

IS THERE HOPE FOR THE HOOSIER FROG? AN UPDATE ON THE STATUS OF CRAWFISH FROGS (*LITHOBATES AREOLATUS*) IN INDIANA, WITH RECOMMENDATIONS FOR THEIR CONSERVATION

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ABSTRACT. Crawfish Frogs (*Lithobates areolatus*) are a State Endangered species that have experienced declines through much of their range in Indiana. We conducted surveys at nine historical sites and detected Crawfish Frogs at only one of them. Data suggest this species has been extirpated from Benton, Fountain, and Vermillion counties in the north, Vanderburgh and Warrick counties in the south, and Morgan and Monroe counties in the east. Robust populations of Crawfish Frogs persist in two areas, at Hillenbrand Fish and Wildlife Area–West in the southwest, and at Big Oaks National Wildlife Refuge in the southeast. One cluster of populations remains in Spencer County, in the south. Our data suggest that there are fewer than 1,000 adult Crawfish Frogs in Indiana: Big Oaks supports about 300 animals, Hillenbrand supports about 200 animals, and remaining animals are scattered among populations that are generally small and located on private lands in southwestern Indiana. Despite these pessimistic data, Crawfish Frogs are resilient and will establish populations at new sites when habitat becomes available and animals are close enough to colonize. If Crawfish Frogs are to persist in Indiana, they must become a component of the management plans on both public and private lands. When this occurs, not only could the precipitous decline of Crawfish Frogs in this state be halted, but Indiana’s public grasslands are extensive enough that intervention could lead to the eventual downlisting of the species.

Keywords: Crawfish Frog, *Lithobates areolatus*, status, conservation, management

INTRODUCTION

Crawfish Frogs (*Lithobates areolatus*), formerly known as Hoosier Frogs (Hay 1892; Test 1893), are secretive, burrow-dwelling anurans inhabiting parts of the central and south-central United States (Smith 1950; Parris & Redmer 2005). In Indiana, Crawfish Frogs occur predominately in the western—especially

the southwestern—portion of the state, although a presumably isolated series of sites now occurs at Big Oaks National Wildlife Refuge (NWR) in southeastern Indiana (Minton 2001; Haswell 2004; Engbrecht & Lannoo 2010). Once considered “locally plentiful” in Indiana, Crawfish Frog declines in the 1970s and 1980s led to their listing as a State Endangered Species in 1988 (Indiana Department of Natural Resources [IDNR] Technical Advisory Committee [TAC] 1987; Minton 2001).

Two of us recently published the known historic distribution of Crawfish Frogs in Indiana (Engbrecht & Lannoo 2010). We relied on records from the literature, museum specimens, IDNR datasets, and unpublished accounts. The purpose of the present study is to

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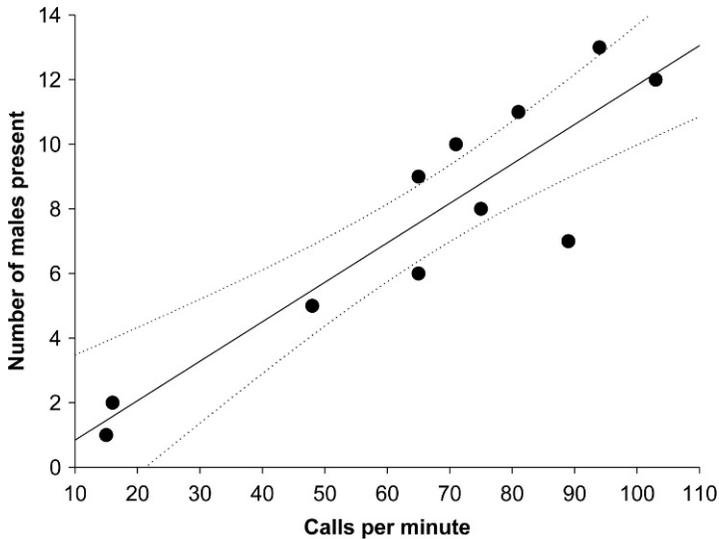


Figure 1.—Graph showing the relationship between call rate (calls/min) and number of *Lithobates areolatus* males present in wetland. Linear regression shows a highly significant correlation between number of males present and maximum call rate ($p = .0001$, $r^2 = 0.83$). Data from Nate's Pond and Cattail Pond at HFWA-W were combined for this analysis.

compare the current known distribution of Crawfish Frogs against this historic baseline and recommend ways in which Crawfish Frogs can be conserved. We provide the results of surveys and give a revised assessment of the species' status in Indiana.

METHODS

We used a number of survey techniques to assess the status of Crawfish Frogs including breeding call surveys (conducted both manually and using automated recording systems [ARS]), egg mass surveys, incidental road kill data, drift fence surveys, aquatic surveys for tadpoles, and terrestrial surveys for newly metamorphosed juveniles (Heyer et al. 1994; Dodd 2010; Heemeyer et al. 2010). Crawfish Frog populations are most easily detected by the loud, distinct calls of breeding males (Swanson 1939; Gerhardt 1975), and thus call surveys offer the best opportunities for detecting populations. Indeed, in this study, the majority of locality data were obtained using call surveys conducted manually or using ARS (Weir & Mossman 2005; Dorcas et al. 2010).

We systematically and opportunistically surveyed for Crawfish Frogs across western and southern Indiana from 2009–2011, visiting previously documented sites and those with the potential to host Crawfish Frog populations. Among these sites we systematically

surveyed nine historic localities (most recent records from 1949–1991; Engbrecht & Lannoo 2010) using Song Meter[®] recording units (Wildlife Acoustics Inc, Concord Massachusetts, USA). Recordings were analyzed using a Dell Latitude[™] E6400 Series laptop computer and Song Scope[®] call recognition software (Wildlife Acoustics Inc, Concord Massachusetts, USA).

To provide a rough estimate of population size at our surveyed wetlands, we used the technique described by Engbrecht (2010). This method couples maximum calling rates to numbers of males present in wetlands (Fig. 1). The association between chorusing intensity and abundance levels has also been noted in other studies of North American anurans (Lepage et al. 1997; Crouch & Paton 2002). For example, Nelson & Graves (2004) found an association between increasing population sizes and increasing call index values in Green Frogs (*Lithobates clamitans*). They state that call rates may provide a more accurate indicator of population density than call index values. We refer the reader to Engbrecht (2010) for a detailed description of this technique.

The overall population size of Hillenbrand Fish and Wildlife Area-West (HFWA-W) was estimated using data collected from drift fences, funnel traps, and chorusing levels. At Big Oaks NWR, population sizes were estimated using egg mass surveys at wetlands where calling

Table 1.—Survey sites where *Lithobates areolatus* was detected in Indiana from 2009–2011. Maximum call rates are given in calls/min. The Hillenbrand FWA-W population estimate is based on pitfall trapping, funnel trapping, and relative chorusing levels. The population estimate for Big Oaks NWR is based on egg mass counts and chorusing levels (see text for details). Maximum call rate at the Ronk Locality was reported by Ron Ronk (pers. comm.).

Site	County	Maximum call rate	Estimated number of calling males	Estimated population size
Daviess County South 1	Daviess	32	3–6	12–24
Daviess County South 2	Daviess	10	1–2	4–8
Daviess County South 3	Daviess	16	2–3	8–12
Klueh Locality	Daviess	–	–	–
Odon 1	Daviess	–	–	–
Odon 2	Daviess	22	2	8
Goose Pond 4	Greene	–	–	–
Goose Pond Private 1	Greene	39	4–7	16–28
Goose Pond Private 2	Greene	21	2–4	8–16
Hillenbrand FWA-W Cluster	Greene	–	–	~200
Hillenbrand Offsite	Greene	–	–	–
Jasonville 1	Greene	6	1	4
Jasonville 2	Greene	–	–	–
Owen County Historic	Owen	84	10–12	40–48
Owen County Recent	Owen	65	7	28
Spencer County Cluster	Spencer	–	–	–
Dugger	Sullivan	56	6	24
Hymera	Sullivan	46	4–6	16–24
Ronk Locality	Sullivan	80	9	36
Stonebraker Locality	Sullivan	36	4	16
Dave's Pond	Vigo	57	6	24
Big Oaks NWR Cluster	Jefferson, Jennings, Ripley	–	–	~300

males were heard, which we assumed equaled the number of females, and a 1:1 sex ratio was applied to estimate population size (Kinney 2011). In cases where distant chorusing was heard at restricted sites and egg masses could not be counted, chorusing levels were used to estimate population counts.

RESULTS

We detected Crawfish Frogs at fewer than 60 sites throughout the state, including 21 localities in southwestern Indiana and > 27 localities at Big Oaks NWR in southeastern Indiana (Table 1; Fig. 2). Crawfish Frogs were detected at only one of nine historic sites (Engbrecht & Lannoo 2010) and were not detected at 25 sites where they had recently been reported (2000–2008; Tables 1, 2). Population estimates ranged from four in the smallest population to 48 in the largest (Table 1). Populations at HFWA-W and Big Oaks National Wildlife Refuge were estimated to be approximately 200 and 300 individuals, respectively (Table 1). To parallel

Engbrecht & Lannoo (2010) we present detailed results by county.

Clay County.—We surveyed for Crawfish Frogs near Brazil where IDNR personnel identified chorusing between 2004 and 2008 (Engbrecht & Lannoo 2010), but did not detect them. We also conducted surveys in areas of extensive grassland habitat at Chinook Fish and Wildlife Area (FWA) but did not detect Crawfish Frogs.

Daviess County.—Crawfish Frogs continue to persist in two distinct clusters in Daviess County, one in the south-central region of the county, the other northeast of Odon (Fig. 2). We identified a new breeding site in the south-central cluster in 2009 (Table 1; Fig. 2). Habitat at this site consists of an old cattle pond surrounded by an abandoned pasture. This population may be in jeopardy as the wetland is currently being used to rear game fish. We also detected Crawfish Frogs at two previously identified localities in this cluster in 2009 and 2010 (Table 1; Fig. 2). A fourth breeding site

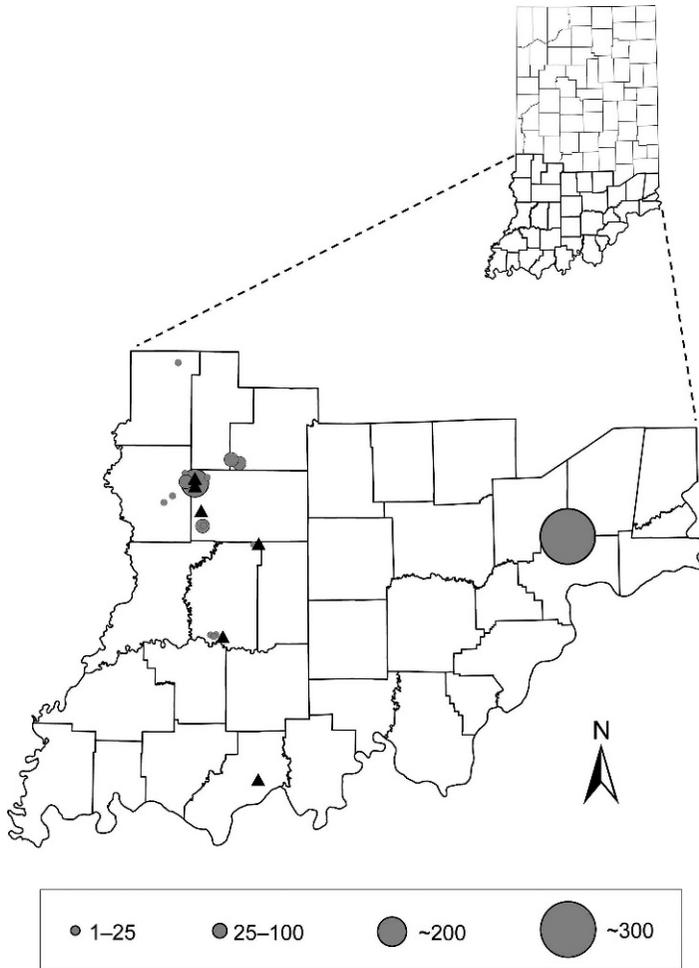


Figure 2.—Population estimates for *Lithobates areolatus* in Indiana. We estimated the overall population size of HFWA-W using data collected from drift fences, funnel traps, and relative chorusing levels. Estimates for Big Oaks are based on egg mass counts and relative chorusing levels. Circle size indicates estimated population size; triangles represent localities that lack data sufficient for calculating population estimates.

located by State Herpetologist Sarabeth Klueh during a March 2011 survey (Klueh, pers. comm.; Table 1; Fig. 2) appears to be a re-confirmation of an IDNR point originally discovered between 2004 and 2008 (Engbrecht & Lannoo 2010). We did not detect Crawfish Frogs at three sites in this cluster identified by IDNR between 2004 and 2008 (Engbrecht & Lannoo 2010; Table 2).

Surveys performed at the cluster northeast of Odon revealed Crawfish Frogs from one new locality (Table 1; Fig. 2). Calling at this site was light in 2009, perhaps representing only one male; we did not detect chorusing here in 2010. Crawfish Frogs were detected at a second,

previously identified locality, in 2009 and 2010. Frogs at this site bred in what appeared to be a small livestock pond adjacent to a cattle pasture. We did not detect Crawfish Frogs at one of the sites where IDNR personnel reported hearing them between 2004 and 2008 (Engbrecht & Lannoo 2010; Table 2).

We surveyed for Crawfish Frogs east of Odon where Minton and W. M. Overlease collected a specimen in 1953 (Engbrecht & Lannoo 2010) but heard no calling (Table 2).

Fountain County.—Engbrecht & Lannoo (2010) noted a single Crawfish Frog locality near Kingman based on a specimen collected by Minton in 1951. We surveyed here but heard no calling

Table 2.—Survey sites where *Lithobates areolatus* was not reconfirmed during surveys performed from 2009–2011. Populations where the status is unknown are represented by (U); populations presumed to have been extirpated are represented by (X).

Site	County	Status	Most recent record
Brazil	Clay	(U)	2004–2008
Daviess County Historic	Daviess	(X)	1953
Daviess County South 4	Daviess	(U)	2004–2008
Daviess County South 5	Daviess	(U)	2004–2008
Daviess County South 6	Daviess	(U)	2004–2008
Odon 3	Daviess	(U)	2004–2008
Fountain County Historic	Fountain	(X)	1951
Goose Pond 1	Greene	(U)	2004–2008
Goose Pond 2	Greene	(U)	2004–2008
Goose Pond 3	Greene	(U)	2004–2008
Greene County Historic	Greene	(X)	1949
Jasonville 3	Greene	(U)	2004–2008
Jasonville 4	Greene	(X)	2004–2008
Linton	Greene	(X)	2004–2008
Scotland	Greene	(U)	2004–2008
Big Oaks	Jefferson	(X)	2006
Monroe County Historic	Monroe	(X)	1991
Morgan County Historic	Morgan	(X)	1987
Spencer County 2	Spencer	(U)	2008
Cass	Sullivan	(U)	2004–2008
Glendora	Sullivan	(U)	2004–2008
Glendora East	Sullivan	(U)	2004–2008
Greene/Sullivan County Line	Sullivan	(U)	2004–2008
Hymera	Sullivan	(U)	2004–2008
Morton Pond South	Sullivan	(U)	2004–2008
Shakamak	Sullivan	(U)	2004–2008
Sullivan County Historic	Sullivan	(X)	1952
Timm 1	Sullivan	(X)	2000
Timm 2	Sullivan	(X)	2000
Timm 3	Sullivan	(X)	2000
Vermillion Historic	Vermillion	(X)	1951
Vigo County Historic	Vigo	(X)	1967
Vigo/Parke County Line	Vigo	(X)	2004–2008

(Table 2). This site is dominated by agriculture and forest, and grassland habitat is sparse. We know of no other records of Crawfish Frogs at this site or anywhere else in Fountain County since 1951.

Greene County.—We identified several new localities in Greene County, most notably at HFWA-W (Table 1; Fig. 2). The land that was to become HFWA-W was severely disturbed by surface mining activities (Lannoo et al. 2009), but restoration efforts by IDNR land managers over the past 25 years have provided prairie and semi-permanent wetland habitats that host about 200 breeding adults (Kinney 2011). We detected chorusing at seven wetlands at HFWA-W, and in 2011, calling was heard from a new, currently unidentified location off site. Hillenbrand FWA-W likely supports the

densest assemblage of Crawfish Frogs in Indiana.

Crawfish Frogs are well known from the Goose Pond basin south of Linton, and IDNR personnel identified Crawfish Frogs at six sites from 2004–2008 (Engbrecht & Lannoo 2010). Our surveys, however, suggest that Crawfish Frogs have declined at Goose Pond. We sampled five of the six previously known localities and detected Crawfish Frogs at only two (from 2009–2011 at the first site, in 2009 and 2010 at the second; Tables 1, 2; Fig. 2). Both of these sites are on adjacent private property. In March 2011, Lee Sternenburg (pers. comm.) detected Crawfish Frogs from a new site on Goose Pond FWA several kilometers from the two sites previously mentioned.

Shortly after, we confirmed light chorusing (perhaps only one or two males) at this new site. Populations at these three sites appear to be at risk due to changes in habitat (encroachment of woody vegetation at privately owned sites; Williams et al. 2012) and small population sizes (e.g., Goose Pond FWA site). Constructing additional fishless wetlands in grassy upland habitat could help secure the persistence of this species in the greater Goose Pond basin.

We also detected chorusing at two previously known sites near Jasonville in 2009 and 2010 (the locality and chorusing rate at one of these sites could not be determined; Engbrecht & Lannoo 2010; Table 1; Fig. 2). We did not detect Crawfish Frogs at four previously known sites near the towns of Scotland, Linton, and Jasonville (Engbrecht & Lannoo 2010).

We surveyed Minton's 1949 collection site near Worthington (Engbrecht & Lannoo 2010) but did not detect Crawfish Frogs (Table 2).

Monroe County.—Crawfish Frogs were reported from the Beanblossom Creek bottoms as recently as 1991 (Engbrecht & Lannoo 2010). We conducted surveys at this historic site but did not detect them (Table 2). Open, grassy habitat is present, although the large wetlands, particularly those that connect with Beanblossom Creek during high water, may now contain fish and may therefore be unsuitable for Crawfish Frog reproduction (Werschul & Christensen 1977; Phillips et al. 1999).

A more recent record comes from Brodman (2003), who detected Crawfish Frogs at an undescribed locality during surveys conducted from 1998–2001. This record represents the last published report of Crawfish Frogs in Monroe County.

Morgan County.—Indiana DNR surveys conducted from 2004–2008 at Robert Luker's historic locality (Engbrecht & Lannoo 2010) failed to detect Crawfish Frogs; we also did not detect them (Table 2). Scattered pastures and grassy fields remain but have been reduced by recent construction. This population appears to be extirpated, and we know of no current populations in Morgan County.

Owen County.—We confirmed Crawfish Frogs at the single known extant site in southwestern Owen County from 2009–2011 (Engbrecht & Lannoo 2010; Table 1; Fig. 2). Surveys conducted in 2011 at Minton's 1954 historic site (Engbrecht & Lannoo 2010) identified Crawfish Frogs calling from at least

two different wetlands (Table 1; Fig. 2). The first consists of a degraded cattle pond. The second, which could not be definitively located, appears to be situated approximately 1 km away. Both sites are located in a relatively large series of pastures and grassy fields.

Spencer County.—Crawfish Frogs are known from two locations in Spencer County (Fig. 2). The first, discovered in March 1998, consists of several breeding sites located northeast of Newtonville (Lodato & Dugas, In Press; Table 1). This area has been visited each year since, and populations persist. In March 2011, a new, sizeable breeding chorus was heard from a wetland located in open, brushy grassland about 500 m northwest of the primary population. This region consists of rolling grasslands and wetland swales on reclaimed surface mined land, and is in private ownership.

A second record is based on a single male Crawfish Frog taken in March 2008 near Chrisney (Lodato & Dugas In Press; Table 2). This site is approximately 6.5 km southwest of the known breeding population northeast of Newtonville, described above. The animal was found on State Route 70 during a nighttime rainstorm. A photograph of this specimen, catalogued in the Illinois Natural History Survey collection (INHS 2011n), serves as the voucher for Crawfish Frogs in Spencer County. Surveys conducted during the springs of 2009, 2010, and 2011 failed to reveal this population (Table 2).

Sullivan County.—We documented two new breeding sites in 2011, both near a large, reclaimed coal mine in the eastern portion of Sullivan County (Fig. 2). The first site, originally reported by retired IDNR biologist Roger Stonebraker, is located in managed grassland on private property (Table 1). This site was converted from agriculture to managed grassland in 2000, with wetland construction taking place around 2003 (Stonebraker, pers. comm.). Stonebraker has heard chorusing at this site since 2009, and choruses have intensified each year. The second Crawfish Frog site, approximately 4.5 km away, is situated in an agricultural field near Dugger (Table 1). Frogs at both sites are likely using nearby state-owned grasslands as terrestrial habitat.

We re-confirmed two previously known populations in Sullivan County (Engbrecht & Lannoo 2010; Fig. 2). The first came from a cluster of breeding sites near Hymera where we

heard chorusing each year from 2009–2011 (Table 1). The second was reported by retired IDNR Property Manager Ron Ronk (Table 1) and confirmed in 2011.

We surveyed for Crawfish Frogs at Minton's 1951 collection site near Shelburn (Engbrecht & Lannoo 2010) but did not detect them (Table 2). This area is heavily farmed and little natural upland or wetland habitat remains.

We did not hear Crawfish Frogs at 10 sites where they had previously been reported in Sullivan County (Table 2). Many of these sites were originally identified by Timm (2001) and by IDNR personnel at Minnehaha FWA. Our surveys here and at Greene-Sullivan State Forest's Dugger Unit failed to reveal any populations.

Vermillion County.—We performed surveys at a historic site near Perrysville (Engbrecht & Lannoo 2010), but Crawfish Frogs were not detected (Table 2). Most of the area has been converted to agriculture. Crawfish Frogs have not been documented in Vermillion County since 1951.

Vigo County.—David Rubin documented Crawfish Frogs at a locality in northeast Vigo County in 1964 (Rubin 1965). We visited this site (now known as "Dave's Pond") and detected Crawfish Frogs each year from 2009–2011 (Table 1; Fig. 2). Dave's Pond may now contain the northernmost population of Crawfish Frogs remaining in Indiana, and currently represents the only known extant population in Vigo County.

We did not detect Crawfish Frogs during surveys at a historic site near Fontanet in northeast Vigo County (Engbrecht & Lannoo 2010; Table 2). This area is characterized by a matrix of agriculture, woods, and grassland habitat. We also failed to detect Crawfish Frogs at a second site located along the Parke/Vigo County line where calling was heard by IDNR personnel between 2004 and 2008.

Jefferson, Jennings, and Ripley counties.—Records for Big Oaks NWR are placed together in this section. We systematically searched portions of Jefferson, Jennings, and Ripley counties contained within Big Oaks NWR, and opportunistically searched areas outside the refuge using call surveys to locate Crawfish Frog breeding choruses.

We confirmed breeding (i.e., found egg masses) at 15 Jefferson County wetlands. Three of these were discovered in 2009, one in 2010,

and nine in 2011. Calling at two wetlands had been heard in previous years (one wetland in 2004, one in 2007). We detected between one and 15 Crawfish Frog egg masses at these sites. The size and shape of the breeding ponds varied, ranging from small round bomb craters to large, shallow, flat-bottomed wetlands. All breeding ponds were in grassland habitat, with the exception of one pond located in a late-successional deciduous forest (Williams et al. 2012).

Crawfish Frogs appear to have been locally extirpated at two sites in the Jefferson County portion of Big Oaks NWR. We heard chorusing at the first site in 2008 and trapped a single male in 2009, but did not detect Crawfish Frogs in 2010 or 2011. We have not heard Crawfish Frogs calling from the second site since 2006.

Within the Jennings County portion of Big Oaks, we confirmed four Crawfish Frog breeding wetlands. We first heard calling at two sites in 2008 and two others in 2011. Each wetland had between three and five egg masses. All four wetlands were small ($< 50 \text{ m}^2$), shallow ($< 1 \text{ m}$), and situated in grassland habitat.

We confirmed seven Crawfish Frog breeding wetlands in the Ripley County portion of Big Oaks. Calling was first heard at two wetlands in 2004, one in 2010, and the other four in 2011. We found from one to five egg masses in each wetland. Wetlands varied in size from 10 m^2 to 150 m^2 , and had maximum depths from 0.5–1.5 m. All were located in grassland habitats. Calling was also heard within the restricted area of the Indiana Air National Guard, Jefferson Range, which is surrounded by Big Oaks NWR. Several of these locations supported large choruses.

DISCUSSION

Crawfish Frogs are listed as State Endangered in Indiana and our data indicate that this level of protection is currently warranted. We did not detect Crawfish Frogs at eight of nine historic sites, and they appear to now be extirpated in 11 of 20 Indiana counties (Fig. 3). These losses have been partially offset by recent recolonizations of large restored grasslands on public lands. Undoubtedly Crawfish Frogs are at risk and are in danger of being extirpated in Indiana within the next half century (Fig. 3).

Current distribution.—Remaining Crawfish Frog populations in Indiana are concentrated

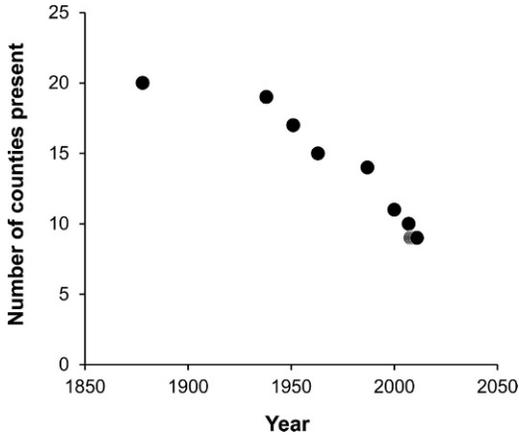


Figure 3.—*Lithobates areolatus* declines in Indiana by county. Extant populations are currently known from only nine Indiana counties. Data are based on last known records of Crawfish Frogs for each county the species occurred in from 1878 through 2011.

in two areas, in Greene and Sullivan counties (especially HFWA-W) in the southwest, and on Big Oaks NWR in the southeast. Hillenbrand FWA-W populations are few (seven), but concentrations of breeding adults are high (> 60 adults at Nate's Pond; > 80 adults at Big Pond), while densities of breeding adults at Big Oaks NWR are low (generally < 30 adults/wetland) but populations are numerous (> 27). Outside of these two areas, with the possible exception of the cluster in Spencer County, populations are smaller and scattered, and generally exist on private property. Our data suggest fewer than 1,000 adult Crawfish Frogs remain in Indiana. Big Oaks NWR supports around 300 breeding animals, HFWA-W supports about 200 breeding animals, and fewer than 500 breeding animals persist in the remaining populations, mostly on private lands (Fig. 2).

While our sampling scheme involved visiting the majority of recent Crawfish Frog localities and many of the historic sites in Indiana, we recognize that undocumented populations may remain. However, even doubling our current estimated number of breeding adults in Indiana places the estimate at only a fraction of the number of eggs contained in a single Crawfish Frog egg mass (2,200–9,900; Trauth et al. 1990; Redmer 2000; Kinney 2011).

Pattern of change in Indiana.—Historically, Crawfish Frogs were known from western

Indiana, ranging from the Ohio River north to Fountain and Benton counties (Engbrecht & Lannoo 2010). However, there are currently no data to suggest the few northern populations in Benton, Fountain, and Vermillion counties persist. Further, in the south, all but one or two known populations from Indiana's Ohio River border counties (Vanderburgh, Warrick, and Spencer) have been extirpated; Crawfish Frogs remain only in a small portion of Spencer County. Crawfish Frog populations in Morgan and Monroe counties may also be extirpated. Collectively, these declines seem to have produced a range contraction in the northern, eastern, and southern portions of the historic range of Crawfish Frogs in Indiana.

This pattern of population extirpation outside areas of expansive grasslands with ephemeral wetlands in Indiana is repeated in every state east of the Mississippi River (Engbrecht & Lannoo 2012a). Crawfish Frogs have been reduced to a handful of populations in Mississippi (T. Mann, pers. comm.) and Tennessee (F. Scott, pers. comm.), and are uncommon and declining in parts of Illinois (Phillips et al. 1999). Besides HFWA-W and Big Oaks NWR, perhaps the healthiest Crawfish Frog populations east of the Mississippi River are now located on the coal spoil prairies of western Kentucky (J. MacGregor, pers. comm.) and perhaps in southern Illinois.

Causes of declines.—The pattern of extirpation and colonization of Crawfish Frogs in Indiana is easily understood from their biology. Crawfish Frogs require three habitat features: 1) large grassland complexes, 2) the presence of burrowing crayfish, and 3) fishless seasonal or semipermanent wetlands for breeding. Further, Kinney (2011) has demonstrated low larval and juvenile survivorship in Crawfish Frogs, but a relatively high (43%) annual survivorship in adults. Heemeyer & Lannoo (2012) have shown that Crawfish Frogs will return to the same upland burrow year-after-year (two years in her study, subsequent data show burrow philopatry over three years and suggest frogs will use the same burrow for much of their life [> 5 years]). Heemeyer & Lannoo (2012) also demonstrate that frogs in burrows are 12 times less likely to be preyed upon than frogs undergoing breeding migrations or ranging behaviors. Taken together, these studies show that the persistence of Crawfish Frog populations depends upon the persistence of long-lived adults, and the persistence of adults depends on the persistence of burrows.

Burrowing crayfish are widespread in Indiana, and none require special attention for their conservation status (Thoma & Armitage 2008).

Superimposed on what may have already been a gradual decline of Crawfish Frogs due to habitat loss was a decline in populations beginning around 1970 (Minton 2001). This decline may have been the result of an epidemic caused by the chytrid fungus (*Batrachochytrium dendrobatidis*; *Bd*), spreading like a wave through vulnerable populations (Kinney et al. 2011). Today, we know that *Bd* is acting in an endemic fashion and produces low rates of mortality among post-breeding adults (Kinney et al. 2011).

The need to manage populations on public and private lands.—While the threat to Crawfish Frog populations from *Bd* appears to have diminished, the threat from habitat loss continues, and may be intensifying as remaining populations on private lands become smaller and more isolated. Indeed, the pattern of decline of Crawfish Frog populations in Indiana (Fig. 3) suggests that in perhaps the next half-century most remaining populations will be on public lands managed by state or federal biologists. It is essential that Crawfish Frogs become a component of the management plans in these areas if they are to avoid extirpation in the state (see Appendix 1 for specific management recommendations).

While the relatively large number of frogs on a handful of public lands provides a buffer against threats such as disease, the smaller, scattered populations on private lands may function to preserve genetic diversity (Nunziata et al., In Press). State and federal biologists who regularly work with private landowners, including coal companies, can help secure remaining populations by providing assistance to preserve these small, scattered populations.

Finally, because of the recent work detailed above, the prospect of restoring populations in Indiana is now within reach. Since Crawfish Frogs will colonize new sites where adequate habitat is available (whether through natural dispersal or anthropogenic reintroduction), land managers have the opportunity to expand and establish populations by managing for grassland ecosystems. If Crawfish Frogs are incorporated into both public and private land management plans, the grasslands in the southern portion of the state are extensive enough to at least double the number of populations, which would enable us to downlist this species from Endangered to Special Concern.

APPENDIX 1:

HABITAT RECOMMENDATIONS

Three key habitat variables are essential for maintaining healthy Crawfish Frog populations: 1) expansive grassy terrestrial habitat, 2) the presence of burrowing crayfish, and 3) fishless, seasonal or semi-permanent wetlands. Here we offer habitat recommendations for conserving Crawfish Frogs.

Terrestrial habitat.—Crawfish Frogs spend most of the year occupying burrows in open, grassy habitat, and will use the same burrows year after year (Hoffman et al. 2010; Heemeyer & Lannoo 2012; Williams et al. 2012). Because of this fidelity to specific burrows, conserving terrestrial habitat is critical. We recommend that landowners and land managers restore and/or maintain open grassy habitat when possible. In order to preserve the structural integrity of burrows, it is critical that land managers on sites that host Crawfish Frogs avoid plowing and disking. If plowing is required for installing food plots or firebreaks, we recommend that plow strips be located as far from wetlands as possible, and that the same areas be plowed year after year.

In Indiana, extant Crawfish Frog populations are associated with several forms of open habitat including managed prairie, grassy meadow, abandoned field, hayfield, shrub land, and livestock pasture. Prescribed burning is frequently used in grassland management plans to control woody vegetation. Fire will kill exposed Crawfish Frogs, but frogs in burrows will avoid injury by retreating underground (Engbrecht & Lannoo 2012b; Heemeyer et al. 2012). Spring burns can put adults migrating to and from breeding wetlands at risk, while late summer burns may put postmetamorphic juveniles at risk. Controlled burns are currently being used to manage grasslands at both HFWA-W and Big Oaks NWR, sites where Crawfish Frog populations in Indiana are most robust. We do not suggest restrictions on this practice; woody encroachment is probably a more potent threat to Crawfish Frog populations than prescribed burns.

Aquatic habitat.—Crawfish Frogs depend on fishless bodies of water for breeding (Bragg 1953; Phillips et al. 1999; Johnson 2000; Minton 2001; but see Palis 2009). If Crawfish Frog populations are to persist, fish introductions must be avoided. To prevent natural

colonizations of predatory fish, wetlands designed to augment Crawfish Frog populations should not be constructed in areas subjected to riparian flooding. Seasonal drying of wetlands will eliminate established fish populations (Lannoo 1996).

Burrowing crayfish.—Crawfish Frogs have a close association with burrowing crayfish and depend on them for the construction of their subterranean burrows. Thoma and Armitage (2008) note that five species of primary burrowing crayfish occur in Indiana, two of which, the painted-hand mudbug (*Cambarus polychromatus*) and the devil crayfish (*C. diogenes*), occur statewide. Delineating management guidelines for burrowing crayfish is beyond the scope of this paper, however Thoma and Armitage (2008) note that no burrowing crayfish species is currently of conservation concern in Indiana.

ACKNOWLEDGEMENTS

This study was funded by State Wildlife Grant E2-08-WDS13 through the Indiana Department of Natural Resources, Division of Fish and Wildlife. We thank the following individuals for their assistance: Katie Smith, Ron Ronk, Brad Feaster, Roger Stonebraker, Randy Millar, Vanessa Terrell, Jennifer Heemeyer, Taihung (Peter) Duong, Sarabeth Klueh, Ron Hellmich, Roger Hedge, David S. Dugas, Lee Sterrenburg, Tom Mann, A. Floyd Scott, John MacGregor, Vicky Meretsky, Anne Timm, Zack Walker, John Whitaker, Jr., Alan Resetar, Greg Schneider, Damon Lowe, Michele Greenan, Tom Anton, Ricka Stoelting, Stephen Rogers, Jonathan Losos, José Rosado, Rod Williams, Toby Hibbitts, Andrew Hoffman, Tenia Wheat, Pete Lannoo, John Ryan, and Austin May. Special thanks to Susie Lannoo for field assistance and for reviewing an earlier draft of this manuscript. Numerous permits issued by the Indiana Department of Natural Resources Division of Fish and Wildlife and Division of Nature Preserves were used in this research; specific permit numbers can be obtained by contacting the lead author. The findings and conclusions in this article are those of the author(s) and do not necessarily represent the views of the U.S. Fish and Wildlife Service.

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Manuscript received 20 October 2012, revised 27 February 2013.