HISTORICAL CHANGES IN THE OCCURRENCE AND DISTRIBUTION OF FRESHWATER MUSSELS IN KANSAS

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ABSTRACT—The surface waters of eastern and central Kansas once supported an impressive variety of native freshwater mussels, but a widespread decline in species richness accompanied the urban, industrial, and agricultural development of this region. Statewide mussel surveys implemented during the past two decades have shed new light on the scope and severity of this decline. Of the 48 mussel species originally known from Kansas, six are now extirpated, one lacks reproductively viable populations (i.e., faces imminent extirpation), and 38 others have suffered evident range reductions or a widespread thinning of former populations. Soil erosion and stream siltation, other forms of water and sediment pollution, physical habitat degradation, stream flow attenuation, and declines in the native fishes serving as biological hosts for larval mussels all have contributed to these changes. Dams and other impediments to fish migration now hinder the reestablishment of mussel colonies following prolonged droughts and major water pollution events. Some mussel populations in this region display unique morphological, developmental, and genetic attributes, implying their continued attrition may lead to the eventual loss of distinctive forms or subspecies.

Key Words: aquatic habitat restoration, freshwater mussels, prairie streams, zoogeographical surveys

INTRODUCTION

Freshwater mussels (Mollusca: Bivalvia: Unionoida) inhabit many of the world's inland waters but attain their greatest taxonomic diversity in the perennial streams of eastern North America (Bogan 1993). A few dozen species range westward into the Great Plains, where they achieve significant population densities and perform several crucial ecological functions. For example, mussels in this region provide an important source of food for numerous predatory fish and wildlife species, and their spent shells afford shelter and egg attachment sites for a wide assortment of aquatic and semiaquatic organisms (Murray and Leonard 1962; Cvancara 1983; Howells et al. 1996). As filter feeders subsisting primarily on suspended bacteria, algae, and organic detritus, mussels enhance the clarity of the water column and facilitate the transfer of nutrients from the water to the bottom substrate and its affiliated biological community (Strayer et al. 1994; Vaughn et al. 2004; Vaughn and Spooner 2006). As active
burrowers, mussels also play a role in the homogenization and aeration of the surficial sediment layer (McCall and Tevesz 1979; McCall et al. 1995). Mussels often form dense beds in favorable aquatic habitats. These features may contain thousands of buried or partially buried individuals, collectively dominating the local benthic biomass and effectively stabilizing the bottom substrate during periods of high stream flow (Strayer et al. 1994; Smith 2001; Zimmerman and de Szalay 2007).

Most freshwater mussel species undergo an extraordinary life cycle that involves a parasitic larval life stage and an elaborate mechanism for transferring larvae to a suitable vertebrate host, usually a fish (Smith 2001; Obermeyer et al. 2006). Gravid females in some species possess anatomical modifications that resemble small fish or other edible organisms, and these act as lures to attract prospective host fish (e.g., Kraemer 1970). In many other instances, larval mussels (glochidia) are embedded within gelatinous masses (conglutinates) mimicking worms or other animals preyed upon by the host species (e.g., Barnhart 1997). Any fish contacting a gravid mussel or ingesting a conglutinate released into the water runs the risk of being infested with hundreds of glochidia. If an infested fish is a compatible host, the glochidia rapidly encyst within its gill or fin membranes, then transform over a period of weeks or months into fully formed juvenile mussels. These eventually detach from the host, settle to the bottom substrate, and begin their lives as free-living organisms. Mussels typically mature within a few years, and maximum life spans may range from less than a decade to more than a century, depending on the species (Smith 2001; Obermeyer et al. 2006). Because these animals spend their entire juvenile and adult lives in the same general location, their populations are unusually sensitive to local changes in water and sediment quality, physical habitat condition, and fish community composition. Accordingly, freshwater mussel communities provide insight into the prevailing environmental condition and often garner the attention of aquatic ecologists and natural resource managers.

More than 40 mussel species reach or approach their western distributional limits in Kansas (Murray and Leonard 1962). Some species range widely across the state and maintain large and conspicuous populations in numerous water bodies. Others are exceedingly rare and known only from a few locations. The first mussel surveys in Kansas were implemented shortly after the settlement of the state (Call 1885a, 1885b, 1885c, 1886, 1887; Popenoe 1885). Subsequent statewide surveys, and more intensive biological studies focusing on specific watersheds and stream reaches, added significantly to the known ranges of many taxa (e.g., Seammon 1906; Clark and Gillette 1911; Isely 1925; Grinnell 1942; Franzen and Leonard 1943; Leonard 1943; Murray and Leonard 1962; Branson 1966; Miller and Hibbard 1972; Liechti and Huggins 1977; Cope 1979, 1981; Schuster 1979; Schuster and DuBois 1979; Hacker 1980; Metcalf 1980; Claassen 1981; Distler and Bleam 1995; Obermeyer et al. 1997; Hoke 1997, 2005; Bleam et al. 1998; Bergman et al. 2000; Van Leeuwen and Arruda 2001). During the latter half of the 20th century, a number of archeological and paleontological (Pleistocene-oriented) studies provided additional data on the historical and prehistorical distributions of mussels in this region (e.g., Kivett 1953; Wedel 1959; Hibbard and Taylor 1960; Miller 1966, 1970; Wilmeth 1970; Bradley 1973; Warren 1974; Thies 1981; Witty 1983; Dorsey 2000).

Recent investigations have documented an alarming decline in the mussel fauna of several major watersheds in Kansas (e.g., Hunter 1993; Distler and Bleam 1995; Hoke 1996, 1997, 2004, 2005; Obermeyer et al. 1997; Bergman et al. 2000; Reed 2002; Mosher 2006; Tiemann 2006; Wolf and Stark 2008). Concerns related to the long-term survival of mussels have led to the designation of 23 species as threatened or endangered (T/E) or as species in need of conservation within the state (KDWP 2005). Thus far, mussel conservation efforts have focused on the development, review, and initial implementation of recovery plans for eight T/E species (Obermeyer 2000, 2002). These plans call for the physical restoration of key aquatic habitats, emphasize the need for major improvements in surface water and sediment quality, and propose artificial propagation and restocking programs for selected T/E taxa. Laboratory propagation methods already have been developed for several mussel species (e.g., O’Beirn et al. 1998; Barnhart 2006), and pilot restocking projects have led to the successful augmentation of mussel populations in a few restricted stream reaches (e.g., Barnhart 2002).

Upcoming recovery efforts will endeavor to restore, to the fullest practicable extent, the diverse mussel communities once found in this region (Simmons 2008). Attainment of this goal will require an accurate understanding of the current and former distributions of each native mussel species. To foster such an understanding, we report on the results of an extensive series of mussel surveys implemented over an 18-year period, examine key records from earlier surveys, and present a set of detailed maps illustrating the contemporary and historical ranges of the state’s known indigenous mussels and two introduced (but widely established) bivalves. We conclude our report.
by reviewing the major factors now limiting the survival and distribution of freshwater mussels in Kansas.

**METHODS**

Statewide mussel surveys were performed by the Kansas Department of Health and Environment (KDHE) and the Kansas Department of Wildlife and Parks (KDWP) during the years 1990–2007 and 1995–2007, respectively. KDHE employed a targeted sampling design that focused initially on larger, perennial streams and later included many intermittent streams and publicly owned lakes and wetlands (KDHE 2005b, 2005c, 2007a). By December 2007, 800 sites (740 stream reaches, 60 lakes and wetlands) had been surveyed for mussels using this targeted sampling approach. To enhance the documentation of rarer taxa, surveys were repeated at least twice in 128 stream reaches, most supporting comparatively diverse mussel communities. Ninety-eight randomly selected stream reaches also were surveyed during 2006 and 2007 as part of a newly implemented probabilistic monitoring program (KDHE 2007b). Surveys performed by KDWP relied primarily on a probabilistic sampling design emphasizing smaller, wadeable streams (e.g., Obermeyer 1997). By the end of 2007, KDWP had completed surveys in 1,294 stream reaches. Eighteen additional stream reaches were sampled in conjunction with annual workshops hosted by this agency (e.g., Miller 2004). Altogether, 2,210 sites were surveyed by the two agencies.

All KDHE and KDWP surveys were implemented by two or more aquatic biologists familiar with the regional mussel fauna, and all were conducted during periods of limited precipitation and runoff when most aquatic habitats were amenable to visual or tactile examination. Stream surveys were concluded following the examination of all targeted mussel habitats (primarily riffles, runs, shoals, chutes, side channels, and backwaters). Sampling reaches generally ranged in length from 100 m to 500 m (KDHE) or from 100 m to 300 m (KDWP), depending on stream size, habitat complexity, and access considerations. Surveys conducted in lakes and wetlands were restricted to shallow (≤1.0 m) littoral areas, and most were performed in the general vicinity of boat ramps or other readily accessible locations. At essentially all survey sites, live mussels were sought by wading and visually examining the bottom substrate in shallower reaches, by manually sweeping and probing the surficial substrate in deeper or more turbid locations, and by manually excavating and sifting small volumes of substrate in selected promising habitats (e.g., gravelly riffles). Live mussels encountered during the surveys were identified and released onsite. Remnant shell materials (vacant shells and disarticulated valves left by dead mussels) were collected from lake and wetland margins, stream shorelines, and sand and gravel bars. Representative shell collections were retained by KDHE and archived at the agency’s headquarters in Topeka, KS (KDHE 2007a). KDWP deposited selected vouchers at the Sternburg Museum of Natural History in Hays, KS, and the University of Kansas Natural History Museum and Biodiversity Research Center in Lawrence, KS.

Mussel databases were developed and maintained independently by KDHE and KDWP but merged for the purposes of this study. Site-specific data on the presence or absence of live mussels and on the condition of any recovered shell materials were used to evaluate the distributional status of each native mussel species. The documentation of live individuals, unweathered shells, or both at a given sampling site was interpreted as evidence of an extant mussel population. The presence of only weathered shell materials (typically, disarticulated valves with eroded margins, flaking periostracum, faded nacre, and worn pseudocardinal and lateral teeth) or subfossil shell materials (typically, heavily worn, partially delaminated, chalky valves) was interpreted as evidence of an extirpated population (KDHE 2007a). At sites sampled on three or more occasions (N = 93), changes in mussel diversity over time were evaluated by comparing the number of species represented by live individuals or unweathered shells to the total number of documented mussel species, that is, by comparing observed taxa richness (OR) to expected taxa richness (ER). Calculation of the ratio OR/ER allowed sites to be ranked according to their degree of departure from the expected richness condition. Maps (1:5.5 million scale) illustrating the current and former ranges of individual mussel species were created using ArcGIS software (version 9.3). Stream coverages represented in these maps were adapted from the U.S. Geological Survey National Hydrography Dataset (U.S. Geological Society 2007). Outlines of the 12 major river basins in Kansas (KWO 1985) were based on aggregated hydrological unit code (level 8) watershed boundaries (Seaber et al. 1987).

An extensive literature review was performed as part of this study (see References). This effort focused primarily on earlier mussel surveys conducted in Kansas and secondarily on surveys covering the adjacent portions of neighboring states (e.g., Aughey 1877; Simpson 1900, 1914; Utterback 1915, 1916; Isely 1925; Branson 1982, 1983, 1984; Hoke 1983, 2000; Oesch 1984; Wu
1989; Cordeiro 1999; Cordeiro et al. 2007). Selected in-state records were added to the geographical database to augment the distributional maps developed using the KDHE/KDWP survey data. Records from archeological and paleontological studies also were included if, in the express opinion of the reporting scientists, the recovered shell materials were derived originally from water bodies near the study sites (e.g., Wedel 1959; Miller 1970; Thies 1981; Dorsey 2000; Warren and Holen 2007). Mussel species documented immediately outside the state, but not within the state, were designated as "possibly native" to Kansas. However, these unconfirmed species were not represented in the final distributional maps.

Several natural history museums and universities were visited or contacted to verify unusual records encountered during the literature review. These institutions included the Field Museum of Natural History (FMNH), Florida Museum of Natural History (FLMNH), Illinois Natural History Survey (INHS), Kansas Biological Survey (KBS), National Museum of Natural History (NMNH), Notebaert Nature Museum (NNM), Ohio State University Museum of Biological Diversity (OSUM), Sternburg Museum of Natural History (SMNH), University of Kansas Natural History Museum and Biodiversity Research Center (KUNHM), University of Michigan Museum of Zoology (UMMZ), University of Nebraska State Museum (UNSM), and Wichita State University Department of Biological Sciences (WSU). Four institutions (FLMNH, OSUM, NMNH, and UMMZ) loaned key vouchers to KDHE for extended examination. Most museum and university specimens were accompanied by labels indicating collection dates and localities, and this information was added selectively to the geographical database. During database entry, obsolete taxonomic synonyms encountered during the literature review and institutional searches were converted to the currently accepted scientific nomenclature (Turgeon et al. 1998; Eberle 2007a).

RESULTS

Altogether, 16,836 mussel occurrence records were generated during the KDHE/KDWP surveys. Live mussels, unweathered shells, or both were documented in each of the state’s 12 major river basins (Fig. 1) and at 1,165 survey sites (53% of all sites). Another 220 sites (10%) produced only weathered or subfossil shell materials, and the remaining 825 sites (37%) yielded no evidence of mussels (Fig. 2). Forty-two mussel species were represented by live individuals and recent shells, whereas one species (Obovaria olivaria) was represented solely by weathered and subfossil shell materials (Table 1). Of the 93 stream reaches sampled on three or more occasions, only 13 seemingly supported their
entire historical complement of mussel species (i.e., OR/ER = 1.0). Taxa richness evidently had declined by at least 25% in 40 stream reaches and by at least 50% in seven stream reaches. Table 2 presents basin affiliations, geographical coordinates, and OR/ER ratios for selected sampling locations, including all stream reaches specifically mentioned in this report.

Streams in the southeastern portion of the state generally exhibited the highest mussel diversity (Appendix I, Figs. A1–A43). Individual sampling sites on Pottawatomie Creek, Cedar Creek (Chase County), and the Caney, Cottonwood, Fall, Little Osage, Marais des Cygnes, Marmaton, Neosho, Spring, and Verdigris rivers each produced evidence of 20 to 29 former species and 11 to 26 current species. Surveys conducted in northeastern Kansas likewise indicated a formerly diverse, but more heavily impacted, mussel fauna. For example, sites on West Branch Mill Creek, Vermillion Creek, and the Big Blue, North Fork Black Vermillion, (lower) Smoky Hill, South Fork Big Nemaha, Wakarusa, and Wolf rivers each produced evidence of 15 to 18 former species and 4 to 16 current species. Sites in central and western Kansas supported less diverse mussel assemblages, ranging upward to 11 former species and nine recent species (Little Arkansas River near Valley Center, KS). We regarded our historical richness estimates for sites in this region as conservative, given that some previous surveys and archeological studies had indicated a more diverse pre-settlement fauna (e.g., Distler and Bleam 1995; Dorsey 2000).

Museum vouchers (and one privately owned voucher) examined during our study confirmed the historical presence of the following additional mussel species: Alasmidonta viridis, Cumberlandia monodonta, Epiblasma triqueta, Lasmigona compressa, and Quadrula fragosa (Table 1; Fig. A44). A single, well-preserved specimen of Lampsilis higginsii (I. Lea, 1857) also was encountered during the institutional searches (FLMNH 269580), but the reported collection location (‘Wichita’) was well outside this mussel’s previously reported range and considered suspect (cf. Cummings and Mayer 1992). Vouchers were not located for several species reported in the historical literature, but known populations in neighboring states and/or detailed shell descriptions accompanying some of the original reports suggested that Fusconaia ebena (I. Lea, 1831), Lampsilis abrupta (Say, 1831), Lampsilis satura (I. Lea, 1852), Leptodea leptodon (Rafinesque, 1820), and Plethobasus cyphus (Rafinesque, 1820) may have occurred formerly in Kansas (Call 1885b, 1885c, 1886; Scammon 1906; Simpson 1914; Hoke 1983; Oesch 1984; Cummings and Mayer 1992). In-state records for Lampsilis reeveiana brevicaula (Call, 1887) and Toxolasma lividus (Rafinesque, 1831) were not encountered during the literature review, and

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<table>
<thead>
<tr>
<th>Family/subfamily/scientific name</th>
<th>Common name</th>
<th>Status</th>
<th>Figure</th>
<th>Remarks (including key vouchers)</th>
</tr>
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<tbody>
<tr>
<td>Margaritiferidae</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Cumberlandia monodontota</em> (Say, 1829)*</td>
<td>Spectacle case</td>
<td>Extirpated</td>
<td>A44</td>
<td>• KUNHM 001247 (Mulhern et al. 2002)</td>
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<td>Unioidae</td>
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<tr>
<td><em>Amblema plicata</em> (Say, 1817)</td>
<td>Three ridge</td>
<td>Declining</td>
<td>A3</td>
<td>• Heavily harvested in Kansas, but moratorium on harvest enacted in 2003 (Mosher 2007; Miller and Mosher 2008)</td>
</tr>
<tr>
<td>Ambilinidae</td>
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<tr>
<td><em>Cyclonaias tuberculata</em> (Rafinesque, 1820)</td>
<td>Purple warty back</td>
<td>Stable</td>
<td>A7</td>
<td>• Rare and confined to one stream reach in Kansas</td>
</tr>
<tr>
<td><em>Elatipto dilatata</em> (Rafinesque, 1820)</td>
<td>Spike</td>
<td>SINC</td>
<td>A10</td>
<td></td>
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<tr>
<td><em>Faunaonais flavo</em> (Rafinesque, 1820)</td>
<td>Wabash pig toe</td>
<td>SINC</td>
<td>A11</td>
<td>• Some (perhaps all) Kansas populations genetically distinct (Burdick and White 2007)</td>
</tr>
<tr>
<td><em>Fusonaia ozarkensis</em> (Call, 1887)</td>
<td>Ozark pig toe</td>
<td>Stable</td>
<td>A12</td>
<td>• Rare and confined to one stream reach in Kansas</td>
</tr>
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<td><em>Megalonaias nervosa</em> (Rafinesque, 1820)</td>
<td>Washboard</td>
<td>SINC</td>
<td>A22</td>
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<tr>
<td><em>Pleurobema sintonia</em> (Rafinesque, 1820)</td>
<td>Round pig toe</td>
<td>SINC</td>
<td>A25</td>
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<tr>
<td><em>Quadrala cylindrica</em> (Say, 1817)</td>
<td>Rabbits foot</td>
<td>E</td>
<td>A31</td>
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<tr>
<td><em>Quadrala fragosa</em> (Conrad, 1835)*</td>
<td>Winged maple leaf</td>
<td>Extirpated</td>
<td>A44</td>
<td>• UMMZ 75811 (see also Bleam et al. 1998; Hoke 2004, 2005)</td>
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<td><em>Quadrala metanebra</em> (Rafinesque, 1820)</td>
<td>Monkeyface</td>
<td>Declining</td>
<td>A32</td>
<td>• Remains abundant in a few stream reaches; remarks for <em>P. plicata</em>, above, also apply to this species</td>
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<tr>
<td><em>Quadrala nodulata</em> (Rafinesque, 1820)</td>
<td>Warty back</td>
<td>SINC</td>
<td>A33</td>
<td></td>
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<tr>
<td><em>Quadrala pustulosa</em> (L. Lea, 1831)</td>
<td>Pimplieback</td>
<td>Declining</td>
<td>A34</td>
<td>• Taxonomy of <em>Q. pustulosa</em> remains unresolved; some populations in Kansas may be genetically distinct</td>
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<tr>
<td><em>Quadrala quadrala</em> (Rafinesque, 1820)</td>
<td>Maple leaf</td>
<td>Declining</td>
<td>A35</td>
<td>• Still widespread, but <em>Q. quadrala form nobilis</em> considered extirpated in Kansas (Couch 1997); remarks for <em>P. plicata</em>, above, also apply to this species</td>
</tr>
<tr>
<td><em>Trigonia verrucosa</em> (Rafinesque, 1820)</td>
<td>Pistol grip</td>
<td>Declining</td>
<td>A38</td>
<td>• Still widespread; locally abundant in ponds, small lakes, and intermittent streams with permanent pools</td>
</tr>
<tr>
<td><em>Unioera tetralasmus</em> (Say, 1831)</td>
<td>Pondshell</td>
<td>Declining</td>
<td>A41</td>
<td></td>
</tr>
<tr>
<td>Anodontidae</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td><em>Alasmidonta marginata</em> Say, 1818</td>
<td>Elk toe</td>
<td>E</td>
<td>A2</td>
<td>• OSUM 66155 (Bleam and Distler 1996)</td>
</tr>
<tr>
<td><em>Alasmidonta viridis</em> (Rafinesque, 1820)*</td>
<td>Slippershell</td>
<td>Extirpated</td>
<td>A44</td>
<td>• Sporadically abundant in a few oxbows, marshes, and floodplain ponds</td>
</tr>
<tr>
<td><em>Anodonta subheliculata</em> Say, 1831</td>
<td>Flat floater</td>
<td>E</td>
<td>A4</td>
<td>• Seemingly on verge of extirpation in Kansas</td>
</tr>
<tr>
<td>Anodontoides ferassaciensis (L. Lea, 1834)</td>
<td>Cylindrical paper shell</td>
<td>SINC</td>
<td>A5</td>
<td>• Still widespread; common in some small streams</td>
</tr>
<tr>
<td><em>Arcidens congruusor</em> (Say, 1829)</td>
<td>Rock pocket book</td>
<td>T</td>
<td>A6</td>
<td>• A single, unnumbered voucher retained by Hoke (1996)</td>
</tr>
<tr>
<td><em>Lamichona complanata</em> (Barnes, 1823)</td>
<td>White hole splitter</td>
<td>Declining</td>
<td>A17</td>
<td>• Still widespread; locally abundant in ponds, small lakes, and intermittent streams with permanent pools</td>
</tr>
<tr>
<td><em>Lamichona compressa</em> (L. Lea, 1834)*</td>
<td>Creek hole splitter</td>
<td>Extirpated</td>
<td>A44</td>
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<tr>
<td><em>Lamichona costata</em> (Rafinesque, 1820)</td>
<td>Fluted shell</td>
<td>T</td>
<td>A18</td>
<td></td>
</tr>
<tr>
<td><em>Pyganodon grandis</em> (Say, 1829)</td>
<td>Giant floater</td>
<td>Declining</td>
<td>A30</td>
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</tr>
<tr>
<td><em>Strophitus undulatus</em> (Say, 1817)</td>
<td>Creeper</td>
<td>SINC</td>
<td>A36</td>
<td>• Still widespread; locally abundant in ponds and small lakes</td>
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<tr>
<td><em>Uterabacia impiccilis</em> (Say, 1829)</td>
<td>Paper pond shell</td>
<td>Declining</td>
<td>A42</td>
<td></td>
</tr>
<tr>
<td>Lampsiliinae</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td><em>Acerina fusiformis</em> (Lamarck, 1819)</td>
<td>Mucket</td>
<td>E</td>
<td>A1</td>
<td>• Kansas populations genetically distinct (Eckert 2003; Serb 2006)</td>
</tr>
<tr>
<td><em>Cyprogenia aberris</em> (Conrad, 1850)</td>
<td>Western fanshell</td>
<td>E</td>
<td>A8</td>
<td>• NMNH 743156 (Scammon 1906)</td>
</tr>
<tr>
<td><em>Ellipsaria lineola</em> (Rafinesque, 1820)</td>
<td>Butterfly</td>
<td>T</td>
<td>A9</td>
<td>• Kansas may support largest remaining population (Angelo et al. 2007)</td>
</tr>
<tr>
<td><em>Epiphasma trioqueter</em> (Rafinesque, 1820)*</td>
<td>Snuff box</td>
<td>Extirpated</td>
<td>A44</td>
<td>• Historically ranked among the state's most abundant mussels (Call 1887; Scammon 1906)</td>
</tr>
<tr>
<td><em>Lampsilis cardium</em> Rafinesque, 1820</td>
<td>Plain pocket book</td>
<td>Declining</td>
<td>A13</td>
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<tr>
<td><em>Lampsilis ransequeana</em> Frierson, 1927</td>
<td>Neosho mucket</td>
<td>E</td>
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<td></td>
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<tr>
<td><em>Lampsilis siliquoides</em> (Barnes, 1823)</td>
<td>Fat mucket</td>
<td>SINC</td>
<td>A15</td>
<td></td>
</tr>
<tr>
<td><em>Lampsilis teres</em> (Rafinesque, 1820)</td>
<td>Yellow sand shell</td>
<td>SINC</td>
<td>A16</td>
<td>• Locally abundant in ponds, small lakes, and small streams</td>
</tr>
<tr>
<td><em>Lepidotha fragilis</em> (Rafinesque, 1820)</td>
<td>Fragile paper shell</td>
<td>Declining</td>
<td>A19</td>
<td>• Locally common in a few large streams</td>
</tr>
<tr>
<td><em>Ligumia recta</em> (Lamarck, 1819)</td>
<td>Black sand shell</td>
<td>Nearly extirpated</td>
<td>A20</td>
<td>• Last live individuals in Kansas observed around 1900 (Scammon 1906)</td>
</tr>
<tr>
<td><em>Ligumia subsulcata</em> (Say, 1831)</td>
<td>Pond mussels</td>
<td>Declining</td>
<td>A21</td>
<td>• Locally common in streams</td>
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### Table 2

<table>
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<tr>
<th>Basin</th>
<th>Stream reach</th>
<th>County</th>
<th>Latitude</th>
<th>Longitude</th>
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<th>OR</th>
<th>ER</th>
<th>OR/ER</th>
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<td>CI</td>
<td>Cimarron River near Forgan (OK)</td>
<td>Meade</td>
<td>37.01163</td>
<td>-100.49189</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>—</td>
</tr>
<tr>
<td>KR</td>
<td>Big Blue River near Oketo</td>
<td>Marshall</td>
<td>39.95781</td>
<td>-96.60998</td>
<td>18</td>
<td>11</td>
<td>16</td>
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Notes: “N” refers to the number of onsite mussel surveys performed by KDHE during 1990–2007, “OR” to the number of mussel species represented by live individuals, unweathered shell materials, or both, and “ER” to the total number of documented mussel species (see text). River basin abbreviations are defined in Figure 1.

These two species evidently lacked museum vouchers from the state. However, both have been reported from the Spring River (Neosho) Basin in southwestern Missouri less than 35 km upstream of Kansas (Oesch 1984; Obermeyer et al. 1997; Angelo et al. 2007).

Formerly, some *Quadrula pustulosa* specimens from Kansas were assigned to the subspecies *Q. pustulosa mortoni* (Conrad, 1835) (OSUM 33086 and 48398). A southern congener, *Quadrula houstonensis* (I. Lea, 1859), also was reported from the state by Call (1885b). Although several *Quadrula* specimens encountered during the KDHE and KDWP surveys resembled *Q. pustulosa mortoni* or *Q. houstonensis*, we opted to assign all such specimens to *Q. pustulosa pustulosa* pending further
investigation (Fig. A34). Historical accounts of Actinonais ligamentina in the Neosho and Verdigris basins were attributed in our study to the superficially similar species, Lampsilis rafinesqueana. The occurrence of L. rafinesqueana in Kansas was recognized originally during the 1970s (e.g., Cope 1979). Most specimens collected before that time were assigned mistakenly to A. ligamentina or one of its earlier synonyms (UMMZ 46137, 52426, 107752, 168722, 231665; Call 1886; Scammon 1906; Grinnell 1942; Murray and Leonard 1962; cf. Eberle 2007a). Lampsilis rafinesqueana and A. ligamentina currently maintain non-overlapping distributions within the state (Figs. A1 and A14).

Previous reports of Potamilus alatus in the Neosho and Verdigris basins (e.g., Murray and Leonard 1962; Liechti and Huggins 1977) and Potamilus purpuratus in the Kansas/Lower Republican and Marais des Cygnes basins (e.g., Popemoe 1885; Liechti and Huggins 1977; Hoke 2005) were not substantiated during our study. Because the conchological attributes of P. alatus and P. purpuratus are variable, and in some individuals nearly indistinguishable, we questioned earlier records for these species from the above-mentioned basins. In preparing the distributional maps for this report, we elected to assign all historical records for P. alatus in the Neosho and Verdigris basins to P. purpuratus (Fig. A28). Conversely, historical records for P. purpuratus in the Kansas/Lower Republican and Marais des Cygnes basins were assigned to P. alatus (Fig. A26). More definitive (e.g., mitochondrial DNA-based) studies of these two species would be useful for clarifying their current ranges in Kansas (see Burdick and White 2007).

Most mussel species in the state have undergone an evident decline in geographical distribution. Actinonais ligamentina, Alasmidonta marginata, Anodontoides feroxaccianus, Arcidens confragosus, Cyprogenia atherci, Lasmigona costata, Quadrula cylindrica cylindrica, and Venustaconcha ellipsoidalis each are relegated to one or two population centers but occupied a larger range in the past (Appendix 1). Only a single live Ligumia recta was encountered during our study, implying that this formerly widespread species now lacks reproducibly viable populations in Kansas (Fig. A20) (Angelo and Cringan 2003). Other species exhibiting marked range contractions or a general thinning of former populations were Amblema plicata, Fusconaia flavia, Lampsilis cardium, Lampsilis rafinesqueana, Lampsilis siliquoides, Lamp- silis teres, Ligumia subrotata, Pleurobema sintonia, Ptychobranchus occidentalis, Strophitus undulatus, Toxolasma parvus, Truncilla truncata, and Uniomerus tetralasmus (Appendix 1). In certain watersheds where they were once common, some of these species have been eliminated outright (e.g., L. cardium in the Kansas/Lower Republican Basin, Fig. A13; S. undulatus in the Walnut Basin, Fig. A36), or they now occur as sparsely scattered individuals (e.g., L. siliquoides in the Kansas/Lower Republican Basin, Fig. A15; T. truncata in the upper Neosho Basin, Fig. A40).

Seventeen additional mussel species (Anodonta suborbiculata, Ellipsaria lineolata, Elliptio dilatata, Lasmigona complanata complanata, Leptodea fragilis, Megalonaias nervosa, Obliquaria reflexa, P. alatus, P. purpuratus, Pyganodon grandis, Quadrula metanevra, Quadrula nodulata, Q. pustulosa pustulosa, Quadrula quadrula, Trilobaria verrucosa, Truncilla donaciformis, and Utterbackia imbicillus) have experienced less dramatic declines, generally involving the loss of isolated headwater or peripheral populations (Appendix 1). Only three species appear to have maintained their presettlement distributions in Kansas: Cyclonaias tuberculata and Fusconaia ozarkensis still occur in restricted stream reaches along the Kansas-Missouri border (Figs. A7 and A12), whereas Potamilus ohiensis continues to range throughout much of the state (Fig. A27). Some authors have suggested that P. ohiensis is expanding its distribution in northwestern Kansas (e.g., Bergman et al. 2000). However, shells recovered from archeological sites in the Solomon Basin imply this species has had a long history in the region (Dorsey 2000).

Two nonindigenous bivalves have established large populations in Kansas and continue to extend their ranges within the state (Figs. A45 and A46). The Asian clam (Veneroida: Corbiculidae: Corbicula fluminea [Müller, 1774]) was discovered initially during the early 1980s (Mackie and Huggins 1983; Cope 1985) and currently is found in all but one major river basin (Upper Republican). In some favorable habitats, this animal attains population densities of 250–500 individuals (adults and juveniles) m⁻² (e.g., Angelo et al. 2007). The zebra mussel (Veneroida: Dreissenidae: Dreissena polymorpha [Pallas, 1771]) was discovered originally in August 2003 in the Walnut Basin (El Dorado Lake). This bivalve has expanded its range in the Walnut Basin and also now occurs in the Kansas/Lower Republican Basin (Perry Lake), the Lower Arkansas Basin (Cheney Reservoir, Lake Afton), and the Neosho Basin (Marion Lake). Maximum reported population densities in Kansas have approached 30,000 individuals m⁻² (El Dorado Lake; J.M. Goecilker, pers. comm. 2008). In comparison, densities as high as several hundred thousand individuals m⁻² have been documented.
in some other states and provinces (e.g., Claudi and Mackie 1994).

DISCUSSION

Freshwater mussel distributions in Kansas are controlled by a broad combination of natural and anthropogenic factors. Key natural factors include the availability of perennially flowing streams, the composition and stability of the benthic substrate, and stream drainage patterns influencing the dispersal of host fishes. Mussel diversity gradually decreases from east to west across the state (Appendix 1), coinciding with a marked reduction in annual average precipitation (Goodin et al. 1995), a decline in the permanency of stream flow (Perry et al. 2004), a higher incidence of sand and shifting sand substrata west of the 97th meridian (Cross 1967), and a decrease in the number of host species (Cross 1967; Cross and Collins 1995). In eastern Kansas, mussel diversity in many streams increases progressively from the spring-fed, nutrient-poor headwater segments to the warmer and more productive downstream segments (e.g., Angelo et al. 2007). Mussels in western Kansas are confined (or historically were confined) primarily to smaller tributaries containing relatively stable substrata (Hoke 1997).

Natural lakes are rare in Kansas, whereas artificial impoundments (ponds and reservoirs) and lakes occupying abandoned quarries and other excavations (pit lakes) now number in the hundreds of thousands (KDHE 2005a). A few mussel species attain high population densities in many smaller impoundments and pit lakes (Table 1). Unconfirmed reports from commercial shell collectors also point to significant populations of A. plicata, P. purpuratus, Q. metanaevra, and Q. quadrala in the upper reaches of a few large reservoirs (Mosher 2007). Some of these reports are unprecedented geographically and may signify the occurrence of new populations originating from the release of bait fish or hatchery-reared fish infested with glochidia (see Gangloff and Gustafson 2000). Unfortunately, artificial lakes fail to accommodate the habitat demands of most native mussel species. Dissolved oxygen requirements, silt tolerances, reproductive strategies, fish host preferences, and other factors generally restrict the distribution of these bivalves to perennially flowing streams (Murray and Leonard 1962).

Droughts lasting for several years are a recurring phenomenon in Kansas (Weaver and Alberton 1936; Bryson 1980) and have led to the temporary cessation of stream flow in large areas of the state (Mead 1896; Deacon 1961; Clement 1991; Putnam et al. 2008). These events undoubtedly have diminished or eliminated many local mussel populations (see Metcalf 1983). Formerly, the resumption of stream flow and the return of host fishes from spring-fed tributaries, permanent pools, and distant stream reaches facilitated the gradual recovery of these populations. Today, dams (large and small), floodgates, culverts, and other impediments to fish migration hinder or preclude the reestablishment of mussels in many watersheds (see Watters 1996; Vaughn and Taylor 1999; Dean et al. 2002).

Dams create additional problems for freshwater mussels. Most notably, the ponds and reservoirs formed by these structures are unusually susceptible to the invasion of nonindigenous fish, shellfish, and other aquatic organisms, including certain forms clearly inimical to native mussels and their host species (Fig. A46) (see Gido et al. 2002; Mammoliti 2002; Eberle 2007b; KDHE 2008). Flood-control reservoirs commonly retain storm-water runoff during late spring and early summer, thereby diminishing the seasonal peak flows associated with spawning in many riverine host fishes (see Cross and Moss 1987; Eberle 2007b). In years of excessive precipitation, some large reservoirs discharge vast quantities of accumulated water well into the late summer or early fall, seasons normally characterized by low stream flow and important for mussel reproduction (Murray and Leonard 1962). These prolonged discharges often destabilize the downstream benthic substrate, displacing juvenile mussels, hampering interactions between gravid mussels and host fishes, and in severe cases eliminating entire mussel assemblages (see Vaughn and Taylor 1999).

Agriculture is another powerful force shaping mussel distributions in Kansas (Angelo et al. 2004). The onset of row-crop production during the middle and late 1800s resulted in widespread soil erosion, and many of the state’s most productive mussel beds and fish-spawning areas were blanketed in silt during this period (Mead 1896; Metcalf 1966; see also Doze 1924; Franzen and Leonard 1943). Although much emphasis was placed subsequently on the mitigation of this problem (Devlin 2000), stream siltation remains a pervasive concern and a limiting factor for mussels in numerous water bodies (Oberneyer et al. 1995; Hoke 1996, 2005; KDHE 2008). Livestock customarily have had access to riparian areas and stream channels throughout much of Kansas, and the seasonal confinement of small herds to sheltered locations near streams remains a common practice in this state (e.g., many cow-calf and winter feeding operations). In some locations, livestock have exacerbated the effects of siltation by overgrazing riparian vegetation, trampling stream banks, and compacting the benthic substrate supporting
mussels (e.g., Hoke 1997). Problems related to substrate compaction are most severe during extended droughts, when surface flows decline (or cease altogether) and livestock congregate for long periods near the remaining pools in the stream channels (Angelo 1994).

Nearly all surface waters in Kansas have been contaminated measurably with chemicals used in agriculture (KDHE 2008). The runoff of nitrogen- and phosphorus-containing fertilizers has led to recurring algal blooms, compositional changes in benthic and suspended microbial communities, and cascading effects on filter-feeding organisms and the broader aquatic food web (see Smith et al. 1999; Nichols and Garling 2000; Downing et al. 2001; Patzner and Müller 2001; Egertson and Downing 2004). Herbicides such as atrazine and metolachlor are detected routinely in surface water and sporadically in fluvial sediment (Carney et al. 1991; Pope 1995, 1998; KDHE 2008). Some insecticides no longer in use (e.g., dieldrin, DDT, various degradation products) persist in sediment and the fatty tissues of fish and shellfish (Havlík and Marking 1987; Pope 1998; Juracek 2004). The combined effects of these compounds on mussels and other aquatic organisms are poorly understood, but the potential for endocrine system disruption and other physiological complications has received growing scientific scrutiny (Cheney et al. 1997; Xie et al. 2005; Suzawa and Ingraham 2008).

Other agricultural contaminants have exerted a more obvious and immediate impact on the regional mussel fauna. For instance, prior to the enactment of state and federal laws regulating the disposal of livestock wastes, pollution from feedlots and slaughterhouses (primarily in the form of un-ionized ammonia and oxidizable solids) devastated the fish and invertebrate communities of many surface waters in eastern Kansas (Cross and Braasch 1968; Gray 1968; Prophet 1969; Cross and Cavin 1971; Prophet and Edwards 1973). The Cottonwood River (Neosho Basin) received large quantities of feedlot runoff and ranked as one of the state’s most heavily contaminated water bodies during the 1960s (e.g., Prophet 1969). Although water quality conditions have improved in recent decades (A.J. Stahl, pers. comm. 2008), some segments of the Cottonwood River now support only half their original number of mussel species (Table 2).

Irrigated crop production in western Kansas has exacted a heavy toll on mussels and other aquatic life by lowering groundwater tables, reducing or eliminating spring flows, transforming perennial streams into intermittent or ephemeral systems, and diminishing the available dilution base for contaminants entering surface waters (Jordan 1982; Cross et al. 1985; Cross and Moss 1987; Angelo 1994; Hoke 1997; Schloss et al. 2000; Eberle et al. 2002; Eberle 2007b). Throughout much of Kansas, but especially in the northeastern portion of the state, many streams have been channelized to expedite storm-water runoff, decrease local flooding, and improve access to farm fields. This practice has destroyed or severely degraded numerous aquatic habitats and dramatically reduced fish and shellfish diversity (Hoke 1996; see also Witt 1970). Intensive crop production also has led to the draining and filling of many marshes, sloughs, oxbows, and other wetlands in Kansas. By the late 20th century, the state had lost about half its pre-settlement wetland surface area (Dahl 1990). This change undoubtedly reduced the overall abundance of certain rapidly growing and short-lived mussel species capable of exploiting wetland habitats (e.g., *A. suborbiculata* (see Schuster 1978; Schuster and DuBois 1979).

Several other anthropogenic factors have played (or soon will play) an important role in the decline of the regional mussel fauna. First, urban and residential sprawl, sand and gravel dredging operations, mining activities (coal, salt, lead, zinc), oil field development, and discharges from storm sewers, factories, and wastewater treatment plants all have altered the physical and chemical properties of many surface waters in Kansas. These factors typically have affected individual water bodies (or individual watersheds) rather than broad regions of the state, but their collective impacts on mussels and other aquatic organisms have been substantial (Doze 1926; Jones 1950; Branson 1963; Cross et al. 1982; Angelo et al. 2002, 2007; KDHE 2008; see also Fuller 1974; Goudreau et al. 1993; NNMCC 1998). Second, mussels have been harvested commercially in the state for more than a century. Demand for mussel shells was fueled originally by the mother-of-pearl industry (Coker 1919) and later by the Asian cultured pearl industry (Cope 1983; Mosher 2007). Harvest pressures have led to precipitous declines in some local mussel populations but have had little apparent impact on mussel distributions (Murray and Leonard 1962; Miller and Mosher 2008). Third, certain fishes serving as biological hosts for larval mussels have been extirpated from entire river basins or the state as a whole (see Haslouer et al. 2005). These losses probably have accelerated the range reductions occurring in several mussel species, including some rapidly declining T/E species (e.g., *Q. cylindrica cylindrica*, Fig. A31) (Mulhern et al. 2002). Fourth, and perhaps most importantly, the invasion and spread of the zebra mussel poses an unprecedented threat to indigenous mussel populations (Fig. A46). Zebra mussels attach themselves in large numbers to the shells
of other bivalves, competing for food and interfering with normal respiration, movement, and valve closure. These animals already have decimated native mussel communities in some areas of eastern North America (e.g., Strayer and Smith 1996; Ricciardi et al. 1998).

Despite these pressing conservation concerns, freshwater mussels have demonstrated at times an impressive capacity for population recovery. Miller and Lynott (2006) documented rapidly increasing densities of several mussel species in a biological sanctuary established in the middle Verdigris River (Verdigris Basin). They attributed these increases to the cessation of commercial mussel harvests within the sanctuary, to the renovation of an upstream sewage treatment plant, and to the aggressive implementation of soil conservation practices within the watershed, leading to lower levels of suspended solids in the river. Angelo et al. (2007) recently documented 10 mussel species in the lower Spring River (Neosho Basin), a stream reach once bereft of mussels owing to pollution from lead and zinc mining operations. The return of these animals coincided with gradual improvements in water and sediment quality following closure of the mines. Proposed revisions to the national surface water quality criteria for certain heavy metals, residual chlorine, and unionized ammonia are expected to benefit mussels and other aquatic organisms, provided these revisions are adopted by federal, state, and tribal water quality agencies (Augspurger et al. 2003; Wang et al. 2007). Furthermore, regulations controlling the commercial harvest of native mussels have become increasingly restrictive in recent decades (Busby and Horak 1993). In 2003, Kansas enacted a moratorium on all such harvests to encourage the recovery of heavily exploited mussel species (Moshier 2007). Kansas also has implemented a program for limiting the spread of zebra mussels and other invasive aquatic species, but the logistical, budgetary, and regulatory challenges confronting this program are admittedly daunting (Goeccker 2005).

A few exceptional streams in Kansas continue to support all, or nearly all, of their historical assortment of freshwater mussel species (Table 2). Several other streams and a few oxbows and marshes retain viable populations of at least one rare mussel taxon. Assuming these surface waters are protected from further degradation, they should provide much of the seed material needed by governmental agencies and other organizations implementing mussel propagation and restocking programs (see Obermeyer 2000, 2002; Barnhart 2002). Some mussel populations in Kansas display unique morphological and developmental attributes (e.g., Eckert 2003) or are distinguishable genetically from counterpart populations in the eastern United States (Barnhart 2001; Serb 2006; Burdick and White 2007). Cooperative efforts between natural resource agencies, landowners, and the general public are needed to avert the extirpation of these distinctive populations. The survey findings discussed and illustrated in this report provide a well-documented baseline for future mussel conservation and recovery efforts in Kansas.

ACKNOWLEDGMENTS

Many individuals and organizations contributed materially to this study. Melissa Hammond (KDHE) assisted with the development of the literature and museum voucher databases, and Layne Knight and Elizabeth Smith (KDHE) and two anonymous reviewers provided comments useful during the revision of our manuscript. The reference personnel of Kansas State Library (Topeka Capitol Complex), Ablah Library (WSU), Mabee Library (Washburn University), William Allen White Library (Emporia State University), and the Linda Hall Library of Science, Engineering, and Technology (University of Missouri–Kansas City) located many of the older documents cited in this report. Eight institutions (FLMNH, KBS, KUNHM, NMNH, OSUM, SMNH, UMMZ, and WSU) provided unfettered access to extensive mussel databases, shell collections, or both. The following individuals shared their time and expertise, supplied relevant data and reports, searched for key voucher specimens on our behalf, or provided other critical forms of support: Liath Appleton (UMMZ); Dan Bleam and Don Distler (WSU); Jim Bussone, Charles Cope, Don George, Jason Goeccker, and Tom Moshier (KDWP); Mike Butler, Ed Carney, Diana Chamberlain, Steve Haslouer, Sarah LaFrenz-Falk, Tony Stahl, and Craig Thompson (KDHE); Stephanie Clark (freelance malacologist); Jen Cramer, Sarah Hazzard, and David Stansbery (OSUM); Mark Eberle (Fort Hays State University and SMNH); David Edds (Emporia State University); Bruce Freske and Tim Menard (U.S. Fish and Wildlife Service); Jochen Gerber (FMNH); Paul Greenhall (NMNH); Ellet Hoke (freelance malacologist); Thomas Labedz (UNSM); Chris Mayer and Jeremy Tiemann (INHS); Brian Obermeyer (Nature Conservancy); John Slapcinsky (FLMNH); Randy Thies (Kansas State Historical Society); and Robert Warren (Illiinois State Museum). Finally, many current and former employees of KDHE and KDWP participated in the statewide mussel surveys. Their enthusiastic efforts in the field and
dedication to the conservation and recovery of freshwater mussels ultimately made this study possible. We thank all of the above individuals and organizations for their willing participation in this investigation.

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APPENDIX 1
FRESHWATER MUSSELS DISTRIBUTIONS IN KANSAS

Figures A1 and A2. Distributions of *Actinonaias ligamentina* (A1) and *Alasmidonta marginata* (A2). In these maps and the maps that follow, sites sampled for mussels during 1990–2007 and supporting the indicated species are shown as solid circles (KDHE/KDWP surveys) or solid triangles (other surveys). Sites yielding only weathered or subfossil shell materials, and other formerly productive sites lacking recent evidence of the species, are shown as open circles (KDHE/KDWP surveys), open triangles (other surveys; museum collections), open diamonds (archeological studies), or open squares (paleontological studies). Sites mentioned in historical documents but lacking specific locality data are depicted as open symbols within parentheses. Directional arrows and scale bars are omitted intentionally from the remaining maps. Informational sources other than KDHE and KDWP are identified in Appendix 2.
Figures A3–A5. Distributions of Amblema plicata (A3), Anodonta suborbiculata (A4), and Anodontoides ferussacianus (A5).
Figures A6–A8. Distributions of *Arcidens confragosus* (A6), *Cyclonaias tuberculata* (A7), and *Cyprogenia aberti* (A8).
Figures A9–A11. Distributions of Ellipsaria lineolata (A9), Elliptio dilatata (A10), and Fusconaia flava (A11).
Figures A30–A32. Distributions of *Pyganodon grandis* (A30), *Quadrula cylindrica cylindrica* (A31), and *Quadrula metanevra* (A32).
Figures A33–A35. Distributions of Quadrula nodulata (A33), Quadrula pustulosa pustulosa (A34), and Quadrula quadrula (A35).
Figures A36–A38. Distributions of Strophitus undulatus (A36), Taxolasma parvus (A37), and Tritogonia verrucosa (A38).
Figures A42–A44. Distributions of *Utterbackia imbecilla* (A42) and *Venustaconcha ellipsiformis* (A43) and former distributions of five extirpated species represented in voucher collections (A44): *Alasmidonta viridis* (1), *Cumberlandia monodonta* (2), *Epioblasma triquetra* (3), *Lasmigona compressa* (4), and *Quadrula fragosa* (5).
Figures A45 and A46. Distributions of two nonindigenous bivalves: *Corbicula fluminea* (A45) and *Dreissena polymorpha* (A46).
## APPENDIX 2

**SOURCES OF SUPPLEMENTAL DATA USED IN MUSSEL DISTRIBUTIONAL MAPS**

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