

State Wildlife Grant Program

State of Illinois

Final Report

Date: December 15, 2011

Reporting Period: August 1, 2008 – July 31, 2011

**Project Number:** T-51-D-1

**Project Title:** Demonstrating the Benefits of In-stream Restoration to Riparian Wildlife in the Cache River Basin

**Project Leaders:**

PI: Matt Whiles, Professor, Department of Zoology and Center for Ecology, Southern Illinois University Carbondale, Mail Code 6501, Carbondale, IL 62901, (618)453-7639, mwhiles@zoology.siu.edu

Graduate Research Assistant: Kaleb Heinrich, Department of Zoology and Center for Ecology, Southern Illinois University Carbondale, Mail Code 6501, Carbondale, IL 62901 (618)453-4645, kalebh@siu.edu

**Approach:**

**PURPOSE OF PROJECT: Demonstrate potential positive influences of rock weirs in the upper Cache River to aquatic insect emergence and insectivorous predators, specifically birds.**

*Objective 1 Quantify and compare differences in seasonal insect emergence production (numbers, biomass, and taxonomic composition of emerging insects) at four restored sites with rock weirs and four unrestored sites without rock weirs.*

Emerging aquatic insects were continuously monitored using six emergence traps (~1/8 m<sup>2</sup> sampling area, 250 µm mesh) at each of 4 restored and 4 unrestored sites during the following periods in 2009 and 2010:

January 22-24, March 19-23, April 16-18, June 5-7, June 27-July 1, August 12-14, September 28-30, November 9-11, February 23-27, April 19-21, May 17-19, June 16-18

Precipitation and river flows precluded more frequent sampling.

For sampling events, floating traps were tethered at each site and were emptied every 48 hours during sampling events. At the conclusion of sampling events, traps were vacuumed to remove all insects, which were returned to the lab and frozen or preserved in formalin.

Insects collected in traps were enumerated and identified. Following identification, they were dried (60°C), weighed, and ultimately expressed as emergence production (g dry mass/m<sup>2</sup>/d) for each trap and site.

Emergence production values for restored and unrestored sites were compared using 2-way repeated measures analysis of variance procedures. Data analyzed from sampling events indicate a difference in insect abundance and diversity at restored and unrestored sites. Insect abundance was higher at unrestored sites ( $P=0.005$ ) and diversity was higher at restored sites ( $P<0.001$ ). Total insect emergence production was not different at restored and unrestored sites. Upon further investigation, large-bodied EPT (Ephemeroptera, Plecoptera, Tricoptera) taxa were found to be significantly higher at restored sites ( $P<0.001$ ).

*Objective 2 Quantify and compare abundance, richness, and diversity of insectivorous birds along restored and unrestored reaches.*

Weekly point counts for all birds at the 4 restored and 4 unrestored sites were performed during March through June of 2009 and 2010. A fixed radius point count was used between the hours of 6:00 and 9:00 at each of the sites, accounting for all bird species detected visually and aurally. The point counts lasted 5 minutes at each site. Approximately 100 different species were recorded.

Data were analyzed to evaluate and compare abundance, richness, and diversity of birds at restored and unrestored sites; results were analyzed using the same statistical procedures as for insects (see above). Data from 2009 and 2010 showed that bird abundance was higher at restored sites (2009,  $P=0.070$ ; 2010,  $P=0.004$ ), but species richness and diversity were not significantly different.

*Objective 3 Quantify and compare nest success, food delivery rates, clutch size, and fledgling rates of insectivorous birds along restored and unrestored reaches.*

A total of 130 nest boxes were placed in the field in early March 2009, 65 at six restored reaches and 65 at six unrestored reaches. Nest boxes were placed approximately 30 m apart from each other and attached to greased conduit to decrease nest predation.

Nests were monitored every 3-4 days to assess nest survival and foraging rates of adults (number of trips/time) were observed for 1 hour in the morning on the day of highest energetic demand, depending on the bird species (day 7 for the Prothonotary Warbler). Over the two-year span, a total of 95 nests contained nesting material, and the vast majority of these were Prothonotary Warblers. Eggs were laid in 50 nests, and 36 nests produced fledglings in which foraging rates were observed.

Data on Prothonotary Warbler nest success, feeding rates, clutch size, and fledgling rates were analyzed using unpaired t-test. There was no difference in the number of host eggs laid in boxes at restored and unrestored reaches. However, the number of hatchlings and fledglings was significantly higher from nest boxes at unrestored reaches ( $P=0.029$  and  $P=0.003$  respectively). The number of cowbird eggs laid in nest boxes was higher ( $P=0.051$ ) at restored sites. Feeding rates were not different between reaches and fledgling rates were higher at unrestored sites ( $P=0.020$ ). Nest success was 0.73 at non-weir sites and 0.52 at weir sites.

## Detailed narrative for T-51-D-1

### Introduction

River restoration activities have increased rapidly in the United States over the last 30 years, with expenses totaling over \$1 billion yr<sup>-1</sup> since 1990 (Bernhardt *et al.*, 2005). Regardless of efforts and expenses, there has been little post-restoration assessment and monitoring (Bernhardt *et al.*, 2005). Considering the abundant financial resources going into river restoration, documenting any positive ecological and/or societal outcomes is important to justify further projects (Palmer *et al.*, 2005; Palmer & Bernhardt, 2006). Further, information generated from post-restoration studies can be used to guide and refine future efforts.

The Cache River, in southern Illinois, has been a focal point for stream restoration activities. A series of rock weirs, modeled after Newbury and Gaboury (1993), was installed in the Cache River to stabilize the channel and control entrenchment. Walther and Whiles (2008) found that these structures also benefited in-stream communities because they provided stable substrata and increased habitat heterogeneity. Biomass of aquatic insects was higher on rock weirs compared to the ambient scoured clay, suggesting that rock weirs might enhance insect emergence production, which could benefit riparian predators (Walther & Whiles, 2008).

Adult aquatic insects are important links between streams and adjacent riparian habitats, as they facilitate flow of energy and nutrients from aquatic systems to terrestrial food webs (i.e. subsidies), potentially benefitting riparian predators (Jackson & Fisher, 1986; Sabo & Power, 2002; Baxter *et al.*, 2005). In particular, adult aquatic insects can be important prey for insectivorous birds (Gray, 1993; Nakano & Murakami, 2001; Iwata *et al.*, 2003; Burdon & Harding, 2008). These insects can constitute the highest proportion of insectivorous bird diets during the autumn - spring defoliation season, when terrestrial prey is scarce, and they can make up an estimated ~26% of the total annual energy budget for entire bird assemblages (Baxter *et al.*, 2005).

As a result of the sometimes tight linkages between birds, stream insects, and riparian habitats, riparian birds are increasingly used as indicators of stream health and biotic integrity. Use of avian communities to assess stream integrity is less labor-intensive than using invertebrates or fish, and is particularly useful for communicating results to the public (Bryce *et al.*, 2002). Birds are a logical focal group for study in the Cache River basin because they are exceptionally diverse in this region, including numerous species that are threatened or of conservation concern.

The goal of our study was to quantify the potential influences of a common stream restoration practice on aquatic insect emergence production and riparian birds. Our specific objectives were to quantify and compare: (1) adult aquatic insect abundance, emergence production, and taxonomic composition at weir sites and non-weir (control) sites; (2) abundance, richness, and diversity of insectivorous birds at weir and control sites; and (3) clutch size, food delivery rates, fledgling rates, and nest success of insectivorous birds at weir and control sites.

### Methods

#### *Study Sites*

The Cache River basin is located in southern Illinois (37°20'N, 88°55'W) near the confluence of the Ohio and Mississippi Rivers. It is located at the junction of 4 physiographic provinces (McNab & Avers, 1994) and is recognized as having nationally and internationally important wetland habitats, hosting >100 threatened and endangered species. Demissie *et al.* (1990) and IDNR (1997) provide thorough descriptions of the Cache River watershed.

The Cache River is a low gradient fifth-order stream that is divided into 2 watersheds: the upper Cache River and the lower Cache River. The Post Creek cutoff, completed ~1915, now drains much of the water from what is now the upper Cache directly into the Ohio River. The cutoff resulted in severe stream entrenchment and lateral gully formation in the upper Cache that is threatening riparian wetlands (Demissie & Xia, 1991).

Our study was conducted in the upper Cache River in the Cache River State Natural Area. The upper Cache River drains a 632-km<sup>2</sup> mosaic of agricultural lands, forests, and wetlands. Mean annual discharge since installation of the first weirs in 2001 is ~10.2 m<sup>3</sup> s<sup>-1</sup>. The USGS station 03612000, Cache River at Forman, Illinois provides additional physicochemical data ([http://waterdata.usgs.gov/nwis/inventory/?site\\_no=03612000](http://waterdata.usgs.gov/nwis/inventory/?site_no=03612000)).

From the 25 weirs now located along the upper Cache River at ~200 m intervals, we selected 4 weir sites and 4 control sites located ~midway between the weir sites. To increase sample sizes, 2 additional weir and control sites were used to examine food delivery rates, clutch size, fledgling rates, and nest success. Home-range sizes for focal insectivorous bird species were accounted for in the site selection process (Poole, 2005).

### *Emergence Production*

We sampled aquatic insect emergence opportunistically when discharge and weather allowed from Jan-2009 to June-2010. We sampled more intensively during spring (21-Mar to 20-June;  $n = 7$ ) to correspond with the expected insect emergence peaks and insectivorous bird nesting. Summer samples ( $n = 4$ ) were collected from 21-June to 20-Sept, fall samples ( $n = 2$ ) from 21-Sept to 20-Dec, and winter samples ( $n = 3$ ) from 21-Dec to 20-Mar.

For each sampling event, we tethered 6 floating emergence traps (0.10-m<sup>2</sup> sampling area, 250- $\mu$ m mesh) at all weir and control sites simultaneously for 3-5 days. Traps were similar to that of Malison *et al.* (2010), with slight modifications to withstand the flow in the upper Cache River. We collected insects from traps every 24-48 hours using a BioQuip Hand-Held Vac/Aspirator. Samples were frozen and later identified to family (Merritt *et al.*, 2008), measured, and expressed as emergence production (g dry mass m<sup>-2</sup> d<sup>-1</sup>) using published length-mass regression models (Rogers *et al.*, 1977; Sample *et al.*, 1993; Stagliano *et al.*, 1998; Sabo *et al.*, 2002). For some analyses, we focused on members of the orders Ephemeroptera, Plecoptera, and Trichoptera (EPT) because they are widely regarded as indicators of healthy aquatic habitats (Barbour *et al.*, 1999).

Water temperature data were collected with HOBO temperature data loggers (Onset Corporation) placed at 2 weir and 2 control sites, and averaged for each site during sampling periods. We estimated canopy cover with a spherical densiometer (Lemmon, 1956) at each site during spring when leaves were present on trees.

### *Birds*

We conducted weekly point counts from Mar-June (to correspond with spring migration and breeding periods) in 2009 and 2010 to estimate bird abundance (birds ha<sup>-1</sup>), species richness, and species diversity at weir and control sites. A 50-m fixed-radius point count was conducted between 0600 and 0900 for 5 minutes at each site, including all bird species detected visually and aurally. Repeated surveys of sites were used to generate detection probabilities, the likelihood that a bird present at a site during a survey was detected. All bird species detected were included in analyses; most species detected were insectivores, and even those not generally considered insectivores can shift their diets in response to high resource availability (Bird & Smith, 1964). Further, young of many bird species require a diet rich in protein to promote rapid growth (Skutch, 1944; Stewart, 1956; Reinecke, 1979).

We examined clutch size, food delivery rates, fledging rates, and nest success at weir and control sites during the breeding season (mid-Apr through June) in spring 2009 and 2010. For these analyses, we focused on Prothonotary Warblers (*Protonotaria citrea*) because they are abundant insectivorous cavity nesters, and they are a focus of local conservation and management activities. Twelve nest boxes, similar to those of Fleming and Petit (1986), were placed at each of the weir and control sites, including two additional weir and control sites to accommodate additional nest boxes. Nest boxes were placed ~30 m apart and attached to greased conduit to decrease predation (Hoover, 2006). Box openings were ~38 mm to reduce parasitism by Brown-headed Cowbirds (*Molothrus ater*) (Hoover, 2003b). We deployed nest boxes in early Mar-2009, before arrival of spring migrants, and monitored them every 3-4 days to estimate nest success, the probability that an egg present at the start of incubation produced a fledgling (Mayfield, 1975).

When cowbird eggs were discovered in boxes, they were immediately removed because brood parasitism can increase food delivery rates and reduce fledgling quality. Cowbird nestlings are larger than host species and have a higher energy demand, and thus will divert food from host nestlings (Hoover & Reetz, 2006). Food delivery rates (number of trips time<sup>-1</sup>) were observed for 1 hour in the morning on the day of highest energetic demand (day 7, determined from published literature; Poole, 2005).

#### *Statistical Analyses*

We used an a-priori  $\alpha$  of 0.05 for all statistical analyses;  $P$  values between 0.05 and 0.1 were considered marginally significant. We compared water temperature and % canopy cover at weir and control sites using 1-way analysis of variance (ANOVA).

We compared insect emergence abundance and production and insectivorous bird abundance, species richness, and species diversity at weir and control sites with 2-way repeated-measures ANOVA using SAS PROC MIXED. Site was the main effect and each sampling date was the repeated-measures effect (version 5, SAS Institute, Cary, North Carolina). Insect abundance, emergence production, and bird abundance data were square-root transformed to reduce heteroscedasticity and improve normality (Zar, 1996). We used simple linear correlation to examine relationships between insect emergence production and insectivorous bird density by matching closest point count date to emergence sampling date.

We estimated bird detection probabilities at weir and control sites for each point count survey date using the program PRESENCE 3.1 (Hines, 2006). Models were compared with and without site type (i.e., weir vs. control) using Akaike information criterion (AIC) statistics.

We used non-metric multidimensional scaling (NMDS; Minchin, 1997) ordination techniques to examine community structure of insects and birds at weir and control sites. Analysis of similarity (ANOSIM) was used to test for differences between site types (McCune & Grace, 2002). A similarity percentage (SIMPER) breakdown was used to identify taxa that were primarily responsible for observed differences in bird assemblages between site types. We used the multivariate statistical package PRIMER 6.0 (Clarke & Gorley, 2006) to perform NMDS, ANOSIM, and SIMPER analyses. We used unpaired  $t$ -tests to compare food delivery rates, clutch size, fledging rates, and nest success of Prothonotary Warblers.

#### **Results**

Average discharge and gage height of the upper Cache River during our study was 10.9 m<sup>3</sup> s<sup>-1</sup> and 4.1 m, respectively, with high variability during the study period. Average water temperature measured on 12 sampling dates at weir sites (19.1°C) and control sites (18.9°C) was similar.

Canopy cover was ~69% and ~89% for weirs and controls, respectively, and differed between site types ( $F_{1,6} = 6.22$ ,  $P = 0.04$ ).

### *Insect Emergence*

Ten insect orders representing 60 families were collected during the study. Emergence abundance (individuals  $m^{-2}$ ) ranged from 2.3-210.0 at weir sites and 3.7-441.3 at control sites, and was lowest in winter and highest in summer at both site types (Fig. 1). Mean emergence abundance (individuals  $m^{-2} \pm 1$  SE) over the study period at weir and control sites was  $83.4 \pm 9.2$  and  $116.1 \pm 16.4$ , respectively. Two-way repeated measures ANOVA indicated significant effects of site type, date, and a site type x date interaction, with higher abundance at control sites during the August-October period, but similar abundance at other times (Fig. 1). Average abundances at weir and control sites in spring 2009 were  $86.1 \pm 20.7$  individuals  $m^{-2}$  and  $88.1 \pm 31.9$  individuals  $m^{-2}$ , respectively. During spring 2010, emergence abundance averaged  $151.3 \pm 51.7$  individuals  $m^{-2}$  at weir sites and  $238.5 \pm 127.2$  individuals  $m^{-2}$  at control sites.

Mean insect species richness (d, Margalef Index) and diversity ( $H'$ , Shannon Index) were higher at weir sites compared to control sites, although both interacted with sampling date (d site x date,  $F_{15,77.4} = 2.11$ ,  $P = 0.018$ ;  $H'$  site x date,  $F_{15,79.7} = 5.32$ ,  $P < 0.001$ ), with higher values at weir sites throughout the year except during winter. Chironomidae accounted for 70% (weirs) to 88% (controls) of total abundance. Chironomidae accounted for 46% (weirs) to 72% (controls) of emergence production. EPT taxa constituted 17% (weirs) to 6% (controls) of total abundance and 37% (weirs) to 20% (controls) of emergence production.

Emergence production ranged from 1.3-94.7 mg dry mass (DM)  $m^{-2} d^{-1}$  at weir sites and 2.2-100.3 mg DM  $m^{-2} d^{-1}$  at control sites. As with abundance, emergence production was lowest during winter and peaked in spring and summer (Fig. 1). Mean emergence production over the study period was  $46.0 \pm 5.0$  mg DM  $m^{-2} d^{-1}$  at weirs and  $42.5 \pm 5.2$  mg DM  $m^{-2} d^{-1}$  at control sites. Emergence production did not differ between weir and control sites, but the interaction between site and date was marginally significant (Fig. 1). Emergence production during spring 2009 was  $53.9 \pm 16.3$  mg DM  $m^{-2} d^{-1}$  at weir sites and  $27.5 \pm 12.9$  mg DM  $m^{-2} d^{-1}$  at control sites. In spring of 2010, average emergence production was  $74.4 \pm 15.6$  mg DM  $m^{-2} d^{-1}$  at weir sites and  $68.9 \pm 24.4$  mg DM  $m^{-2} d^{-1}$  at control sites. Average individual mass of emerging insects was higher at weir sites ( $0.66 \pm 0.06$  mg) compared to control sites ( $0.47 \pm 0.03$  mg) (site,  $F_{1,32.2} = 9.77$ ,  $P = 0.004$ ; date,  $F_{15,79.3} = 1.67$ ,  $P = 0.074$ ).

Mean EPT emergence abundance was greater at weir sites compared to control sites, with site and date effects, and an interaction between site and date, whereby temporal patterns at weir and control sites differed (Fig. 1). Mean EPT emergence production was also greater at weir sites, with site and date effects, but no interaction effect (Fig. 1).

### *Insect Assemblage Structure*

Ordinations performed on insect abundance and emergence production revealed distinct assemblages at weir sites and control sites. Minimum stress values were 0.01 for abundance and 0.05 for emergence production. The ANOSIM procedure indicated differences between weir and control site assemblages for abundance ( $R = 1$ ;  $P = 0.029$ ) and emergence production ( $R = 0.938$ ;  $P = 0.029$ ).

### *Birds*

A total of 113 bird species were detected at least once during 2009 and 2010 spring surveys. Mean bird density (individuals  $ha^{-1}$ ) was  $22.0 \pm 0.7$  at weir sites and  $20.0 \pm 0.6$  at control sites in 2009, and  $24.4 \pm 0.8$  at weir sites and  $20.3 \pm 0.6$  at control sites in 2010. In 2009, the site effect was marginal ( $F_{1,29.5} = 3.53$ ,  $P = 0.070$ ) and date effect was significant ( $F_{14,74.4} = 3.85$ ,  $P <$

0.001), but there was no site x date interaction. In 2010, site and date effects were significant (site,  $F_{1,18.7} = 10.44$ ,  $P = 0.004$ ; date,  $F_{13,66.7} = 1.98$ ,  $P = 0.036$ ) with no interaction. Overall, bird densities were higher at weir sites. Analyses of only insectivorous bird species showed similar patterns in 2009 (site,  $F_{1,34.9} = 4.72$ ,  $P = 0.037$ ; date,  $F_{14,73.6} = 12.15$ ,  $P < 0.001$ ), and 2010 (site,  $F_{1,20.1} = 7.66$ ,  $P = 0.012$ ; date,  $F_{13,68.7} = 3.35$ ,  $P < 0.001$ ).

Models of detection probabilities without site type had more support than with site type, indicating no difference in detectability between weirs and control sites. For both years, average detection probability for all species did not differ between site types (Table 1).

Insect emergence production and insectivorous bird density were positively correlated across spring sample dates ( $R^2 = 0.36$ ,  $P = 0.009$ ). An even stronger correlation ( $R^2 = 0.74$ ,  $P = 0.001$ ) was evident between larger-bodied EPT taxa emergence production and insectivorous bird density (Fig. 2).

Bird species richness (d, Margalef Index) and diversity ( $H'$ , Shannon Index) did not vary between site types in 2009, but there was a date effect for both (d date,  $F_{14,74} = 5.68$ ,  $P < 0.001$ ;  $H'$  date,  $F_{14,74} = 7.28$ ,  $P < 0.001$ ). However, species richness and diversity were higher at weir sites than control sites in 2010, with significant site and date effects (d site,  $F_{1,18.3} = 4.46$ ,  $P = 0.048$ ; d date,  $F_{13,69.5} = 5.82$ ,  $P < 0.001$ ;  $H'$  site,  $F_{1,16.9} = 3.95$ ,  $P = 0.063$ ;  $H'$  date,  $F_{13,68.8} = 5.95$ ,  $P < 0.001$ ).

Ordinations showed separation of bird assemblages associated with site types (Fig. 3). SIMPER analysis of dissimilarity indicated 43 species accounted for ~90% of the observed differences between site types in 2009 and 53 species accounted for ~90% of observed differences in 2010. Bird species that contributed to differences and were generally more abundant at weir sites were primarily insectivores.

### *Nesting*

During spring 2009 and 2010, 95 nest boxes contained nesting materials. Eggs were laid in 50 nests (26 in 2009 and 24 in 2010), with 42 belonging to Prothonotary Warblers. Of the 42 nests with eggs, 31 produced fledglings for which foraging rates were observed. The number of eggs laid in boxes did not differ between site types. However, number of hatchlings and fledglings was higher at control sites (Table 2). Conversely, the number of cowbird eggs in nest boxes was ~1.7x higher at weir sites. Feeding rates (trips  $hr^{-1}$ ) were marginally higher at control sites, but when considered per hatchling (trips  $hr^{-1}$  hatchling $^{-1}$ ), were similar between sites. Percentage of hatchlings that fledged at weir sites was ~20% lower than control sites (Table 2). Prothonotary Warbler nest survival was 0.52 at weir sites and 0.73 at control sites.

## **Discussion**

### *Insect responses and mechanisms*

Our study demonstrates that a common in-stream restoration procedure (rock weirs) can have far reaching effects through increasing stable, heterogeneous habitats for aquatic insects. This habitat modification enhanced diversity and emergence production of some aquatic insect groups, particularly EPT taxa, which are relatively large-bodied and are considered indicators of good habitat and water quality (Barbour *et al.*, 1999). Total insect abundance was higher at control sites because of one group, chironomid midges, which thrive in the ambient scoured clay streambed (Walther & Whiles, 2008). However, midges are small, and thus total emergence production was similar between weir and control sites because of tradeoffs between numbers and individual body size.

Weirs in the Cache promote insect diversity and production of larger-bodied groups through a variety of mechanisms. Mid- to large-sized low-gradient rivers, such as the Cache, are

often stable substrate limited; stable substrata such as large rocks and woody debris often yield higher invertebrate biomass than ambient fine sediments, and thus are important foraging habitats for fishes and other insectivores (Benke *et al.*, 1984). Increased habitat heterogeneity associated with larger substrata also provides a wider range of microhabitats that promotes insect species richness (Minshall, 1984; Jacobsen *et al.*, 1997). The rock weirs in the upper Cache River also represent artificial riffles that influence water velocity and turbulence. Invertebrates respond to and segregate across velocity gradients (Malas & Wallace, 1977; McCreadie & Colbo, 1993), and invertebrate communities in pools and riffles of the same system can be very different (Wallace *et al.*, 1995).

Our results suggest that an earlier study in the Cache River underestimated potential contributions of chironomids to emergence production at control sites. Based on benthic samples, Walther and Whiles (2008) estimated that emergence production would be ~2x higher from weirs compared to the streambed. However, we saw no difference in total insect emergence production between site types because of large contributions of chironomids at control sites. Although some chironomids may benefit from increased stable substrata and heterogeneity at the weirs, many species thrive in relatively homogeneous substrata, where they can dominate aquatic insect communities (Beck, 1977; Flinn *et al.*, 2005). Others have also found that midges often dominate emerging aquatic insect assemblages (Paasivirta *et al.*, 1988; Iwakuma, 1992; Whiles & Goldowitz, 2001).

#### *Bird responses and riparian subsidies*

Beyond in-stream responses, construction of weirs appears to enhance biological connectivity between the river and forest. Birds responded positively to emerging aquatic insects, particularly larger bodied taxa, and thus weirs appear to function as feeding 'hot spots' for insectivorous birds and possibly other riparian insectivores. As such, weirs in the Cache River enhance stream to riparian energy and nutrient subsidies, and overall connectivity between stream and riparian food webs (e.g., Baxter *et al.*, 2005).

Positive effects of weirs may reach beyond the spatial scale we considered. Fletcher *et al.* (2007) found that restoration may affect areas at least 200-300 m away from a restored site because birds that increased in restorations were also more abundant adjacent to restored areas compared to areas near control sites. In our study, weirs may have benefited insectivores at control sites through dispersal of insects emerging from weirs. Jackson and Resh (1989) found that adult aquatic insects dispersed 150 m from the stream channel. Some adult mayflies and caddisflies can disperse >1 km (Kovats *et al.*, 1996) and stoneflies at least 1 km (Briers *et al.*, 2004). Although some adult aquatic insects are capable of dispersing considerable distances, overall positive responses to weirs by birds in our study was likely because densities of larger-bodied adult aquatic insects attenuated with distance from weirs.

Variation among point counts at a site likely occurred because of habitat structure, ambient noise, wind conditions, and other factors (Wolf *et al.*, 1995). Both site types had features that could reduce detectability of birds. Most notable was the noise from the water flowing over the weirs at weir sites, and the somewhat denser forest associated with control sites. Thus, bird numbers were likely underestimated before accounting for detection at both weir and control sites. Regardless, detection probabilities at both site types were similar, supporting our hypothesis that birds were responding to enhanced availability of larger insect prey at weirs.

Based on optimal foraging theory (MacArthur & Pianka, 1966), birds should select larger, more profitable prey items when they are available (e.g., Krebs *et al.*, 1977), such as the more abundant EPT taxa at the weir sites. Average body size of emerging insects was 1.4x larger



at weir sites than control sites. The significant correlation between emergence production and bird densities, particularly with larger EPT taxa, further supports our hypothesis that birds were responding to insect prey availability. Similar bird responses to emerging aquatic insect biomass were documented along a prairie stream (Gray, 1993); these represent numerical responses, whereby predators immigrate to an area in response to enhanced prey density (e.g., Andersson & Erlinge, 1977; Yunker, 2002).

Although our results indicate positive responses by insects and birds, and enhanced connections between stream and riparian food webs, avian reproductive success was lower at weir sites. Installation of rock weirs involves the removal of some trees and may reduce the availability of natural cavities and canopy cover, while increasing edge habitat. Cowbirds prefer edge habitats (Brittingham & Temple, 1983), and this is consistent with the higher parasitism rates and lower nest success we observed at weir sites. Bock and Jones (2004) also noted that in areas with more anthropogenic disturbance, bird density and reproductive success were often negatively related. Cowbird parasitism rates will likely wane as the riparian forest adjacent to weirs re-establishes (Brittingham & Temple, 1996). Regardless, future projects should work to minimize disturbance to riparian forests, as disturbance may offset some of the ecological benefits of restoration.

Until the trees around weirs are re-established, Prothonotary Warblers may suffer higher cowbird parasitism and predation, and lower reproductive success. Prothonotary Warblers are migratory and are likely to return to the same breeding site if they are reproductively successful; they will choose to reproduce elsewhere if nest success is low (Hoover, 2003). However, brood parasitism does not produce the same response as predation (Hoover, 2003), which may be a result of evolutionary lag (e.g., Rothstein & Robinson, 1988). Hoover and Robinson (2007) also found that if the parasite egg is ejected, female cowbirds may destroy entire clutches or broods in retaliation, and that cowbirds may “farm” hosts or force re-nesting attempts to create more opportunities for nest parasitism. Although breeding density of Prothonotary Warblers has not been correlated with nest parasitism or predation (Hoover, 2001), nest parasitism rates are higher in open-canopy habitats (Brittingham & Temple, 1996), and rates of nest predation have been positively correlated with habitat fragmentation (Hoover *et al.*, 1995; Robinson *et al.*, 1995).

Approaches for assessing the success of a restoration include measuring physicochemical characteristics or biological responses, but standard criteria for deeming restorations successful do not exist (Palmer *et al.*, 2005; Ruiz-Jaen & Aide, 2005). Ongoing restoration efforts in the Cache River offer many opportunities to evaluate and monitor restorations. Our results, along with other studies, can help develop standard approaches for evaluating restoration success in an ecological context, and refine, promote, and justify further restoration efforts. Our investigations showed both positive (enhanced production of large insects) and negative (decreased hatchling production) effects associated with weirs, allowing for a comprehensive assessment of overall ecological success and improvement of methods. Our results also underscore the importance of measuring ecological responses at large spatial scales.

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Table 1. Model comparisons for detection probabilities ( $P$ ) at weir sites and control sites in the Cache River using Program Presence.

| Year                  | AIC <sub>c</sub> | ΔAIC <sub>c</sub> | AIC <sub>c</sub><br>Weight | Weir estimates | Control<br>estimates |
|-----------------------|------------------|-------------------|----------------------------|----------------|----------------------|
| 2009                  |                  |                   |                            |                |                      |
| p( <i>constant</i> )  | 7104.06          | 0.00              | 0.91                       |                |                      |
| p( <i>site type</i> ) | 7108.71          | 4.65              | 0.09                       | 0.275 ± 0.009  | 0.287 ± 0.009        |
| 2010                  |                  |                   |                            |                |                      |
| p( <i>constant</i> )  | 7232.80          | 0.00              | 0.94                       |                |                      |
| p( <i>site type</i> ) | 7238.22          | 5.42              | 0.06                       | 0.283 ± 0.009  | 0.289 ± 0.010        |

Table 2. Means ( $\pm$  SE) of nest data for Prothonotary Warbler (host) nest boxes from 2009 and 2010. Differences were considered significant when  $P < 0.05$ , and marginally significant when  $0.05 < P < 0.1$ . The test statistic ( $t$ ) and number of nests ( $n$ ) are indicated.

|                     | Host eggs<br>$t = 0.55$<br>$P = 0.29$ | Cowbird eggs<br>$t = 1.67$<br>$P = 0.05$ | Hatchlings<br>$t = 1.97$<br>$P = 0.029$ | Fledglings<br>$t = 3.01$<br>$P = 0.003$ | Feeding rate $\text{h}^{-1}$<br>$t = 1.62$<br>$P = 0.06$ | Feeds nestling $^{-1} \text{h}^{-1}$<br>$t = 0.35$<br>$P = 0.37$ | % hatchlings fledged<br>$t = 2.05$<br>$P = 0.02$ |
|---------------------|---------------------------------------|--|---|---|--|--|--|
| Weir<br>$n = 20$    | 4.0 (0.3)                             | 1.0 (0.2)                                | 3.1 (0.4)                               | 3.0 (0.4)                               | 9.7 (0.7)  | 2.9 (0.2)  | 81.9 (8.7)                                       |
| Control<br>$n = 22$ | 4.2 (0.4)                             | 0.6 (0.1)                                | 4.0 (0.3)                               | 4.2 (0.2)                               | 11.5 (0.8)   | 2.8 (0.2)  | 100.0 (0.0)                                      |

## Figure Legends

Figure 1. Total insect emergence abundance (a) (site,  $F_{1,32.5} = 9.23$ ,  $P = 0.005$ ; date,  $F_{15,79.7} = 15.99$ ,  $P < 0.001$ ; site x date,  $F_{15,79.7} = 4.47$ ,  $P < 0.001$ ), Total EPT (Ephemeroptera, Plecoptera, and Trichoptera) taxa emergence abundance (b) (site,  $F_{1,22.8} = 15.12$ ,  $P < 0.001$ ; date,  $F_{15,80.3} = 10.62$ ,  $P < 0.001$ ; site x date,  $F_{15,80.3} = 2.88$ ,  $P = 0.001$ ), total insect emergence production (c) (site,  $F_{1,29} = 0.35$ ,  $P = 0.561$ ; date,  $F_{15,80.6} = 7.37$ ,  $P < 0.001$ ; site x date,  $F_{15,80.6} = 1.76$ ,  $P = 0.055$ ), and EPT emergence production (d) (site,  $F_{1,24.2} = 8.17$ ,  $P = 0.009$ ; date,  $F_{15,81.1} = 7.32$ ,  $P < 0.001$ ; site x date,  $F_{15,81.1} = 1.30$ ,  $P = 0.221$ ) at weir (filled symbols) and control (open symbols) sites in 2009 and 2010. Asterisks (\*) indicate significant differences between weir and control sites ( $P < 0.05$ ). Plus signs (+) indicate marginally significant differences ( $P < 0.1 > 0.05$ ). Error bars indicate 1 standard error.

Figure 2. Relationship between mean bird densities (insectivores only) and mean insect emergence production (a) ( $R^2 = 0.36$ ,  $P = 0.009$ ,  $n = 14$ ), and mean insectivorous bird densities and mean EPT emergence (b) ( $R^2 = 0.74$ ,  $P = 0.001$ ,  $n = 14$ ) at weir (filled symbols) and control (open symbols) sites on spring sampling dates in the upper Cache River in 2009 and 2010.

Figure 3. NMDS ordinations of bird abundance at weir (filled symbols) and control (open symbols) sites during 2009 (a) (ANOSIM:  $R = 0.188$ ;  $P = 0.08$ ; stress 0.1) and 2010 (b) (ANOSIM:  $R = 0.208$ ;  $P = 0.11$ ; stress 0.05).







