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Effects of Lowhead Dams on Freshwater Mussels in the Vermilion River Basin, Illinois, with Comments on a Natural Dam Removal

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ABSTRACT

We sampled freshwater mussels at 12 sites centered around three lowhead dams in the Vermilion River basin (Wabash River drainage) to address their effects on the freshwater mussel fauna and to obtain baseline data prior to their removal. Compared with reference sites, impounded areas and plunge zones had lower mussel abundance and extant species richness. We also examined literature accounts and museum collections to determine species distributions in the basin and compared those data to locations of the three dams and location of the former Homer Park Dam, which was removed over 50 years ago. Two species, Yellow Sandshell (*Lampsilis teres*) and the state-threatened Black Sandshell (*Ligumia recta*), are now found only downstream of the Danville Dam. Pimpleback (*Amphinaias pustulosa*) and Mapleleaf (*Quadrula quadrula*), which was found only downstream of the Homer Park Dam prior to 1950, has expanded its range upstream since the dam was removed. Data collected during this study contributes insights into the effects of lowhead dams on freshwater mussel abundance and species richness in Midwestern streams, and will be used as a baseline to compare to future post-dam removal collections.

INTRODUCTION

Freshwater mussels (Bivalvia: Unionoida) are among the most imperiled groups of organisms in the world (Bogan 1993; Williams et al. 1993; Lydeard et al. 2004; Strayer et al. 2004). In North America, nearly 74% of the approximate 300 species are listed as endangered, threatened or in need of conservation status. Anthropogenic disturbances resulting in habitat fragmentation and environmental degradation are among factors affecting mussels (Haag 2012).

Impoundments are one of the major sources of anthropogenic disturbances in streams and affect river systems in a myriad of ways (Baxter 1977). Conversion of lotic habitats to lentic habitats by dams has cascading effects on the stream's hydrogeomorphology, which includes modified flows regimes, altered physicochemical parameters, increased siltation upstream from dams, and scoured substrates downstream from dams (Tiemann et al. 2004; Maloney et al. 2008; Csiki and Rhoads 2010; Csiki and Rhoads 2014). Resulting effects on native mussels are equivocal, but include reduced species richness and abundance, fragmented populations, restricted distributions, and alterations of host-fish assemblages (Baker 1922; Watters 1996; Vaughn and Taylor 1999; Dean et al. 2002; Tiemann et al. 2004; Tiemann et al. 2007b; Galbraith and Vaughn 2011).

The objective of this study was to investigate if lowhead dams (< 4 m in height) have affected the freshwater mussel fauna in the Vermilion River basin (Wabash River drainage), Illinois. Two of the three dams we investigated are scheduled for demolition, and data from this study will be used to assess the baseline condition of the mussel fauna prior to removal. These data also will be used during post-dam removal monitoring, as mussel populations are likely to take decades to colonize previously impounded reaches (Kappes and Haase 2012).

STUDY AREA

The Vermilion River basin (Wabash River drainage) drains nearly 4,000 km^2 of eastern Illinois and western Indiana. The mainstem and its three largest tributaries (Salt Fork, Middle Fork, and North Fork) are relatively free-flowing except for four dams in Danville, Vermilion County, Illinois (Figure 1): Danville Dam (or Vermilion Dam) on the mainstem Vermilion River; Ellsworth Park Dam on the North Fork, 1.8 km upstream of the Danville Dam; Aqua Illinois Dam (or Waterworks Dam) on the North Fork 3.8 km upstream of the Ellsworth Park Dam; and Lake Vermilion Dam on the North Fork, 4.1 km upstream of the Aqua Illinois Dam (Tiemann 2008; Csiki and Rhoads 2014). Other human-induced modifications in the basin include draining of wetlands, dredging of streams, pollution from agriculture and industrial sources, and development of floodplains (Baker 1922; Smith 1968; Page et al. 1992; Larimore and Bayley 1996). Despite these disturbances, the Vermilion River basin remains one of the highest quality and biodiverse stream systems in Illinois (Smith 1968; Page et al. 1992) with 45 species of freshwater mussels (Tiemann et al. 2007a; Stodola et al. 2013) and over 100 species of fishes (Retzer 2005; Tiemann 2008) known from the basin. Although the watershed is primarily agriculture, most stream reaches have largely intact riparian zones and sand, gravel, and cobble substrates (Smith 1968; Page et al. 1992).

METHODS

The study design is similar to that of Dean et al. (2002) and Tiemann et al. (2004). We sampled 12 sites centered around three lowhead dams (Aqua Illinois, Ellsworth Park, and Danville) to assess effects of lowhead dams on the freshwater mussel fauna (Figure 1). Around each dam were site-types, which included reference sites, the impounded area, and the plunge zones. Reference sites were free-flowing (to 0.5 m/s during base flow), were 0.5-1.0 m in depth, and predominantly contained gravel/pebble substrates; these areas were outside the zone of direct dam influence on flow and we deemed these sites to be appropriate surrogates for presently free-flowing portions of the Vermilion River. Impounded areas were located <0.25 km upstream from the dam, had no flow, were 0.5-2+ m in depth, and primarily contained sandy substrates with small pockets of silt. Plunge zone sites were located <0.1 km downstream from

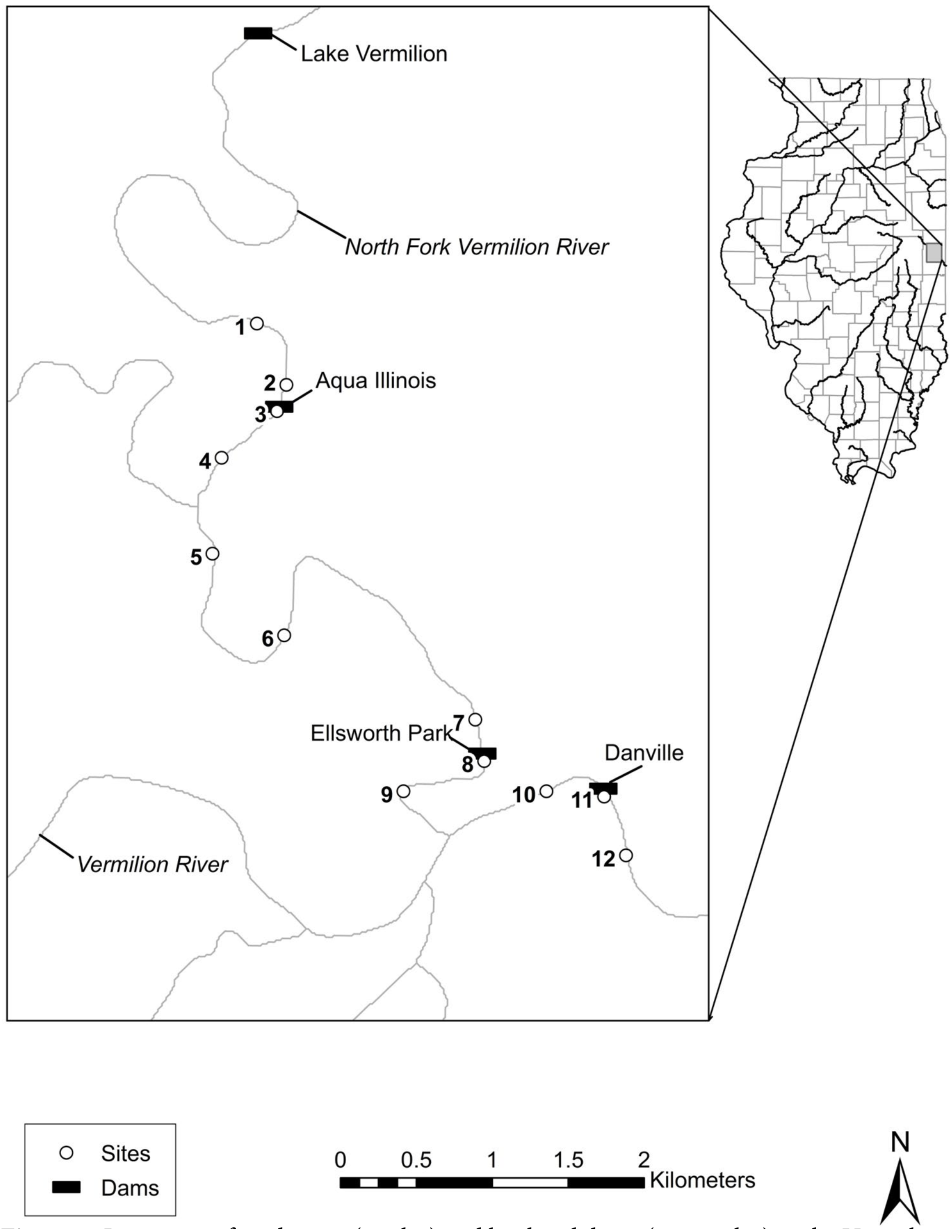

Figure 1. Locations of study sites (circles) and lowhead dams (rectangles) in the Vermilion River basin, in Danville, Vermilion County, Illinois.

the dam, were 0.5-2 m in depth, and had a diverse substrate composition, including gravel/pebble and cobble.

Live freshwater mussels and valves of dead specimens were collected by hand grabbing (e.g., feeling the substrate with one's hands) for four person-hours at each of the 12 sites during the summer of 2014. All sites were <100 m in length and efforts were made to cover all available habitat types present at a site including riffles, runs, pools, slack water, and areas of differing substrates. Individuals were identified before being returned to the site. Shell material was classified as fresh-dead (periostracum present, nacre pearly, and soft tissue may be present) or relict (periostracum eroded, nacre faded, shell chalky) based on condition of the best shell found. A species was considered extant at a site if it was represented by live or fresh-dead shell material. Voucher specimens of all species were deposited in the Illinois Natural History Survey (INHS) Mollusk Collection, Champaign, and scientific names follow Graf and Cummings (2007), except for recent taxonomic changes to the gender ending of species in the genus *Toxolasma*, which follow Williams et al. (2008).

Data were pooled for analysis at the site-type level (Tiemann et al. 2004; Tiemann et al. 2007b). We calculated an index of freshwater mussel abundance (number of individuals per hour; henceforth referred to as abundance) and extant species richness (number of species collected alive or as fresh-dead). Analysis of variance (ANOVA) was conducted to test the hypothesis that the assemblage varied by site-type, and Tukey's studentized range test was used for pairwise comparisons among site-types (Zar 1999).

We reviewed pertinent literature (e.g., Baker 1906; Zetek 1918; Baker 1922; Van Cleave 1940; Matteson and Dexter 1966; Suloway et al. 1981b; Cummings and Mayer 1997; Szafoni et al. 2000; Tiemann et al. 2007a; Stodola et al. 2013) and examined museum specimens and associated data (e.g., Academy of Natural Sciences at Drexel, Philadelphia; Chicago Academy of Science; Carnegie Museum of Natural History, Pittsburgh; Field Museum of Natural History, Chicago; Florida Museum of Natural History, Gainesville; the now combined Illinois Natural History Survey and University of Illinois Museum of Natural History, Champaign; Illinois State Museum, Springfield; Museum of Comparative Zoology, Cambridge, MA; Ohio State University Museum of Zoology, Columbus; and University of Michigan Museum of Zoology, Ann Arbor) to determine species distributions within the Vermilion River basin. A species was considered extant at a site if it had been collected there since 1970 (Cummings and Mayer 1997; Tiemann et al. 2007a). To recognize whether dams affected unionid distribution, we determined presence of a given species and compared those data to locations of the lowhead dams in the Danville areas as well as the former Homer Park Dam (e.g., Watters 1996; Tiemann 2007b). The Homer Park Dam was a lowhead dam on the Salt Fork that Baker (1922) stated was "an effective barrier" to the upstream migration of 12 species of mussels. This dam, which was near the Illinois Route 49 bridge north of the village of Homer, washed away between 1939 and 1958 (Matteson and Dexter 1966).

RESULTS

Freshwater mussel abundance ($F = 12.86$; $df = 2, 9$; $P = 0.002$) and extant species rich-

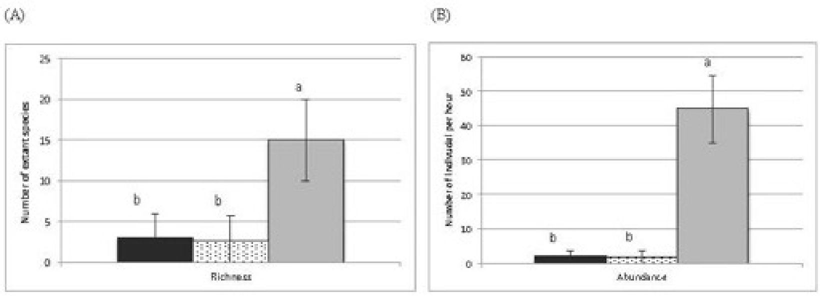

Figure 2. Mean freshwater mussel abundance (A) and extant species richness (B) with standard deviation bars by site-type from the Vermilion River basin, in Danville, Vermilion County, Illinois. Impounded areas are first column (black), followed by plunge areas (white with speckling), and reference areas (gray). The lowercase letters in the lowest panel indicate significant groupings according to Tukey's test.

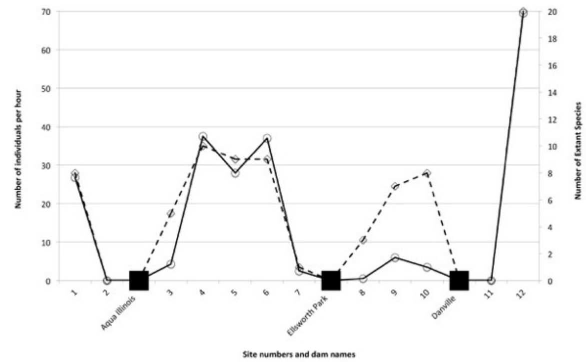

Figure 3. Abundance (solid lines with open circles) and extant species richness (dashed line with open diamonds) of freshwater mussels by site and the location of dams (solid squares) in the Vermilion River basin, in Danville, Vermilion County, Illinois. Figure 1 lists the locations of sites and dams. Sites progress from upstream (site 1) to downstream (site 2).

ness (F = 6.78; df = 2, 9; P = 0.02) differed significantly among site types. Tukey's test revealed that both abundance and extant species richness were greater at reference sites than at either impounded areas or plunge zones. Reference sites had abundances that varied from 26.8 to 69.5 individuals per hour (mean = 37.67), whereas impounded areas varied from 0 to 3.5 (mean = 2.00) and plunge areas varied from 0 to 4.3 (mean = 1.63) (Figure 2; Figure 3). Extant species richness varied from 8 to 20 (mean = 11.8) in reference areas compared to 0 - 8 (mean = 3.0) in impounded areas and 0 to 5 (mean = 2.7) in plunge zones (Figure 2; Figure 3). It is important to note that of the 8 extant species at Site 10 (the Danville Dam impounded area), only one was alive and the remaining were fresh-dead and could have washed downstream.

Examination of literature (n = 14 articles) and museum data (n >4,000 specimens) from the Vermilion River basin suggests that the Danville Dam (downstream most dam in the basin) appears to now limit the upstream distribution of five species. Three species, Threehorn Wartyback (*Obliquaria reflexa*), Hickorynut (*Obovaria olivaria*), and Fawnsfoot (*Truncilla donaciformis*), have records only downstream of the Danville Dam, and we excluded them from this analysis. All three species are considered a large river species that occasionally are found in the lower end of medium-sized streams (Cummings and Mayer 1992; Cummings and Mayer 1997; Tiemann et al. 2007a; Stodola et al. 2014). Hickorynut has never been very abundant in the lower Vermilion River mainstem (INHS Mollusk Collection), thus we do not expect it to be common upstream of the dams. However, both Threehorn Wartyback and Fawnsfoot are expanding their ranges across Illinois and are colonizing new basins (Tiemann et al. 2007a). Threehorn Wartyback and Fawnsfoot were recorded for the first time in the Vermilion River basin in 2006 and 2007 (INHS Mollusk Collection), respectively, thus they may eventually migrate upstream of the dam.

Based upon 14 records in the Vermilion River basin, Yellow Sandshell (*Lampsilis teres*) occurred as far upstream in the Salt Fork as the former Homer Park Dam near Homer (INHS 36874) and as far upstream in the Middle Fork as the US Highway 150 bridge near the village of Oakwood (INHS 37235) (Figure 4). Twenty-two records exist for Black Sandshell (*Ligumia recta*) in the Vermilion River basin, including records as far upstream in the Middle Fork as the Vermilion County Road 900E bridge (= "Higginsville Bridge") near the village of Collison (INHS 14463) and as far upstream in the Salt Fork as Vermilion County Road 130E bridge near the village of Homer (INHS 45733) (Figure 4).

Examination of literature and museum collection holdings suggested that, of the 12 species listed by Baker (1922), only Pimpleback (*Amphinaias pustulosa*) and Mapleleaf (*Quadrula quadrula*) have expanded their ranges upstream of the former Homer Park Dam. However, of the remaining 10 species, seven are imperiled – Round Hickorynut (*Obovaria subrotunda*) is extirpated from Illinois, Clubshell (*Pleurobema clava*) is federally-endangered and was considered only extant in the North Fork, Purple Lilliput (*Toxolasma lividum*) is state-endangered and extirpated from the Salt Fork, Wavyrayed Lampmussel (*Lampsilis fasciola*) is state-endangered and found throughout the Vermilion River basin, Purple Wartyback (*Cyclonaias tuberculata*) is state-threatened and found throughout the basin, Monkeyface (*Theliderma metanevra*) is listed as a species in greatest-need-of-conservation and found throughout the basin, and Ellipse (*Venustaconcha ellipsiformis*) is extirpated from the basin. These seven species, in addition to Yellow Sandshell referenced above, all have experienced substantial range reductions in the Vermilion River basin since Baker's (1922) study and, if still extant in the basin today, are present in low numbers (Stodola et al. 2013; INHS Mollusk Collection); therefore, we concluded that these species are not representative of the success of recolonization following dam removal. Two species, Pistolgrip (*Tritogonia verrucosa*) and Mucket (*Actinonaias ligamentina*), are currently extant in the Salt Fork, although in low abundances, and appear extant downstream of the former Homer Park Dam but not upstream of it (Stodola et al. 2013; INHS Mollusk Collection).

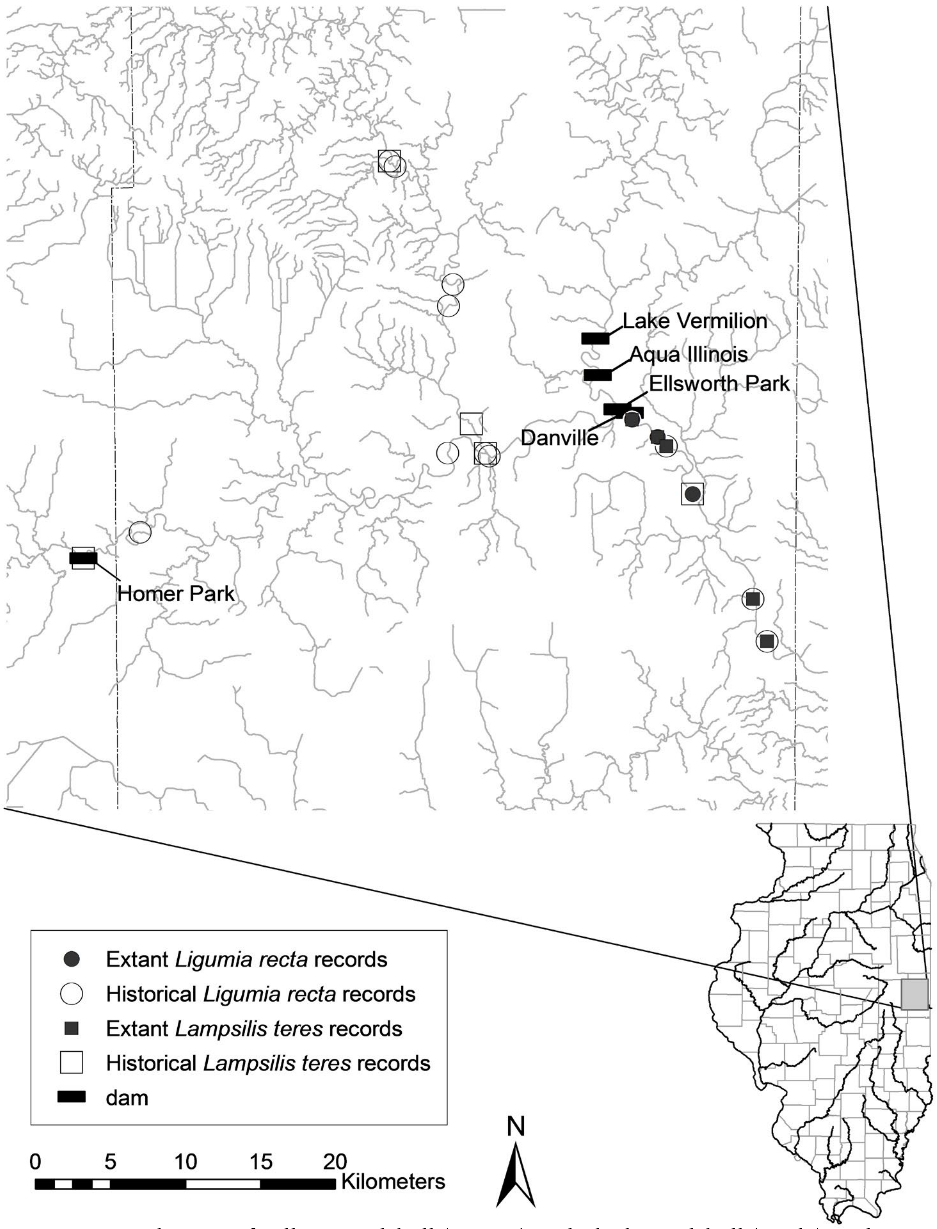

Figure 4. Distribution of Yellow Sandshell (square) and Black Sandshell (circle) in the Vermilion River basin (Wabash River drainage). Solid symbols denote sites where specimens have been found extant since 1970, whereas open symbols are historical records. Solid rectangles are locations of dams and include Lake Vermilion dam, as well as Aqua Illinois, Ellsworth Park, and Danville lowhead dams.

DISCUSSION

The significant differences in mussel abundance and extant species richness observed among site-types are likely the result of degraded habitats in the impounded areas and plunge zones. Csiki and Rhoads (2014) measured geomorphologic parameters in the Vermilion River basin around Ellsworth and Danville dams, and reported that although Ellsworth and Danville dams have minimal fine-sediment trapping ability, substantial fine sediment accumulation was documented in both impoundments. Freshwater mussels usually prefer free-flowing environments with clean heterogeneous substrates (Cummings and Mayer 1992; Williams et al. 1993; Watters et al. 2009; Haag 2012). In impounded areas, reduced water velocities allow silt and debris to accumulate and smother sand and gravel substrates (Tiemann et al. 2004; Csiki and Rhoads 2014), thus creating habitat unsuitable for most mussel species (Baker 1922; Suloway et al. 1981a; Dean et al. 2002; Tiemann et al. 2007b).

Dams also can affect downstream habitat directly through physical stresses (e.g., scouring). Counter to some studies from the southeastern United States that suggest dams enhance conditions for mussel growth in downstream reaches by stabilizing substrates downstream from the impoundment (Gangloff 2013, and references therein), studies from the Midwest suggest that dams increase scouring of substrates immediately downstream from the impoundment (Tiemann et al. 2004; Csiki and Rhoads 2014). Midwestern streams often flow through fluvial and glaciofluvial deposits that are easily erodible, and tailwaters frequently scour substrates in an attempt to obtain a water flux – sediment load equilibrium (Kondolf 1997). In the Vermilion River basin, plunge zones had undercut and slumping banks, minor streambed scouring near the base of the dam, and considerable gravel accumulation just downstream of the plunge pool (Csiki and Rhoads 2014).

Upstream movement of host-fish is a primary factor in mussel distribution, and recolonization of mussels can take many years. The colonization time following the Homer Park Dam failure in the middle of the 20th century suggests that recolonization of mussels can take decades, and is dependent upon available habitat and source populations of both mussels and host-fishes, as well as their life history strategies (Kappes and Haase 2012). Baker (1922) reported that the upstream distributions of 12 species were hindered by the presence of the Homer Park Dam; of those 12, only four have viable populations in the Vermilion River basin today (Stodola et al. 2013; INHS Mollusk Collection). Watters (1996) and Tiemann et al. (2007b) subsequently suggested that Mapleleaf and Pimpleback, both of which were included in Baker's 12 species, had dam-limited distributions due to the nature of their host-fishes. An examination of the INHS Mollusk Collections database revealed recent collections of a live Mapleleaf and a fresh-dead Pimpleback ~2.5 river kilometers upstream of the former dam in 2010, so we know that recolonization after dam removal occurs. Two other species, Pistolgrip and Mucket, are still extant near the former Homer Park

Dam but have lower population numbers in the Salt Fork (Stodola et al. 2013). Neither species has been found upstream of former impoundment. Mapleleaf, Pimpleback, and Pistolgrip utilize Channel Catfish (*Ictaluris punctatus*) and Flathead Catfish (*Pylodictis olivaris*) as hosts, whereas the Mucket uses a variety of fishes, including sunfishes and black basses (Watters et al. 2009). These fishes are common in the area and have somewhat large home ranges (INHS Fish Collection; Warren 2009; Tiemann et al. 2010). Prior to the passage of the *Clean Water Act*, the Salt Fork was heavily polluted with raw sewage and the freshwater mussel fauna was severely affected (Baker 1922; Van Cleave 1940; Matteson and Dexter 1966). It is possible that poor water quality may have prevented fish movement and subsequent mussel colonization of upstream reaches until recently. Today, the Salt Fork has several reaches with high mussel and fish diversity (Larimore and Bayley 1996; Tiemann 2008; Stodola et al. 2013).

Some freshwater mussels have experienced dramatic range reductions. When a basin contains multiple dams, as in the case in the Vermilion River, populations can become disjunct and fragmented partially due to dams restricting upstream movement of host-fishes, thus making recolonization difficult (Williams et al. 1993; Watters 1996; Cummings and Mayer 1997; Tiemann et al. 2007b). Two species, Yellow Sandshell and Black Sandshell, once occurred in both the Middle Fork and Salt Fork but are now found only downstream of the Danville Dam (INHS Mollusk Collection). These two species occur sporadically and often disjunctly throughout Illinois in medium to large rivers in firm sand and gravel substrates (Cummings and Mayer 1997; Tiemann et al. 2007a; Douglass and Stodola 2014; Stodola et al. 2014). Populations of the Black Sandshell, a state-threatened species, are increasing in several basins throughout its range (Douglass and Stodola 2014). Yellow Sandshell is thought to parasitize gars (*Lepisosteus* sp.), whereas Black Sandshell parasitize percids (e.g., *Sander* sp.) and centrarchids (*Lepomis* sp., *Micropterus* sp., and *Pomoxis* sp.) (Watters et al. 2009). Although the Danville Dam has a fish ladder present, its effectiveness of fish passage has not been tested or evaluated.

FUTURE CONSIDERATIONS

This study contributes insights into the effects of lowhead dams on freshwater mussel faunas in the Midwest, and suggests that they reduce mussel abundance and species richness immediately upstream and downstream from impoundments. These results are similar to those reported for fishes (Tiemann et al. 2004; Santucci et al. 2005; Slawski et al. 2008), mussels (Watters 1996; Dean et al. 2002; Tiemann et al. 2007b), and aquatic insects (Lessard and Hayes 2003; Tiemann et al. 2005; Maloney et al. 2008). Results from this project will help guide plans for the upcoming dam removal projects. Post-removal monitoring will allow for appropriate evaluation of changes in the mussel fauna following dam removal.

When making a decision to repair or remove a dam, it is important to consider that not all dams and dam removals have the same environmental consequences (Bednarek 2001; Sethi et al. 2004; Gangloff 2013). It is important to establish specific project objectives and examine all available data, despite the fact that some might be contradictory. Two of the dams (Ellsworth Park and Danville) in our study are scheduled for removal in the near future. Dam removal is viewed as a useful tool for stream restoration of altered habitat and reconnecting formerly isolated areas (Kanehl et al. 1997; Catalano et al. 2007; Maloney et al. 2008; Burroughs et al. 2009). With controlled demolition, dam removals can have little or no effect on downstream mussel fauna (Heise et al. 2013). Freshwater mussels would have an opportunity to naturally recolonize upstream regions of the Vermilion River basin if habitat conditions are optimal, host-fishes are extant, and source populations are in close proximity (Sietman et al. 2001; Tiemann et al. 2007b). Because these dams do not appear to be sediment traps (Csiki and Rhoads 2014), it seems unlikely that legacy sediments would smother mussels similar to those reported by Sethi et al. (2004). Another by-product of dam removal is stranding, desiccation, and predation of mussels within the former impounded area (Sethi et al. 2004). Given the geomorphology of the area, which includes differences in channel width and depth in relation to the dams (Csiki and Rhoads 2014), efforts could be made by natural resource agencies to return stranded mussels to the river to reduce mortality.

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