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Response of breeding bird communities to forest harvest around seasonal ponds in northern forests, USA

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Abstract

We examined response of breeding bird communities to varying levels of timber harvest in and around 16-forested seasonal ponds in northern Minnesota, USA. This experimental study employed a before-after-control-impact design with three different harvest treatments. Treatments were assigned randomly ($n = 4$ ponds/treatment) and were applied within 17 m wide buffers outward from the ponds' edge: clear-cut harvest (reduction of basal area to <2 m^2/ha), partial cut harvest (reduction of basal area to 7–10 m^2/ha), and no harvest (no cut). Forest stands around treatment buffers ($n = 12$) were clear-cut harvested (ranging from 6.5 to 12.5 ha). Ponds with no harvest in the adjacent forests (controls) or buffers surrounding the ponds ($n = 4$) were maintained throughout the 5-year study. Prior to harvest, we found no significant difference ($P > 0.05$) in bird community composition around seasonal ponds versus nearby forest habitat, suggesting that seasonal ponds do not affect bird community structure in a mature forest setting at this scale. Overall bird numbers and species richness increased ($P < 0.05$) in all pond buffers compared to controls over the 4 years after harvest. Increases in bird numbers on treated versus control pond buffers were found across all migration and nesting guilds, and among the forest edge guild. Bird community species composition also changed within the treated versus control pond buffers after harvest. Differences in bird communities among treatments were small the first year after harvest, but continued to diverge from controls over the 4 years after harvest. Bird communities of the clear-cut treatment were most dissimilar to controls. Both the partial and no cut buffer bird communities were more similar to the control than the clear-cut treatment. Treated pond buffers had more birds associated with early successional habitat. In contrast, many interior forest-associated bird species did not occur in any of the buffers after harvest. We found no difference in breeding bird community composition between pond buffers and other residual patches left on harvested sites, but there was a significant difference between harvest treatments when we combined pond buffer and residual patch birds on each site. Early successional habitat-associated bird species were more abundant in residual patches on sites that had a clear-cut pond buffer and forest-associated species were more abundant in residual patches on sites with no cut pond buffers. Habitat for mature forest-associated bird species can be maintained on harvest sites by leaving no cut or partial cut buffers around seasonal ponds or in similar sized residual patches in other areas of the harvest.

Keywords: Breeding bird communities; Forest harvest; Seasonal ponds

1. Introduction

Small wetlands and seasonal ponds (implies an ephemeral hydroperiod) are important landscape features that provide habitat and contribute to the diversity of woodland animals, including amphibian species such as the wood frog (*Rana sylvatica*) and blue-spotted salamander (*Ambystoma laterale*) (Roble and Kitteridge, 1991; DiMauro and Hunter, 2002; Lichko and Calhoun, 2003; Baldwin, 2005). Little scientific attention has been given, however, to the potential ecological role that these ponds have in conserving breeding and migratory bird populations. While it has been shown that temporary ponds and wetlands provide food for migrating shorebirds and waterfowl in California (Silveira, 1998), and that beaver ponds in forest landscapes provide important habitat for both breeding and migrating birds (Edwards and Otis, 1999), many wetlands and seasonal ponds in a forested matrix may be too small to provide sufficient habitat for wetland-associated breeding bird species such as the wood duck (*Aix sponsa*) (Sousa and Farmer, 1983). Small, temporary ponds may be important as local food sources for both breeding and migrating individuals due to the presence of emerging insects from the ponds and to fruit from

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shrubs that grow in riparian areas adjacent to the ponds. In addition, diversity in vertical habitat structure associated with canopy gaps around seasonal ponds in a forested landscape may be important for avian species such as the least flycatcher (*Empidonax minimus*) that requires an open subcanopy for foraging (Breckenridge, 1956; Briskie, 1994).

Few or no studies have documented the utilization of small seasonal ponds in a forested landscape by breeding or migrating birds or the effects of forest management in and around seasonal ponds on these species. Forested riparian areas associated with streams, rivers, and lakes are important to migrant birds and breeding bird species richness and overall bird abundance is higher in forests adjacent to water (Wegner, 1999; Hanowski et al., 2003). When harvest occurs in forest areas with seasonal ponds, it is likely most critical to protect the integrity of the wetland by maintaining hydroperiod and wetland-associated habitat features. Current forest management guidelines in Minnesota seek to maintain seasonal pond integrity by limiting slash deposit and movement of harvest equipment through these areas to prevent rutting (Roble and Kitteridge, 1991; Minnesota Forest Resources Council, 1999). In addition, guidelines recommend that all or a portion of residual trees left remaining on a site during harvest should be concentrated within 17 m around open water wetlands or seasonal ponds (Minnesota Forest Resources Council, 1999). Residual trees surrounding ponds should maintain microclimate conditions (e.g. lower ambient temperature and higher humidity) in and around these ponds, but their habitat value to breeding birds has not been documented.

Previous studies in northern Minnesota found that residual patches of forest left on clear-cut harvest sites provided valuable contributions to forest bird diversity, especially patches >1 ha (Merrill et al., 1998). If landowners follow current forest management guidelines and leave trees in buffers around seasonal ponds, fewer residual trees and patches could be left on other areas of the harvest site, while harvesting a similar amount of wood from a site. The trade-off, in terms of maintaining a mature forest component on a harvest site by retaining a portion of the site in residual patches around seasonal ponds versus patches in other areas of the harvest site has not been studied.

This study was designed to determine how forest management on harvest sites with seasonal ponds should be designed to maintain a mature forest breeding bird component on harvest sites. We first asked whether breeding bird communities adjacent to seasonal ponds in a mature forest setting were different than bird communities in similar forest types without seasonal ponds. Secondly, we conducted a forest harvest experiment that asked how varying levels of forest management in forest buffers around seasonal ponds affected breeding bird community composition. Finally, we compared breeding bird composition of seasonal pond forest retention buffers and

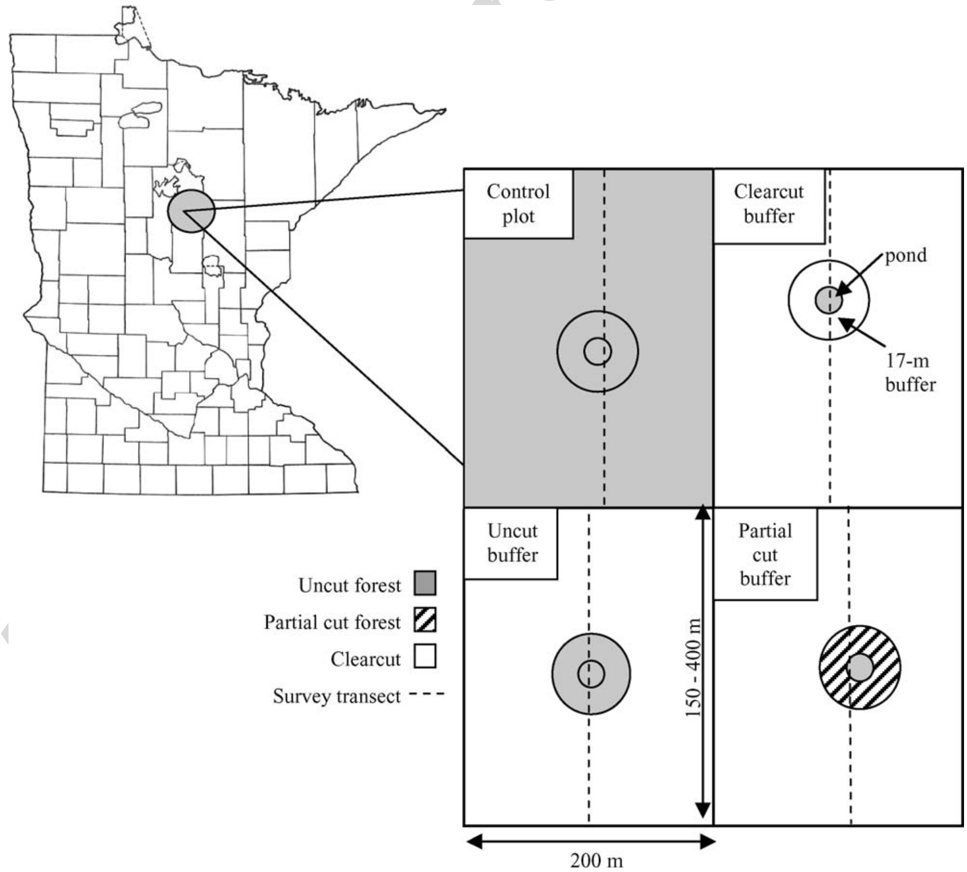

Fig. 1. Location of study area in northern Minnesota and general schematic of one of the four blocks of seasonal ponds, survey transects, and treatments that were applied. Clear-cuts surrounding treatment buffers ($n = 12$) ranged from 6.5 to 12.5 ha.

residual patches not associated with seasonal ponds on the same site to determine how each contributes to breeding bird composition and diversity on the site.

2. Methods

2.1. Study area and experimental design

Sixteen seasonal ponds were selected for study in Cass and Aitkin Counties in northern Minnesota (46°50–57′ N, 93°40′–94°05′W) in deciduous forests approaching rotation age (about 60 years). To minimize potential bias due to differences in overstory species composition, each study plot was established in a similar upland mixed forest stand dominated by sugar maple (*Acer saccharum*) and quaking aspen (*Populus tremuloides*). Black ash (*Fraxinus nigra*) trees were present within the ponds. Ponds were from 0.2 to 0.5 ha in size and had ephemeral water; wet in the spring after snowmelt and becoming drier during the summer months. Four ponds were grouped in four blocks within a study area of approximately 20,000 km^2. The four blocks were separated by 4–30 km, and the four ponds within each block were separated by 200–2500 m.

We employed a before-after-control-impact (BACI) experimental design, with 1 pre-treatment year and 4 post-treatment years (Stewart-Oaten et al., 1986). Each experimental unit consisted of three elements: a pond, a 17 m buffer around the pond, and the forest matrix (ranging from 6.5 to 12.5 ha) surrounding the pond and buffer (Fig. 1). The forest matrix surrounding three randomly-selected ponds in each block was clear-cut up to the buffer; pond buffers in these three units were randomly assigned one of three treatments: no cut, partial cut (reduction of basal area to 7–10 m^2/ha), or clear-cut (reduction of basal area to <2 m^2/ha). Both the forest matrix and the buffer surrounding the fourth pond in each block were left uncut and served as a control. All harvesting occurred between the summers of 2000 and 2001.

2.2. Bird surveys

Three bird surveys were conducted on each unit 1 year before harvest (2000) and in each year for 4 years after harvest (2001–2004). The first survey was conducted in mid-May to document early breeding species, primarily resident species (e.g. chickadees and woodpeckers). The second survey, completed in mid-June, was during the peak-breeding season for migrant bird species, and the third survey, in early-July, documented the later breeding species (e.g. goldfinches). Surveys were completed by experienced individuals who had passed a bird identification test, hearing test, and received training (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).

Because we were interested in documenting locations of birds relative to the ponds, we used a line transect survey to conduct the counts (Hanowski et al., 1990). Transects were 200 m fixed-width (100 m on each side) and ranged from 150 to 400 m in length. The position of the pond varied in relationship to transects on each site, but transects always went through or were immediately adjacent to the pond. Residual patches of tree and single trees in the clear-cut matrix were retained at variable locations along transects. We conducted 5 min counts at the start and endpoints of each transect, and at 100 m intervals along transects. We also recorded individuals encountered while we walked between survey points. Data sheets were scaled to the dimension of each transect and we documented the exact position of all individuals observed, noting whether they occurred in the pond complex, residual patch or tree, or the forest matrix. Individuals not recorded in pond complexes (pond area and buffer), or residual patches or trees were not included in the analyses.

2.3. Statistical analysis

To examine how seasonal ponds in a mature forest setting influenced breeding bird community composition, we used data collected on each study site in the pre-harvest year (2000). On each completed field data sheet, we centered a 1 ha square on the seasonal pond and located a paired 1 ha square in the adjacent forest in a random direction at a distance greater than 100 m from each pond ($n = 32$ total squares). For each square, we compiled the maximum count of each species observed within the square over three visits. We ran blocked multi-response permutation procedure (MRPP) in PC-ORD (McCune and Mefford, 1999) to test whether species composition was different on pond-centered squares versus random forest squares using site as a blocking factor. We tested for a block effect (differences in bird community composition across the four study areas) using unblocked multi-response permutation procedure.

We evaluated univariate responses of bird guilds to post-harvest residual basal area in buffers using generalized estimating equations (GEEs) in SAS Proc GENMOD (SAS Institute, 2000). GEEs are used in BACI designs to account for within-subject correlation through time (McDonald et al., 2000). Dependent variables were compiled for each experimental unit as the maximum count of three visits for each species observed (using only birds observed within the ponds and pond buffers), summed across all species in each of nesting, migration, and habitat guilds. We used guilds because it was not possible to compare abundance of individual species because of the small sample size for each year. Species were assigned to guilds based on published literature sources (Ehrlich et al., 1988; Freemark and Collins, 1992; Hanowski et al., 2003). Guild analysis allowed us to examine response of species that have similar life history strategies to various harvest levels in buffers around seasonal ponds. We transformed the dependent variables with $\ln + 1$ to satisfy assumptions of normally distributed residuals and homoscedasticity. One ANOVA was completed for each guild (nest, migration, habitat) with four levels of treatment (control, no cut, partial cut and clear-cut).

We evaluated the bird community response to post-harvest residual area in buffers using principal response curves (PRC) in CANOCO (ter Braak and Šmilauer, 1998). This method summarizes information on bird communities simultaneously, and therefore, effects of experimental manipulation at the community level can be identified (Kedwards et al., 1999a,b; Van den Brink and ter Braak, 1999). PRC is a recent extension of redundancy analysis 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; Sibley et al., 2001; see Hanowski et al., 2003, 2005 for more details and examples).

We used MRPP and correspondence analysis on bird community data to determine how bird community composition differed between seasonal pond forest retention buffers, residual patches, and single residual trees left during harvest. For these analyses we used bird data collected only in the last year of the study (2004) because this year represented the biggest change in bird communities in treatments compared to control pond buffers. The first test compared pond and residual patch bird communities on the same site ($n = 10$ pairs, as we did not compare control plots and two sites had no residual patches). In the second test, we pooled birds observed in pond buffers and residual patches on the same site and tested for an overall treatment due to harvest effect.

3. Results

3.1. Pond and random square forest birds

There was no difference in bird community composition between forests around seasonal ponds and random forest squares (Table 1), suggesting that seasonal ponds do not influence bird community composition in the mature forest setting that we studied in northern Minnesota at the small site level scale that we analyzed.

Table 1
Results of blocked multi-response permutation procedure comparing forest bird community composition on 1 ha squares centered on seasonal ponds to bird composition on randomly located 1 ha squares of forest

Test group	Number of species	A[a]	P-value
All species	28	−0.002	0.534
Species ≥ 2 sites	19	−0.004	0.562
Species ≥ 3 sites	12	−0.014	0.759

Study area ($n = 4$) was blocked in the analysis and there were four replicates per block. Tests were completed three times with a different number of species included dependent upon their occurrences on the sites.

[a] A is the chance-corrected within-group agreement, a descriptor of within-group homogeneity compared to the random expectation. When A is negative, there is less homogeneity within groups than expected by chance.

Table 2
Results of multi-response permutation procedure that compared forest bird community composition between study areas ($n = 4$ sites per area)

Test group	Number of species	A[a]	P-value
All species	46	0.144	0.0004
Species ≥ 2 sites	32	0.153	0.0004
Species ≥ 3 sites	27	0.162	0.0004

Tests were completed three times with a different number of species included dependent upon their occurrences on the sites.

[a] A is the chance-corrected within-group agreement, a descriptor of within-group homogeneity compared to the random expectation. When A is positive, there is more homogeneity within groups than expected by chance.

3.2. Treatment differences among guilds

There was a significant difference in bird community composition between study areas (Table 2), and because of this, we blocked study areas in analyses of treatment effects. The treatment by year interaction was significant ($P < 0.001$)

Table 3
Back-transformed least square mean number and percent change in abundance from 2000 (pre-treatment) to 2004 (4 years post-treatment) for bird community and guild metrics on control, clear-cut, partial cut, and no cut pond buffers associated with seasonal ponds in northern Minnesota ($n = 4$ in each group)

Bird metric	Treatment	2000	2004	% change
Species richness	Control	1.4	3.2	139
	Clear-cut	2.5	8.2	234
	Partial cut	1.9	8.6	349
	No cut	2.6	10.3	299
Total individuals	Control	1.7	3.9	121
	Clear-cut	2.9	9.5	223
	Partial cut	2.5	11.7	374
	No cut	2.8	14.7	419
Edge birds	Control	0.6	1.4	158
	Clear-cut	0.9	4.7	449
	Partial cut	0.9	3.9	358
	No cut	1.0	5.6	456
Forest interior birds	Control	0.6	1.1	98
	Clear-cut	1.2	1.6	34
	Partial cut	0.7	3.1	357
	No cut	1.5	2.5	62
Long-distant migrants	Control	1.0	3.4	244
	Clear-cut	2.7	6.4	141
	Partial cut	2.0	7.8	295
	No cut	2.6	9.2	258
Permanent residents	Control	0	0	
	Clear-cut	0	0.3	
	Partial cut	0	0.5	
	No cut	0	0.3	
Short-distant migrants	Control	0.5	0.5	0
	Clear-cut	0.2	2.5	1204
	Partial cut	0.5	2.1	315
	No cut	0.2	4.6	2027
Canopy nesters	Control	0.1	0.5	1808
	Clear-cut	0	0.2	
	Partial cut	0.2	0	
	No cut	0	2.2	
Cavity nesters	Control	0	0.4	
	Clear-cut	0.2	0.4	118
	Partial cut	0.5	0.9	73
	No cut	0.1	1.2	9289
Ground nesters	Control	1.0	0.8	−19
	Clear-cut	1.5	2.9	102
	Partial cut	0.7	3.6	419
	No cut	1.4	2.3	61
Shrub nesters	Control	0.7	2.2	228
	Clear-cut	0.9	4.9	467
	Partial cut	0.9	5.6	552
	No cut	1.2	7.5	513

Percent change was not calculated for metrics when the 2000 or 2004 mean value was zero.

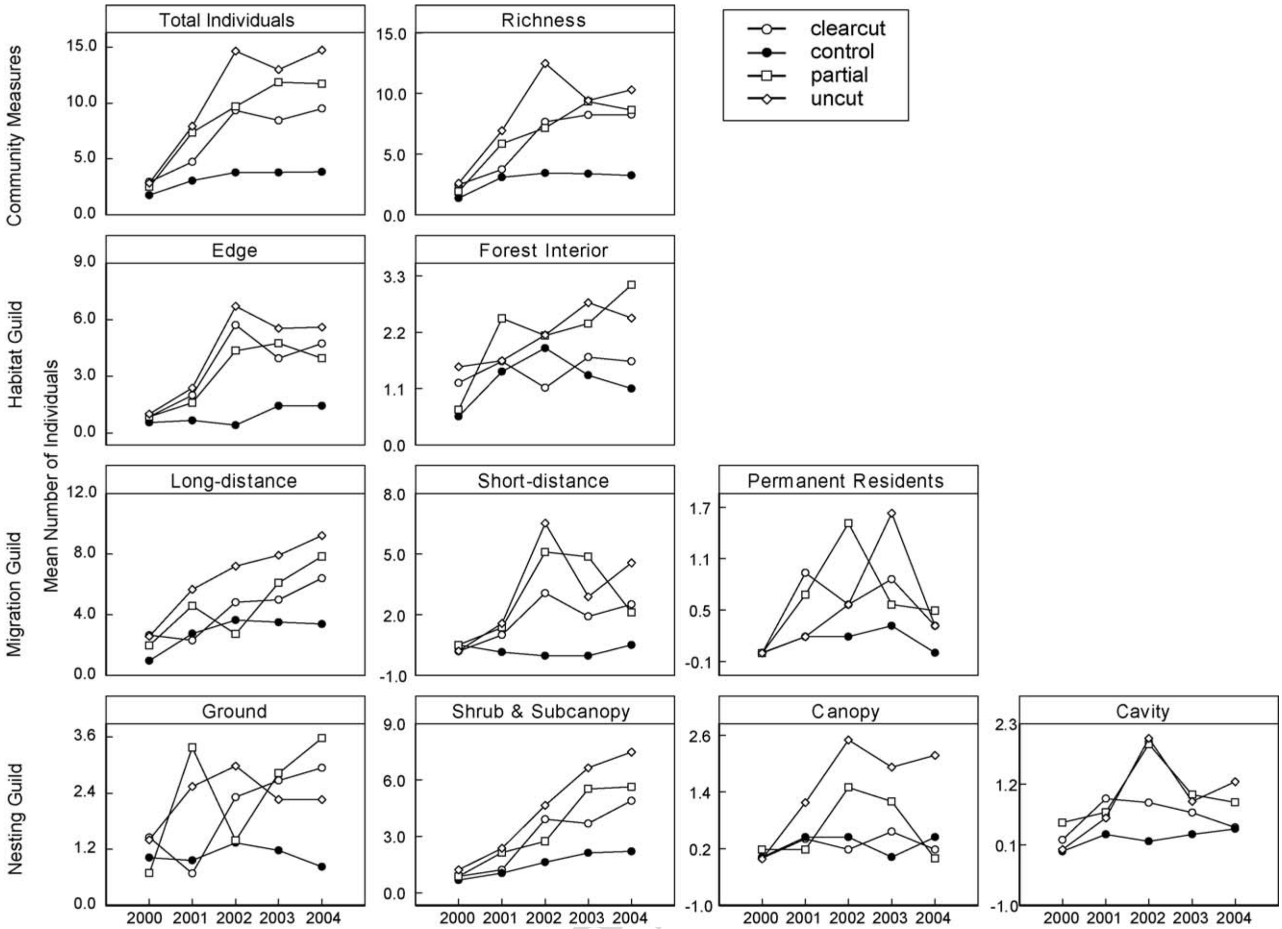

Fig. 2. Back-transformed mean number of individuals per survey for 1 pre- and 4 post-treatment years for total individuals, species and bird habitat, migration and nesting guilds. The treatment effect is significant for all responses except forest interior ($P < 0.05$ for permanent residents but $P < 0.0001$ for all others). The treatment × year interaction is significant ($P < 0.0001$) for all responses.

for all guild response variables indicating that the influence of treatment on guild composition was not consistent across years. In most cases, the significant interaction indicated that the harvested sites became more different from controls through time; that is, the difference was in the magnitude, not direction of change between treatment groups in each year (Fig. 2). For most guilds, the clear-cut and partial cut treatments diverged a greater distance from the control as time proceeded (Fig. 2).

Overall bird numbers and species richness increased ($P < 0.001$) in all pond buffers compared to controls over the 4 years after harvest regardless of treatment type (Fig. 2). Increase in species richness from 2000 to 2004 was highest in the partial cut buffers and bird numbers increased by over 400% from 2000 to 2004 in the no cut pond buffers (Table 3). Increases ($P < 0.001$) in bird numbers on treated versus control buffers were evident for all migration guilds (Fig. 2). The largest percent increase among migrant groups from pre- (2000) to post-harvest (2004) was observed for short-distant migrant birds in the clear-cut and no cut buffers (Table 3). Individuals of edge species (see Appendix A) were higher in all treatment groups than in the control group (Fig. 2), but no difference ($P > 0.05$) was detected for birds that prefer forest interior habitat between treatments. Numbers of birds that are associated with forest edge habitat increased >350% from 2000 to 2004 in all pond buffers regardless of treatment (Table 3). The increase in overall bird numbers in pond buffers was also equally distributed among bird nesting guilds. Ground, shrub and subcanopy, canopy, and cavity nesting birds all increased ($P < 0.01$) in treatment buffers of all types compared to controls after treatment harvest was applied (Fig. 2 and Table 3).

3.3. Treatment differences among communities

The first axis of the PRC was significant ($P < 0.01$) and explained 29% of the variation in bird communities among treatments (Fig. 3). Compositional differences among treatments were small the first year after harvest, but communities continued to change relative to the controls over the 4 years after harvest. Clear-cut treatment bird communities were most dissimilar to controls. The partial and no cut buffer bird communities were similar to each other and more like the controls than the clear-cut buffer treatment communities. In general, birds associated with early successional habitat, such as gray catbird (*Dumetella carolinensis*), chestnut-sided

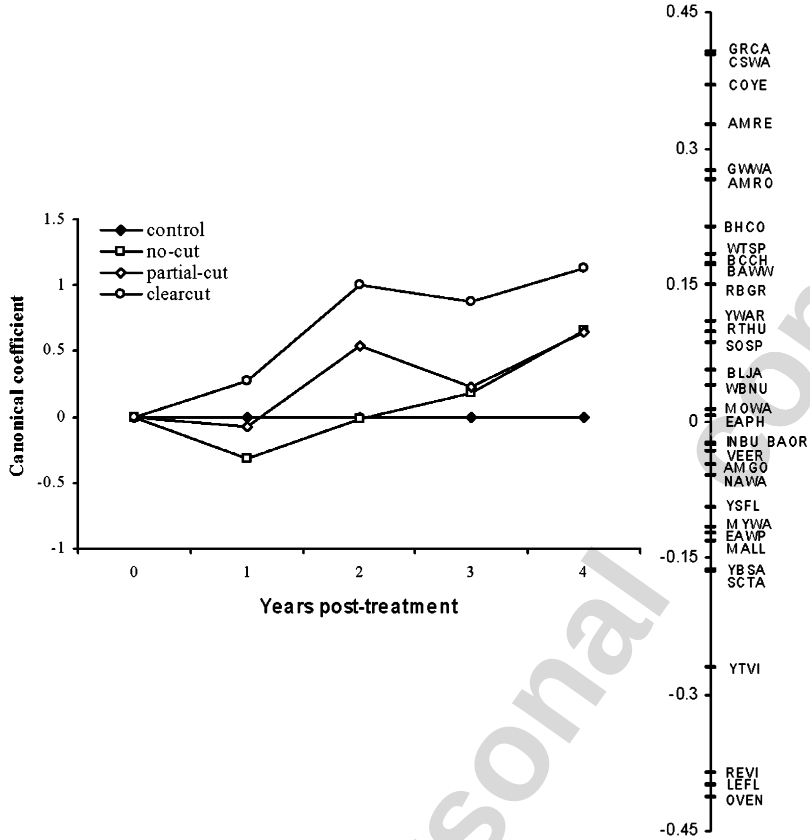

Fig. 3. First principle response curve (PRC) diagram with species weights for birds on the vertical axis. Influence of harvest treatment is indicated by curves that depart from the reference condition (control). The vertical axis represents 29% of the variation in the treatment regime and is significant ($P = 0.001$).

warbler (*Dendroica pensylvanica*), common yellowthroat (*Geothlypis trichas*), American redstart (*Setophaga ruticilla*) and golden-winged warbler (*Vermivora chrysoptera*) were more abundant in all treated buffers than in the control buffers. These species had positive weightings on the first PRC axis (Fig. 3). In contrast, mature forest bird associated species such as ovenbird (*Seiurus aurocapilla*), least flycatcher (*Empidonax minimus*), yellow-throated vireo (*Vireo flavifrons*), and red-eyed vireo (*Vireo olivaceus*) were less abundant in treated buffers (especially the clear-cut and partial cut) after harvest was applied. These species had negative weightings on the first PRC axis (Fig. 3).

The second PRC axis was also significant ($P < 0.005$) and explained an additional 27% of the variation in bird communities due to harvest treatment. This axis primarily separated bird communities in the no cut buffer from the control buffers. There were more American goldfinch (*Carduelis tristis*), rose-breasted grosbeak (*Pheucticus ludovicianus*) and eastern wood-pewee (*Contopus virens*) in the no cut pond buffers after harvest compared to the control buffers, but fewer common yellowthroat, black-capped chickadee (*Poecile atricapillus*), gray catbird, and ovenbird. It is important to note that species weightings on the negative side of the second PRC were lower in magnitude than species weightings on the positive side. This indicates that the largest response or difference in treatment bird communities relative to controls was in abundance of species on the positive side of the response axis (e.g. American goldfinch and rose-breasted grosbeak) (Fig. 4).

3.4. Differences among residual patch and pond buffer bird communities

We found no difference in breeding bird community composition when we compared pond buffers to residual patches on the same harvest site, but there was a significant difference ($P < 0.008$) between harvest treatment types when we pooled pond and residual patch birds on each site. Harvest sites that had clear-cut buffers were grouped together on the right side of the ordination diagram and had more early successional species such as alder flycatcher, common yellowthroat, yellow warbler (*Dendroica petechia*), and American robin (*Turdus migratorius*). Harvest sites (no cut buffers) on the left side of the ordination had more forest-associated birds such as the eastern wood pewee, white-breasted nuthatch (*Sitta carolinensis*) and blue jay (*Cyanocitta cristata*) (Fig. 5). Pond buffer and residual patches on harvest sites that received partial cut treatment were grouped below the first axis and had more ovenbirds, mourning warblers (*Oporornis philadelphia*) and yellow-bellied sapsuckers (*Sphyrapicus varius*) (Fig. 5). With one exception (residual patch in the upper right quadrant of Fig. 5), bird species

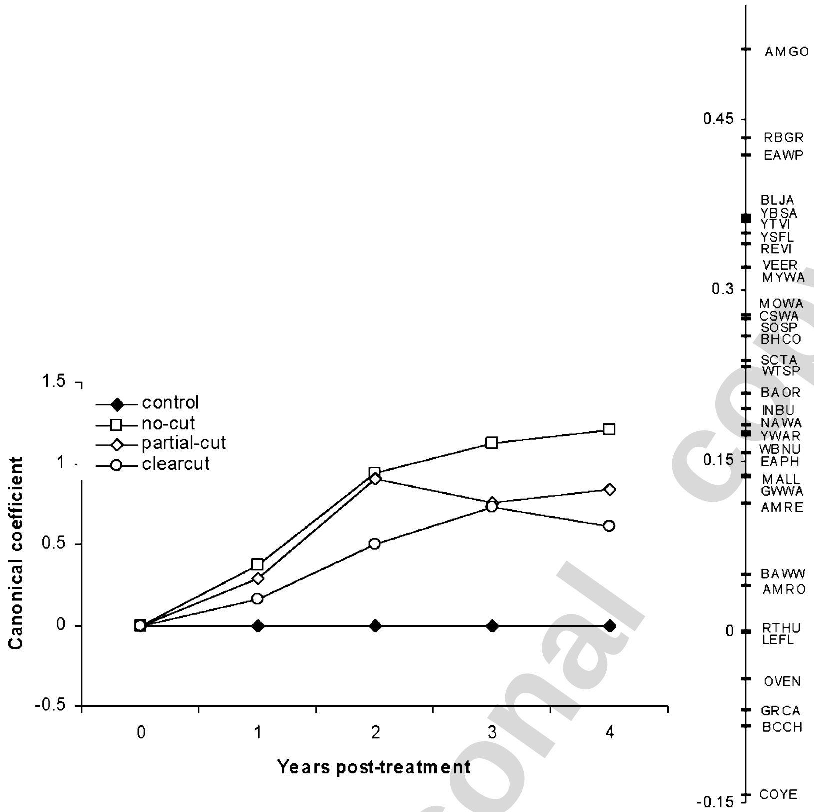

Fig. 4. Second principle response curve (PRC) diagram with species weights for birds on the vertical axis. Influence of harvest technique is indicated by curves that depart from the reference condition (control). The vertical axis represents 27% of the variation in the treatment regime and is significant ($P = 0.005$).

composition of residual patches on sites that had clear-cut harvest were more similar to both pond buffer and residual patch bird communities that had either no cut or partial cut treatments. In general, bird communities in pond buffers treated with the clear-cut harvest stood out as having different species composition than any of the other pond buffer treatment types or any of the residual patch bird communities, regardless of the treatment that the pond buffer received.

4. Discussion

Information provided by this study provides an initial understanding of the ecological importance of seasonal ponds in a northern forest setting to breeding forest bird communities and their response to varying amounts of basal area removed in buffers around these ponds. Our study addressed only the response of breeding bird communities to various harvest treatments and not effects of treatments on breeding bird productivity.

4.1. Do seasonal ponds attract a unique breeding bird community?

A first step in developing forest management recommendations for harvest around seasonal ponds in this region is to understand the contribution that these ponds may have to forest bird diversity. In this study, we found no difference in bird communities between forested areas surrounding seasonal ponds and random forested areas away from seasonal ponds before harvest. This result suggests that forests in the immediate vicinity of seasonal ponds do not contribute uniquely to bird community composition in northern forests. The lack of an observed difference may be partially explained by the relatively small size of seasonal ponds that we studied, the landscape context of our study area, or to the low statistical power. All of the ponds that we studied were less than 1 ha in size and were likely too small to provide habitat for breeding waterfowl. We observed three species of ducks during the 4 years (4 wood duck, 9 mallard (*Anas platyrhynchos*), and 1 hooded merganser (*Lophodytes cucullatus*)). Wood ducks, a forest wetland breeding species requires wetlands that have deeper water and are greater than 4 ha (Sousa and Farmer, 1983). There are many small wetlands and seasonal ponds in northern Minnesota and individually each pond may not provide unique or distinctive habitat for birds in this region. In landscapes where there are fewer ponds, individual ponds may be more important to both breeding and migrating birds in the region (Silveira, 1998).

Past forest management activities on sites we studied may also partially explain the lack of observed difference between breeding bird communities around seasonal ponds and adjacent forests. Forests that we studied were historically a northern hardwood type (Almendinger et al., 2000) and have been clear-cut harvested on at least two rotations. The stands were approximately 60 years of age when they were harvested for this study. Due to past clear-cut harvest treatments, quaking

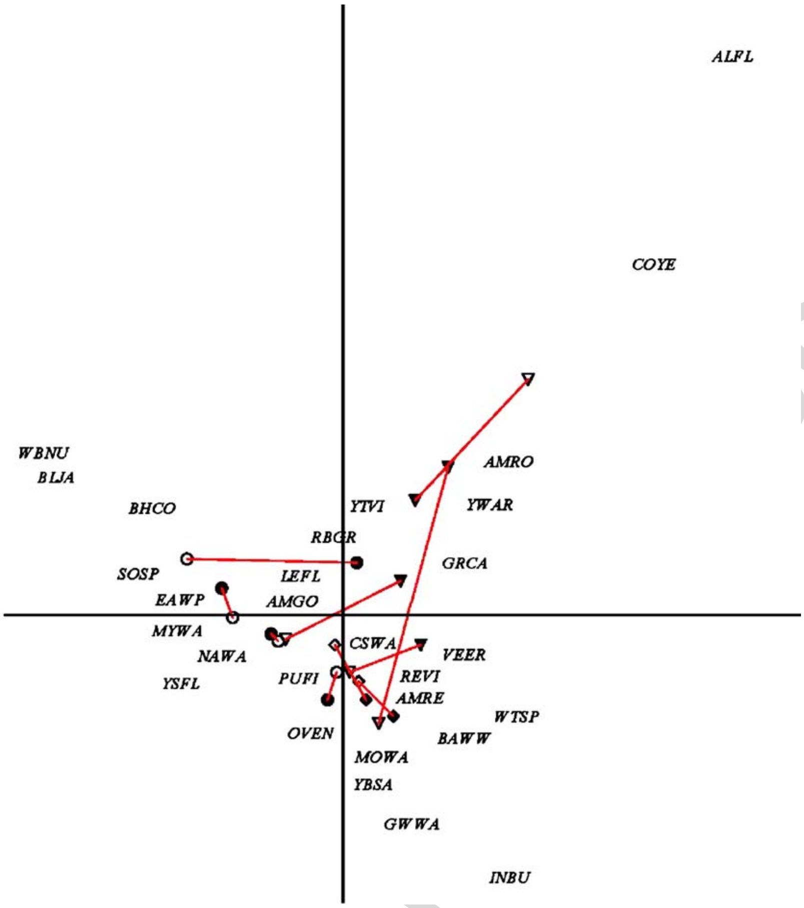

Fig. 5. Correspondence analysis diagram for residual patch and pond bird communities on 10 sites (control sites and two sites that did not have residual patches were excluded). Twelve species (of 41) present on fewer than two records were excluded. Closed symbols indicate ponds, open symbols indicate residual patches. Lines connect the pond and residual patch at each site. Triangles, clear-cut; circles, no cut; diamonds, partial cut.

aspen has become the dominant over-story tree species and current stand structure is less diverse both floristically and structurally (Mladenoff and Pastor, 1993). Forests around seasonal ponds in this region may have historically been important breeding habitat for larger bodied cavity nesting birds such as the pileated woodpecker (*Dryocopus pileatus*) which were subsequently used by secondary cavity nesting species (e.g. wood duck). However, due to the relatively young tree age, these stands may not have adequate cavity trees for this and other species that require large diameter trees for nesting. Retaining residual trees in buffers around seasonal ponds during harvest in the current rotation would have longer term benefits for cavity nesting species, especially if longer lived and wind resistant tree species were left standing in the buffers.

4.2. Effect of harvest treatment on breeding bird community composition

As expected, different harvest levels in buffers around seasonal ponds impacted breeding bird communities differently. The clear-cut treatment resulted in the biggest change to the bird community, followed by the partial cut treatment. Bird communities in the no cut buffers were most similar to controls. Bird species that either colonized or remained in seasonal pond buffers after harvest responded to amount of basal area left in the buffers. This result is similar to what we found in two previous forest harvest experiments in riparian forests along small streams in northern Minnesota (Hanowski et al., 2003, 2005). In those studies, more early successional bird species occurred in clear-cut buffers, however, no forest-associated bird species occurred in any riparian buffers in those studies 2–3 years after harvest, regardless of the amount of basal area removed. In this study, patches of residual forest around seasonal ponds and forest patches left in other parts of the harvest continued to provide habitat for some forest-associated bird species 4 years after harvest. Our results are similar to what Merrill et al. (1998) found in their study of the importance of residual patches to forest bird diversity in clear-cuts in northern Minnesota. The patches they studied continued to support forest-associated bird species such as ovenbird, veery, black-throated green warbler, and rose-breasted grosbeak 4–9 years after harvest. The difference in results between this study and our previous studies in riparian buffers along narrow streams could be attributed to the shape and size of residual patches. Forest riparian buffers along streams are long and linear and have more edge habitat (defined as the area of uncut forest adjacent to a recently harvested forest) and little or no forest interior habitat. In contrast, riparian buffers around seasonal ponds and residual patches on harvest sites are generally non-linear and, if large enough, will likely have some interior forest habitat.

4.3. Comparison of breeding bird composition of seasonal pond buffers and residual patches

An important consideration to landowners when applying forest management guidelines to harvest sites is the negative economic consequence of leaving additional residual material on the site. Current site level forest management guidelines in Minnesota recommend that seasonal ponds and wetland inclusions be protected during harvest. Slash should not be moved into wetlands or seasonal ponds, and harvest equipment should not cross these areas. In addition, guidelines recommend leaving up to 5% of the harvest area as legacy patches or as single trees to provide structural and biological diversity in future forests (Minnesota Forest Resources Council, 1999). We found that bird communities responded similarly to residual patches left on a harvest site and to buffers left around seasonal ponds. Therefore, if the management goal is to provide continued habitat for forest breeding bird species on a harvest site, location of residual patch on the site is apparently not important (either away from or around a seasonal pond). However, because buffers around seasonal ponds may protect micro-climate condition of ponds for aquatic invertebrates, plants and vertebrate species (especially frogs and salamanders), until response of these organisms to harvest level in buffers are documented, it may be preferential to leave residuals around seasonal ponds.

5. Conclusion

Results of this study conducted in northern Minnesota indicate that residual patches of forests left either around seasonal ponds or in other areas of the harvest site will provide habitat for some forest-associated bird species. These results will likely have application to similar mixed deciduous tree species stands in landscapes that have seasonal ponds. No cut buffers around seasonal ponds provided the most intact habitat for forest species and the partial cut buffers were used by a subset of forest bird species that were less sensitive to partial canopy removal. Conversely, early successional bird species were prevalent on study sites with the clear-cut buffer treatment. Residual patches increased bird diversity on harvest sites compared to sites with no patches.

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Appendix A. Guild assignments and common and scientific names with codes of bird species depicted in Figs. 2–5

Common name	Scientific name	Code	Nest type	Migration type	Edge/interior
Alder flycatcher	*Empidonax alnorum*	ALFL	Shrub or subcanopy	Long distance	Edge
American goldfinch	*Carduelis tristis*	AMGO	Shrub or subcanopy	Short distance	Edge
American redstart	*Setophaga ruticilla*	AMRE	Shrub or subcanopy	Long distance	Edge
American robin	*Turdus migratorius*	AMRO	Shrub or subcanopy	Short distance	Edge
Baltimore oriole	*Icterus galbula*	BAOR	Canopy	Long distance	Edge
Black-and-white warbler	*Mniotilta varia*	BAWW	Ground	Long distance	Interior
Black-capped chickadee	*Poecile atricapillus*	BCCH	Cavity	Permanent resident	Not used
Blue jay	*Cyanocitta cristata*	BLJA	Canopy	Permanent resident	Not used
Brown-headed cowbird	*Molothrus ater*	BHCO	Not used	Short distance	Edge
Chestnut-sided warbler	*Dendroica pensylvanica*	CSWA	Shrub or subcanopy	Long distance	Edge
Common yellowthroat	*Geothlypis trichas*	COYE	Ground	Long distance	Not used
Eastern phoebe	*Sayornis phoebe*	EAPH	Shrub or subcanopy	Short distance	Not used
Eastern wood-pewee	*Contopus virens*	EAWP	Canopy	Long distance	Not used
Golden-winged warbler	*Vermivora chrysoptera*	GWWA	Ground	Long distance	Edge
Gray catbird	*Dumetella carolinensis*	GRCA	Shrub or subcanopy	Long distance	Not used
Indigo bunting	*Passerina cyanea*	INBU	Shrub or subcanopy	Long distance	Edge
Least flycatcher	*Empidonax minimus*	LEFL	Shrub or subcanopy	Long distance	Interior
Mallard	*Anas platyrhyncos*	MALL	Ground	Short distance	Not used
Mourning warbler	*Oporornis philadelphia*	MOWA	Ground	Long distance	Edge
Myrtle (yellow-rumped) warbler	*Dendroica coronata*	MYWA	Canopy	Short distance	Interior
Nashville warbler	*Vermivora ruficapilla*	NAWA	Ground	Long distance	Edge
Ovenbird	*Seiurus aurocapillus*	OVEN	Ground	Long distance	Interior
Purple finch	*Carpodacus purpureus*	PUFI	Canopy	Short distance	Not used
Red-eyed vireo	*Vireo olivaceus*	REVI	Shrub or subcanopy	Long distance	Not used
Rose-breasted grosbeak	*Pheucticus ludovicianus*	RBGR	Shrub or subcanopy	Long distance	Not used
Ruby-throated hummingbird	*Archilochus colubris*	RTHU	Canopy	Long distance	Edge
Scarlet tanager	*Piranga olivacea*	SCTA	Canopy	Long distance	Interior
Song sparrow	*Melospiza melodia*	SOSP	Ground	Short distance	Edge
Veery	*Catharus fuscescens*	VEER	Ground	Long distance	Interior
White-breasted nuthatch	*Sitta carolinensis*	WBNU	Cavity	Permanent resident	Interior

Appendix A (*Continued*)

Common name	Scientific name	Code	Nest type	Migration type	Edge/interior
White-throated sparrow	*Zonotrichia albicollis*	WTSP	Ground	Short distance	Edge
Yellow warbler	*Dendroica petechia*	YWAR	Shrub or subcanopy	Long distance	Edge
Yellow-bellied sapsucker	*Sphyrapicus varius*	YBSA	Cavity	Short distance	Not used
Yellow-shafted flicker	*Colaptes auratus*	YSFL	Cavity	Short distance	Not used
Yellow-throated vireo	*Vireo flavifrons*	YTVI	Canopy	Long distance	Not used

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