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PROTHONOTARY WARBLERS AS INDICATORS OF HYDROLOGICAL CONDITIONS IN BOTTOMLAND FORESTS

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Abstract. Indicator species provide important information on habitat quality and the ecological integrity of ecosystems. Indicator species have been studied to sound the alarm when ecosystems are degraded or threatened, but they also may be used to measure the success of habitat management and conservation activities. Bottomland forest bird communities are threatened by the channelization of rivers and streams, which can lead to the formation of lateral gullies that connect streams to adjacent forested wetlands and drain them. Each spring these forested wetlands may be attractive breeding habitat for birds, but the unusually-rapid draining of the wetlands may expose birds to nest predators. I monitored the reproductive success of Prothonotary Warblers (*Protonotaria citrea*), a migratory songbird that breeds preferentially over water within forested wetlands, in the Cache River watershed in Illinois during 1993-2007. Here I highlight how this warbler is an indicator of hydrological conditions in forested wetlands and of ecosystem integrity and the success of habitat restoration in bottomland forests. Nest predation by raccoons (*Procyon lotor*) was the primary factor limiting reproductive success of Prothonotary Warblers and rates of nest predation decreased with increased water depth beneath nests. Natural processes (e.g., water control structures built by beavers; *Castor canadensis*) and conservation activities (e.g., plugging lateral gullies), which hold water in forested wetlands, increased the reproductive success and densities of Prothonotary Warblers and other wetland-dependent birds. Results from this Prothonotary Warbler study also indicate that efforts of conservationists to reduce the fragmentation of bottomland forest habitat will reduce rates of cowbird parasitism. Documenting changes in warbler densities and reproductive success in response to conservation actions ultimately provides a means to measure the success of restoration activities in bottomland forest ecosystems.

Key Words: bottomland forest, hydrological processes, indicator species, Prothonotary Warbler, *Protonotaria citrea*, wetland restoration.

EL CHIPE (REINITA) PROTONOTARIO COMO INDICADOR DE CONDICIONES HIDROLÓGICAS EN BOSQUES RIBEREÑOS

Resumen. Las especies indicadoras proporcionan información importante sobre la calidad del hábitat y la integridad ecológica de los ecosistemas. Estas especies han sido estudiadas a fin de que alerten cuando los ecosistemas resultan degradados o amenazados, pero también con el fin de medir el éxito de la gestión sobre el hábitat y las actividades de conservación. Las comunidades de aves en los bosques ribereños, están amenazadas por la canalización de ríos y arroyos, que pueden traer consigo la formación de arroyuelos laterales, cuyos cauces se conectan a los humedales boscosos adyacentes y los drenan. Cada primavera estos humedales boscosos se convierten en atractivos hábitat de reproducción para las aves, pero el inusualmente rápido drenaje de los humedales, expone a quienes allí anidan a sus depredadores. Monitoreé, de 1993 a 2007, el éxito reproductivo del Chipe (Reinita) Protonotario (*Protonotaria citrea*), un ave cantora migratoria que cría preferentemente por encima del agua dentro de los humedales boscosos, en la cuenca del Río Cache, en Illinois. En este trabajo, destaco cómo esta reinita es un indicador de: condiciones hidrológicas en los humedales boscosos, integridad del ecosistema y éxito de la restauración del hábitat en bosques ribereños. La depredación de los nidos por parte de mapaches (*Procyon lotor*) fue el principal factor limitante en el éxito reproductivo del Chipe (Reinita) Protonotario. Al agua alcanzar una mayor profundidad debajo de ellos, la taza de depredación de los nidos disminuyó. Tanto los procesos naturales, dígase estructuras de control de agua construidas por castores (*Castor canadensis), como* las actividades de conservación, tales como el bloqueo de cauces laterales por el hombre, son factores que ayudan a la retención del agua en los humedales boscosos. Su presencia aumentó el éxito reproductivo y la densidad de población del Chipe (Reinita) Protonotario y de otras aves dependientes de humedales. Los resultados de este

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estudio sobre el Chipe (Reinita) Protonotario, también indican que los esfuerzos de los conservacionistas por reducir la fragmentación del hábitat en los bosques ribereños, reducirán también las tasas de parasitismo del pájaro garrapatero. La documentación de los cambios en la densidad y éxitos reproductivos de las reinitas, como resultado de las acciones de conservación, provee en última instancia un medio para medir el éxito de las actividades de restauración en los ecosistemas forestales de bosques ribereños.

INTRODUCTION

The indicator species concept is attractive to conservationists and land managers because indicator species can provide a time- and cost-effective way to assess the effects of natural and human-induced disturbances on an ecosystem (Hilty and Merenlender 2000, Carignan and Villard 2002). Indicator species have been used widely to identify spatial patterns of biodiversity (Pearman and Weber 2007), predict species richness (Fleishman et al. 2005), assess habitat quality (Canterbury et al. 2000), and monitor the ecological integrity of various ecosystems (Brooks et al. 1998, Moyle and Randall 1998, Carignan and Villard 2002). It is impossible for land managers to measure everything of potential interest within an ecosystem and deciding what to monitor can be challenging (Noss 1999). Therefore, identifying one or more species that can serve as an indicator of ecological integrity can greatly improve the management and conservation of particular ecosystems.

There are a number of characteristics that add to the value of a species as an indicator (Noss 1990, Carignan and Villard 2002). These characteristics include providing an early warning of habitat degradation or loss of ecosystem integrity, indicating the cause of the problem and not just that a problem exists, providing assessment over a wide range and intensity of degradation, and being cost-effective to monitor and relatively easy to study. In addition, an indicator species may be particularly useful if it is emblematic of, or strongly associated with, a particular habitat, tightly linked to ecosystem processes, and representative of how other ecologically-similar species are being affected (Lambeck 1997, Noss 1999). Even though indicator species have been used to sound the alarm when ecosystems are degraded or threatened, they also may be used to measure the success of habitat management and conservation activities. Species from several taxonomic groups have been used as indicators (Hilty and Merenlender 2000), and among vertebrates, birds have been used extensively (O'Connell et al. 1998, Canterbury et al. 2000, Bryce et al. 2002, Chase and Guepel 2005).

Populations of breeding birds continue to be threatened by the fragmentation and degradation of natural habitats (Wilcove et al. 1998, Askins 2000). For example, bottomland forest habitat has suffered tremendous losses in the United States (an 80% reduction in area) and what remains is highly fragmented and embedded within a matrix dominated by agriculture (Abernethy and Turner 1987, Gosselink and Lee 1989, Twedt and Loesch 1999). 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. 1995a), populations of birds breeding in bottomland forests are threatened by the alteration and degradation of "natural" hydrologic processes (Hoover 2006, 2009). Channelization of streams and rivers has led to channel incision and the subsequent formation of lateral gullies that connect the main channel of streams to adjacent (off-channel) wetlands, altering the hydrology of 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, Hoover 2009).

Prothonotary Warblers (*Protonotaria citrea*) preferentially breed in forested wetlands in the eastern half of the U.S. and are therefore an emblematic species of bottomland forest ecosystems (Petit 1999). Prothonotary Warblers prefer to nest over water, a preference thought to be associated with food (i.e., insect) availability (Petit and Petit 1996) and selective pressure from terrestrial nest predators (e.g., raccoons, *Procyon lotor*; Hoover 2006). Therefore, these warblers are threatened not only by habitat loss and habitat fragmentation, but also by the channelization of streams and the subsequent cascade of events that degrade hydrological processes associated with off-channel forested wetlands (Hoover 2009).

Habitat specificity, a tight link to hydrological processes, and the fact that they can be studied in great detail during the breeding season make Prothonotary Warblers well-suited to be an indicator species. My objectives here are to present a synthesis of the large body of research completed during 1993–2007 on the breeding ecology of Prothonotary Warblers in the Cache River watershed in southern Illinois, and to

TABLE 1. EXAMPLES OF HOW RESULTS FROM RESEARCH ON PROTHONOTARY WARBLERS MAY ASSIST IN ASSESSING THE INTEGRITY OF DIFFERENT ATTRIBUTES OF BOTTOMLAND FOREST ECOSYSTEMS. RESEARCH CONDUCTED DURING 1993-2007 IN THE CACHE RIVER WATERSHED, ILLINOIS.

Result	Attributes	Implications	Reference
Increased nesting success with increased water depth beneath nests	Hydrological processes and habitat configuration	Forested wetlands with water deeper than 40 cm are important breeding habitat	Hoover 2006
Increased nesting success in response to off-channel wetland restoration	Hydrological processes	Plugging lateral gullies increases nesting success of warblers in off-channel wetlands	Hoover 2009
Increased warbler densities in response to off-channel wetland restoration	Hydrological processes	Local warbler populations respond favorably to local conservation actions	Hoover 2009
Increased between-year breeding-site fidelity of adults with increased nesting success	Hydrological processes	Adult warblers return to "good" sites and avoid returning to "bad" sites	Hoover 2003
Most warbler offspring that return to breed do so to within 3 km of where they were produced	Hydrological processes	Conservation actions that increase nesting success promote growth of local warbler populations	Hoover and Reetz 2007; Hoover and Hauber 2007
Decreased cowbird parasitism of warbler nests with increased forest cover within a 3-km radius	Habitat configuration	Reversing the fragmentation of bottomland forests should reduce rates of cowbird parasitism	Hoover and Hauber 2007

highlight ways that Prothonotary Warblers may serve as an indicator species for the integrity of hydrological conditions in forested wetlands specifically, and the integrity of bottomland forests in general.

METHODS

Detailed descriptions of methodologies and data analyses associated with the various studies of Prothonotary Warblers discussed here can be found in the references listed in Table 1. Below I highlight some of the general techniques and research protocols used to study the warblers over a 15-year period.

This research was conducted within the Cache River watershed located in southern Illinois in the U.S. The Cache River has a total length of 176 km and meanders through the southern tip of Illinois to the Ohio River, draining 1537 km^2 of land. Study sites (>20) were isolated forested off-channel wetlands located within a 192 km^2-portion of the watershed. The hydrological fluctuations of individual study sites 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%).

I studied the nesting ecology of Prothonotary Warblers from 1 April to 15 August during 1993–2007. 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 U.S. (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 2003, 2006).

In 1993 I gathered preliminary data on the reproductive success of the warblers by monitoring their nests in natural cavities. Reproductive success in nest boxes was similar to that in natural cavities, and accurately represented the levels of reproductive success achieved by the warblers during the breeding season (Hoover

2001, 2003, 2006). Starting in 1994, I placed nest boxes made from modified 1.9-L cardboard milk and juice cartons (Fleming and Petit 1986) on study sites to cover areas of suitable habitat (inter-box spacing of 30–40 m). Nest boxes had openings that were similar in diameter to natural cavity nests (32–64 mm), and were placed on trees at the average height (1.7 m above ground level) of natural cavity nests in this area (Hoover 2001). There were approximately 1000 nest boxes distributed among 20–25 study sites each year during 1994–2007.

Nest boxes were monitored every 4 days from April through July. During each visit, I documented whether or not there was an active nest (e.g., eggs or nestlings present) in the box, and for active nests recorded the number of eggs or nestlings and the identity of the adult warblers. Nests were visited more frequently (every 1–2 days) around the time when nestlings were estimated to fledge to obtain accurate measures of reproductive output. I knew the fate (e.g., failure caused by a nest predator, or success) of nearly every (>95%) nesting attempt within these wetlands. The identity of the nest predator responsible for any nesting failure was inferred (based on the condition of the nest and its contents; Hoover 2006) for every such event. Beginning in 1995, I measured the depth (to the nearest 5 cm) of water beneath each active nest on every visit to the nest.

Each year, every adult warbler nesting within the study wetlands was re-sighted or captured and color-marked with a unique combination of a numbered aluminum (United States Biological Survey; USGS) 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 USGS aluminum band when they were 9–10 days old (ca. 1 to 2 days before fledging from the nest box).

From 2002 through 2007, I used 5-min point counts, one count per year per wetland, to assess the density of prothonotary warblers and other species at various sites (Ralph et al. 1995, Hamel et al. 1996). Point counts were conducted each year during the period from 20 May to 20 June at permanently marked sampling points spaced at least 150 m apart. Only birds seen or heard within 50 m of the sampling point were used in analyses. Counts were made between 06:00 and 10:00 local standard time. Counts were not made on mornings when it rained or when wind speeds exceeded 16 km per hour. Each point count yielded the number of species present as well as the number of individuals present within a particular species. These counts are no more than indices to density and diversity that were, nonetheless, sufficient for the objectives the research.

I monitored the preliminary effects of gully plugs, a management tool to reduce the unnaturally-rapid draining of off-channel wetlands by lateral gullies, on Prothonotary Warblers during 1998–2001. Each of four wetlands was being drained by a lateral gully during 1998–1999. Similar to other wetlands in this watershed that are not drained by lateral gullies, the four study wetlands filled during 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 flooded area (e.g., 50% reduction in 2 weeks). The lateral gullies associated with two of the wetlands were plugged (plugs consisted of a combination of rock, sediment cloth and soil) at the river channel during the winter of 1999, 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 two wetlands served as treatment (gully plugs added) sites. The lateral gullies associated with the other two wetlands were not plugged and these wetlands served as control (gully plugs not added) sites.

Data Analyses

I documented the outcome of every nesting attempt of prothonotary warblers within the two treatment and two control wetlands during 1998–2001 and determined the number of offspring produced per female per year (productivity) for treatment and control wetlands during the pre- (1998–1999) and post- (2000–2001) treatment periods. I randomly selected 10 females per site per year so that sample sizes (n=40 females) were similar among the four wetland categories. To test the prediction that warbler productivity would increase in the treatment (gully-plug) but not in the control wetlands during the post-treatment period, I used a Kruskal-Wallis test (SYSTAT 2000) to determine whether productivity differed among the four categories of wetland. If there was a significant difference among all categories, I used multiple Mann-Whitney U-tests to make multiple pairwise comparisons. Nominal P-values for the multiple comparisons were

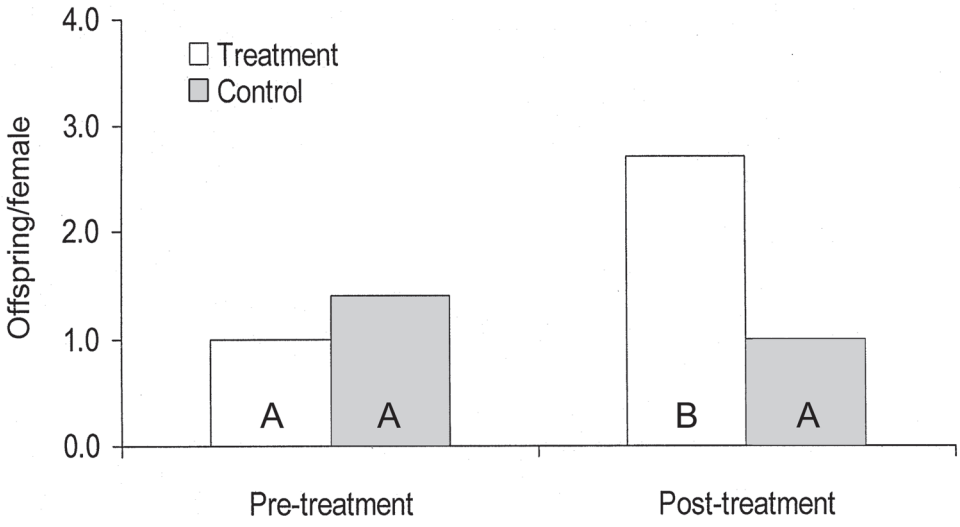

FIGURE 1. The productivity was higher for Prothonotary Warblers breeding in gully-plug wetlands in the post-treatment period than the other three categories of wetland. Bars represent average values for 40 female warblers in each category of wetland. Bars with the same letter inside are not different ($P > 0.05$, Bonferroni-adjusted for multiple comparisons) from each other.

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).

RESULTS

The placement of nest boxes on study sites did not result in an increase in warbler densities (Hoover 2001). During the period from 1993–2007, numerous field assistants and I collected data on reproductive success and return rates from approximately 250 pairs of color-banded Prothonotary Warbler adults each year. In total I have overseen data collection on information from over 6000 nesting attempts and field personnel have banded over 5700 warbler offspring. Nest predators caused the failure of approximately half of all nesting attempts and raccoons were responsible for the vast majority (ca. 85%) of nest predation events (Hoover 2001, Hoover 2006, Hoover 2009). A summary of important results stemming from this long-term research and large database is given in Table 1. Included (Table 1) are the attributes of the bottomland forest ecosystem associated with each result, general implications of each result, and references where the results are discussed in greater detail.

The annual productivity (number of warbler offspring produced per female per year) was known for all female warblers breeding within the four wetlands that were part of the preliminary gully plug experiment during 1998–2001. The range of values for productivity was 0–8 offspring. The average productivity differed among the four categories of wetland (Kruskal-Wallis test: $H_3 = 15.50$, $P < 0.001$) and was significantly greater in the post-treatment gully-plug wetlands (2.7) than in the other three categories of wetland (1.0–1.4; Fig. 1).

Beavers (*Castor Canadensis*) obstructed the flow of water out of one wetland (dammed a lateral gully) for a four-year period (2002–2005) during 1994–2007. This "natural experiment" allowed me to document changes in productivity and in numbers of pairs of warblers occupying the wetland that occurred while the beaver dam was present. During the eight years prior to the beaver dam being in place, the range of values for the average annual productivity of the warblers was 0.3–3.1 (Fig. 2a) and there were 11–21 pairs on the site in a given year (Fig. 2b). The productivity of the warblers increased during the years when the beaver dam was in place (range = 4.2–5.7 over four years) then decreased after the dam was destroyed (Fig. 2a). The number of warblers using the wetland grew during the four years with the dam in place, more than tripled by the fourth year, then started to decrease after the dam was destroyed (Fig. 2b).

DISCUSSION

In bottomland forest ecosystems, hydrological processes are responsible for modifying

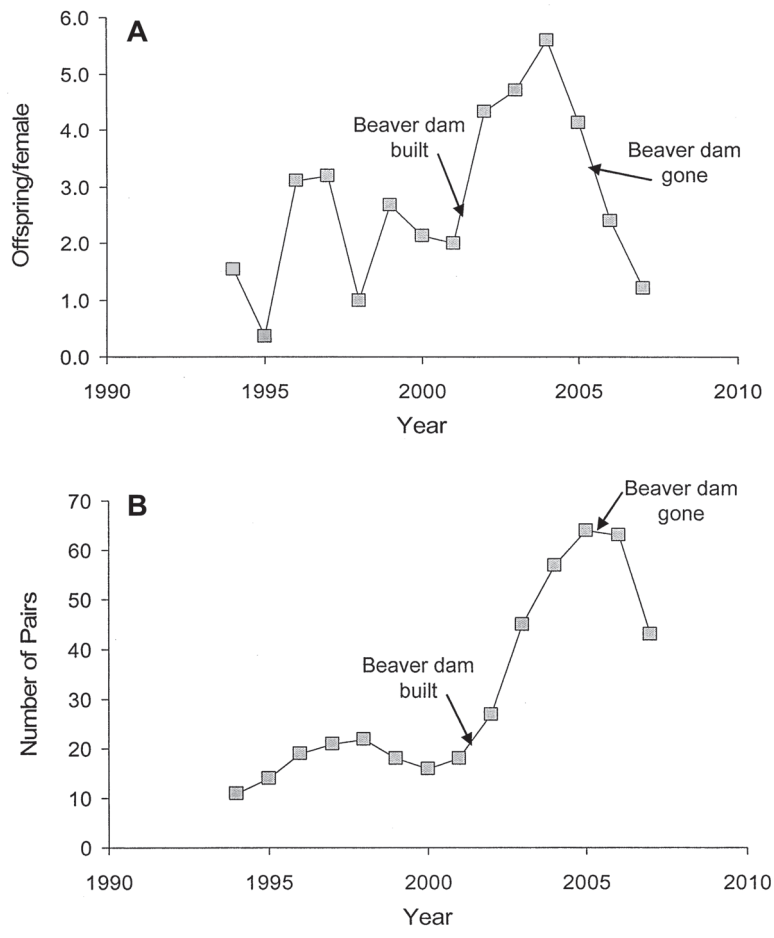

FIGURE 2. The (a) productivity and (b) number of pairs of Prothonotary Warblers increased dramatically on a wetland in the Cache River watershed after a beaver dam was constructed, and then decreased after the dam was destroyed.

and perpetuating the habitat within the system (Pashley and Barrow 1993). The interplay of topography and hydrology creates and maintains habitat complexity 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). Even within highly-fragmented bottomland forest ecosystems which promote high densities of raccoons and other nest predators (Dijak and Thompson 2000, Heske et al. 2001, Chalfoun et al. 2002), forested wetlands may provide birds with breeding habitat where nest predation is reduced because of the presence of relatively deep water (Hoover 2006, 2009). However, the benefits of nesting in forested wetlands are diminished when channel incision and the subsequent formation of lateral gullies expose birds breeding in forested wetlands to some of these predators (Hoover 2009). 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. Scientists using radio-telemetry to track the movements of raccoons have found that 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). The relatively deep water

in forested wetlands that lack lateral gullies, or wetlands where the gullies have been plugged (either by beavers or by humans), provide some safety from nest predators and a substantial increase in reproductive output (Hoover 2006, 2009; Figs. 1, 2a). It is likely that several bird species breeding in wetland habitats in North America have an evolutionary history that includes nest predation by raccoons and other wetland-associated nest predators. Nesting over deep water may not eliminate nest predation by terrestrial mammals, but it may greatly reduce it (Shipley 1979, Picman et al. 1993, Cain et al. 2003, Fletcher and Koford 2004).

The number of Prothonotary Warblers using particular forested wetlands can vary dramatically across years in association with hydrological processes (Hoover 2009; Fig. 2b). Warbler densities increased or were maintained at high levels in forested wetlands where hydrological processes had been either restored or not degraded (Hoover 2009). This positive effect of hydrological conditions on the density of warblers is the result of a chain of events that begins with forested wetlands retaining their water for much of the breeding season (April-July). The presence of relatively deep water in these "higher-quality" wetlands leads to decreased rates of nest predation which, in turn, lead to increased productivity (Hoover 2006, 2009). 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 attracts other prothonotary warblers that are looking for a place to breed for the first time (conspecific attraction; Stamps 1991) or avoiding a nearby site where their reproductive performance was poor the previous year (Hoover 2003).

An increase in reproductive success obviously puts more Prothonotary Warbler offspring out in the environment. I have previously documented that if these offspring return the following year to breed, they usually do so within 3 km of where they were produced (Hoover and Reetz 2006, Hoover and Hauber 2007). This is another factor that can contribute to an increase in warbler densities within highly productive forested wetlands. The results from my research on Prothonotary Warblers support the conclusion that conservation practices that conserve or restore the integrity of forested wetlands, are benefiting local populations of breeding birds. Habitats that promote low or reduced rates of nest predation and high annual fecundity, such as the deeper-water areas of forested wetlands, are important to local population dynamics and may be critical to the maintenance of populations over larger geographic scales (Robinson et al. 1995a, Hoover 2003).

Results from a six-year study of 20 forested wetlands, where half of the wetlands had their hydrological processes improved (lateral gullies plugged) and the others not (gullies not plugged), showed that there were a number of positive and no clear negative effects of this conservation action on the breeding bird community in these forested wetlands (Hoover 2009).

In addition to Prothonotary Warblers, there were five other species that also responded favorably to the gully-plug treatment. Two species, the Belted Kingfisher (*Megaceryle alcyon*) and Common Grackle (*Quiscalus quiscula*), were never detected at point count stations during the pre-treatment period (i.e., prior to the installation of gully plugs) and were only detected within the gully-plug wetlands during the post-treatment period. The number of nests of Wood Ducks (*Aix sponsa*), Yellow-crowned Night-Herons (*Nyctanassa violacea*), and Hooded Mergansers (*Lophodytes cucullatus*) 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. However, during the post-treatment period, there were averages of six, five, and three nests per year, respectively, for Wood Ducks, Yellow-crowned Night-Herons and Hooded Mergansers in the 10 gully-plug wetlands and no nests were located in the 10 non-gully-plug wetlands (Hoover 2009).

It is not yet know whether the reproductive success of other songbirds (particularly canopy-nesters) nesting in forested wetlands is correlated with that of the Prothonotary Warbler. Raccoons likely have little effect on the reproductive success of canopy-nesting species in forested wetlands and the restoration of hydrological processes that results in the presence of deep water is less likely to affect rates of nest predation for those species. The presence of water may, however, elevate reproductive output in canopy-nesters if it increases food (i.e., insect) availability (Petit and Petit 1996). In addition, water in forested wetlands promotes habitat features that favor particular species. For example, Yellow-throated Warblers (*Dendroica dominica*), which have an affinity for baldcypress (*Taxodium distichum*) in bottomland forests (Graber et al. 1983, Hall 1996, Gabbe et al. 2002), should benefit from the retention of water in forested wetlands because the presence of water helps to retain and expand areas of baldcypress. An important next step is to

determine the extent of these potential benefits to the other bottomland forest birds.

Prothonotary Warblers can also serve as an indicator of the effects of forest fragmentation and habitat configuration on brood parasitism by Brown-headed Cowbirds (*Molothrus ater*). The relative severity of cowbird parasitism can be assessed by placing Prothonotary Warbler nest boxes in a number of forested wetlands that vary in some measure of habitat fragmentation within a particular study system. In southern Illinois, rates of cowbird parasitism in Prothonotary Warblers were negatively correlated with the percent of forest cover within a 3-km radius around study sites (Hoover and Hauber 2007).

In general, a suite of forest-dwelling migratory songbirds (e.g., Eastern Wood-peewee, *Contopus virens*; Acadian Flycatcher, *Empidonax virescens*; Red-eyed Vireo, *Vireo olivaceus*; Wood Thrush, *Hylocichla mustelina*; Kentucky Warbler, *Oporornis formosus*; and Summer Tanager, *Piranga rubra*) breeding in the midwestern United States suffer increased rates of cowbird parasitism with increased levels of forest fragmentation (Robinson et al. 1995a, 1995b, 2000, Hoover et al. 2006). Based on the results of these studies, it is likely that conservation actions that reverse the fragmentation of bottomland forests (land acquisition and afforestation) will reduce rates of brood parasitism not only for Prothonotary Warblers, but also for many other species (Robinson et al. 2000).

Habitat specificity, a tight link to hydrological processes, and the fact that they can be studied efficiently and in great detail during the breeding season make Prothonotary Warblers an ideal indicator species. Prothonotary Warblers have provided important information on the integrity of different attributes (hydrological processes and habitat fragmentation) of bottomland forest ecosystems by highlighting how stream channelization and the formation of lateral gullies, along with forest fragmentation, has degraded the quality of forested wetlands for breeding birds. As demonstrated here, indicator species have great potential to evaluate the benefits of conservation efforts. Continued research on Prothonotary Warblers will be critical to measure the success of habitat management and conservation activities designed to benefit not only the warblers, but the integrity of the bottomland forest ecosystem.

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