these forests. For breeding bird conservation, it may be sensible to take a dichotomous approach for managing forests adjacent to water bodies. In riparian forests where suitable habitat and aquatic resources currently support or could provide habitat for larger-bodied riparian-associated species, or forest-associated species like those in our study, a much wider buffer may be required than any currently used or previously tested. In forests along narrow, headwater streams, narrower buffers could be applied to protect water quality and aquatic habitats. These buffers would provide diverse habitat structure for current and future breeding bird communities, and if harvest occurred there, it would support greater proportions of edge-associated and early-successional species.

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Appendix 1. Common and scientific names with codes of bird species depicted in Figs. 4 and 5.

Common name	Scientific name	Code
American robin	<i>Turdus migratorius</i>	AMRO
American redstart	<i>Setophaga ruticilla</i>	AMRE
black-and-white warbler	<i>Mniotilta varia</i>	BAWW
black-capped chickadee	<i>Poecile atricapillus</i>	BCCH
brown-headed cowbird	<i>Molothrus ater</i>	BHCO
blue jay	<i>Cyanocitta cristata</i>	BLJA
black-throated green warbler	<i>Dendroica virens</i>	BTNW
blackburnian warbler	<i>Dendroica fusca</i>	BLBW
canada warbler	<i>Wilsonia canadensis</i>	CAWA
chestnut-sided warbler	<i>Dendroica pensylvanica</i>	CSWA
common yellowthroat	<i>Geothlypis trichas</i>	COYE
downy woodpecker	<i>Picoides pubescens</i>	DOWO
hermit thrush	<i>Catharus guttatus</i>	HETH
magnolia warbler	<i>Dendroica magnolia</i>	MAWA
mourning warbler	<i>Oporornis philadelphia</i>	MOWA
Nashville warbler	<i>Vermivora ruficapilla</i>	NAWA
ovenbird	<i>Seiurus aurocapillus</i>	OVEN
purple finch	<i>Carpodacus purpureus</i>	PUFI
red-eyed vireo	<i>Vireo olivaceus</i>	REVI
ruffed grouse	<i>Bonasa umbellus</i>	RUGR
red-breasted nuthatch	<i>Sitta canadensis</i>	RBNH
song sparrow	<i>Melospiza melodia</i>	SOSP
swamp sparrow	<i>Melospiza georgiana</i>	SWSP
veery	<i>Catharus fuscescens</i>	VEER
wood thrush	<i>Hylocichla mustelina</i>	WOTH
white-throated sparrow	<i>Zonotrichia albicollis</i>	WTSP
yellow-bellied sapsucker	<i>Sphyrapicus varius</i>	YBSA
winter wren	<i>Troglodytes troglodytes</i>	WIWR