Freshwater Mussels of the Rock River

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Preface

While broad geographic information is available on the distribution and abundance of mussels in Illinois, systematically collected mussel-community data sets required to integrate mussels into aquatic community assessments do not exist. In 2009, a project funded by a US Fish and Wildlife Service State Wildlife Grant was undertaken to survey and assess the freshwater mussel populations at wadeable sites from 33 stream basins in conjunction with the Illinois Department of Natural Resources (IDNR)/Illinois Environmental Protection Agency (IEPA) basin surveys. Inclusion of mussels into these basin surveys contributes to the comprehensive basin monitoring programs that include water and sediment chemistry, instream habitat, macroinvertebrate, and fish, which reflect a broad spectrum of abiotic and biotic stream resources. These mussel surveys will provide reliable and repeatable techniques for assessing the freshwater mussel community in sampled streams. These surveys also provide data for future monitoring of freshwater mussel populations on a local, regional, and watershed basis.

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Introduction

Freshwater mussel populations have been declining for decades and are among the most seriously impacted aquatic animals worldwide (Bogan 1993, Williams et al. 1993). It is estimated that nearly 70% of the approximately 300 North American mussel taxa are either federally-listed as endangered or threatened, extinct, or in need of conservation status (Williams et al. 1993, Strayer et al. 2004). In Illinois, 25 of the 62 extant species (44%) are listed as threatened or endangered (Illinois Endangered Species Protection Board 2011). While broad geographic information is available on the distribution and abundance of mussels in Illinois, systematically collected mussel-community data sets required to integrate mussels into aquatic community assessments do not exist. Baker (1926) conducted the first comprehensive review of mussel fauna in the Rock basin; however, since then, only sporadic sampling has occurred. This report summarizes the mussel survey conducted in conjunction with IDNR and IEPA basin survey sites in the Rock River mainstem and its minor tributaries in 2009, with an additional survey in 2012 (Appendix 2).

The Rock River originates in Wisconsin at Horicon Marsh, Dodge County, flows southward into Winnebago County, Illinois then shifts southwesterly through Ogle, Lee, Whiteside, Henry, and Rock Island counties (Sinclair 1996, Figure 1). The mainstem of the river flows for 163 miles in Illinois, encompassing a total of 318 miles from Wisconsin to its mouth on the Mississippi River (Sinclair 1996). The Rock River drains approximately 27,270 km² (10,915 mi²), with an approximate drainage of 9,200 km² (3,550 mi²) in Illinois (Luman 2002). Three major tributaries, the Green, Pecatonica, and Kishwaukee Rivers, drain into the Rock River. This report focuses on the Rock River mainstem and direct minor tributaries whereas the three major tributaries are covered in the Rock River Tributaries report.

Major portions of the Rock mainstem and its minor tributaries flow through the geographic division of the Rock River Hill Country (Knapp 1998). Other natural divisions within the basin include the Northeastern Morainal, Grand Prairie, Middle Mississippi Border, and Upper Mississippi River and Illinois River Bottomlands (Schwegman 1973). Rolling hills and surficial bedrock, creating scenic rocky bluffs and ravines, characterize the Rock River Hill Country physiography (IDNR 2001). Baker (1926), qualifying this area of the state, wrote “the Rock River system is admirably adapted for ecological study on account of its diversity of form, embracing every variation of vital character—large and small lakes, swamps, creeks, small, medium and large size rivers. For comparison of fauna with physiography it is unsurpassed.”

Land use and Instream Habitat

Historically, expansive wetlands along with prairies (approximately 1/3 of the landscape) and forests covered the basin (IDNR 2001). Many of the wetlands have been drained, tiled, and
converted to cropland that today accounts for 61% of land use in the basin (IDNR 2001, Page et al. 1992). Grasslands, including pastures and some prairie, now account for approximately 23% of land use (IDNR 2001).

Two major urban areas in the Rock River basin are Rockford and Rock Island/Moline with populations of about 154,000 and 60,250, respectively (US Census Bureau 2010). Seven dams exist on the Rock River and are located at Rock Island/Moline, Sterling/Rock Falls, Dixon, Oregon, Rockford, and Rockton. These dams alter flow regime, river depth, and create sluggish pools throughout the river system (Page et al. 1992). The Rock River has acquired residential and industrial pollution from municipal and industrial development (Miller 1972, Page et al. 1992). The Rock River is considered ‘fully supporting’ of aquatic life and fish consumption based on IEPA standards, although primary and secondary contact levels were not assessed (IEPA 2010). However, much of the mainstem contains mercury and polychlorinated biphenyls from toxic deposition; in addition, fecal coliform is present around municipal areas like Rockford and Rock Island/Moline, largely due to urban runoff and storm sewer discharge (IEPA 2010).

In late summer, the Rock River typically becomes shallow and wadeable in various areas throughout the river and islands often appear mid-stream (Figure 2). Substrates in the main channel of the Rock River vary from predominately cobble, consolidated gravel and sand, to sand and silt in slack water areas near islands or banks. Exposed bedrock is uncommon but outcrops along banks occasionally. A forested riparian zone is common along the majority of the Rock River. The minor tributaries of the Rock River naturally meander and consist largely of consolidated gravel and sand substrate in runs (Figure 3) to cobble riffles and sandy pools. Claypan or silt is commonly found along banks. One site was predominately cobble and gravel (site 30, Franklin Creek) and one site (site 36, Rock Creek) was mostly unconsolidated sand and claypan. These minor tributary sites are normally wadeable with average depths of less than a meter throughout the summer and fall months.

Methods

During the 2009 survey, freshwater mussel data were collected at 36 sites: 22 mainstem and 14 tributary sites in the Rock River basin (Figure 1; Table 1). Locations of sampling sites are listed in Table 1 along with IDNR/IEPA sampling type information. In most cases, mussel survey locations were the same as IDNR/IEPA sites. Due to a fish kill that occurred on the Rock River in July 2009, a more intensive sampling effort was conducted on the river with the help of IDNR and the U. S. Fish and Wildlife Service biologists. These sites are identified by “MU” under sampling type in Table 1.

Live mussels and shells were collected at each sample site to assess past and current freshwater
mussel occurrences. Live mussels were surveyed by hand grabbing and visual detection (e.g., trails, siphons, exposed shell) when water conditions permitted. Efforts were made to cover all available habitat types present at a site including riffles, pools, slack water, and areas of differing substrates. A four-hour timed search method was implemented at each site. Live mussels were held in the stream until processing.

Following the timed search, all live mussels and shells were identified to species and recorded (Tables 2 and 3). For each live individual, shell length (mm), gender, and an estimate of the number of growth rings were recorded. A species was considered extant at a site if it was represented by live or recently dead shell material (Szafoni 2001). Based upon condition of the best shell found, shell material was classified as recent dead (periostracum present, nacre pearly, and soft tissue may be present) or relict (periostracum eroded, nacre faded, shell chalky). Additional mainstem sites (sites 5-11, and 19) were added focusing solely on presence/absence of mussels to further investigate any impact from the 2009 fish kill on the mussel populations. At these sites, shell length, gender, and growth ring counts were not recorded due to time restraints. The nomenclature employed in this report follows Turgeon et al. (1998) except for recent gender updates to Toxolasma species (Williams et al. 2008, Appendix 1). Voucher specimens were retained and deposited in the Illinois Natural History Survey Mollusk Collection. All non-vouched live mussels were returned to the stream reach where they were collected.

Other parameters recorded comprised of extant and total species richness, presence of rare or listed species, and individuals collected, expressed as catch-per-unit-effort (CPUE; Tables 2 and 3). A population was considered to indicate recent recruitment if individuals less than 30 mm in length or with three or fewer growth rings were observed. Finally, mussel resources were classified as Unique, Highly Valued, Moderate, Limited, or Restricted (Tables 2 and 3) based on the above parameters (Table 4) and following criteria outlined in Table 5 (Szafoni 2001).

**Results**

**Species Richness**

In our survey, 27 species were found to be extant (live + dead shell) within the basin (Tables 2 and 3). The number of live species collected in the Rock River mainstem ranged from 2 to 13, the number of extant collected ranged from 3 to 16, and total number of species (live + dead + relict) collected in the mainstem ranged from 4 to 20. The pimpleback (*Quadrula pustulosa*) was observed at all 22 mainstem sites sampled (Figure 5a). The plain pocketbook (*Lampsilis cardium*), fragile papershell (*Leptodea fragilis*), state-threatened black sandshell (*Ligumia recta*), Wabash pigtoe (*Fusconaia flava*), and pink papershell (*Potamilus ohiensis*) were other commonly occurring species across sites (ranging between 86% and 50%, Figure 5a).
The number of live and extant species collected in the minor tributaries ranged from 0 to 10, and the total number of species collected was 0 to 11. The plain pocketbook and white heelsplitter (*Lasmigona complanata*) occurred most often throughout the minor tributaries (5 of 14 sites, 36% each, Figure 5b). Other commonly occurring species included the fatmucket (*Lampsilis siliquoidea*; 29%), the Wabash pigtoe and ellipse (*Venustaconcha ellipsiformis*; both 21%).

The mainstem sites with the greatest species richness were sites 17 and 18, with 13 live species collected. In the minor tributaries, two sites on the Kyte River had the greatest species richness with 9 and 10 live species (sites 28 and 29, respectively).

**Abundance and Recruitment**

On the mainstem, a total of 1358 individuals were collected across 22 sites. Live mussels were observed at all sampling sites. The number of live specimens collected at a given site ranged from 2 to 284, with an average of 61 mussels per site (Table 2). Mussel abundance at individual mainstem sites ranged from low to moderately high and CPUE ranged from 1 to 68 individuals/collector-hour (Table 2). A total of 88 collector-hours were spent sampling in mainstem sites, with an average of 15 mussels collected per hour. The mainstem site with the greatest mussel density was site 17 yielding 284 individuals. The most common species observed across mainstem sites were the pimpleback (*n=621*), plain pocketbook (*n=192*), fragile papershell (*n=140*), threehorn wartyback (*Obliquaria reflexa*, *n=129*), and black sandshell (*n=74*), which, when combined, comprised 86% of total mainstem collections.

In the minor tributaries, a total of 331 individuals were collected across 8 of 14 sites (Table 3). The number of live specimens collected ranged from 1 to 203, with an average of 41 mussels per site. Mussel abundance at tributary sites ranged from none to moderately high and CPUE ranged from 0 to 51 individuals/collector-hour (Table 3). A total of 56 collector-hours were spent sampling in tributary sites, with an average of 10 mussels collected per hour at sites where mussels were present. The most common species observed were the plain pocketbook (*n=146*), white heelsplitter (*n=41*), elktoe (*Alasmidonta marginata*, *n=39*), pimpleback (*n=35*), and cylindrical papershell (*Anodontoides ferussacianus*, *n=21*), which, when combined, comprised 85% of total tributary collections.

Five species made up 80% of the total collection across the basin. These species include pimpleback (39%), plain pocketbook (20%), fragile papershell (8%), threehorn wartyback (8%), and black sandshell (5%).

Recruitment for each species was determined by the presence of individuals less than 30 mm or with three or fewer growth rings. Smaller (i.e., younger) mussels are harder to locate by hand grab methods and large sample sizes can be needed to accurately assess population.
reproduction. However, a small sample size can provide evidence of recruitment if it includes individuals that are small or possess few growth rings. Alternatively, a sample consisting of very large (for the species) individuals with numerous growth rings suggests a senescent population. Recruitment levels are referred to in Table 4 as Reproduction Factor.

Additional mainstem sites (5-11, and 19) focused solely on presence/absence of mussels to further investigate any impact from the 2009 fish kill on the mussel populations; therefore, eight sites were not included in calculating MCI parameters and scores since we did not record lengths and growth ring counts of specimens. These sites are excluded from Figure 5a. Recruitment at individual mainstem sites ranged from low to high across the basin. Seven sites (1, 4, 13, 17, 18, 20, 22) exhibited moderate to high (30-50%) to very high recruitment (over 50%) while the remaining four sites (12, 14, 15, 16) had none to minimal recruitment (0-30%; Figure 5a).

Among tributary sites, four sites exhibited high recruitment (sites 24, 26, 27, 28; 40-50%), one site had moderate recruitment (site 29; 30%), and the other nine sites had zero to minimal recruitment (0-10%). Six of these nine sites (23, 30, 32, 33, 35, 36) had no live individuals found and were excluded from Figure 5b.

**Mussel Community Index Score**

Based on the data collected in the 2009 basin survey, nearly 79% (11 of 14 sites) of the Rock River sites are classified as Highly Valued or Unique mussel resources under the current MCI classification system (Table 2, Figure 5). Three sites (17, 20, 21) ranked as Unique mussel resources due to high species richness, listed species present, moderate densities, and high recruitment (Figure 5a). Eight sites (1, 3, 4, 12-14, 18, 22) ranked as Highly Valued mussel resources and the remaining three sites (2, 15, 16) were ranked as Limited mussel resources.

In the minor tributaries, six sites (23, 25, 32-33, 35-36) were Restricted mussel resources, indicating no live mussels were present and minimal or no shell material was found. Three sites (24, 31, 34) were Limited mussel resources, Franklin Creek (site 30) was a Moderate mussel resource, and three sites (Stillman, Leaf, and Kyte Rivers, sites 26-28) were Highly Valued mussel resources. One site on the Kyte River (site 29) ranked as a Unique mussel resource (Table 2; Figure 5b) because of high species diversity, number of intolerant species found, and moderate reproductive success.

**Noteworthy Finds**

In the mainstem, the first live record since 1986 for rock pocketbook (*Arcidens confragosus*) and the second shell record for the washboard (*Megalonaias nervosa*) were recorded at site 18 (INHS Mollusk Collection Database). The state-threatened fanshell (*Ellipsaria lineolata*) was
located by relict shell further upstream than previous records. Historical species not found in the 2009 survey included flat floater (*Anodonta suborbiculata*), yellow sandshell (*Lampsilis teres*), and state-listed species such as elephantear (*Elliptio crassidens*), snuffbox (*Epioblasma triquetra*), ebonyshell (*Fusconaia ebena*) and spectaclecase (*Cumberlandia monodonta*), and federally-endangered Higgins eye (*Lampsilis higginsii*).

In the minor tributaries, the third live record for black sandshell was found (site 29; Figure 3). The first shell (relict) record for purple wartyback (*Cyclonaias tuberculata*) was recorded at site 31 and a second shell record of flutedshell (*Lasmigona costata*) since the late 1800s was recorded from site 34. Pink papershell and creek heelsplitter (*Lasmigona compressa*) has been found live previously in the Kyte River, but it was not found at the two sites sampled in 2009 (e.g., site 29, Kyte River 2004; INHS Mollusk Collection Database).

**Discussion**

The first mussel surveys of the Rock River basin were conducted in the late 1800s and early 1900s. Baker (1926) compiled previous survey information regarding the Rock River basin and Miller (1970) updated Baker’s work with a survey of the mainstem. Baker (1926) reported a total of 31 live species while Miller (1970) collected 21 live species. During our survey, we collected 22 live (23 extant) species (Table 2). Species we did not collect live in the mainstem that have been recorded live or extant within the last two decades include: spike (*Elliptio dilatata*), butterfly, purple wartyback, pistolgrip (*Tritogonia verrucosa*), wartyback, and monkeyface (*Quadrula metanevra*). Other shells collected from species such as the flutedshell and ellipse appear to have undergone a major decline or were historically rare (e.g., ellipse) (INHS Mollusk Collection Database). The rock pocketbook appears to be rare throughout the mainstem, since we collected one live specimen. This species was recorded previously at the mouth of the Rock River in 1986 (INHS Mollusk Collection Database). Several species not found in our survey, such as the flat floater and state-endangered ebonyshell, elephantear, and federally-endangered Higgins eye also appear to have been historically rare in the mainstem (INHS Mollusk Collection Database).

Species compositions from historical records to our present survey have changed slightly. In general, there appears to be a major loss of intolerant Amblemine species, while tolerant species persist such as pimpleback and Wabash pigtoe, which have ictalurid and centrarchid host fish, respectively. There is an increased presence of Lampsilinae species in the mainstem (Table 2). Several live species were only found from the mouth of the Rock River to site 17 and 18, just below the dams at Dixon and Sterling/Rock Falls (Table 2). Miller’s (1970) study highlighted the loss of large mussel beds in the Rock River and a noticeable decline in mussel density, particularly downstream of Sterling/Rock Falls. His survey was conducted a year after clamming practices for the pearl button industry ended in 1969. During our survey, extensive
mussel beds were not observed, with the possible exception of sites 14 (n=188, near Grand Detour) and 17 (n=284, south of Anna Page Park at Dixon). However, these two sites were dominated by two or three common species (Table 2). Other sampling procedures, such as brailing and diving, would be useful to fully assess the extent and intactness of mussel beds throughout the mainstem.

In the minor tributaries, two species not collected during this survey included the creek heelsplitter and pink papershell. Creek heelsplitters are generally rare throughout their range and the lack of collection during this survey could mean they were simply not detected. Recent records for pink papershell are from sites not sampled during our survey; these sites would need to be sampled to determine if the species still persists in this basin. The state-listed black sandshell was detected alive further upstream than any previous records. This may suggest minor range expansion from the mainstem into smaller tributaries. Possible causes could include fish introductions or movements or non-detection in previous surveys due to the species’ rarity in these minor tributaries. Black sandshell is a generalist and uses walleye, plus other common centrarchid and cyprinid hosts. This species appears to be doing well in the mainstem (n=74, Table 2). The IDNR actively manages the Rock River, stocking fish most years. Prior to 2009, walleye was the dominant fish stocked. In 2009, walleye, smallmouth bass, and channel catfish were stocked in the Rock River mainstem, and in 2010, walleye, channel catfish and bluegill were stocked. The 2009/2010 fish stockings were in response to the fish kill that occurred in summer 2009 where over 72,000 fish were killed (Bowman 2009). Our intensive survey efforts detected minimal adult mussel mortality; however, fresh dead shell of pimpleback was frequently observed throughout the river where the fish kill occurred. Given the necessity of fish hosts for glochidia (mussel larvae) transformation, a mussel cohort for 2009 or a large number of potential fish hosts may have been lost, but long-term effects on these mussel populations are unknown. Some of the walleye released in 2010 were inoculated with black sandshell glochidia before being released into the mainstem in the hopes of successful transformation and recruitment of this threatened species (IDNR, personal communication).

**Mussel Community Index and Recruitment**

In spite of the impact of dams and historical clamming practices (e.g., commercial harvest for button and pearl industries), 11 Rock River sites (1, 3, 4, 12-14, 17,18, 20-22) sampled in 2009 are considered Highly Valued or Unique resources according to the Mussel Community Index. Eight sites (5-11, 19) were not included in MCI calculations as previously mentioned. These 8 sites had 4 to 9 live species and 4 to 12 extant species present with numerous live individuals observed (Table 2). Several of these sites displayed fairly intact mussel fauna suggesting that these mussel communities are viable and self-maintaining at this time. Three mainstem sites
(2, 15, 16) were considered Limited resources with minimal mussel representation. This may have been due to lack of viable habitat (shifting sandbars) or failure to collect all species present, including juveniles, because of sampling conditions or methods (qualitative vs. quantitative). Sampling methods to target juvenile mussels would be necessary to better assess the reproductive status of these populations.

In the minor tributaries, most streams were assessed as fully supporting aquatic life (Sinclair 1996; IEPA 2010) and, for example, approximately 87% of the Kyte River and its tributaries had sites with Highly Valued or Unique mussel resources along with Franklin Creek (site 30), which had a Moderate mussel resource (Table 3). Other streams that were classified as full support for aquatic life included Elkhorn Creek and Rock Creek. At Rock Creek (a Restricted mussel resource) we did not find any live mussels or shell, but this could have been due to stream conditions (high water level) and lack of suitable substrate for mussels (shifty sand, clay banks, high gradient). Elkhorn Creek, a Limited mussel resource, historically had greater mussel species richness but has since dwindled and according to more recent assessments appears to be impacted with polychlorinated biphenoyls (IEPA 2012). One site listed as not fully supporting aquatic resources and where we did not find any live mussels was Keith Creek. Keith Creek flows through the city of Rockford before emptying into the Rock River and catches urban and stormwater runoff, hence serious water quality issues (i.e., arsenic, methoxochlor, pH, zinc, fecal coliform) and sediment contamination exist (IEPA 2010).

**Mussel community of the Rock River basin**

Historically, 45 species were present in the Rock River and its minor tributaries, but in our survey a total of 27 extant species were collected (INHS Mollusk Collection Database; Tables 2 and 3). Large portions of the Rock River and its minor tributaries have been classified as a Highly Valued Aquatic Resource (Page et al. 1992; IDNR 2001). Even with this listing, species richness within the mainstem is declining. Plausible reasons for an initial decline may be due to historical clamming practices and installation of the seven dams, thereby impeding fish passage and altering instream habitat (Baxter 1977, Watters 2000). Increased sedimentation from historical habitat degradation and intensive agricultural practices compounded with the release of municipal and industrial waste into the mainstem has likely been detrimental to mussel populations. It appears mussel fauna in the minor tributaries remains intact at sites with live mussels present. Continued monitoring of mussel species’ gains and losses, in conjunction with other aquatic fauna, will be important for assessing and recognizing trends in the overall biological integrity within the Rock River basin.
Literature Cited


U.S. Census Bureau. 2010. Census National Summary File of Redistricting Data; generated by Sarah Bales; using American FactFinder; <http://factfinder2.census.gov>; (January 2012)


Table. 1. 2009 Rock River Intensive Basin Survey. Sites are listed from upstream to downstream, mainstem (1-22) and its minor tributaries (23-36). Types of samples include MU-mussel sampling, BE-boat electrofishing, ES-electric fish seine, SH-fish seine hauls, W-water chemistry, S-sediment, H-habitat, M-macroinvertebrate, FF-fish flesh contaminant.

<table>
<thead>
<tr>
<th>Site Number</th>
<th>FIPA Code</th>
<th>Stream</th>
<th>Types of Samples</th>
<th>County</th>
<th>Location</th>
<th>Watershed Area (km²)</th>
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<td>1</td>
<td>P-05</td>
<td>Rock River</td>
<td>MU</td>
<td>Winnebago</td>
<td>2 mi S of Rockton; Hinckley Forest Preserve</td>
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<td>P-27</td>
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<td>MU, BE, SH, W, S, M</td>
<td>Winnebago</td>
<td>Alwood Homestead Forest Preserve boat ramp</td>
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<td>P-23</td>
<td>Rock River</td>
<td>MU, BE, W, S, M</td>
<td>Winnebago</td>
<td>Rockford; Blackhawk Park</td>
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<td>P-16</td>
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<td>Ogle</td>
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<td>2 mi SW of Dixon; S of Anna Paige Park</td>
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<td>Whiteside</td>
<td>2 mi downstream Prophetstown; head of Indian island</td>
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<td>21</td>
<td>P-46</td>
<td>Rock River</td>
<td>MU, BE, W, S, H, M, FF</td>
<td>Whiteside</td>
<td>Public launch S of Erie; Erie Co Rd bridge</td>
<td>24317.25</td>
</tr>
<tr>
<td>22</td>
<td>P-25</td>
<td>Rock River</td>
<td>MU</td>
<td>Rock Island</td>
<td>Rock Island; downstream Route 67 bridge</td>
<td>27833.04</td>
</tr>
<tr>
<td>23</td>
<td>PT-01</td>
<td>Kinnikinnick Creek</td>
<td>MU, ES, W, S, H, M</td>
<td>Boone</td>
<td>Kinnikinnick Creek Conservation Area</td>
<td>24.91</td>
</tr>
<tr>
<td>24</td>
<td>PSB-01</td>
<td>North Fork, Kent Creek</td>
<td>MU, ES, W, S, H, M</td>
<td>Winnebago</td>
<td>Anna Page Conservation Area</td>
<td>38.33</td>
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<td>PR-09</td>
<td>Keel Creek</td>
<td>MU, ES, W, S, H,M</td>
<td>Winnebago</td>
<td>Rockford; 10th Aven. Park</td>
<td>35.27</td>
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<tr>
<td>26</td>
<td>PP-01</td>
<td>Stillman Creek</td>
<td>MU, ES, W, S, H,M</td>
<td>Ogle</td>
<td>2 mi S of Stillman Valley; Holcomb Rd bridge</td>
<td>42.71</td>
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<td>Ogle</td>
<td>3 mi NW of Leaf River; White Eagle Camp</td>
<td>82.16</td>
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<tr>
<td>28</td>
<td>PL-18</td>
<td>Kyte River</td>
<td>MU, BE, W, S, K,M</td>
<td>Ogle</td>
<td>4.5 mi NW of Rochelle; Flag Rd bridge</td>
<td>306.90</td>
</tr>
<tr>
<td>29</td>
<td>PL-05</td>
<td>Kyte River</td>
<td>MU</td>
<td>Ogle</td>
<td>5.5 mi SE of Oregon; Rocky Hollow Rd bridge</td>
<td>330.72</td>
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<tr>
<td>30</td>
<td>PK-01</td>
<td>Franklin Creek</td>
<td>MU, ES, W, S, H,M</td>
<td>Lee</td>
<td>3 mi NW Franklin Grove; Franklin Creek State Park</td>
<td>74.22</td>
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<tr>
<td>31</td>
<td>PJ-01</td>
<td>Pine Creek</td>
<td>MU, ES, W, S, H,M</td>
<td>Ogle</td>
<td>White Pines Forest State Park</td>
<td>117.38</td>
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<td>32</td>
<td>PZR-03</td>
<td>Three Mile Branch</td>
<td>MU, ES, W, S, H,M</td>
<td>Lee</td>
<td>4.5 mi E of Rock Falls; Nelson Rd bridge</td>
<td>94.71</td>
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<td>33</td>
<td>PHE-01</td>
<td>Buffalo Creek</td>
<td>MU, ES, W, S, H,M</td>
<td>Whiteside</td>
<td>10 mi N of Sterling; James Rd bridge</td>
<td>69.59</td>
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<tr>
<td>34</td>
<td>PH-16</td>
<td>Elk Creek</td>
<td>MU, BE, W, S, H,M, FF</td>
<td>Whiteside</td>
<td>8 mi N of Sterling; Pilgrim Rd bridge</td>
<td>374.25</td>
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<tr>
<td>35</td>
<td>PHB-01</td>
<td>Sugar Creek</td>
<td>MU, ES, W, S, H,M</td>
<td>Whiteside</td>
<td>4 mi N of Sterling; Fults Rd bridge</td>
<td>62.87</td>
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<tr>
<td>36</td>
<td>PE-06</td>
<td>Rock Creek</td>
<td>MU, BE, W, S, H,M</td>
<td>Whiteside</td>
<td>Morrison; Rt. 30 bridge</td>
<td>410.96</td>
</tr>
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</table>
Table 2. Mussel data for mainstem sites sampled during 2009 surveys (Table 1). Numbers in columns are live individuals collected, “D” and “R” indicates that only dead or relict shells were collected. Proportion of total is number of individuals of a species divided by total number of individuals at all sites. MCI scores and Resource Classification are based on values in Tables 4 and 5 (R=Restricted, L=Limited, M=Moderate, HV=Highly Valued, and U=Unique). NDA = no data available. Species in bold are federally or state-listed species or species in Greatest Need of Conservation by IL DNR. *Total historical species represents all species found in the Rock River and minor tributaries; species not included in this table are three tributary restricted species, Alasmidonta viridis, Anodontoides ferussacianus, and Lasmigona compressa, and historical species Anodonta suborbiculata, Fusconaia ebena, Lampsilis higginsii, Lampsilis teres, and Quadrula nobilis.

<table>
<thead>
<tr>
<th>Species</th>
<th>Rock River Site Number</th>
<th>Proportion of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22</td>
<td></td>
</tr>
<tr>
<td>Subfamily Margaritifera</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cumberlandia monodonta</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subfamily Anodontinae</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alasmidonta margarita</td>
<td>D R D</td>
<td>0.1%</td>
</tr>
<tr>
<td>Arcidens confragosus</td>
<td>R R</td>
<td>0.1%</td>
</tr>
<tr>
<td>Lasmigona complanata</td>
<td>R R R 1 1 D 1 4 1</td>
<td>0.6%</td>
</tr>
<tr>
<td>Lasmigona costata</td>
<td>R R</td>
<td></td>
</tr>
<tr>
<td>Pyganodiscus grandis</td>
<td>2 D 2</td>
<td>0.5%</td>
</tr>
<tr>
<td>Straphylium undulatum</td>
<td>R R</td>
<td>0.4%</td>
</tr>
<tr>
<td>Utterbackia imbecillis</td>
<td>1</td>
<td>0.2%</td>
</tr>
<tr>
<td>Subfamily Amblydeiidae</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amblydeiella picata</td>
<td>R R R R D</td>
<td>0.4%</td>
</tr>
<tr>
<td>Cyclonaias tuberculata</td>
<td>R R R R R R R R</td>
<td></td>
</tr>
<tr>
<td>Elliptio crassidens</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elliptio dilatata</td>
<td>R R R R R R R R</td>
<td></td>
</tr>
<tr>
<td>Fusconaia flava</td>
<td>2 1 3 1 R 11 .4 1 R 1 2 1 R 2 2 R 1 D 2 4%</td>
<td></td>
</tr>
<tr>
<td>Méganeleia nervosa</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>Pleurobema cypryns</td>
<td>R R R R R R</td>
<td></td>
</tr>
<tr>
<td>Pleurobema rubrum</td>
<td>R R R R R</td>
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</tr>
<tr>
<td>Pleurobema sintonix</td>
<td>D R 1</td>
<td>0.3%</td>
</tr>
<tr>
<td>Quadrula meteneum</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quadrula nodulata</td>
<td>R R R R R R</td>
<td></td>
</tr>
<tr>
<td>Quadrula pustulosa</td>
<td>6 4 23 12 40 31 16 26 55 10 49 68 65 2 24 144 9 13 1 14 6 45 7%</td>
<td></td>
</tr>
<tr>
<td>Quadrula quadrula</td>
<td>1 3 3</td>
<td>0.5%</td>
</tr>
<tr>
<td>Tiriogonias verrucosus</td>
<td>R R R R R</td>
<td></td>
</tr>
<tr>
<td>Subfamily Sphaeriidae</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Actionaxa ligamentina</td>
<td>R R R R R 1 20 2 1</td>
<td></td>
</tr>
<tr>
<td>Ellipsaria lineolata</td>
<td>R R R R R</td>
<td></td>
</tr>
<tr>
<td>Epioblasma triqueta</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lampsilis cardium</td>
<td>4 R 3 15 5 6 20 6 19 2 1 11 7 57 D 8 5 13 8 2 2 14 1%</td>
<td></td>
</tr>
<tr>
<td>Lampsilis ellipticae</td>
<td>R R</td>
<td></td>
</tr>
<tr>
<td>Leptodea fragilis</td>
<td>10 1 1 7 4 10 10 7 3 1 4 4 5 3 D 5 2 1 1 9 10 3%</td>
<td></td>
</tr>
<tr>
<td>Lithinia recta</td>
<td>1 D D 1 6 10 6 1 1 13 3 7 3 2 25 R 7 D D 5 4%</td>
<td></td>
</tr>
<tr>
<td>Ophiacantha flexana</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Obelia crassidens</td>
<td>10 R 7 6 3 8 2 9 5 9%</td>
<td></td>
</tr>
<tr>
<td>Obovatella ovale</td>
<td>4 7 1 5 5 1 6 6 5 1 6%</td>
<td></td>
</tr>
<tr>
<td>Potamilus oculus</td>
<td>25 2 2 2 D D 2 2 2%</td>
<td></td>
</tr>
<tr>
<td>Potamilus ohiensis</td>
<td>2 1 1 4 2 D 4 3 5 2 1 2 2%</td>
<td></td>
</tr>
<tr>
<td>Tococosa parvum</td>
<td>1</td>
<td>0.1%</td>
</tr>
<tr>
<td>Truncilla tanaformis</td>
<td>1 D 1 R 1 3 R D 1</td>
<td></td>
</tr>
<tr>
<td>Truncilla truncata</td>
<td>R D 2 3 2 R 0.5%</td>
<td></td>
</tr>
<tr>
<td>Veneriaconcha elongiformis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Individuals collected</td>
<td>26 2 9 45 28 77 88 48 57 61 14 76 94 181 3 29 2M 87 48 36 28 30 13 8%</td>
<td></td>
</tr>
<tr>
<td>Live Species</td>
<td>7 2 5 7 6 6 7 8 7 5 6 8 9 2 2 13 13 9 10 10 6 6 22</td>
<td></td>
</tr>
<tr>
<td>Extant Species</td>
<td>8 4 8 8 6 9 7 8 7 5 10 9 10 5 3 11 16 12 11 7 12 23</td>
<td></td>
</tr>
<tr>
<td>Total Species</td>
<td>17 12 15 13 9 14 7 8 11 4 10 17 14 13 14 4 19 20 19 17 15 18 34</td>
<td></td>
</tr>
<tr>
<td>Historical Species</td>
<td>10 16 16 17 8 8 1 8 16 16 16 16 15 17 7 5 13 13 14 24 1 12 45%</td>
<td></td>
</tr>
<tr>
<td>Catch per unit effort (CPU)</td>
<td>6.5 1.0 2.3 11.3 7.0 19.0 22.0 11.0 14.3 13.3 13.5 19.0 47.0 46.2 0.7 6.4 676 21.8 11.4 86 6.7 7.2</td>
<td></td>
</tr>
<tr>
<td>Mussel Community Index (MCI)</td>
<td>12 7 13 14 NDA NDA NDA NDA NDA NDA NDA NDA NDA NDA NDA NDA NDA NDA NDA NDA NDA NDA</td>
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</tr>
<tr>
<td>Resource Classification</td>
<td>HV L HV HV NDA NDA NDA NDA NDA NDA NDA NDA NDA NDA NDA NDA HV HV HV L L U HV NDA U U HV</td>
<td></td>
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</table>
Table 3. Mussel data for minor tributary sites sampled during 2009 surveys (Table 1). Numbers in columns are live individuals collected, “D” and “R” indicates that only dead or relict shells were collected. Shaded boxes indicate historic collections at the specific site location obtained from the INHS Mollusk Collection records. Extant species is live + dead shell and total species is live + dead + relict shell. Proportion of total is number of individuals of a species divided by total number of individuals at all sites. MCI scores and Resource Classification are based on values in Tables 4 and 5 (R=Restricted, L=Limited, M=Moderate, HV=Highly Valued, and U=Unique). Species in bold are federally or state-listed species or species in Greatest Need of Conservation by IL DNR. *includes Tritogonia verrucosa and Potamilus ohiensis not represented in the table.

<table>
<thead>
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<th>Species</th>
<th>Tributary Site Number</th>
<th>Proportion of Total</th>
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<td></td>
<td>23</td>
<td>24</td>
</tr>
<tr>
<td>Subfamily Anodontinae</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alasmidonta marginata</td>
<td>38</td>
<td>1</td>
</tr>
<tr>
<td>Alasmidonta viridis</td>
<td>D</td>
<td>1</td>
</tr>
<tr>
<td>Anodontoides ferussacianus</td>
<td>D</td>
<td>D</td>
</tr>
<tr>
<td>Lasmigona complanata</td>
<td>3</td>
<td>27</td>
</tr>
<tr>
<td>Lasmigona compressa</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lasmigona costata</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pyganodon grandis</td>
<td>11</td>
<td>1</td>
</tr>
<tr>
<td>Strophitus undulatus</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Subfamily Ambleminae</td>
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<td></td>
</tr>
<tr>
<td>Amblema picata</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cyclonaias tuberculata</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ellipta dilatata</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fusconaia flavia</td>
<td>9</td>
<td>1</td>
</tr>
<tr>
<td>Quadrula pustulosa</td>
<td>34</td>
<td>1</td>
</tr>
<tr>
<td>Subfamily Lampsiliniae</td>
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</tr>
<tr>
<td>Actinonaias ligamentina</td>
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<td></td>
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<tr>
<td>Lampisila cardium</td>
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<td>Lampisila siliquoida</td>
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<td>1</td>
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<td>Leptodea fragilis</td>
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<tr>
<td>Ligumia recta</td>
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<td></td>
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<tr>
<td>Potamilus australis</td>
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<td></td>
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<tr>
<td>Toxolasma parvum</td>
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<td></td>
</tr>
<tr>
<td>Venustaconcha elliptiformis</td>
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<table>
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<th>72</th>
<th>2</th>
<th>10</th>
<th>0</th>
<th>0</th>
<th>6</th>
<th>0</th>
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<td>1</td>
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<td>0</td>
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<td>0</td>
<td>5</td>
<td>3</td>
<td>10</td>
<td>10</td>
<td>1</td>
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<td>9</td>
<td>1</td>
<td>1</td>
<td>18</td>
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<td>20</td>
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<td>NDA</td>
<td>NDA</td>
<td>NDA</td>
<td>NDA</td>
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<td>NDA</td>
<td>NDA</td>
<td>6</td>
<td>NDA</td>
<td>NDA</td>
<td>23*</td>
</tr>
<tr>
<td>Catch per unit effort (CPU)</td>
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<td>0.3</td>
<td>0.0</td>
<td>6.3</td>
<td>3.0</td>
<td>52.1</td>
<td>17.9</td>
<td>0.5</td>
<td>2.5</td>
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<td>0.0</td>
<td>15</td>
<td>0.0</td>
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<td>0</td>
<td>12</td>
<td>12</td>
<td>15</td>
<td>16</td>
<td>8</td>
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<td>Resource Classification</td>
<td>R</td>
<td>L</td>
<td>R</td>
<td>HV</td>
<td>HV</td>
<td>HV</td>
<td>U</td>
<td>M</td>
<td>L</td>
<td>R</td>
<td>R</td>
<td>L</td>
<td>R</td>
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</table>
Table 4. Mussel Community Index parameters and scores.

<table>
<thead>
<tr>
<th>Extant species in sample</th>
<th>Species Richness</th>
<th>Catch per Unit Effort (CPUE)</th>
<th>Abundance (AB) Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1-3</td>
<td>2</td>
<td>1-10</td>
<td>2</td>
</tr>
<tr>
<td>4-6</td>
<td>3</td>
<td>&gt;10-30</td>
<td>3</td>
</tr>
<tr>
<td>7-9</td>
<td>4</td>
<td>&gt;30-60</td>
<td>4</td>
</tr>
<tr>
<td>10+</td>
<td>5</td>
<td>&gt;60</td>
<td>5</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>% live species with recent recruitment</th>
<th>Reproduction Factor</th>
<th># of Intolerant species</th>
<th>Intolerant species Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
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<td>0</td>
<td>1</td>
</tr>
<tr>
<td>1-30</td>
<td>3</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>&gt;30-50</td>
<td>4</td>
<td>2+</td>
<td>5</td>
</tr>
<tr>
<td>&gt;50</td>
<td>5</td>
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</tbody>
</table>

Table 5. Freshwater mussel resource categories based on species richness, abundance, and population structure. MCI = Mussel Community Index Score

<table>
<thead>
<tr>
<th>Resource Type</th>
<th>MCI</th>
<th>Description</th>
</tr>
</thead>
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<tr>
<td>Unique Resource</td>
<td>MCI ≥ 16</td>
<td>Very high species richness (10+ species) &amp;/or abundance (CPUE &gt; 80); intolerant species typically present; recruitment noted for most species</td>
</tr>
<tr>
<td>Highly Valued Resource</td>
<td>MCI = 12-15</td>
<td>High species richness (7-9 species) &amp;/or abundance (CPUE 51-80); intolerant species likely present; recruitment noted for several species</td>
</tr>
<tr>
<td>Moderate Resource</td>
<td>MCI = 8-11</td>
<td>Moderate species richness (4-6 species) &amp;/or abundance (CPUE 11-50) typical for stream of given location and order; intolerant species likely not present; recruitment noted for a few species</td>
</tr>
<tr>
<td>Limited Resource</td>
<td>MCI = 5-7</td>
<td>Low species richness (1-3 species) &amp;/or abundance (CPUE 1-10); lack of intolerant species; no evidence of recent recruitment (all individuals old or large for the species)</td>
</tr>
<tr>
<td>Restricted Resource</td>
<td>MCI = 0-4</td>
<td>No live mussels present; only weathered dead, sub-fossil, or no shell material found.</td>
</tr>
</tbody>
</table>
Figure 1. Sites sampled in the Rock River basin in 2009. Site codes referenced in Table 1. Sites 9-12 in square B were sampled at islands or along the bank thus not residing on the river.
Figure 2. Rock River with substrate predominately gravel/sand and cobble (site 14, on left) with exposed islands (site 18, on right).

Figure 3. Male and female black sandshells (on left) and the Kyte River (site 29) at Rocky Hollow Bridge road—substrate gravel/sand mix (on right).
Figure 4. Rock River basin species occurrence by percentage: number of sites with live species collected compared to the number of total sites sampled (22 mainstem, 14 tributary).
Figure 5. Comparison of Mussel Community Index (MCI) and its parameter scores for the Rock River basin based on factor values from Table 4.

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<th>Status</th>
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<td>rock pocketbook</td>
<td>SGNC</td>
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<td>Lasigmona costata</td>
<td>flutedshell</td>
<td>SGNC</td>
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<td>Pygamonon grandis</td>
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<td>paper pondshell</td>
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<td>elephantear</td>
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<td>Higgins eye</td>
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<td>threehorn wartyback</td>
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<td>hickorynut</td>
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<td>Potamilus ohensis</td>
<td>pink paper shell</td>
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<td>fawnsfoot</td>
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<tr>
<td>Venustaconcha ellipsiformis</td>
<td>ellipse</td>
<td>SGNC</td>
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</table>
Appendix 2. Supplemental tables and figure from 2012 surveys in the Rock River Basin.

**Basin Update**

Fifteen other sites were sampled during 2012 (Table A.2.1). Three additional species were collected, the flat floater, *Anodonta suborbiculata* (site 7, 1 individual, juvenile), flutedshell, *Lasmigona costata* (site 4, 2 individuals) and creek heelsplitter, *Lasmigona compressa* (site 11, dead shell), which raises the total live species to 28 (Table A.2.2). Thirty extant species of freshwater mussels were observed in the Rock River basin, and 38 in total, based on the 2009 and 2012 surveys. Nine of the fifteen sites, the Kyte River and all eight Rock River sites, sampled during 2012 were classified as Unique or Highly Valued mussel resources due to high species richness and abundance, presence of intolerant species, and recruitment was observed (Figure A.2.1). The remaining six tributary sites were classified as Restricted, Limited, or Moderate mussel resources (Table A.2.2).

**Table A.2.1.** 2012 Rock River basin and/or special survey sites. Sites are listed from upstream to downstream, mainstem (1-8) and its tributaries (9-15). Types of samples include MU-mussel sampling, BE-boat electrofishing, W-water chemistry, S-sediment, H-habitat, M-macroinvertebrate, FF-fish tissue sample.

<table>
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<tr>
<th>Site Number</th>
<th>IEPA Code</th>
<th>Stream</th>
<th>Types of Samples</th>
<th>County</th>
<th>Location</th>
<th>Watershed Area (km²)</th>
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<tbody>
<tr>
<td>37</td>
<td>P-15</td>
<td>Rock River</td>
<td>MU</td>
<td>Winnebago</td>
<td>5 of Rockton; Rt 75 bridge</td>
<td>16344.93</td>
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<tr>
<td>38</td>
<td>P-44</td>
<td>Rock River</td>
<td>MU</td>
<td>Winnebago</td>
<td>1.5 mi SW Rockford; Belt Line Rd bridge</td>
<td>16974.17</td>
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<td>39</td>
<td>P-89</td>
<td>Rock River</td>
<td>MU</td>
<td>Winnebago</td>
<td>2.8 mi downstream Rt 20; at confluence with Kishwaukee River</td>
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<td>40</td>
<td>P-84</td>
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<td>MU</td>
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<td>6.0 mi N Byron; Rt. 2, Fuller Forest Preserve</td>
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<td>41</td>
<td>P-30</td>
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<td>4 mi SW Byron; upstream confluence with Leaf River</td>
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<tr>
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<td>P-97</td>
<td>Rock River</td>
<td>MU</td>
<td>Lee</td>
<td>1.5 mi SW of Nelson; 0.5 mi S railroad bridge</td>
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<td>43</td>
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<td>Rock River</td>
<td>MU, BE, W, S, H</td>
<td>Whiteside</td>
<td>NW edge of Rock Falls; Lawrence Park, 12th Avenue bridge</td>
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<td>P-06</td>
<td>Rock River</td>
<td>MU</td>
<td>Whiteside</td>
<td>2 mi W Rock Falls; Rt 30 bridge</td>
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<td>45</td>
<td>PV-01</td>
<td>Dry Creek</td>
<td>MU</td>
<td>Winnebago</td>
<td>3.5 mi SE Rockton; Hononegah Forest Preserve</td>
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<td>46</td>
<td>PU-01</td>
<td>North Kinnikinnick Creek</td>
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<td>Winnebago</td>
<td>2 mi NNE Roscoe; Love Rd bridge</td>
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<td>PU-WE-C2</td>
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<td>Winnebago</td>
<td>0.6 mi downstream Dana-Warner Electric WWTP Discharge; Elevator Rd bridge</td>
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<td>4 mi SW Byron; Rt 2 bridge</td>
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<td>Kyte River</td>
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<td>1 mi E of Daysville; Honey Creek Rd bridge</td>
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<td>51</td>
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<td>Elkhorn Creek</td>
<td>MU</td>
<td>Carroll</td>
<td>3.5 mi NE Milledgeville</td>
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</table>
Table A.2.2. Mussel data for the Rock River basin sampled during 2012 (Table A.2.1). Numbers in columns are live individuals collected, “D” and “R” indicates only dead or relict shells collected. Shaded boxes indicate historic collections at the specific site location obtained from the INHS Mollusk Collection database. Extant species is live + dead shell and total species is live + dead + relict shell. Proportion of total is number of individuals of a species divided by total number of individuals at all sites from 2009-2012 surveys. MCI scores and Resource Classification are based on values in Tables 4 and 5 (R=Restricted, L=Limited, M=Moderate, HV=Highly Valued, and U=Unique). NDA = no data available. Species in bold are federally or state-listed species or species in Greatest Need of Conservation by IL DNR. *Includes total historical species for the Rock River and its minor tributaries (see Appendix 1).

<table>
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<th>Species</th>
<th>Rock River and Tributaries Site Number</th>
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<td>Venustacantha ellipseformis</td>
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</table>

| Individuals collected        | 298 | 135 | 354 | 243 | 109 | 61 | 125 | 121 | 0 | 24 | 0 | 4 | 0 | 178 | 2 | 3443 |
| Live Species                 | 9 | 7 | 9 | 8 | 6 | 13 | 9 | 0 | 1 | 0 | 0 | 0 | 9 | 0 | 28 |
| Extant Species               | 11 | 9 | 11 | 9 | 8 | 6 | 13 | 10 | 0 | 1 | 0 | 0 | 0 | 9 | 1 | 30 |
| Total Species                | 12 | 10 | 12 | 11 | 11 | 6 | 13 | 13 | 1 | 1 | 1 | 0 | 0 | 11 | 2 | 38 |
| Historical Species           | 9 | NDA | NDA | 9 | 1 | NDA | 23 | 18 | NDA | NDA | NDA | NDA | NDA | NDA | 14 | NDA | 45* |
| Catch per unit effort (CPUF) | 745 | 33.8 | 88.7 | 60.9 | 27.1 | 15.3 | 11.3 | 30.3 | 0 | 6 | 0 | 1 | 0 | 69.2 | 0.5 |
| Mussel Community Index (MCI) | 16 | 18 | 17 | 18 | 16 | 12 | 16 | 15 | 0 | 10 | 2 | 9 | 0 | 17 | 5 |

| Resource Classification      | U | U | U | U | U | U | U | U | R | R | M | M | R | R | R | U | L |
Figure A.2.1. Comparison of Mussel Community Index (MCI) and its parameter scores for the Rock River basin based on factor values from Table 4.