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Forest Ecology and Management 174 (2003) 315–328
Forest Ecology and Management
www.elsevier.com/locate/foreco

Breeding bird response to riparian forest harvest and harvest equipment

JoAnn Hanowski*, Nick Danz, Jim Lind, Gerald Niemi

Center for Water and the Environment, Natural Resources Research Institute, University of Minnesota Duluth, 5013 Miller Trunk Highway, Duluth, MN 55811, USA

Received 18 October 2001; accepted 17 January 2002

Abstract

We examined response of breeding bird communities to timber harvest in riparian areas using two harvest techniques (full tree harvest and cut-to-length (CTL)) along first to third order streams in northern Minnesota, USA. Although many studies have quantified bird response to riparian buffer harvest, we are unaware of any study that examined the response of breeding birds to riparian forest harvest using different cutting practices. We compared community composition, total abundance and species richness, as well as abundance of six individual species on plots within four treatments (three plots/treatment) completed within 30 m on both sides of the stream. Treatments in the riparian area (30 m on both sides of the stream) were: (1) riparian control (no harvest); (2) reduction of basal area to an average of 7–10 m^2/ha with full tree harvest system; (3) reduction of basal area to an average of 7–10 m^2/ha with CTL harvest system; and (4) control (no harvest in riparian area or upland). For treatments 1, 2, and 3, adjacent upland forests on the plots were clearcut. Bird surveys were completed 1 year prior to, and 3 years after harvest and revealed a significant response of the bird community to timber harvest in the riparian area. Bird communities were most affected by tree removal with both harvest methods, but harvest type also affected bird communities. Early-successional species, e.g. song sparrow (*Melospiza melodia*), white-throated sparrow (*Zonotrichia albicollis*), mourning warbler (*Oporornis philadelphia*), and chestnut-sided warbler (*Dendroica pensylvanica*) were associated with harvested plots, whereas forest species, e.g. scarlet tanager (*Piranga olivacea*) and black-throated green warbler (*Dendroica virens*) were associated with riparian control and control plots. Of six individual species tested for response to riparian harvest treatment over time, only the ovenbird (*Seiurus aurocapillus*) showed a significant time by treatment interaction. Ovenbird numbers decreased in both the CTL and full tree harvest plots through 2000, when no individuals were observed. Two other forest-dependent species, black-throated green warbler and hermit thrush (*Catharus guttatus*), showed similar responses to treatment as the ovenbird. The winter wren (*Troglodytes troglodytes*) responded positively to the greater amount of slash that was left on-plot with the CTL harvest system. However, with the exception of the winter wren, we found that bird species and communities did not differ in their response to harvest system.

Keywords: Breeding bird communities; Buffers; Cut-to-length; Forest; Harvest; Minnesota; Riparian; Principle response curves; Streams; Buffers

1. Introduction

The role of riparian areas in protecting water quality and in-stream habitat for aquatic organisms, as well as providing wildlife habitat, has been documented in

* Corresponding author. Tel.: +1-218-720-4311; fax: +1-218-720-4328.
E-mail address: jhanowsk@nrri.umn.edu (J. Hanowski).

0378-1127/02/$ – see front matter
PII: S0378-1127(02)00040-3

several regions of North America (see Wegner, 1999 for review). Protection of forest riparian areas for wildlife habitat during timber harvest has become a common management consideration in current forest practices. Most riparian guidelines recommend set buffer widths and amount of residual basal area of trees that would be required to protect or conserve riparian habitat function (Knopf, 1985). However, in many situations, riparian area protection is often inferred without documenting benefits to wildlife or water quality (Wigley and Melchoirs, 1993).

Buffer widths that have been recommended to protect riparian forest function vary considerably across North America. For example, Darveau et al. (1995) recommended a 60 m riparian buffer in boreal forests, Keller et al. (1993) suggested that a 100 m buffer was required in eastern deciduous forests, and Pearson and Manuwal (2001) calculated that a 45 m buffer on both sides of streams in the Pacific Northwest was required to maintain breeding bird communities. Lambert and Hannon (2000) found that a 100–200 m buffer was required to maintain ovenbird (*Seiurus auracapillus*) populations in riparian forests in Alberta. One study reported that narrow buffers acted as habitat sinks due to predation and have suggested that wider buffers (150 m) were required to reduce edge-related predation (Vander Haegen and DeGraaf, 1996). In a study on juvenile bird dispersal from riparian forests, a 100 m buffer was recommended (Machtans et al., 1996).

Some investigators have questioned the long-term value of leaving narrow riparian buffer strips for wildlife populations. For example, Darveau et al. (1995) found that strips less than 15 m wide had limited long-term value due to their susceptibility to windthrow. Hanowski et al. (2000) demonstrated that set-width riparian buffers applied across a landscape would significantly increase the amount of edge habitat. An increase in edge habitat could have negative effects on birds breeding in riparian buffers because these birds would be more susceptible to predation. This would be especially true for ground nesting birds (Flashpohler et al., 2001). Additionally, recent studies suggest that harvest events occurring on a watershed scale versus at the plot level are more important than buffer width at explaining lake water quality response to harvest (Prepas et al., 2001). As Parker et al. (1998) indicated, there are many miles of narrow forest ribbons designed to protect the health of aquatic systems left unharvested along streams and lakes under current buffer guidelines. These areas have not been harvested, but it is unknown whether they provide suitable long-term habitat for breeding birds.

At a regional level, we lack information to develop forest management guidelines needed to protect ecological features of riparian forests. For example, few replicated experimental harvest studies have been completed that adequately address the response of breeding bird communities to forest harvest in riparian areas (but see Parker et al., 1998; Lambert and Hannon, 2000; Pearson and Manuwal, 2001). Moreover, we are unaware of any study that examined the response of breeding birds to riparian forest harvest with different cutting practices. The whole tree harvest system is currently the most common harvest method used in northern Minnesota. With this operation, trees are felled and then skidded across the plot to a landing where they are processed. The newer cut-to-length (CTL) harvest system cuts and processes the tree without skidding. Because trees are not skidded across the plot, this system generally results in a harvest area that has less exposed organic and mineral soil and more undisturbed slash (Perry et al., 1998). More slash and ground vegetation resulting from harvest with the latter system would benefit bird species that require these structural features.

The objective of our study was to describe breeding bird response to harvest and type of harvest technique used in riparian forests. The harvest types used here were the more traditional harvest method using whole-tree grapple skidding (GPL) and harvest with the new CTL harvest equipment. Our null hypothesis was that removal of basal area to an average of 7–10 m^2/ha and type of harvest system used would not affect breeding bird communities in riparian forests. However, if an effect of forest harvest was identified, we expected that differences between treatments and controls would be larger with the traditional harvest system (GPL) because this practice resulted in a greater amount of disturbance to the understory and forest floor vegetation than the CTL harvest system.

2. Methods

2.1. Study area

We conducted the study along three tributary streams to Pokegama Lake (Pokegama Creek, Little

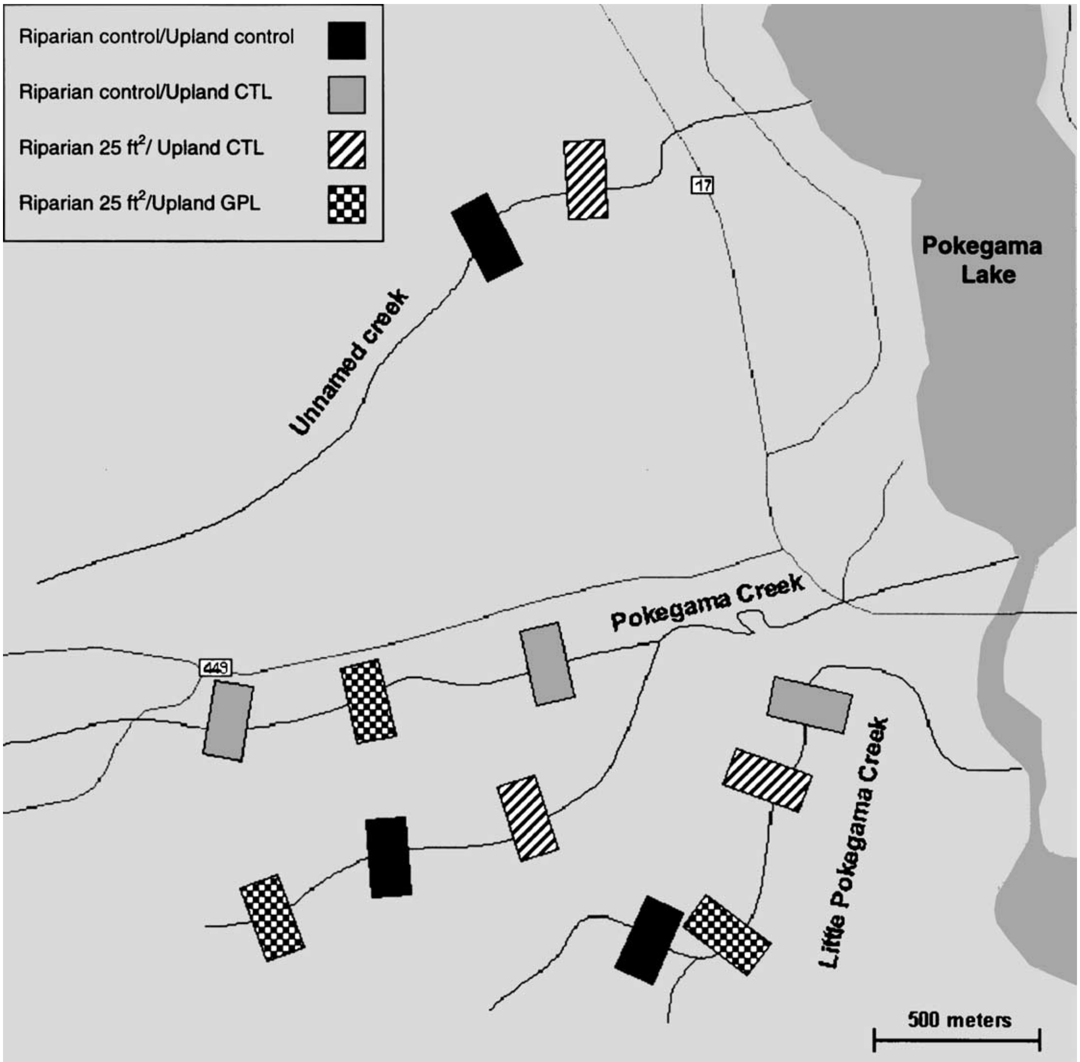

Fig. 1. Location of 12 study plots along three streams in northern Minnesota. Treatments were randomly assigned to plots.

Pokegama Creek, unnamed stream) (Fig. 1) in northern Minnesota (47′ 05″ N latitude 93′ 35″ W longitude). Dominant tree species on plots were sugar maple (*Acer saccharum*), paper birch (*Betula papyrifera*), basswood (*Tilia americana*), and quaking aspen (*Populus tremuloides*). Streams were narrow (1–3 m wide), which is typical of first- to third -order streams in this region. This area was chosen because it had a forest cover at rotation age (about 80 years of age), the stream morphology was similar along all stream reaches, and the landowner was willing to harvest stands with the designated treatment. The individual study plots (12 total) were located along three separate streams within a 2 km^2 area (Fig. 1). Study plots were 4.6 ha in size and were located along the streams such that the areas along the streams were separated from each other by at least 100 m. Biological independence, for example assuring that the same individual was not recorded on more that one plot, was accomplished by separating the plots in space (Fig. 1). Tests for independence (Moran's I) (Sokal and Oden, 1978) indicated that bird communities on adjacent plots were as independent from each other as compared with plots greater than 1 km away. Study plots for the experiment were selected in the winter of 1996–1997. All experimental plots (9 total) were harvested in late-summer of 1997.

The experimental design consisted of a randomized block design. Treatment combinations consisted of one level of over-story manipulation combined with two types of harvesting operation, whole tree harvest with GPL and CTL. Over-story treatments within riparian areas were designed to test best management practices (BMPs) for water quality in Minnesota. This included leaving an average of 6–10 m^2/ha basal area within 30 m of either side of the stream. A block of uncut riparian control plots was retained in the experimental design as well as a total control (no harvest in the study plot). Treatments were assigned to plots randomly with the restriction that a riparian harvest plot was not immediately upstream of a control plot. This was done to accommodate the water quality and aquatic components of the study (Perry et al., 1998). Adjacent uplands (outside the 30 m riparian buffers) were clearcut to make them commercially operational and also representative of normal operating conditions.

2.2. Bird surveys

We conducted three breeding bird surveys on each plot in each year from 1997 to 2000. Before-harvest data were collected on all plots in 1997 and post-harvest data were collected in 1998–2000. One survey was done in mid-May to document early breeding and permanent resident species (e.g. chickadees and woodpeckers), one in mid-June to capture peak singing of long-distance migrants, and one in early-July for the later breeding species (e.g. goldfinches). Because we were interested in documenting locations of birds relative to the stream, we used line-transects to conduct bird surveys (Hanowski et al., 1990). One line transect (300 m in length) was placed through the middle of each plot perpendicular to the stream (Fig. 2). Surveys were completed by four experienced observers who passed a bird identification test and a hearing test, and received training to standardize counts (Hanowski and Niemi, 1995). All surveys were completed during early morning hours (within 4 h of sunrise) and with good weather conditions (no rain and winds < 20 kph).

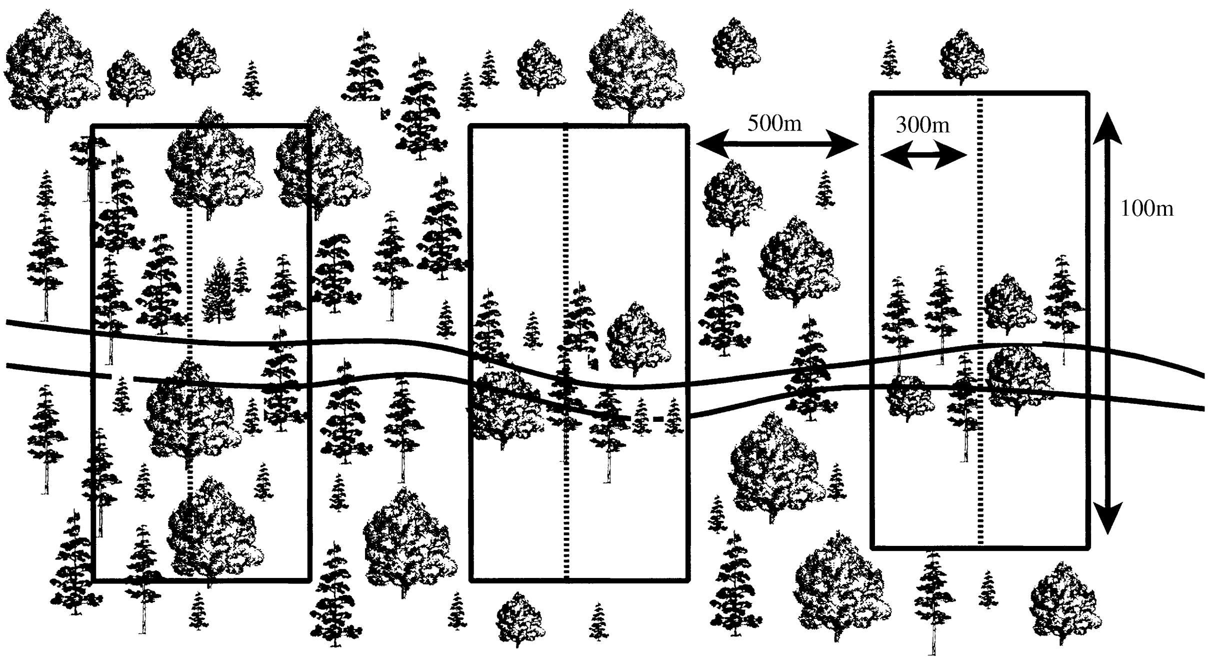

Fig. 2. Schematic of three plots indicating location of transects and stream.

2.3. Data analyses

We were interested in making general conclusions regarding breeding bird response to harvest and type of harvest system used in riparian forests in our region. In order for us to infer a causal relationship between forest harvest technique and bird responses, it would be necessary that treatments were randomly assigned to experimental units and that our riparian areas were typical for northeastern Minnesota (Stewart-Oaten et al., 1986, McDonald et al., 2000). Our replicated, before-after-control-impact (BACI) design satisfies both of these criteria. We were not interested in developing bird/habitat relationships and therefore, no vegetation data were collected.

A sample is defined as three bird surveys on a transect in a year. For each sample ($n = 48$), we generated response (dependent) variables for individual bird species abundance and for bird community parameters. Because we were primarily interested in bird response to harvest in the buffers, we used only those birds observed within the designated riparian zone (30 m) on both sides of the stream. For each species, we used the maximum count of individuals observed on either the May–July survey. We transformed all of our individual species maximum counts by in(count + 0.2) for two reasons. First, we felt that a multiplicative model had more general utility for forest bird populations (McDonald et al., 2000), and second, to correct a violation of the normal distribution of errors assumption when the data were untransformed. Species richness was calculated by tallying the number of species observed per sample. Total bird abundance per sample was calculated by summing the maximum counts for each species observed. Bird community data were generated by collating the individual species data. From the pool of 52 species observed in the riparian buffer over the 4-year-sampling period, we excluded 24 species that were present on fewer than 4 of 48 samples. This resulted in a matrix of 48 samples (rows) and 28 species (columns). The cells of the matrix contained the in-transformed maximum counts for each species.

For univariate community measures (species richness, total bird abundance) and the maximum abundance of black-throated green warbler (*Dendroica virens*), hermit thrush (*Catharus guttatus*), mourning warbler (*Oporornis philadelphia*), ovenbird, red-eyed vireo (*Vireo olivaceus*), and winter wren (*Troglodytes troglodytes*), we used repeated-measures ANOVA models in SAS (SAS Institute, 2000). We did not compute ANOVAs for all species due to the large number of zero counts (e.g. 16 species were observed on fewer than half of the samples). In BACI designs there are both before and after measurements, therefore, the interaction between treatment and time is of greater interest than both the time and treatment main effects, and it corresponds to the effect of the experimental manipulation. In all tests, subjects were individual transects, the within-subjects factor was time (year), and the between-subjects factor was treatment.

We analyzed the response of riparian bird communities to harvest and harvest type using the multivariate methods redundancy analysis (RDA) and principal response curves (PRCs) (Ter Braak and Šmilauer, 1998). These methods are preferred (over univariate methods) because they summarize all information on bird communities simultaneously, therefore, effects of experimental manipulation at the community level can be identified (Kedwards et al., 1999a, b; Van den Brink and Ter Braak, 1999). In addition, multivariate methods can accommodate the large number of sequential zeroes that are often present in ecological community data. RDA is a constrained form of principal components analysis in which variation in bird community composition is explained by a set of environmental variables (e.g. treatment type and time). For BACI designs, results of RDA are plotted in a two-dimensional ordination diagram that displays bird community trajectories through time for each treatment. PRC is a recent extension of 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). We chose to present analyses of both PRC and RDA so that graphical results could be directly compared. Although we know of no published work that has presented an analysis of bird community responses to treatment using PRC, 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).

RDA was completed in CANOCO 4 (Ter Braak and Šmilauer, 1998). Because we were interested in the effect of treatments through time, we used the product of 4 times and 4 treatments (coded as 16 individual dummy variables) as a set of explanatory variables (Ter Braak and Šmilauer, 1998). The RDA thus allowed us to partition the explained variance in the species data into that attributable to time, treatment, and their interaction. The 16 dummy variables ensured that plots with the same treatment (replicates) received identical sample scores in each year and resulted in each treatment group receiving one score along each canonical axis. By plotting scores along each canonical axis, we generated an ordination diagram that displayed differences between samples that could be explained by the explanatory variables. In the ordination diagram, the distance between two sample points in two-dimensional space is directly proportional to the compositional similarity between the two points. Bird species points in the ordination diagram are located nearer to plots on which they have greater abundance.

One problem with interpreting RDA diagrams is that changes in treatments are difficult to visualize because the plot trajectories through time do not follow a straight line. PRC overcomes this problem by focusing on the differences between species compositions of treatment and control plots at corresponding times. With PRC, the trajectory of the bird community on control plots is displayed as a horizontal line against which deviations of communities in the treatment plots are displayed.

We followed guidelines of Van den Brink and Ter Braak (1999), and Ter Braak and Šmilauer (1998) to compute the first PRC. PRC is based upon *partial* RDA, a redundancy analysis in which explanatory variables are used to explain variation in 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 nine dummy variables that consisted of all combinations of the three non-control treatments and three post-treatment times. This set of explanatory variables is a subset of variables that were used in the RDA described above, but excludes variables that denote control treatments or pre-treatment times. By excluding these variables, 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 PRC was generated by plotting the first principle component of the treatment effects against time for each treatment group.

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

The interpretation of bird species responses in the PRC diagram is aided by a line graph of species weights. In our case, a positive weight indicates an increase in abundance following harvest, while a negative weight indicates a decline. Species with weights farther from zero have increased or decreased by greater amounts than species with weights nearer zero. The quotient $\exp(b_k \times c_{dt})$, 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. See Section 3 for a worked example.

3. Results

3.1. Bird community composition

We found a significant response of the bird community to forest harvest in the riparian area based on the RDA (Fig. 3). The explanatory variables (year and treatment) accounted for 43% of the variation in the bird community data. This was significant on the first canonical axis ($P = 0.002$) as well as all canonical axes combined ($P = 0.002$). If we examine locations of treatment plots ($n = 3$ in each point) in the ordination diagram over time we can see a few patterns. First, pre-harvest bird communities on plots within all treatment groups were similar. For example, the initial point (pre-harvest information) for all treatment groups occur on the left side of the ordination space (Fig. 3). Second, control plot bird communities remained relatively stable over the 4-year-period. These plots moved around slightly in the RDA space, but occurred close together on the left side of the RDA in all 4 years of the study (Fig. 3). Uncut (riparian

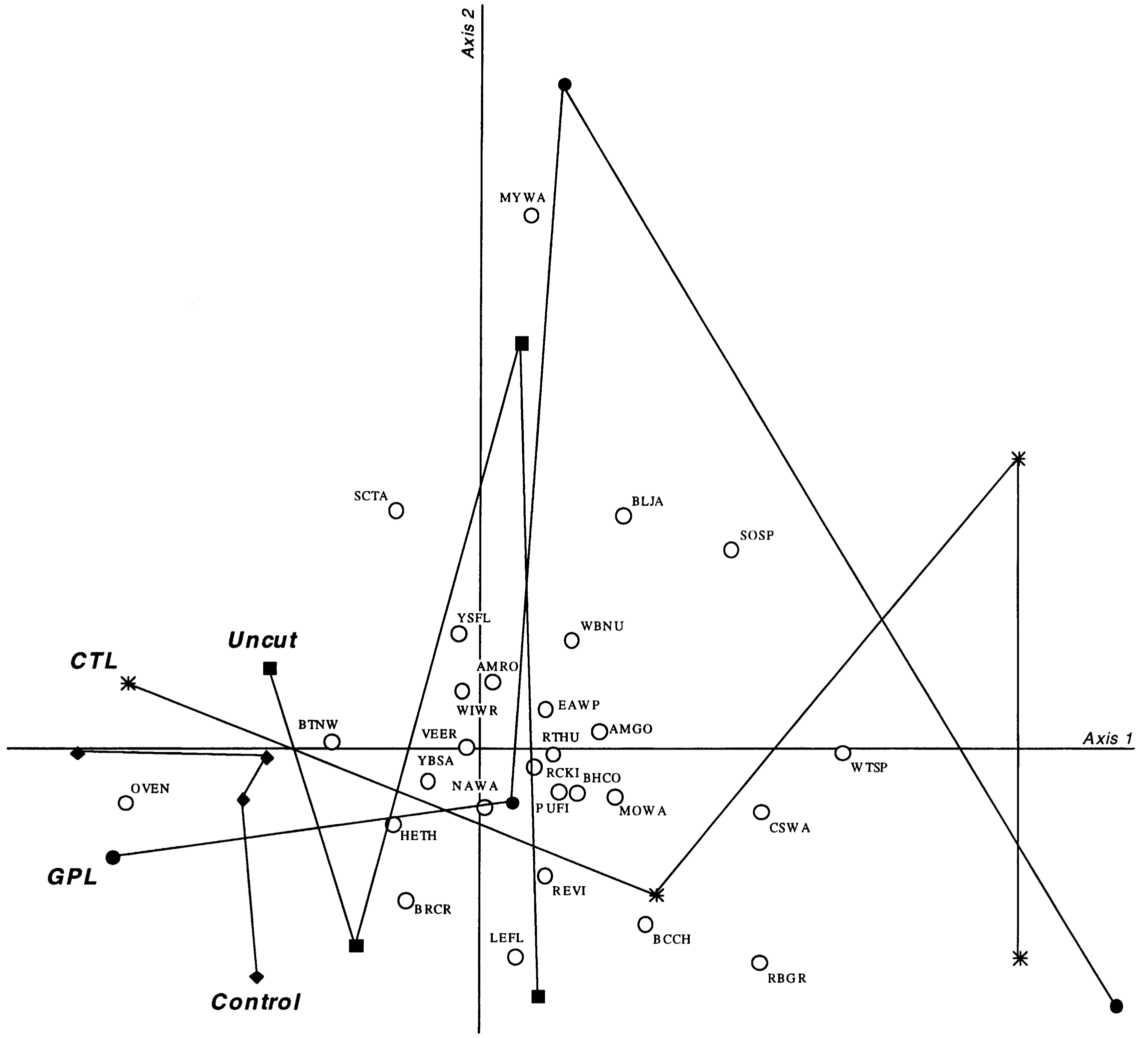

Fig. 3. Ordination diagram (redundancy analysis) indicating effects of forest harvest technique on riparian bird communities. The sampling period covered 1 year prior to treatment and three years post-treatment. Lines connect successive time periods for each treatment group, and indicate the compositional trajectory of the treatments; the label for each treatment is nearest the pre-treatment year. The interactions of time and treatment were used as explanatory variables. Of all variance in species composition, 43% can be attributed to the explanatory variables. Of this explained variance, 45% is displayed in this diagram. See Appendix A for identification of bird codes.

control) plot bird communities changed relative to control plots primarily in the second and third years after harvest (Fig. 3). Overall, bird communities were most affected by overstory tree removal with both harvest methods (Fig. 3). The bird community changed similarly on both CTL and GPL plots the first and third years after harvest, however, after the third year following harvest, bird communities were markedly similar in the CTL and GPL plots (Fig. 3).

The first PRC explained 32% of the treatment variation and was significant ($P < 0.002$). Response of the bird community along the first PRC showed that bird community composition in harvested sites deviated more from control plots (bottom line in Fig. 4) as time since harvest increased. In each year after harvest, bird communities in riparian control plots (no harvest in the riparian area) were more similar to control plots than they were to plots that

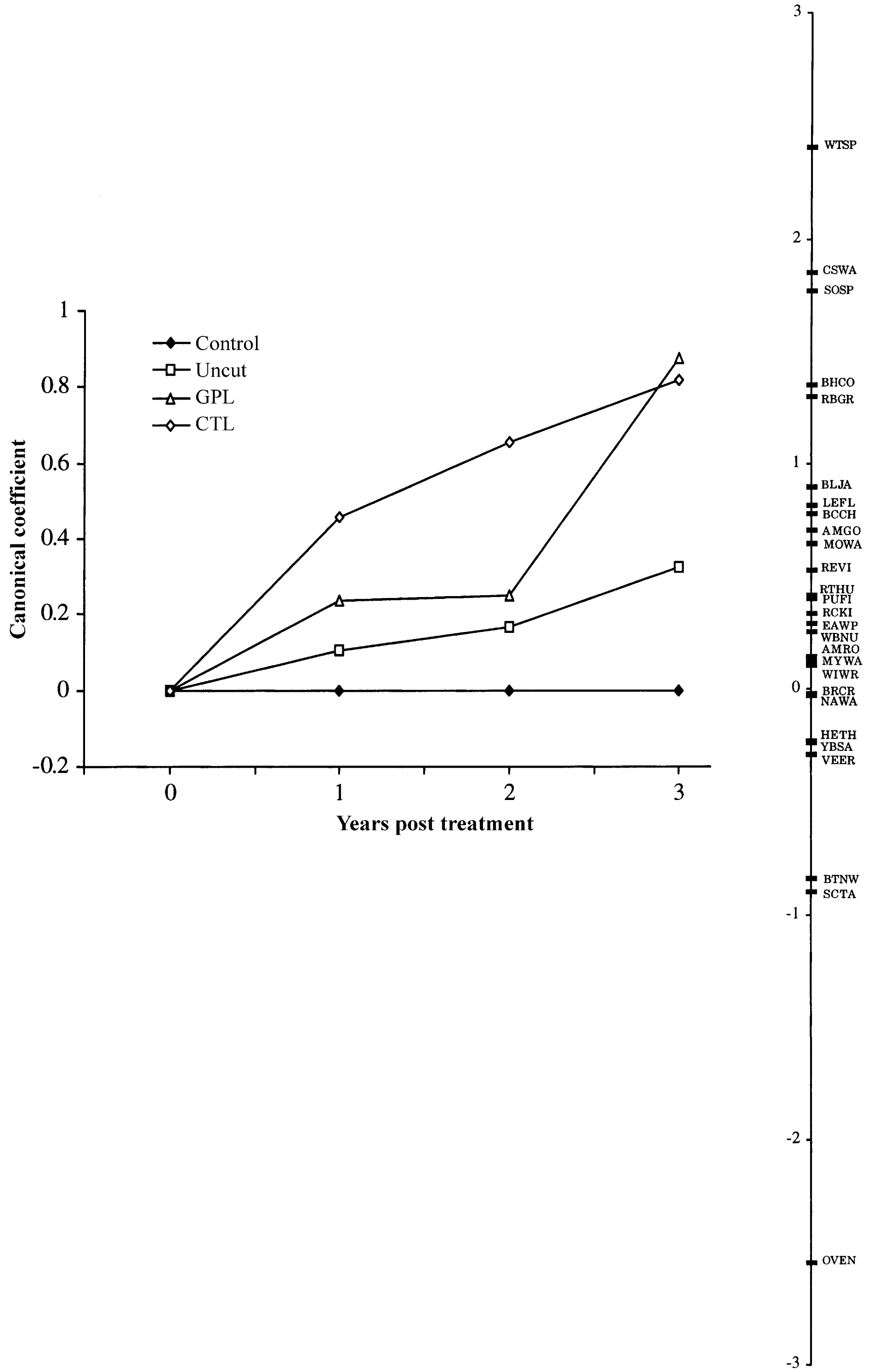

Fig. 4. First principal response curve (PRC) diagram indicating the effects of harvest technique. The vertical axis represents the first principal component of the treatment effects and explains 32% of the variation in the treatment regime ($P = 0.002$). The line graph of species weights indicates how species responded to the treatment regime (see Section 2). Appendix A lists bird codes.

were harvested (Fig. 4). In contrast, bird communities in plots harvested with GPL and CTL were most different from the control plots.

Bird species positions along the vertical axis in Fig. 4 are useful for interpreting the response of individual bird species to timber harvest. For example, the canonical coefficient of the GPL treatment at 3 years post-treatment is 0.876. For ovenbird, which has a species weight of −2.55, the change in geometric mean count is $\exp(-2.55 \times 0.876) = 0.11$. The PRC analysis thus predicts ovenbird relative abundance in GPL-harvested areas to be 11% of ovenbird relative abundance in non-harvested areas after three breeding seasons. Early-successional species like the song sparrow (*Melospiza melodia*), white-throated sparrow (*Zonotrichia albicollis*), mourning warbler, and chestnut-sided warbler (*Dendroica pensylvanica*) were associated with treatment plots (Fig. 4) along the first principal response curve. Forest species such as the scarlet tanager (*Piranga olivacea*) and black-throated

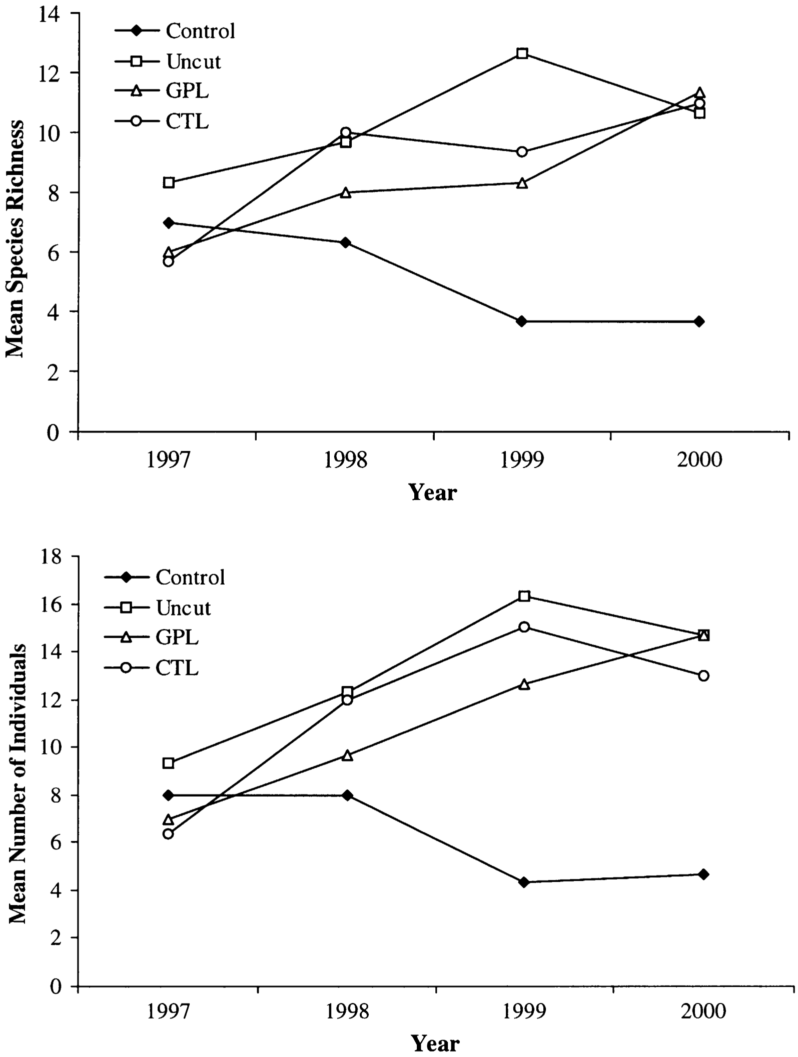

Fig. 5. Mean count of individuals (top) and species (bottom) observed on three replicate transects per treatment. Neither variable showed a significant treatment by time interaction with the repeated measures ANOVA.

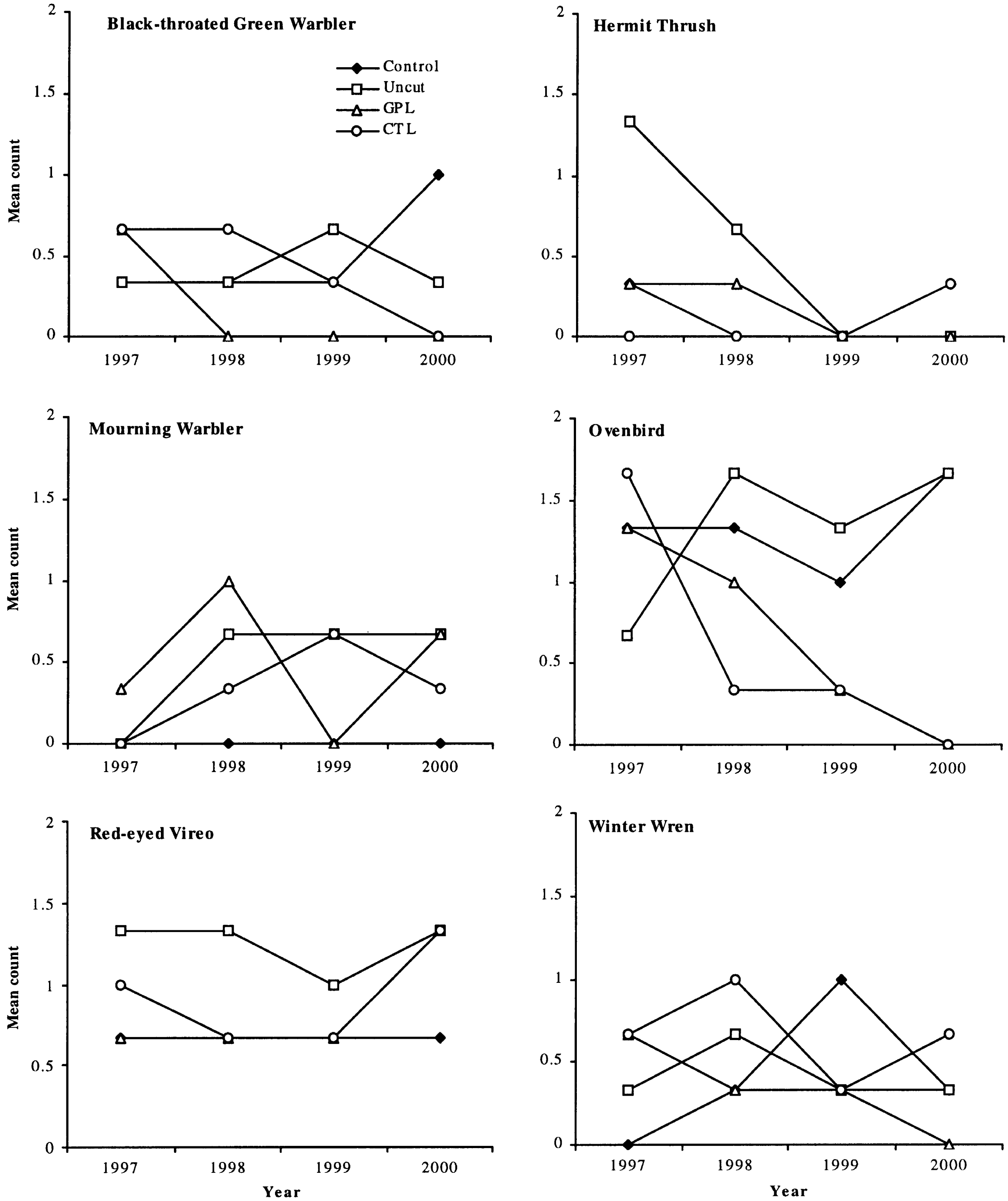

Fig. 6. Mean count of individuals observed on three replicate transects per treatment. All species were tested with repeated measures ANOVA and only ovenbird showed a significant treatment by time interaction.

green warbler were on the opposite end of the bird gradient, and were associated with control plots along the first PRC.

3.2. Bird numbers and species richness

Numbers of species and individuals on transects within treatment groups were similar before treatment (1997) (Fig. 5). After treatment, species richness and total numbers of individuals decreased in control transects and increased in all treatment transects (Fig. 4). Results from the repeated measures ANOVA did not indicate any significant differences among treatments in either total numbers of individuals or species.

3.3. Individual species response to treatment

Of six individual species tested for response of riparian harvest treatment over time, only the ovenbird showed a significant ($P < 0.03$) time by treatment interaction in the repeated measures ANOVA (Fig. 6). Numbers of ovenbirds increased over the four year time period in both control and uncut riparian plots. Numbers decreased in both the CTL and GPL plots through 2000, when no individuals were observed (Fig. 6). Response of two other forest dependent species, black-throated green warbler and hermit thrush, showed similar responses to treatment as the ovenbird, however, no significant effect was found in the repeated measures ANOVA (Fig. 6). Both species became less abundant and then absent from both the CTL and GPL plots two years after harvest. Of these three forest dependent species, the hermit thrush declined on the uncut riparian plots as well as the CTL and GPL plots (Fig. 6). Another forest dependent species, the red-eyed vireo, was not sensitive to harvest in the riparian area (Fig. 6). Numbers of individuals of this species observed over the 4-year-study either remained the same or increased on all study plots.

4. Discussion

4.1. Bird community response to harvest and harvest system

We found that bird community composition changed in response to harvest and harvest system in forests adjacent to small (1–3 m wide) streams in northern Minnesota. As expected, bird communities in the CTL and GPL treatment groups changed more relative to control plots than plots where the riparian forest was left uncut. Similar to Darveau et al. (1995), we did not find significant changes in species composition on treatment plots until the second year after harvest. In our study, bird community composition, even 3 years after harvest, continued to diverge from control plots, especially on harvested plots (both CTL and GPL).

Breeding bird composition of harvested riparian plots included more early-successional species than either control and uncut plots as time since harvest increased. This result was not unexpected because a significant amount of basal area was removed from the treated riparian forest plots and a small amount of residual basal area was left on the upland portions of the plots (about $10\ m^2/ha$) (Perry et al., 1998). Although trajectory patterns of the bird communities in the PRC were not identical on the CTL and GPL plots, type of harvest system used did not appear to impact breeding bird community composition.

Total number of individual birds and numbers of species increased on all treatment plots relative to control areas in all years after treatment. This finding agrees with results from a study in the Pacific Northwest (Pearson and Manuwal, 2001). However, unlike results presented by Darveau et al. (1995), numbers of individuals and species in our treated plots continued to increase two years after treatment and then slightly decreased in the third year after harvest. This result is likely due to two contributing factors. First, although we did not mark individuals, it is likely that forest dependent individuals occupying treated plots before they were harvested returned to the same plots the first year after harvest. In addition, individuals that were displaced by the clear-cut harvest of mature forest in the surrounding upland forest on the plots likely occupied remaining forest patches left in these riparian strips. We found this result in studies of birds occupying forests adjacent to right-of-ways the first year after the right-of-way was established (Hanowski et al., 1994). This ‘‘species-packing’’ effect was likely evident in our study plots the first year after harvest. After this time, increase in numbers of individuals and species in the harvested riparian and uncut plots was due to an increase in individuals of species associated with early-successional habitat in the CTL and GPL plots and edge species in the uncut riparian plots.

The observed decline in species richness and total bird abundance in control plots in 1999 and 2000 could be related to a variety of factors. The declines could reflect a regional decline (since 1990) that we have observed for several of the most abundant species that occurred on these plots. For example, we have observed significant regional declines for the Eastern wood-pewee (*Contopus virens*), ovenbird, winter wren, scarlet tanager and hermit thrush in northern Minnesota (Lind et al., 2001).

4.2. Individual species response to harvest and harvest type

The ovenbird was the only species that we tested that showed a significant response to harvest in the riparian areas. This response is due to the species' dependence on forests and forest interior habitat (Lambert and Hannon, 2000). Our observation that ovenbirds continued to occupy uncut riparian buffer is contrary to what has been reported for this species in Alberta. Lambert and Hannon (2000) reported that ovenbirds were absent from 20 m buffer strips and that a 100 m strip was required to sustain their populations. Although we observed ovenbirds in the uncut riparian buffers in our study, we did not assess the breeding status of individuals. For example, these individuals may be occupying the area but may not be mated. In addition, due to the narrowness of the riparian corridor, these ground nesting birds may be more susceptible to nest predation (see Paton, 1994 and Andren, 1995) and therefore not successfully reproducing.

Two other forest dependent species, black-throated green warbler and hermit thrush, responded negatively to both harvest types. The 30 m uncut buffer was adequate to maintain the black-throated green warbler but not the hermit thrush. In contrast, another forest dependent species, the red-eyed vireo, was not affected by any riparian forest treatment regime. This species nests in shrubs and saplings which were not removed during harvest.

The winter wren was the only species that appeared to be affected by type of harvest system, being more abundant in CTL than GPL plots. This species occurs in forests that have coarse woody debris or upturned trees, which it requires for nesting habitat (Roberts, 1932). Because the GPL harvest method involves whole-tree skidding and trees are processed at landings, less slash is left on the sites. In contrast, the CTL harvest system processes trees where they are felled, no skidding is required, and more slash is left on the plot (Perry et al., 1998). The use of CTL results in less disturbance to the ground and under story vegetation (Perry et al., 1998).

4.3. Study design and implementation

Field studies to test hypotheses regarding biotic response to harvest or harvest systems in riparian areas are difficult to complete for several reasons. For example, it is difficult to find large forest areas adjacent to streams within small watersheds so that treatments can be replicated. In addition, because ownership of forest land is fragmented, it is difficult to locate large areas of similarly aged forests with the landowners willing to participate in an experiment. Our study, with three replicates per treatment, had a similar number of replicates as previous studies. For example, two replicates were used in New Brunswick, five replicates in Quebec, four or five replicates in Alberta, and five or six in the Pacific Northwest (Pearson and Manuwal, 2001). The most significant problem with low replication is that statistical tests will usually have low power. Therefore, the ability to develop standards and guidelines for forest management practices are difficult. One way to remedy the problem of low power with univariate tests is to conduct multivariate community response statistics. We used a newly developed method (PRC) that allowed us to examine effects of treatment on bird communities. The graphic output of PRC was useful to depict changes that occurred over time in treatment groups and also allowed us to illustrate which species were most responsible for differences. For example, univariate tests for the ovenbird indicated that this species responded negatively to canopy removal in the riparian area with both GPL and CTL harvest systems. The ovenbird is located at the bottom of the species weights in the diagram of the PRC indicating the most positive association with the control and uncut buffer plots (Fig. 4).

The PRC method could be a useful analytical method in management response studies where it is not feasible to have a high number of replicates. Our test was significant for the first PRC axis and illustrated response of the bird community to harvest types and systems that are biologically meaningful. From the PRC diagram we can predict which species are sensitive to riparian treatments studied, here including the ovenbird, scarlet tanager, black-throated green warbler, veery, yellow-bellied sapsucker (*Sphyrapicus virus*), and hermit thrush (bottom of Fig. 4). Species that responded positively to removal of canopy from the riparian area included several early-successional species such as the white-throated sparrow, chestnut-sided warbler, song sparrow, and rose-breasted grosbeak (*Pheucticus ludovicianus*). Individual species in the middle of Fig. 3 are those that are less likely to tolerate canopy removal, but that could occupy a narrow uncut riparian buffer.

Acknowledgements

This project was funded by Minnesota's Forest Resources Council and National Council for Air and Stream Improvement. We thank UPM-Blandin Corporation for access to their property. Thanks to Rita Hawrot and Tom Savre for helping with the bird surveys.This is contribution number 312 of the Center for Water and the Environment of the Natural Resources Research Institute.

Appendix A

Common names for species depicted by their abbreviations within Figs. 3 and 4.

AMGO	American goldfinch
AMRO	American robin
BCCH	Black-capped chickadee
BHCO	Brown-headed cowbird
BLJA	Blue jay
BRCR	Brown creeper
BTNW	Black-throated green warbler
CSWA	Chestnut-sided warbler
EAWP	Eastern wood-pewee
HETH	Hermit thrush
LEFL	Least flycatcher
MAWA	Magnolia warbler
MYWA	Yellow-rumped warbler (myrtle)

Appendix A. (*Continued*)

NAWA	Nashville warbler
OVEN	Ovenbird
PUFI	Purple finch
RBGR	Rose-breasted grosbeak
RCKI	Ruby-crowned kinglet
REVI	Red-eyed vireo
RUGR	Ruffed grouse
RTHU	Ruby-throated hummingbird
SCTA	Scarlet tanager
SOSP	Song sparrow
VEER	Veery
WBNU	White-breasted nuthatch
WIWR	Winter wren
WTSP	White-throated sparrow
YSFL	Yellow-shafted flicker
YBSA	Yellow-bellied sapsucker

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