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Effects of Off-channel Wetland Restoration on Breeding Bird Communities

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Abstract: Channelization of rivers and streams threatens bottomland forest bird communities because it results in channel incision and can lead to the formation of lateral gullies that connect streams to adjacent wetlands and drain the wetlands when water levels in the stream drop below flood stage. These adjacent forested wetlands may fill during spring floods and be attractive breeding habitat for birds, but the unnaturally rapid draining of the wetlands early in the breeding season may expose some birds to high rates of nest predation. I studied how the hydrologic restoration of off-channel wetlands (plugging gullies that drain off-channel wetlands) affects the diversity, abundance, and nesting success of birds breeding within forested wetlands within the Cache River watershed in Illinois. I compared surface area, water depth, bird diversity, bird densities, and nesting success between treatment (gully plugs added) and control (gully plugs not added) wetlands pre- and post-treatment. During the breeding season of birds, treatment wetlands retained more surface area and greater depths of water compared to control wetlands. Bird diversity was unaffected by the installation of gully plugs. The density and nesting success of prothonotary warblers (*Protonotaria citrea*) was higher in treatment wetlands than in control wetlands. Other species associated with forested wetlands (yellow-throated warblers, *Dendroica dominica*; wood ducks, *Aix sponsa*; and yellow-crowned night-herons, *Nyctanassa violacea*) also increased in number within the treatment wetlands. Documenting changes in the bird community in response to this conservation action provides a means to measure the success of restoration activities in the Cache River watershed and inform conservation plans and restoration efforts in other bottomland forest ecosystems.

Key Words: breeding birds, hydrology, prothonotary warbler, nesting success, wetland restoration

INTRODUCTION

Bottomland forests are a prime example of an ecosystem in peril, because in the U.S. only about 20 percent remains of an historical area of over 100 million ha and the loss of bottomland hardwoods is nearly five times greater than for any other major hardwood forest type (Abernethy and Turner 1987, Gosselink and Lee 1989). In bottomland forest ecosystems, hydrology is the ecosystem process responsible for modifying and perpetuating the habitat within the system (Pashley and Barrow 1993). The interplay of topography and hydrology creates and maintains this complexity of habitats and promotes high levels of biodiversity (Huffman and Forsythe 1981, Kozlowski 2002). Intact bottomland forest ecosystems are important habitats for many species of bird (Twedt et al. 1999, Wakeley et al. 2007) and are especially valuable because they support a high diversity and density of breeding Neotropical migratory birds (Wakeley and Roberts 1996, Sallabanks et al. 2000).

Populations of breeding birds continue to be threatened by the fragmentation and degradation of natural habitats (Wilcove et al. 1998, Askins 2000). In addition to the negative effects of forest fragmentation (e.g., increased brood parasitism by cowbirds and increased nest predation; Hoover et al. 1995, Robinson et al. 1995), populations of birds breeding in bottomland forests are threatened by the alteration and degradation of “natural” hydrologic processes (Hoover 2006). Channelization of streams and rivers has led to channel incision and the subsequent destruction and degradation of stream corridor habitats (Shields et al. 1998 and references therein). Channel incision is a worldwide issue (Giller 2005), but is particularly prevalent in warmwater streams of Southeastern U.S. Channel incision often leads to the formation of lateral gullies that connect the main channel of streams to adjacent (off-channel) wetlands, draining the wetlands (Shields et al. 1998). This process degrades off-channel wetlands and threatens the integrity of bottomland ecosystems and the quality of bottomland forests as breeding habitat for Neotropical migratory birds (Pashley and Barrow 1993, Sallabanks et al. 2000).

Stream channelization in Cache River watershed in southern Illinois has led to channel incision in the Cache River. This channel incision has caused the formation of lateral gullies that are currently de-watering (draining) more than 20 off-channel wetlands (forested wetlands adjacent to the main river channel). The unnaturally rapid de-watering of off-channel wetlands in bottomland forest ecosystems may expose birds breeding in these habitats to nest predators like raccoons (*Procyon lotor* Linnaeus) (Hoover 2006), and alter the plant community in ways that reduce bird diversity (Wakeley and Roberts 1996). Recent advances in the science of river and stream restoration have led to the development of weirs to slow the rate of channel incision and subsequently reduce lateral gullying (Shields et al. 1998, Bhuiyan et al. 2007). In the Cache River watershed, conservation practitioners have implemented a habitat management action to restore several off-channel wetlands. Twenty-four riffle weirs have been placed in the main channel of the Cache River since 2002 and more than 10 lateral gullies have been plugged. The habitat management practice of plugging lateral gullies should alter (make more “natural”) the hydrologic processes of the off-channel wetlands attached to the gullies. The restoration of these hydrologic processes is paramount to the successful restoration of the bottomland forest ecosystem (Sparks et al. 1998).

The purpose of this study was to document the effects of gully plugs on the hydrological attributes of, and breeding bird community within, off-channel forested wetlands. Specifically, I studied 10 control (no gully plug added) and 10 treatment (gully plug added) off-channel wetlands during pre- and post-treatment periods to determine the effects of gully plugs on 1) the surface area and water depth of off-channel wetlands during two months of the breeding season of birds, 2) the diversity of birds present during the breeding season, 3) the density of each species of bird present during the breeding season, and 4) the nesting success of prothonotary warblers (scientific names of birds given in Table 3 and Appendix 1), a forested wetland specialist.

METHODS

Study Area

This research was conducted within the Cache River Watershed (CRW) located in southern Illinois, USA (Fig. 1). The Cache River has a total length of 176 km and meanders through the southern tip of Illinois to the Ohio River, draining 1,537 km^2 of land. Study sites (20) were isolated forested off-channel wetlands (wetlands hereafter) located within a 4 km^2 portion of the watershed. All individual study sites were within 800 m of the Cache River (Fig. 1) and their hydrologic fluctuations were influenced to varying degrees by within-channel (river) water depth, runoff from adjacent lands following localized rain events, and the draining of wetlands by lateral gullies that connect the wetlands to the river channel. Within the entire watershed, these wet forested habitats were embedded in a landscape consisting primarily of agriculture (32%), grassland/pasture (31%), upland forest (26%), and bottomland forest (9%).

Each of the 20 wetlands was connected to the main river channel by a lateral gully during 2002-2004. These lateral gullies ranged in size from 14 m wide and 6m deep to 3 m wide and 2 m deep. Similar to other wetlands in this watershed that are not connected to the river by lateral gullies, the 20 study wetlands filled during winter and spring flood events. However, once the water in the river channel dropped below flood stage, the wetlands connected to lateral gullies would rapidly diminish in size (e.g., 50% reduction in size in just 2 weeks). The lateral gullies associated with ten of the wetlands were plugged (plugs consisted of a combination of rock, sediment cloth and soil) at the river channel during the winter of 2004, thereby preventing the de-watering of the wetlands by the gullies. The gully plugs were designed to not affect the maximum capacity of wetlands, but rather their ability to retain the water that accumulates in them during flood and rain events. These ten wetlands served as treatment (gully plugs added) sites. The lateral gullies associated with the other ten wetlands were not plugged and these wetlands served as control (gully plugs not added) sites.

Measuring Wetland Attributes

Measuring Wetland Area: During each year of the study (2002-2007), the surface area (measured to the nearest 1/100 ha) of each of the 20 off-channel wetlands was estimated by averaging four measurements taken over a 2-month period (May-June). The four measurements of surface area were taken during the first and third weeks of both May and June. Measuring surface area over a 2-month period was more appropriate than just measuring the maximum area of each wetland in a given year because a) the 2-month period corresponds with the peak of the breeding season of birds in this location and b) gully plugs were designed to not affect the maximum capacity of wetlands, but the ability of wetlands to retain water. To measure surface area, I used a GARMIN GPS unit to record the location of the perimeter of each wetland. I then used the GARMIN software (MAPSOURCE) to plot the perimeter of each wetland on paper. A 10-m x 10-m grid (scaled to the plotted wetlands) was placed over each plotted wetland and the number of cells (each cell representing 1/100 ha) comprising the wetland was recorded. I then determined the effect of gully plugs on the surface area of these wetlands by comparing pre-treatment to post-treatment values for the 10 treatment (gully plugs added) and 10 control (gully plugs not added) wetlands.

Measuring Water Depth: I determined the average water depth for each of the 20 wetlands every year. Within each wetland, I established five measuring stations by randomly choosing nest box locations from the pre-established nest box grid (see monitoring nesting success below). I then used a meter-stick to measure the depth of water at each station during the first and third weeks of both May and June (four measurements per station per year) yielding 20 water depth values per wetland each year. I then determined the effect of gully plugs on the average water depth of these wetlands by comparing pre-treatment to post-treatment values for the 10 treatment (gully plugs added) and 10 control (gully plugs not added) wetlands.

Bird Surveys

From 2002 through 2007, I used 5-min point counts, one count per year, to sample breeding birds in the control and treatment wetlands (Ralph et al. 1995, Hamel et al. 1996). Point counts were conducted during mid-May through mid-June at permanently marked sampling points spaced at least 150-m apart. One sampling point was located in the center of each wetland, and four wetlands were large enough to establish a second point that was at least 150 m away. Only birds seen or heard within 50 m of the sampling point were used in these analyses and counts were averaged over the pre-treatment and post-treatment periods within the control and treatment wetland groups. Counts were made in the morning, generally between a half-hour and 10:00 local standard time. Counts were not made on mornings when it rained or when wind speeds exceeded 10 mph. Each point count yielded the number of species present (diversity) as well as the number of individuals present within a particular species (density). The use of common names is well established in the ornithological sciences (American Ornithologists' Union 1998); therefore, common names are used throughout the text. Scientific names with full authorities of birds detected in this study are listed in Table 3.

Monitoring Nesting Success

Focal Species. The Prothonotary Warbler is a migratory bird that winters in the Neotropics and breeds in forested wetlands throughout much of the eastern half of the United States (Petit 1999). This species is territorial and socially monogamous, nests in secondary cavities, and associates closely with standing water in forested wetlands. Prothonotary warblers prefer to nest over water (Petit and Petit 1996), readily use nest boxes when available (Blem and Blem 1994, Hoover 2003), and can be studied in great detail during the breeding season (Petit and Petit 1996, Hoover 2006). Nesting success in nest boxes is similar to that in natural cavities, and accurately represents the levels of reproductive success they achieve during the breeding season (Hoover 2003, 2006). Raccoons are the primary nest predator for this species and rates of nest predation decrease with an increase in water depth below warbler nests (Hoover 2006). Nests over water that is deeper than 45 cm (1.5 ft) are particularly successful.

Monitoring Nest Boxes. Nest boxes were made from 1.9-liter (half-gallon) milk and juice cartons (Petit 1989) placed approximately 1.7 m above ground on trees on grids with 30-m spacing between boxes within each of the 20 forested wetlands (Hoover 2003). Nest boxes were monitored every 4 days from April through July. During each visit, I documented whether or not there was an active nest in the box, and for active nests recorded the exact contents (e.g., number of eggs or nestlings) of the box and the identity of the adult warblers using it. Nests were visited more frequently (every 1-2 days) around the time when nestlings were fledging in order to get accurate measures of reproductive output. I knew the fate of each nesting attempt (e.g. failure caused by a nest predator, or success) within these wetlands. The identity of the nest predator responsible for any nesting failure was determined (based on the condition of the nest and its contents; Hoover 2006) for every such event.

Capturing and Banding Birds. Each year, all individual adult warblers nesting within the 20 wetlands were captured and color-marked with a unique combination of a numbered aluminum (United States Fish and Wildlife Service; USFWS) leg band and multiple colored plastic leg bands (Hoover 2003). Males were captured using a mist net, decoy, and taped playback of a male song. Females were captured while in the nest box incubating their eggs. I observed individuals throughout each breeding season and recorded, for each warbler, nest-site location(s) and the number of fledglings produced. Prothonotary warbler nestlings were banded with a USFWS aluminum band when they were 9-10 days old (approximately 1 to 2 d before fledging from the nest box).

Data Analyses

Wetland Surface Area. To determine the effect of gully plugs on the surface area of wetlands, I recorded the average surface area for each of the 20 wetlands during the pre-treatment and post-treatment periods. I divided post-treatment values by pre-treatment values to estimate the proportion change in size of each wetland between the two periods. For the response variable I used the proportion change in surface, rather than change in area, so that no wetland (larger versus smaller) would have a disproportionate effect on the analysis. I then used a one-tailed two-sample t-test (assuming unequal variances) to test the prediction that the proportion change in surface area would be greater for treatment (gully plugs added) than for control (no gully plugs added) wetlands. Three gully plugs failed (i.e. were blown out by an unusual flood event) during the post-treatment period (two after the first year and one after the second year), and for these three treatment wetlands I included surface area measurements only from those post-treatment years when the gully plugs were still in place.

Wetland Water Depth. To determine the effect of gully plugs on the depth of water within wetlands, I recorded the average water depth for each of the 20 (10 control and 10 treatment) wetlands during the pre-treatment and post-treatment periods. I then used a single factor analysis of variance (ANOVA; SYSTAT 2000) to determine if water depth varied significantly between all four categories. If there was a significant difference between all categories, I used two-tailed t-tests to make pairwise comparisons between groups. Nominal P-values for the multiple comparisons were Bonferroni-adjusted based on the number of comparisons made to guarantee that the family comparison error rate was not larger than the critical value of 0.05 (SYSTAT 2000). I included information on water depth from the three treatment wetlands where gully plugs failed only from those post-treatment years when the gully plugs were still in place.

Diversity of Breeding Birds. Each point count was placed into one of four categories (pre- or post-treatment, control or treatment wetlands) and the number of species detected at each point (diversity) was determined. I then used a single factor analysis of variance (ANOVA; SYSTAT 2000) to determine if diversity varied significantly between all four categories. If there was a significant difference between all categories, I used two-tailed t-tests to make pairwise comparisons between groups (nominal P-values for the multiple comparisons were Bonferroni-adjusted).

Densities of Breeding Birds. There were 23 species that occurred at enough of the point count locations (>10%) to be included in the density analyses. Each point count was placed into one of four categories (pre- or post-treatment, control or treatment wetlands) and, for each of the 23 species separately, the number of individuals detected at each point was determined. The number of individuals detected per point (density) was 0, 1, 2, 3, or 4. This response variable is categorical rather than continuous. Therefore I used a Kruskal-Wallis test (SYSTAT 2000) for each species to determine whether density differed between the four categories of wetland. If there was a significant difference between all categories, I used multiple Mann-Whitney U tests to make pairwise comparisons between categories (nominal P-values for the multiple comparisons were Bonferroni-adjusted).

Nesting Success of Prothonotary Warblers. I documented the outcome of every nesting attempt of prothonotary warblers within the four categories of wetland including the number of nests that were preyed upon. I used a chi-square test to determine whether the frequency of nest depredation differed between all categories of wetland, and if there was a significant difference between all categories, I then used multiple chi-square tests to make pairwise comparisons (nominal P-values Bonferroni-adjusted) between categories. Each year, individual female warblers were placed into one of the four wetland categories based on which wetland they used. Within a given year, most (>95%) females occupied nest boxes within a particular wetland for the entire breeding season. Those that switched from one category of wetland to another within a breeding season were not included in the productivity analyses. I recorded the number of offspring produced per female per year (productivity), and I used a Kruskal-Wallis test (SYSTAT 2000) to determine whether productivity differed between the four categories of wetland. If there was a significant difference between all categories, I used multiple Mann-Whitney U tests to make pairwise comparisons between categories (nominal *P*-values Bonferroni-adjusted).

RESULTS

Wetland Attributes

Wetland Surface Area. I estimated the surface area of the 10 control and 10 treatment wetlands both before and after the installation of gully plugs, and calculated the proportion change in surface area for each wetland (Table 1). The surface area of control wetlands remained the same between pre- and post-treatment periods. The proportion change in surface area of the treatment (gully plug) wetlands between time periods was 4.4 and was significantly greater than that of the control wetlands ($t_9 = 4.84$, $P < 0.001$; Fig. 2a).

Wetland Water Depth. I estimated the average water depth of the 10 control and 10 treatment wetlands both before and after the installation of gully plugs (Table 2b). Water depths differed significantly between all four wetland categories ($F_{3,39} = 25.0$, $P < 0.001$), and were greater for the post-treatment wetlands where gully plugs had been added (55 cm) than for the other three wetland categories (21-23 cm; Fig. 2b).

Bird Diversity and Density

Diversity of Breeding Birds. There were a total of 42 species detected at least once within 50 m of a point count location (Table 3 plus Appendix 1). The range of values for the number of species detected per point was from 2 to 16. Species diversity differed significantly between all four wetland categories ($F_{3,149} = 2.90$, $P = 0.037$). During the pre-treatment period, nearly 9 species per point were detected within both treatment and control wetlands (Fig. 3). However, pairwise comparisons yielded differences that were only nearly statistically different and the number of species detected per point was somewhat diminished during the post-treatment period, particularly within control wetlands (Fig. 3).

Densities of Breeding Birds. There were 23 species that were detected at 10% or more of all of the point counts (Table 3). The number of point counts within each of the four wetland categories is given in Table 3. The densities of four of the 23 species differed significantly between all wetland categories. These species included prothonotary and yellow-throated warblers, carolina chickadee and indigo bunting (Table 3). The two species of warbler responded to the gully plug treatment and had significantly higher densities in the post-treatment gully plug wetlands than in the other wetland categories (Fig. 4). Carolina chickadees and indigo buntings did not respond to the gully plug treatment, rather they each had lower densities in the post-treatment period than the pre-treatment period (Fig. 4).

There were five species not included in Table 3 that also responded to the gully plug treatment. Two species, the belted kingfisher and common grackle, were never detected at point count stations during the pre-treatment period and were only detected (at low densities) within the gully plug wetlands during the post-treatment period. Three species, the wood duck, yellow-crowned night-heron (*Nyctanassa violacea* Linnaeus), and hooded merganser (*Lophodytes cucullatus* Linnaeus), were poorly sampled by the point count technique. The number of nests of these three species found during the study suggests that they also responded to the gully plug treatment. During the pre-treatment period for all 20 wetlands combined, there was an average of one nest per year for wood ducks and yellow-crowned night-herons, and none for hooded mergansers. During the post treatment period, however, there were averages of six, five, and three nests per year for wood ducks, yellow-crowned night-herons and hooded mergansers, respectively, and all were located in gully plug wetlands.

Nesting Success

Nest Depredation. I documented the outcome of a total of 539 nesting attempts of prothonotary warblers breeding within the 20 wetlands during the 6-year period of study. Nest predators caused the failure of 271 (50%) of the nesting attempts. Raccoons were responsible for the vast majority (85%) of nest predation events. The frequency of nest predation differed between the four categories of wetland ($X^2_3 = 79.0$, $P < 0.001$; Fig. 5a). Nests were preyed upon much less frequently in the post-treatment gully plug wetlands (24%) than in the other three categories of wetland (56 to 67%; Fig. 5a).

Productivity. The annual productivity (number of offspring produced per female per year) was known for 417 females breeding within the 20 wetlands during the 6-year period of study. The range of values for productivity was 0 to 13 warbler offspring produced by female warblers in a given year. Productivity differed between the four categories of wetland (Kruskal-Wallis test: $H_3 = 103.7$, $P < 0.001$) and was much greater in the post-treatment wetlands (4.1) than in the other three categories of wetland (1.2 to 1.6; Fig. 5b).

DISCUSSION

The natural interplay of topography and hydrology creates and maintains habitat complexity in bottomland forest ecosystems and promotes particularly diverse bird assemblages (Pashley and Barrow 1993, Wakeley and Roberts 1996, Sallabanks et al. 2000). Channel incision, the formation of lateral gullies, and the subsequent de-watering of off-channel wetlands are widespread in many bottomland systems and can jeopardize this bird diversity. The results of this study demonstrate that some species of bird occur at lower densities and experience lower nesting success in off-channel wetlands that are drained by gullies. On the other hand, when gully plugs were installed, the affected wetlands retained their water for a longer period of time and at a greater depth than their counterparts that did not receive gully plugs, resulting in a number of positive and no negative effects of gully plugs on the breeding bird community.

Wetland Attributes

It is important to reiterate that the changes in surface area of the wetlands in this study were not changes in the maximum size of the wetland, but rather changes in the ability of the wetlands to retain water after spring flood events or early-summer rain events. The installation of gully plugs resulted in water being held for longer periods and at greater depths than wetlands not receiving gully plugs. This way of measuring surface area and water depth (e.g. the average of measurements taken over a 2-month period that coincided with the peak of the breeding season for most species of bird) made sense from the perspective of trying to understand how the gully plugs affected birds breeding within the wetlands. Gully plug wetlands were still capable of losing water to evapotranspiration and ground water seepage, and were by no means a static wetland that remained permanently full. Gully plug wetlands retained and lost water in a manner similar to the forested wetlands in the watershed that were not yet connected by a lateral gully to the main channel of the river, and could dry up completely during extended dry periods over the course of a year (J. Hoover, personal observations). Gully plug wetlands did not, however, lose their water over the course of just days as did the control (no gully plug) wetlands.

The use of gully plugs to modify the hydrology of off-channel wetlands will have a higher chance of succeeding over the long term if used in conjunction with riffle weirs or some other structures that reduce or stop channel incision. If the problem of channel incision is not dealt with, lateral gullies may work their way around gully plugs, or new lateral gullies may form. The gully plugs were only as good as their construction and it was important that the work was performed by contractors that did a thorough job while taking care to disrupt the natural system as little as possible. The specific size and design of the gully plugs were were somewhat dependent on the size and location of the gully. For example, three gully plugs failed after either one or two years because of a design that did not allow for enough water to spill over the plug (without eroding it) during extraordinary rain events when runoff from nearby uplands created tremendous force against the wetland side of the plugs. Future installations will be modified to take into account the possibility of such rain events and reduce the chance of gully plug failure (information on specifications and installation of gully plugs and riffle weirs can be obtained from Mark Guetersloh of the Illinois Department of Natural Resources; mark.guetersloh@illinois.gov)

Diversity and Densities of Breeding Birds

The diversity of birds breeding within the forested wetlands (as assessed by the number of species detected per point count) was not affected by the installation of gully plugs. Many studies in bottomland forest ecosystems have compared bird diversity between various forest types (e.g. forested wetlands, levee forest, flatwoods) and found significant differences (e.g., Sallabanks et al. 2000, Wakely et al. 2007). All of my study sites were forested wetlands and the main difference between the control and treatment categories of wetlands was the amount and depth of water retained in the wetland during the breeding seasons in the post-treatment period only. It is possible that the longer-term effects of gully plugs on the plant community (structure and species composition; Huffman and Forsythe 1981, Wakeley and Roberts 1996, Kozlowski

2002) and on the densities of birds that were detected poorly by point counts (e.g., wood duck, yellow-crowned night-heron and hooded merganser) would lead to an increase in species diversity in gully-plug wetlands relative to non-gully plug wetlands. In addition, there is great potential for birds to respond favorably to these managed forested wetlands during the winter and migration. For example, wet forests can be critical over-winter habitat for various species of waterfowl (Ehrle et al. 1995, Heitmeyer 2006) and for rusty blackbirds (*Euphagus carolinus* Müller; Avery 1995) and important to various species of bird during migration (Pashley and Barrow 1993, Wilson and Twedt 2003).

Densities of most of the species detected during point counts were unaffected by the installation of gully plugs. However, prothonotary warblers and yellow-throated warblers both increased in density within the gully plug wetlands during the post-treatment period (Figure 4). It is important to note that, for these two species, this increase was not simply more birds existing on larger wetlands but rather a true increase in density (number per unit area of wetland). The relatively immediate increase in the density of yellow-throated warblers was unexpected. They are known to have an affinity for baldcypress (*Taxodium distichum* Linnaeus) in the bottomland forests in the southeastern U.S. and in southern Illinois (Graber et al. 1983, Hall 1996, Gabbe et al. 2002). Many of the forested wetlands in both the treatment and control categories contained baldcypress. The increase in the density of yellow-throated warblers in the gully plug wetlands suggests that they are cueing in on not only the presence of baldcypress, but also the presence of water. Over several years or even decades, gully plugs and the effect they have on the hydrology in these forested wetlands should promote the retention, expansion and further development of baldcypress which should in turn increase the number of yellow-throated warblers in the area.

An increase in density was expected for prothonotary warblers given what is known about their preference to nest over or near water (Petit and Petit 1996), the effect of water on their nesting success (Hoover 2006, Wood and Cooper submitted, this study), and the between-year breeding-site fidelity of adult warblers that produce offspring (Hoover 2003). The density of prothonotary warblers increased within the gully plug wetlands because of a chain of events that began with the increase in the depth of water in those wetlands. The presence of relatively deep water in the gully plug wetlands resulted in decreased rates of nest predation which, in turn, led to increased productivity (Fig. 5a, b). The more successful prothonotary warblers are, the more likely they are to return to the same breeding location the following year (Hoover 2003). The presence of these returning adults at the beginning the breeding season likely attracted other prothonotary warblers that were looking for a place to breed for the first time or avoiding a nearby site where their reproductive performance was poor the previous year (Hoover 2003).

Some species that were poorly detected by the point counts also seemed to increase in number in response to the installation of gully plugs. I found more yellow-crowned night-heron and wood duck nests during the post-treatment period, all within gully plug wetlands. I found no hooded merganser nests during the pre-treatment period, and only found merganser nests within gully plug wetlands during the post-treatment period. Wood ducks and hooded mergansers nest in tree cavities (usually over water) and rear their broods in the wet areas of the forested wetlands where they are nesting (Hepp and Bellrose 1995, Dugger et al. 1994). Yellow-crowned night-herons build stick nests on mid-canopy branches that are often located over water (Watts1989, 1995), and usually provision their brood with prey items they capture in the wet areas near their nest (Laubhan et al. 1991). Belted kingfishers and common grackles did not breed in the forested wetlands, but were observed foraging in the wet areas within the gully plug wetlands during the post-treatment period. Great blue herons, known for their commuting behavior (Custer et al. 2004), also visited the gully plug swamps to gather food for their broods which were located some kilometers away.

The gully plugs benefited a number of species that are conservation priorities. Prothonotary warblers and yellow-throated warblers are Birds of Conservation Concern within the Bird Conservation Region (BCR) where this study was conducted, or in neighboring BCRs (U.S. Fish and Wildlife Service. 2002.). Prothonotary warblers are also on the Partners in Flight (PIF) U.S. Watchlist (http://www.partnersinflight.org/WatchListNeeds/). Yellow-crowned night-herons are an Illinois' state-listed species (Endangered) and are on the list of Illinois' Species in the Greatest Need of Conservation (SGNC) (http://dnr.state.il.us/ORC/WildlifeResources/theplan/birds.asp). Hooded mergansers and wood ducks are two additional species that are to be promoted as part of the Cache River Joint Ventures restoration and conservation efforts.

Nesting Success

Even within highly fragmented landscapes, forested wetlands may provide birds with breeding habitat where nest predation is reduced because of the presence of relatively deep water (Hoover 2006, this study). The benefits of nesting in forested wetlands are diminished, however, by human-induced changes to bottomland forest ecosystems. The continued fragmentation of bottomland forest habitat will likely promote even higher densities of raccoons and other nest predators (Dijak and Thompson 2000, Heske et al. 2001, Chalfoun et al. 2002). Channel incision and the subsequent formation of lateral gullies can further expose birds breeding in forested wetlands to some of these predators (this study). Degraded wetlands may fill during spring floods and be attractive breeding habitat for birds, but the unnaturally rapid draining of the wetlands early in the breeding season may lead to high rates of nest predation. Therefore, habitat fragmentation and channel incision may act synergistically to elevate rates of nest predation for those birds breeding in forested wetlands.

Raccoons were the primary nest predator responsible for the failure of prothonotary warbler nesting attempts. Raccoons generally concentrate their activities near wet features in the landscape (Dijak and Thompson 2000) or within wet habitats (Gehrt and Fritzell 1998), and much of their diet is associated with aquatic areas (Greenwood 1982). Densities of raccoons have increased in recent decades as a result of habitat fragmentation, the conversion of natural habitats to agricultural lands, the suppression of top predators (‘‘mesopredator release’’), and decreases in the harvest of raccoons for the fur trade (Heske et al. 199, Dijak and Thompson 2000, Gehrt et al. 2002). The relatively deep water in the gully plug wetlands during the post-treatment period provided some safety from nest predators and an increase in reproductive output. The installation of gully plugs seems to be an effective way to reduce the negative consequences raccoons can have for birds breeding in off-channel wetlands.

The productivity of prothonotary warblers on sites where rates of nest predation were low can be substantial (Fig. 5b; Hoover 2006). An increase in reproductive success not only increases local densities through the pathway described above (i.e. more success = more site fidelity = more attraction of other adults) but it also obviously puts more warbler offspring out in the environment. If these offspring return the following year to breed, they usually do so within 2 km of where they were produced (Hoover and Reetz 2006). This is another factor that can contribute to an increase in warbler densities within highly productive (gully plug) wetlands. It is certain that this conservation practice, applied locally within the Cache River watershed in Illinois is benefiting local populations of prothonotary warblers. Habitats that promote low or reduced rates of nest predation and high annual fecundity, such as the deep-water areas of gully-plug wetlands, are important to local population dynamics and may be critical to the maintenance of populations over larger geographic scales in coming years (Hoover 2003).

Channel incision and the fragmentation of bottomland forests will continue to threaten the integrity of bottomland forest systems throughout much of the U.S. and around the world (Shields et al. 1998, Giller 2005). Conservation and restoration efforts that attempt to stop or reverse these threats will be particularly beneficial to those bird species that depend on forested wetlands for breeding. Conservation partners in the Cache River watershed of Illinois are attempting to consolidate bottomland forests through land acquisition and afforestation, and restore “natural” hydrologic processes by installing riffle weirs to reduce channel incision and gully plugs to negate the harmful effects of lateral gullies on off-channel wetlands. Placing these management efforts within a before-after treatment-control experimental design allowed me to document the direct and immediate effects of gully plugs on the hydrological attributes of, and breeding bird community within, off-channel wetlands. Documenting changes in attributes of wetlands and their associated bird community in response to conservation actions has provided a means to measure the success of restoration activities in the Cache River watershed and inform conservation plans and restoration efforts in many other bottomland forest systems. Riffle weirs and gully plugs could become valuable tools to aid in restoring off-channel wetlands and improving conditions for birds breeding in bottomland forest ecosystems.

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LITERATURE CITED

Abernethy, Y. and R. Turner. 1987. U.S. forested wetlands: status and changes 1940-1980. Bioscience 37:721-727.

American Ornithologists' Union. 1998. Checklist of North American Birds, 7th ed. American Ornithologists' Union, Washington, D.C.

Askins, R. A. 2000. Restoring North America's birds. Yale University Press, New Haven, Connecticut, USA.

Avery M. L. 1995. Rusty Blackbird (*Euphagus carolinus*). *In* A. Poole and F. Gill (eds.) The birds of North America, Number 200. The Birds of North America, Incorporated, Philadelphia, Pennsylvania.

Bhuiyan, F., R. D. Hey and P. R. Wormleaton. 2007. Hydraulic evaluation of w-weir for river restoration. Journal of Hydraulic Engineering 133:596-609.

Blem, C. R. and L. B. Blem. 1994. Composition and microclimate of prothonotary warbler nests. Auk 111:197–200.

Chalfoun, A. D., F. R. Thompson III and M. J. Ratnaswamy. 2002. Nest predators and fragmentation: a review and meta-analysis. Conservation Biology 16:306–318.

Custer, C. M., S. A. Suarez and D. A. Olsen. 2004. Feeding habitat characteristics of the great blue heron and great egret nesting along the Upper Mississippi River. Waterbirds 27:454-468.

Dijak, W. D. and F. R. Thompson III. 2000. Landscape and edge effects on the distribution of mammalian predators in Missouri. Journal of Wildlife Management 64:209–216.

Dugger, B. D., K. M. Dugger and L. H. Fredrickson. 1994. Hooded Merganser (*Lophodytes cucullatus*). *In* A. Poole and F. Gill (eds.) The birds of North America, Number 098. The Birds of North America, Incorporated, Philadelphia, Pennsylvania.

Ehrle, B., R. M. Kaminski, B. D. Leopold and W. P. Smith. 1995. Aquatic invertebrate resources in Mississippi forested wetlands during winter.

Gabbe, A. P., S. K. Robinson and J. D. Brawn. 2002. Tree-species preferences of foraging insectivorous birds: implications for floodplain forest restoration. Conservation Biology 16:462-470.

Gehrt, S. D. and E. K. Fritzell. 1998. Resource distribution, female home range dispersion and male spatial interactions: group structure in a solitary carnivore. Animal Behaviour 55:1211–1227.

Gehrt, S. D., G. F. Huber and J. A. Ellis. 2002. Long-term population trends of raccoons in Illinois. Wildlife Society Bulletin 30:457–463.

Giller, P. S. 2005. River restoration: seeking ecological standards. Editors introduction. Journal of Applied Ecology 42:201-207.

Gosselink, J. G. and L. C. Lee. 1989. Cumulative impact assessment in bottomland hardwood forests. Wetlands 9:83-174.

Graber, J. W., R. R. Graber and L. E. Kirk. 1983. Illinois birds: wood warblers. Illinois Natural History Survey Biological Notes 118.

Greenwood, R. J. 1982. Nocturnal activity and foraging of prairie raccoons (*Procyon lotor*) in North Dakota. American Midland Naturalist 107:238–243.

Hall, G. A. 1996. Yellow-throated warbler (*Dendroica dominica*). *In* A. Poole and F. Gill (eds.) The birds of North America, Number 223. The Birds of North America, Incorporated, Philadelphia, Pennsylvania.

Hamel, P. B., W. P. Smith, D. J. Twedt, J. R. Woehr, E. Morris, R. B. Hamilton and R. J. Cooper. 1996. A Land Manager's Guide to Point Counts of Birds in the Southeast. USDA Forest Service, Asheville, NC, General Technical Report SO-120, p. 1-39.

Heitmeyer, M. E. 2006. The importance of winter floods to mallards in the Mississippi alluvial valley. Journal of Wildlife Management 70:101-110.

Hepp, G. R. and F. C. Bellrose. 1995. Wood Duck (*Aix sponsa*). *In* A. Poole and F. Gill (eds.) The birds of North America, Number 169. The Birds of North America, Incorporated, Philadelphia, Pennsylvania.

Heske, E. J., S. K. Robinson and J. D. Brawn. 1999. Predator activity and predation on songbird nests on forest-field edges in east-central Illinois. Landscape Ecology 14:345–354.

Heske, E. J., S. K. Robinson and J. D. Brawn. 2001. Nest predation and neotropical migrant songbirds: piecing together the fragments. Wildlife Society Bulletin 29:52–61.

Hoover, J. P. 2003. Decision rules for site fidelity in a migratory bird, the Prothonotary Warbler. Ecology 84:416-430.

Hoover, J. P. 2006. Water depth influences nest predation for a wetland-dependent bird in fragmented bottomland forests. Biological Conservation 127:37-45.

Hoover, J. P. and M. J. Reetz. 2006. Brood parasitism increases provisioning rate, and reduces offspring recruitment and adult return rates, in a cowbird host. Oecologia 149:165-173.

Huffman, R.T. and S. W. Forsythe. 1981. Bottomland hardwood forest communities and their relation to anaerobic soil conditions. p. 187-196. *In* J. R. Clark and J. Benforado (eds)

Wetlands of Bottomland Hardwood Forests. Elsevier Science Publishing Co., Amsterdam.

Kozlowski, T. T. 2002. Physiological-ecological impacts of flooding on riparian forest ecosystems. Wetlands 22:550-561.

Laubhan, M. K., W. D. Rundle, B. I. Swartz and F. A. Reid. 1991. Diurnal activity patterns and foraging success of Yellow-crowned Night-Herons in seasonally flooded wetlands. Wilson Journal of Ornithology 103: 272–277.

Landwehr, K. and B. L. Rhoads. 2003. Depositional response of a headwater stream to channelization, east central Illinois, USA. River Research and Applications 19:77-100.

Pashley, D. N., and W. C. Barrow. 1993. Effects of land use practices on neotropical migratory birds in bottomland hardwood forests. p. 315-320. *In* D. M. Finch and P. W. Stangel (eds.) Status and Management of Neotropical Migratory Birds. USDA Forest Service General Technical Report RM-229.

Petit, K. E. 1989. Milk carton nest box use by Prothonotary Warblers. Ohio Department of Natural Resources Nongame Quarterly 3:5.

Petit, L. J. 1999. Prothonotary Warbler (*Protonotaria citrea*). *In* A. Poole and F. Gill (eds) The Birds of North America, Number 408. The Birds of North America, Incorporated, Philadelphia, Pennsylvania.

Petit, L. J. and D. R. Petit. 1996. Factors governing habitat selection by Prothonotary Warblers: field tests of the Fretwell-Lucas models. Ecological Monographs 66:367-387.

Ralph, C. J., J. R. Sauer and S. Droege (eds.). 1995. Monitoring bird populations by point counts. General Technical Report PSW-GTR-149. Pacific Southwest Research Station, Albany, CA.

Robinson, W. D. and S. K. Robinson. 1999. Effects of selective logging on forest bird populations in a fragmented landscape. Conservation Biology 13:58-66.

Robinson, S. K. and W. D. Robinson. 2001. Avian nesting success in a selectively harvested north temperate deciduous forest. Conservation Biology 15:1763-1771.

Robinson, S. K., F. R. Thompson III, T. M. Donovan, D. R. Whitehead and J. Faaborg. 1995. Regional forest fragmentation and the nesting success of migratory birds. Science 267:1987-1990.

Sallabanks, R., J. R. Walters and J. A. Collazo. 2000. Breeding bird abundance in bottomland hardwood forests: habitat, edge, and patch size effects. Condor 102:748-758.

Shankman, D. and L. J. Smith. 2004. Stream channelization and swamp formation in the US Coastal Plain. Physical Geography 25:22-38.

Shields, F. D. Jr., S. S. Knight and C. M. Cooper. 1998. Rehabilitation of aquatic habitats in warmwater streams damaged by channel incision in Mississippi. Hydrobiologia 382:63-86.

Sparks, R. E., J. C. Nelson and Y. Yin. 1998. Naturalization of the flood regime in regulated rivers. Bioscience 48:706-720.

SYSTAT, 2000. Version 10.0. SPSS Science, Chicago, IL.

Twedt, D. J., R. R. Wilson, J. L. Henne-Kerr and R. B. Hamilton. 1999. Impact of forest type and management strategy on avian densities in the Mississippi Alluvial Valley, USA. Forest Ecology and Management 123:261-274.

U.S. Fish and Wildlife Service. 2002. Birds of conservation concern 2002. Division of Migratory Bird Management, Arlington, Virginia. 99 pp.

Wakeley, J. S. and T. H. Roberts. 1996. Bird distributions and forest zonation in a bottomland hardwood wetland. Wetlands 16:296-308.

Wakeley, J. S., M. P. Guilfoyle, T. J. Antrobus, R. A. Fischer, W. C. Barrow Jr. and P. B. Hamel. 2007. Ordination of breeding birds in relation to environmental gradients in three southeastern United States floodplain forests. Wetlands Ecology and Management 15:417-439.

Watts, B. D. 1989. Nest-site characteristics of Yellow-crowned Night-Herons in Virginia. Condor 91: 979–983.

Watts, B. D. 1995. Yellow-crowned Night-Heron (*Nyctanassa violacea*). *In* A. Poole and F. Gill (eds.) The birds of North America, Number 161. The Birds of North America, Incorporated, Philadelphia, Pennsylvania.

Wood, L. A. and R. J. Cooper. *Submitted*. Response of prothonotary warblers to flooding and timber harvest in a bottomland hardwood forest. Wetlands.

Wilcove D. S., D. Rothstein, J. Dubow, A. Phillips and E. Losos. 1998. Quantifying threats to imperiled species in the United States. BioScience 48:607-615.

Wilson, R. R. and D. J. Twedt. 2003. Spring bird migration in Mississippi alluvial valley forests. American Midland Naturalists 149:163-175.

Table 1. Surface area of 10 control and 10 treatment wetlands before (2002 to 2004) and after (2005 to 2007) the installation of gully plugs in the Cache River watershed in southern Illinois, U.S.

	Mean (1SE) wetland surface area (ha)		
Sites	Before	After	Proportion Change
Control			
FTS3	0.14 (0.016)	0.12 (0.012)	0.86
FTS4	0.10 (0.011)	0.12 (0.012)	1.20
MS1	0.28 (0.027)	0.20 (0.025)	0.71
MS2	0.10 (0.008)	0.07 (0.010)	0.71
SS2	0.09 (0.008)	0.11 (0.009)	1.22
SS3	0.21 (0.008)	0.17 (0.013)	0.82
HP2	2.27 (0.053)	2.40 (0.059)	1.06
HP4	0.32 (0.014)	0.25 (0.019)	0.80
HP6	0.16 (0.013)	0.15 (0.015)	0.94
XS2	1.84 (0.034)	1.90 (0.044)	1.03
Treatment			
FTS1	0.05 (0.003)	0.43 (0.026)	8.69
FTS2	0.45 (0.034)	2.22 (0.095)	4.93
FTS5	0.43 (0.016)	2.88 (0.020)	6.70
SS1	0.28 (0.013)	1.05 (0.015)	3.74
SS4	0.87 (0.028)	3.09 (0.017)	3.55
HP1	0.34 (0.014)	1.44 (0.034)	4.24
HP3	0.20 (0.024)	0.45 (0.025)	2.25
HP5	0.05 (0.003)	0.30 (0.032)	6.00
HP7	2.57 (0.053)	3.45 (0.067)	1.34
XS1	3.85 (0.067)	9.45 (0.144)	2.45

Table 2. Water depth within 10 control and 10 treatment wetlands before (2002 to 2004) and after (2005 to 2007) the installation of gully plugs in the Cache River watershed in southern Illinois, U.S.

	Mean (1SE) water depth (cm)		
Sites	Before	After	Change (cm)
Control			
FTS3	17 (1.6)	15 (1.3)	-2
FTS4	22 (1.7)	21 (1.3)	-1
MS1	26 (1.5)	24 (1.6)	-2
MS2	6 (1.1)	4 (0.8)	-2
SS2	30 (1.7)	35 (1.7)	+5
SS3	26 (1.9)	31 (1.9)	+5
HP2	22 (1.9)	28 (2.1)	+6
HP4	19 (2.0)	12 (1.6)	-7
HP6	24 (1.6)	22 (1.6)	-2
XS2	33 (2.3)	41 (2.2)	+8
Treatment			
FTS1	16 (1.6)	52 (1.2)	+36
FTS2	22 (1.9)	57 (2.6)	+35
FTS5	13 (1.1)	53 (1.2)	+40
SS1	13 (1.4)	32 (1.6)	+19
SS4	34 (1.3)	86 (1.9)	+52
HP1	24 (1.4)	58 (1.7)	+34
HP3	16 (1.5)	46 (1.5)	+30
HP5	20 (1.5)	46 (1.6)	+26
HP7	20 (1.3)	55 (1.4)	+35
XS1	32 (2.5)	67 (2.5)	+35

Table 3. Density estimates for individual bird species detected within 50 m of each sampling point during one 5-min point count each summer (mid-May to mid-June) from 2002 to 2007 in 10 treatment and 10 control wetlands before and after the installation of gully plugs in the Cache River watershed in southern Illinois, U.S.

	Density (1SE) (number/ha)				
	Before treatment		After treatment		
	Control	Treatment	Control	Treatment	
Species	(n=36)	(n=38)	(n=46)	(n=29)	P-value*
Yellow-billed Cuckoo (*Coccyzus americanus* Linnaeus)	0.39 (0.10)	0.33 (0.09)	0.28 (0.08)	0.26 (0.10)	0.760
Ruby-throated Hummingbird (*Archilochus colubris* Linnaeus)	0.25 (0.09)	0.33 (0.09)	0.28 (0.09)	0.31 (0.10)	0.873
Red-bellied Woodpecker (*Melanerpes carolinus* Linnaeus)	0.21 (0.08)	0.20 (0.07)	0.19 (0.07)	0.18 (0.10)	0.923
Downy Woodpecker (*Picoides pubescens* Linnaeus)	0.64 (0.15)	0.80 (0.16)	0.41 (0.09)	0.39 (0.14)	0.205
Eastern Wood-Peewee (*Contopus virens* Linnaeus)	0.28 (0.09)	0.40 (0.11)	0.25 (0.09)	0.44 (0.15)	0.578
Acadian Flycatcher (*Empidonax virescens* Vieillot)	1.91 (0.19)	1.51 (0.18)	1.85 (0.17)	1.58 (0.22)	0.375
Great Crested Flycatcher (*Myiarchus crinitus* Linnaeus)	0.28 (0.10)	0.27 (0.10)	0.28 (0.09)	0.26 (0.10)	0.998
Carolina Chickadee (*Poecile carolinensis* Audubon)	1.70 (0.22)	2.21 (0.23)	1.22 (0.20)	0.88 (0.21)	**0.001**
Tufted Titmouse (*Baeolophus bicolor* Linnaeus)	1.20 (0.22)	1.37 (0.25)	1.19 (0.20)	1.45 (0.27)	0.858
White-breasted Nuthatch (*Sitta carolinensis* Latham)	0.92 (0.20)	1.27 (0.23)	1.24 (0.20)	1.36 (0.22)	0.488
Carolina Wren (*Thryothorus ludovicianus* Latham)	0.50 (0.14)	0.54 (0.13)	0.53 (0.13)	0.35 (0.12)	0.809
Blue-gray Gnatcatcher (*Polioptila caerulea* Linnaeus)	1.77 (0.23)	2.18 (0.18)	2.35 (0.22)	1.80 (0.21)	0.160
Yellow-throated Vireo (*Vireo flavifrons* Linnaeus)	0.18 (0.07)	0.30 (0.09)	0.22 (0.07)	0.13 (0.07)	0.499
Northern Parula (*Parula americana* Linnaeus)	0.25 (0.09)	0.64 (0.14)	0.36 (0.09)	0.48 (0.15)	0.167
Yellow-throated Warbler (*Dendroica dominica* Linnaeus)	0.11 (0.06)	0.07 (0.09)	0.03 (0.03)	0.26 (0.10)	**0.033**
Prothonotary Warbler (*Protonotaria citrea* Boddaert)	1.24 (0.17)	1.14 (0.18)	0.47 (0.11)	2.06 (0.21)	**0.000**
Louisiana Waterthrush (*Seiurus motacilla* Vieillot)	0.28 (0.10)	0.13 (0.06)	0.05 (0.04)	0.13 (0.07)	0.179
Kentucky Warbler (*Opornis formosus* Wilson)	0.71 (0.18)	0.30 (0.10)	0.36 (0.09)	0.26 (0.13)	0.155
Summer Tanager (*Piranga rubra* Linnaeus)	0.35 (0.12)	0.23 (0.08)	0.11 (0.05)	0.22 (0.09)	0.356
Northern Cardinal (*Cardinalis cardinalis* Linnaeus)	0.25 (0.10)	0.57 (0.14)	0.53 (0.11)	0.57 (0.17)	0.192
Indigo Bunting (*Passerina cyanea* Linnaeus)	0.81 (0.18)	0.37 (0.09)	0.30 (0.09)	0.31 (0.12)	**0.049**
Brown-headed Cowbird (*Molothrus ater* Boddaert)	0.35 (0.14)	0.33 (0.14)	0.17 (0.08)	0.26 (0.13)	0.833
American Goldfinch (*Carduelis tristis* Linnaeus)	0.28 (0.10)	0.23 (0.09)	0.33 (0.10)	0.18 (0.10)	0.641

Common and scientific names and authorities according to the American Ornithologists' Union (1998)

**P* -values based on Kruskal-Wallis statistical test comparing the number of individuals recorded per sampling point among the four categories.

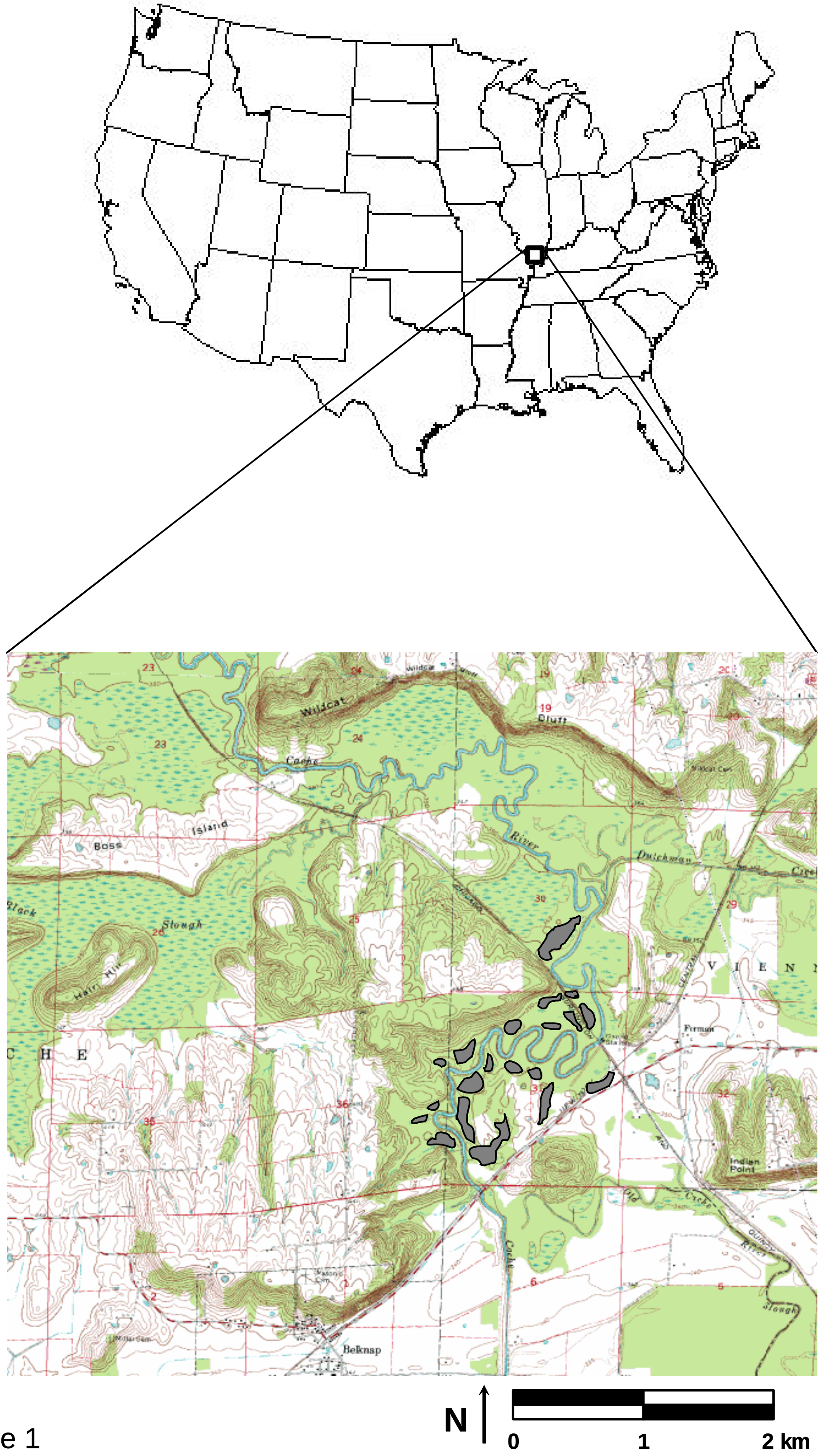
Wildcat
Bluff
Cache
River
Dutchman
Creek
Boss
Island
Black
Slough
Hair Hill
V I E N N
C H E
Forman
Indian Point
Belknap
N
0
1
2 km

Figure 1

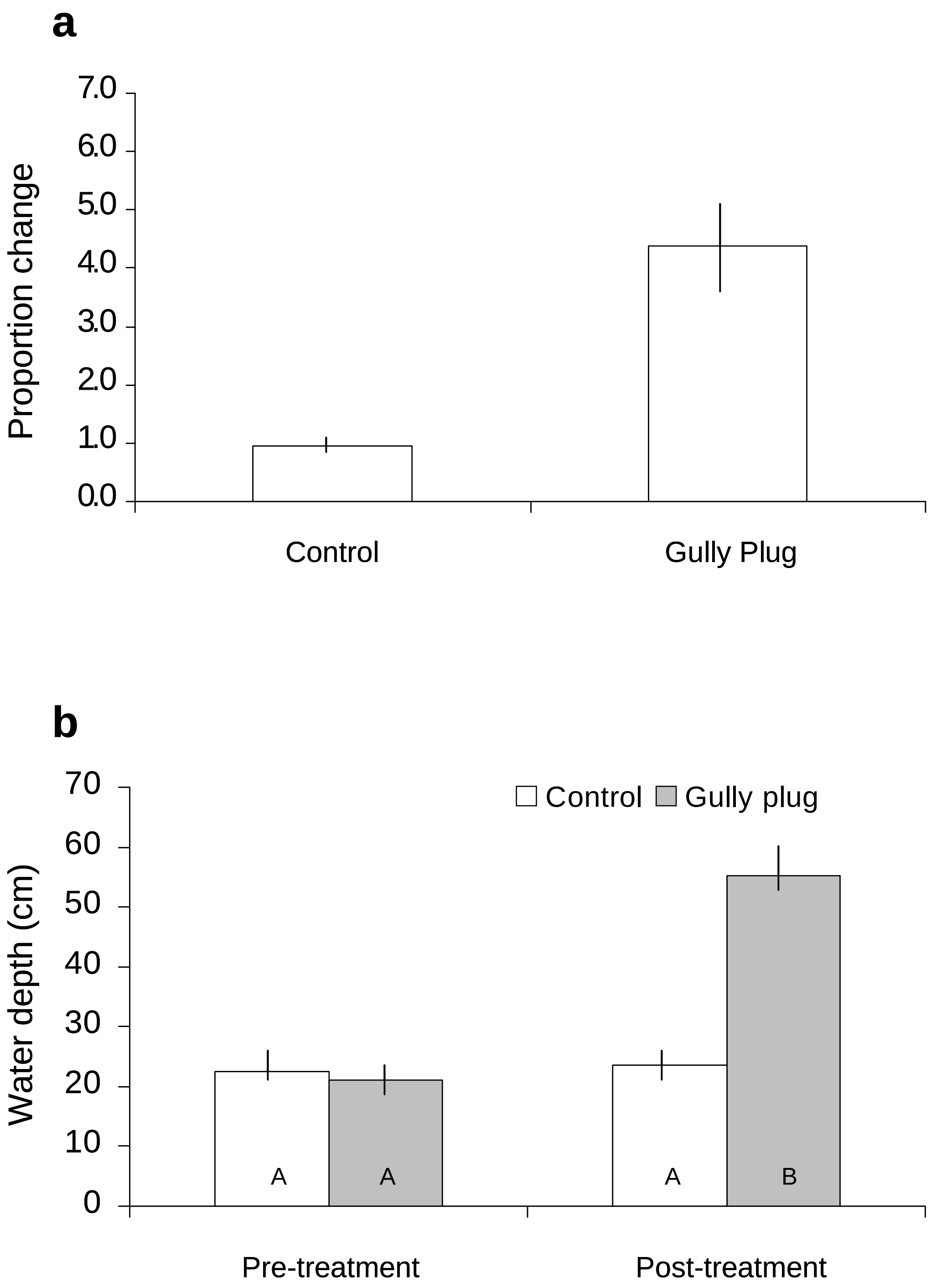
a
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Proportion change
Control
Gully Plug
b
70
60
50
40
30
20
10
0
Water depth (cm)
☐ Control
▨ Gully plug
A
A
A
B
Pre-treatment
Post-treatment

Figure 2

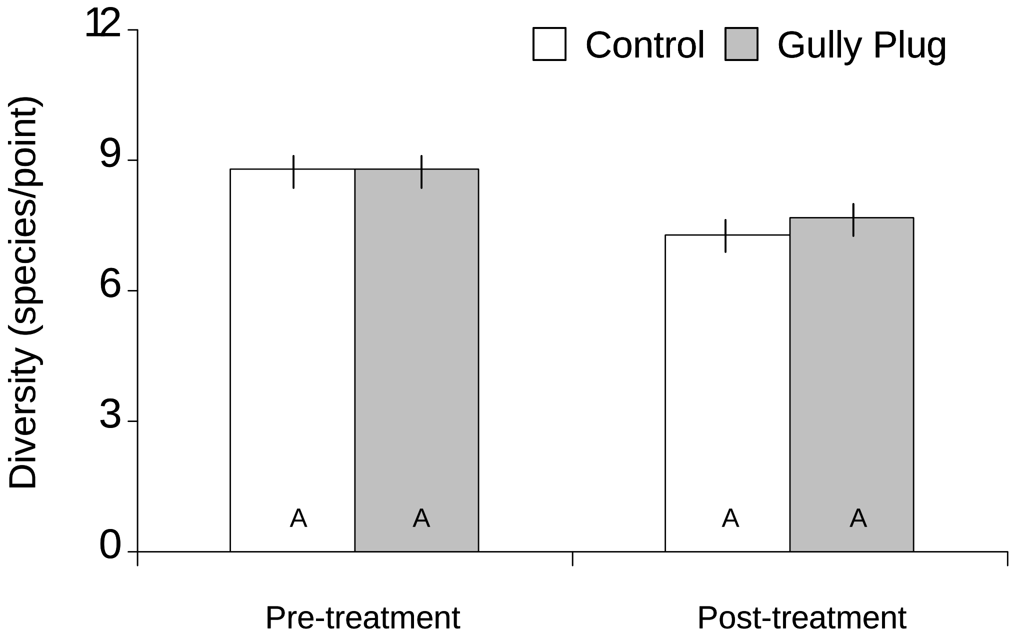
12
9
6
3
0
Diversity (species/point)
Control
Gully Plug
A
A
A
A
Pre-treatment
Post-treatment

Figure 3

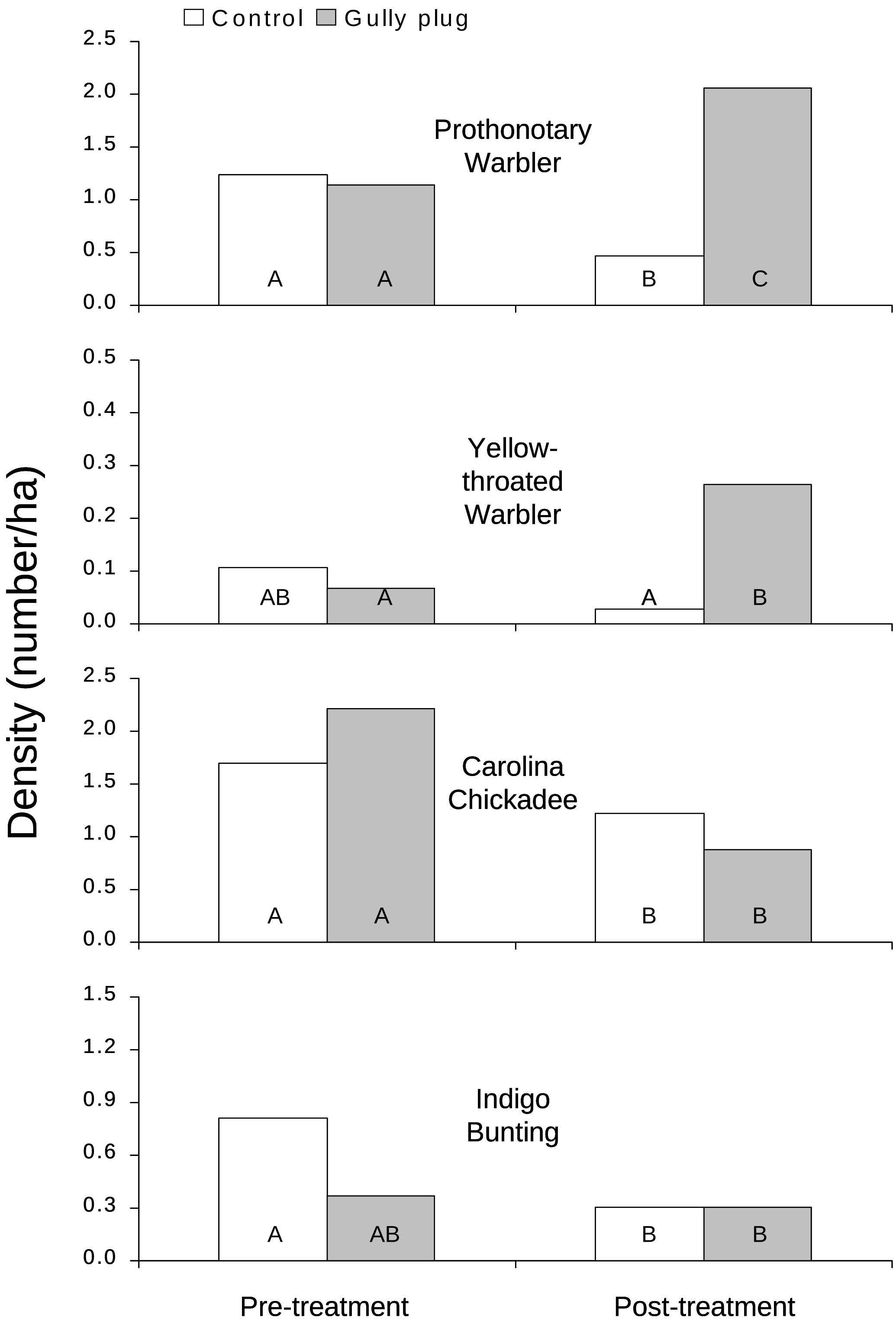
☐ Control ▨ Gully plug
Density (number/ha)
Prothonotary Warbler
2.5
2.0
1.5
1.0
0.5
0.0
A
A
B
C
Yellow-throated Warbler
0.5
0.4
0.3
0.2
0.1
0.0
AB
A
A
B
Carolina Chickadee
2.5
2.0
1.5
1.0
0.5
0.0
A
A
B
B
Indigo Bunting
1.5
1.2
0.9
0.6
0.3
0.0
A
AB
B
B
Pre-treatment
Post-treatment

Figure 4

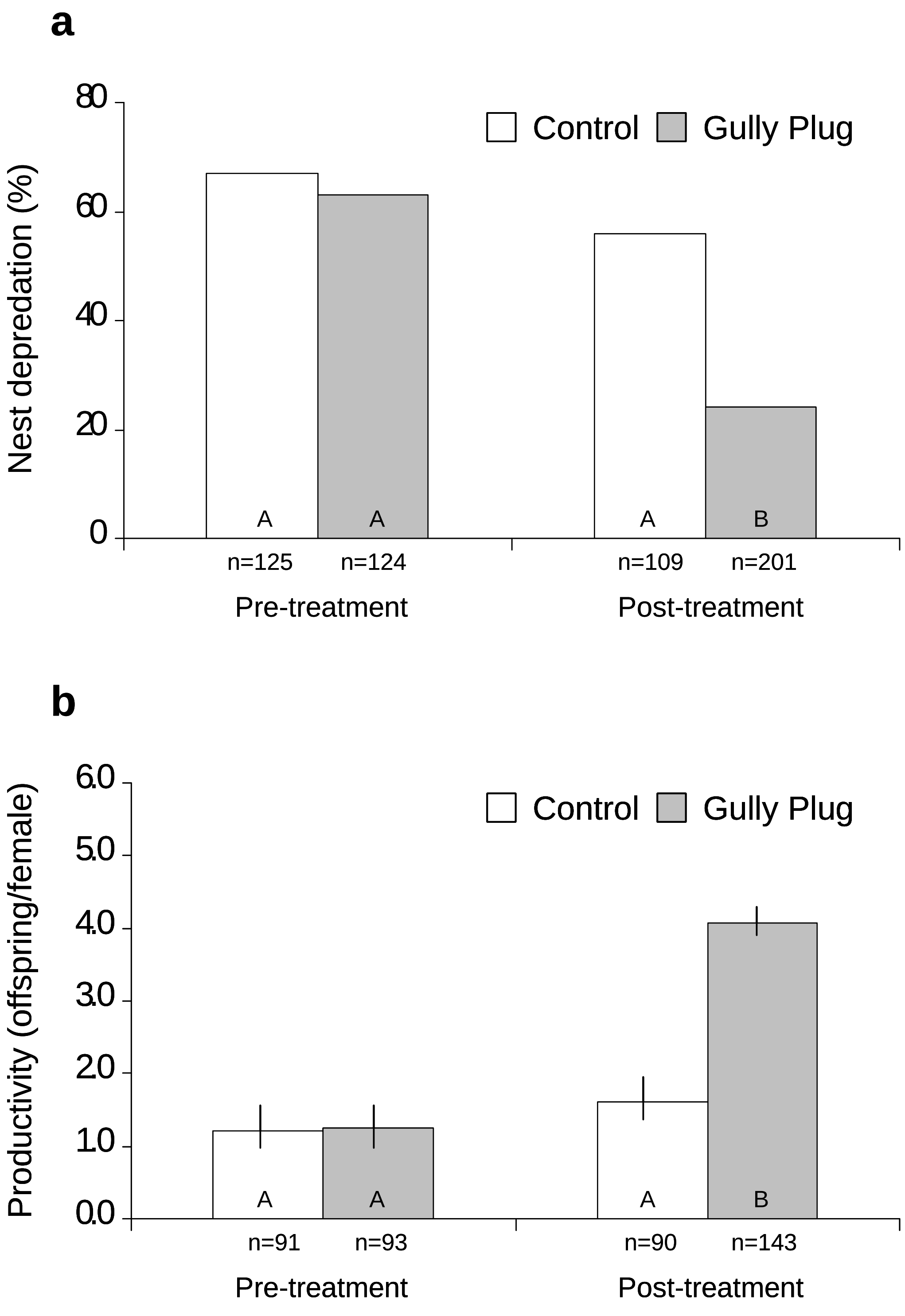
a
80
60
40
20
0
Nest depredation (%)
Control
Gully Plug
A
A
A
B
n=125
n=124
n=109
n=201
Pre-treatment
Post-treatment
b
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Productivity (offspring/female)
Control
Gully Plug
A
A
A
B
n=91
n=93
n=90
n=143
Pre-treatment
Post-treatment

Figure 5

Figure Legends

Figure 1. Location of study sites in the Cache River watershed in southern Illinois, U.S.

Figure 2. (a) Proportional change in surface area between pre- and post-treatment periods was greater for gully plug wetlands than for control wetlands and (b) water depth increased in those wetlands where gully plugs were installed. Bars represent mean values for 10 wetlands in each category and lines at the tops of bars represent ± 1 SE. Bars with the same letter inside are not different ($P > 0.05$, Bonferroni-adjusted for multiple comparisons) from each other (b).

Figure 3. The diversity (number of species detected per point count) of breeding birds was unaffected by the gully plug treatment. Bars represent mean values for 10 wetlands in each category and lines at the tops of bars represent ± 1 SE. Bars with the same letter inside are not different ($P > 0.05$, Bonferroni-adjusted for multiple comparisons) from each other.

Figure 4. The densities of four species of bird differed between the four categories of wetland. Bars represent average densities (number per ha), whereas the number of individuals detected per point count were used for statistical analyses. Bars with the same letter inside are not different ($P > 0.05$, Bonferroni-adjusted for multiple comparisons) from each other.

Figure 5. The (a) frequency of nest predation was lower and (b) productivity higher for gully plug wetlands in the post-treatment period than the other three categories of wetland. Sample sizes (a: number of nests; b: number of females) are given at the base of each bar. Bars represent mean values for females in each category and lines at the tops of bars represent ± 1 SE (b only). Bars with the same letter inside are not different ($P > 0.05$,

Bonferroni-adjusted for multiple comparisons) from each other.

Appendix 1. Other bird species detected at least one time within 50 m of a sampling point, but at fewer than 10% of all points sampled (mid-May to mid-June) from 2002 to 2007 in 10 treatment and 10 control wetlands before and after the installation of gully plugs in the Cache River watershed in southernIllinois, U.S. Species included in diversity analysis.

Great Blue Heron (*Ardea herodias* Linnaeus)
Wood Duck (*Aix sponsa* Linnaeus)
Red-shouldered Hawk (*Buteo lineatus* Gmelin)
Mourning Dove (*Zenaida macroura* Linnaeus)
Barred Owl (*Strix varia* Barton)
Chimney Swift (*Chaetura pelagica* Linnaeus)
Belted Kingfisher (*Megaceryle alcyon* Linnaeus)
Hairy Woodpecker (*Picoides villosus* Linnaeus)
Pileated Woodpecker (*Dryocopus pileatus* Linnaeus)
Eastern Phoebe (*Sayornis phoebe* Latham)
American Crow (*Corvus brachyrhynchos* Brehm)
Brown Thrasher (*Toxostoma rufum* Linnaeus)
White-eyed Vireo (*Vireo griseus* Boddaert)
Red-eyed Vireo (*Vireo olivaceus* Linnaeus)
Cedar Waxwing (*Bombycilla cedrorum* Vieillot)
Common Yellowthroat (*Geothlypis trichas* Linnaeus)
Yellow-breasted Chat (*Icteria virens* Linnaeus)
Eastern Towhee (*Pipilo erythrophthalmus* Linnaeus)
Common Grackle (*Quiscalus quiscula* Linnaeus)

Common and scientific names and authorities according to the American Ornithologists'