Status assessment report for the snuffbox, *Epioblasma triquetra*, a freshwater mussel occurring in the Mississippi River and Great Lakes Basins

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for the

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Title page photo credit—Ronald R. Cicerello and Guenter A. Schuster (male on top, female on bottom) (from Cicerello and Schuster 2004)

Disclaimer

This document is a compilation of biological data and a description of past, present, and likely future threats to the snuffbox (*Epioblasma triquetra*). It does not represent a decision by the U.S. Fish and Wildlife Service (Service) on whether this taxon should be designated as a candidate species for listing as threatened or endangered under the Federal Endangered Species Act (Act). That decision will be made by the Service after reviewing this document; other relevant biological and threat data not included herein; and all relevant laws, regulations, and policies. The result of the decision will be posted on the Service's Region 3 Web site (refer to: http://midwest.fws.gov/eco_serv/endangrd/lists/concern.html). If designated as a candidate species, the taxon will be added subsequently to the Service's candidate species list that is published periodically in the Federal Register and posted on the World Wide Web (refer to: http://endangered.fws.gov/wildlife.html). Even if the taxon does not warrant candidate status it should benefit from the conservation recommendations that are contained in this document.

Common name: snuffbox

Scientific name: *Epioblasma triquetra*

Controversial or unsettled taxonomic issues

The snuffbox is a member of the freshwater mussel family Unionidae and was described as *Truncilla triqueter* Rafinesque, 1820. The specific epithet was later emended to *triquetra*, from the Latin *triquetrous* meaning “having three acute angles” (Simpson 1900), a reference to the general shape of the female. The type locality is the Falls of the Ohio (Ohio River, Louisville, Kentucky) (Parmalee and Bogan 1998). The synonomy of the snuffbox was summarized by Johnson (1978), Parmalee and Bogan (1998), and Roe (no date). This species has also been considered a member of the genera *Unio*, *Dysnomia*, *Plagiola*, *Mya*, *Margarita*, *Margaron*, and *Epioblasma* at various times since its description. The monotypic subgenus *Truncillopsis* was created for this species (Ortmann and Walker 1922). The genus *Epioblasma* was not in common usage until the 1970s (e.g., Stansbery 1973, 1976; *contra* Johnson 1978) where it currently remains (Turgeon et al. 1998). *Unio triqueter*, *U. triangularis*, *U. triangularis longisculus*, *U. triangularis pergibosus*, *U. cuneatus*, and *U. formosus* are recognized as synonyms of *E. triquetra*. Tricorn pearly mussel is another common name (Clarke 1981a).

Physical description of the taxon

The following description of the snuffbox is summarized from Simpson (1914), Oesch (1984), and Parmalee and Bogan (1998). The snuffbox is a small to medium-sized mussel that reaches at least 3.5 inches in length. Sexual dimorphism is pronounced with males achieving greater lengths. The shape of the shell is somewhat triangular (females), oblong, or ovate (males) with the valves solid, thick, and very inflated. The beaks are located somewhat anterior of the middle, swollen, turned forward and inward, and extended above the hingeline. Beak sculpture consists of three or four faint double-looped bars. The anterior end of the shell is rounded and the posterior end is truncated, highly so in females. The posterior ridge is prominent, being high and rounded, while the posterior slope is widely flattened. The posterior ridge and slope in females is covered with fine ridges and grooves, and the posterioventral shell edge is finely toothed. When females are viewed from a dorsal or ventral perspective, the convergence of the two valves on the posterior slope is nearly straight due to being highly inflated. This gives the female snuffbox a unique broadly lanceolate or cordate perspective when viewed at the substrate/water column interface (Ortmann 1919, van der Schalie 1932). The ventral margin is slightly rounded in males and nearly straight in females. The periostracum (external shell surface) is generally smooth and yellowish or yellowish-green in young individuals becoming darker with age. Green squarish, triangular, or chevron-shaped marks cover the umbone but become poorly delineated stripes with age. Internally, the left valve has two high, thin triangular, emarginate pseudocardinal teeth (the front tooth being thinner than the back tooth) and two short, strong, slightly curved, and finely striated lateral teeth. The right valve has a high, triangular pseudocardinal tooth with a single short, erect, and heavy lateral tooth. The interdentum is absent and the beak cavity is wide and deep. The color of the nacre (mother-of-pearl) is white, often with a silvery luster, and a gray-blue or gray-green tinge in the beak cavity. The soft anatomy was described by Lea (1863), Ortmann (1911, 1912), Simpson (1914), Utterback (1916), Baker (1928), Oesch (1984), and Williams et al. (2007).

Key characters useful for distinguishing the snuffbox from other species include its unique color pattern, shape (especially in females), and high degree of inflation. Photographs have appeared in various publications (e.g., Murray and Leonard 1962, Johnson 1978, Clarke 1981a), many in color (e.g., Parmalee 1967; Buchanan 1980; Williams et al. 1993, 2007; Cummings and Mayer 1992; Parmalee and Bogan 1998; Cicerello and Schuster 2004; Harris and Gordon no date).

Summary of biology and natural history

Biological information on the snuffbox is sparse, therefore this section also contains information for riverine mussels in general, particularly taxa considered closely related to this species.

Feeding ecology

Our knowledge of feeding ecology in unionids is incomplete (Raikow and Hamilton 2001, Strayer et al. 2004). Adult freshwater mussels are suspension feeders (Brim Box and Mossa 1999, Strayer et al. 2004), siphoning phytoplankton, diatoms, and other microorganisms from the water column (Allen 1921, Fuller 1974). Variation in diet among species appears to be low (Raikow and Hamilton 2001, Christian et al. 2004). Deposit feeding (consumption of particles from the sediment) by adult unionids, although recorded for this molluscan family (Singh et al. 1991), is considered atypical (Raikow and Hamilton 2001). A food resource mixing model was used to suggest that a community of lotic mussels in Michigan (12 species) was consuming 80% deposited (epipsammon, or detritus and possibly algae mixed with sand) and 20% suspended particulate organic material (Raikow and Hamilton 2001).

The commonly accepted simplistic model of feeding has been questioned (Strayer et al. 2004).

Recent evidence emphasizes the uptake and assimilation of detritus and bacteria over algae (Silverman et al. 1997, Nichols and Garling 2000, Christian et al. 2004). Dissolved organic matter may also be a significant source of nutrition (Strayer et al. 2004). Mussel diets more accurately consist of algae, bacteria, detritus, microscopic animals, and dissolved organic matter. This array of foods, containing essential long-chain fatty acids, sterols, amino acids, and other biochemicals, may be necessary to supply total nutritional needs (Strayer et al. 2004).

Newly-metamorphosed juvenile mussels employ foot (pedal) feeding for the first several months, and use either pedal-sweep feeding or pedal-locomotory feeding (Reid et al. 1992). Pedal-sweep feeding involves using the foot to sweep potential food particles from the substrate. During pedal-locomotory feeding, detrital particles that attach to the foot during normal locomotor activities (alternate foot extension/retraction) become potential dietary items. Detrital particles that adhere to the foot are moved via ciliary action into the pedal valve gape where material is sorted for ingestion or egestion (Yeager et al. 1994). Thus, juvenile mussels are deposit feeders (Reid et al. 1992), although they may also suspension feed on interstitial pore water (Yeager et al. 1994). Higher juvenile growth and survival rates resulted from mussels being reared in fine sediments (Hudson and Isom 1984, Gatenby et al. 1996), which raises several possibilities: microbial and organic components of silt may provide nutritional value (Hudson and Isom 1984), juveniles ingest foods (e.g., algae, bacteria) adhered to silt particles (Yeager et al. 1994), or substrates simply provided juveniles a place to collect food (Gatenby et al. 1996).

Growth and longevity

Growth rates tend to be rapid for the first few years (Isely 1914, Chamberlain 1931, Scruggs 1960, Negus 1966). Early juveniles produce byssal threads, strong proteinaceous strands used to attach to substrate particles (Isely 1911), before developing a foot to anchor themselves in the substrate. After the initial phase growth is reduced (Bruenderman and Neves 1993, Hove and Neves 1994), presumably at sexual maturity, as a result of energy being diverted from growth to gamete production (Baird 2000). Growth rates vary among species; heavy-shelled species grow slowly relative to thin-shelled species (Coon et al. 1977, Hove and Neves 1994). Snuffbox grew

0.55 inches in one year and another 0.75 inches after two years in Wisconsin (Dunn et al. 2000).

Mussels are extremely long-lived, generally living from a few years to several decades, but possibly 100 to as much as 200+ years in extreme instances (Ziuganov et al. 2000). Thick-shelled species generally live longer than thin-shelled species (Stansbery 1961). Mortality rates tend to be highest in young juveniles then decline until advanced age gradually depletes older cohorts (Hastie 2006). Mussels annually lay down growth rings or bands (annuli) in their shells (Isely 1914) and enumeration of these rings is routinely used to estimate age (Isely 1914, Vaughn and Pryor 1995) despite being replete with problems (e.g., umbonal erosion, false annuli formation, difficulty of reading growth rings in older individuals, age underestimation) (Neves and Moyer 1988, Downing et al. 1992, Rogers et al. 2001, Jones and Neves 2002). Thin-sectioning shells to count internal rings is more accurate (Neves and Moyer 1988, *contra* Kesler and Downing 1997). The assertion that internal growth ring enumeration may underestimate age (Anthony et al. 2001) is generally unaccepted (Neves and Moyer 1988, Veinott and Cornett 1996). Sound longevity information for the snuffbox is scant. Ages of 18-20 years were estimated by counting external growth rings from the Wolf River, Wisconsin (J. Lee, Ecological Specialists, Inc. [ESI], personal communication [pers. comm.], 2003) and a Cumberland River, Tennessee, specimen was estimated to be 27 years (Koch 1983).

Reproductive biology

The snuffbox and most unionid mussels have separate sexes. The age at sexual maturity, which is unknown for this species, is highly variable among and within species (0-9 years) (Haag and Staton 2003), and may be sex dependent (Smith 1979). The literature generally reports 1:1 sex ratios for mussels (Bauer 1987, Haag and Staton 2003), but sex ratios for snuffbox populations often deviate from this norm. Male-biased sex ratios were ~8:1 in Big Darby Creek, Ohio (collections made between July and October of 1986 and 1990) (Watters 1990, 1994), 5:1 in Davis Creek, Michigan, summer 2005 (D.T. Zanatta, Royal Ontario Museum [ROM], pers. comm., 2005), and 4:1 male-biased in the Olentangy River, Ohio, regardless of season (Stein 1963). The ratio was 6:1 male-biased in the Wolf River, Wisconsin, in July 1995, changing to

20:1 male-biased in June 1997 (J. Lee, ESI, pers. comm., 2003). Another researcher anecdotally noted that sex ratios on the substrate surface varied from ~9:1 female-biased to roughly the same ratio male-biased over a three-week period in the Clinton River, Michigan, ~1991 (W.R. Hoeh, Kent State University, pers. comm., 1992). Divergent sex ratios may result when population size becomes very small (Bauer 1987).

Males expel sperm into the water column, which are drawn in by females through their incurrent siphons. Fertilization takes place in the suprabranchial chambers above the gills, and the resulting zygotes develop into specialized larvae termed glochidia within the gills. The snuffbox utilizes a specialized portion of its outer gills as a marsupium for its developing glochidia.

Hermaphroditism has been recorded in several mussel species (van der Schalie 1966, Bauer 1987) but not the snuffbox, and may be more prevalent in unionids than previous studies have inferred (Neves 1997). This reproductive mechanism is rare in dense populations but tends to be more characteristic in low density, isolated populations, or in environmentally stressed populations (Heard 1975). A low frequency of hermaphroditism suggests that hermaphrodites do not significantly contribute to reproduction (Heard 1979). Females changing to hermaphrodites may be an adaptive response (Bauer 1987) assuring that recruitment classes are not consistently lost in small populations. It has been hypothesized that "many (most?) females of the Unionidae are facultative hermaphrodites, capable of cross- or perhaps self-fertilization under situations of low density, highly skewed sex ratio, or other extrinsic conditions that induce hermaphroditism" (Neves 1997). If hermaphroditism does occur in the snuffbox, it may explain the occurrence of very small but persistent populations (e.g., Elk River, Tennessee).

The snuffbox is bradytictic or a long-term brooder (Ortmann 1912, 1919). The glochidia (figured by Ortmann 1911) measure 0.0083 inches in both length and height (Hoggarth 1988) and are brooded from September to May (Ortmann 1912, 1919; Baker 1928). Reproduction and glochidial release in the Clinton River, Michigan, was reported by Sherman (1993, 1994). Fertilized eggs were found in marsupial pouches from 26-30 July at water temperatures of 64-81°

F. Spawning and fertilization occurred from mid-July to August when water levels were low, facilitating sperm transfer to female mussels (Zale and Neves 1982). Females with swollen marsupia and developing glochidia were found from early December to late July (Sherman 1994). Glochidia are individually released from pores opening at the distal ends of the watertubes. Glochidial release (from drift samples) began on 17 May (water temperature = 62° F), peaked on 11 June (74° F), and ended by 15 July (84° F) (Sherman 1994).

Mussel fecundity has been positively related to body size and inversely related to glochidia size (Bauer 1994) or primarily related to shell length and secondarily to age (Haag and Staton 2003). Large individuals are therefore important in the maintenance of mussel populations, but very large or old individuals tend to exhibit a decline in fecundity (Haag and Staton 2003).

From parasitic glochidia to free-living subadults

Unionid glochidia are specialized for a parasitic existence and must come into contact with a specific host fish(es) in order for their survival to be ensured. Juvenile snuffbox have successfully transformed on logperch (*Percina caprodes*), blackside darter (*P. maculata*), rainbow darter (*Etheostoma caeruleum*), Iowa darter (*E. exile*), blackspotted topminnow (*Fundulus olivaceous*), mottled sculpin (*Cottus bairdi*), banded sculpin (*C. carolinae*), Ozark sculpin (*C. hypselurus*), largemouth bass (*Micropterus salmoides*), and brook stickleback (*Culaea inconstans*) in laboratory tests (Sherman 1993, 1994; Yeager 1986; Yeager and Saylor 1995; Hillegass and Hove 1997; Barnhart 1998; Barnhart et al. 1998; Hove et al. 2000; McNichols and Mackie 2002, 2003, 2004; Sherman Mulcrone 2004). Hornyhead chub (*Nocomis biguttatus*) is a potential host (Sherman 1994). Logperch is widely considered to be the best host for the snuffbox (Sherman 1994, McNichols and Mackie 2004, Sherman Mulcrone 2004). There was a statistically significant correlation between snuffbox and logperch when analyzing both density and relative abundance data for mussels and fishes (Sherman Mulcrone 2004).

The snuffbox and certain congeners employ a unique behavior to attract and infest host fish. Gravid females lie at the substrate surface with their valves widely agape. Foraging darters, which probe among stones or flip stones in the case of the logperch, may poke their snout or head into the gape of a snuffbox and elicit a “snapping” behavior. The female mussel holds the fish with recurved denticles on the posterior edge of the valves. Once “caught,” the mussel uses her specialized spongy, inflatable mantle margins (cymapallia) to make a gasket seal around the fishes’ snout, and pumps her glochidia into the host’s buccal cavity with rhythmic pulses (Jones 2004, Barnhart 2005). A logperch with its snout trapped by a snuffbox was first observed in Davis Creek, Michigan, in 1999 (Sherman Mulcrone 2004). Darters have been found inside live *Epioblasma* in the Clinch River, Tennessee (Jones 2004), and in laboratory-held northern riffleshell, *Epioblasma torulosa rangiana* (Lea, 1838), from the Allegheny River, Pennsylvania (G.T. Watters, Ohio State University Museum of Biological Diversity [OSUM], pers. comm., 2006). Video recordings showing logperch flipping gaped, displaying, and partially buried females out of the substrate (they remained gaped during displacement) and mussels snapping the fishes’ snouts (Barnhart 2005, http://unionid.missouristate.edu/gallery/Epioblasma/default.htm). This behavior results in an extremely high glochidial infestation rate relative to the very low rates known for other host fishes (Haag and Warren 1999, Layzer et al. 2003). Over 2,000 glochidia were found on a single bank of gills on an infected logperch after a snapping encounter (M.C. Barnhart, Missouri State University, pers. comm., 2005).

Glochidia generally spend from two to six weeks as parasites, the duration of encystment being dependent on the species and water temperature (Zimmerman and Neves 2002). Transformation rates of snuffbox glochidia to juveniles on logperch varies: southeastern Michigan, 9 days (no temperature recorded) (Sherman 1994); Powell River, Tennessee and Virginia, 24-33 days at 62.8 °F (Yeager and Saylor 1995); Bourbeuse River, Missouri, 21-27 days (peak 24 days) at 68.0 °F (Barnhart 1998, Barnhart et al. 1998); and St. Croix River, Minnesota and Wisconsin, 26-51 days (no temperature recorded) (Hove et al. 2000).

Newly-metamorphosed juveniles drop off to begin a free-living existence on the stream bottom, and will die if they settle in unsuitable habitat (Isely 1911). Thus, complex life histories of unionids has many weak links that may prevent successful reproduction and/or recruitment (e.g., spatial aggregation of adults too dispersed for successful fertilization, flows not conducive for successful fertilization, host-fish densities too low during glochidial release period, newly-metamorphosed juveniles drop off host fish in unsuitable habitat, and low juvenile survival rates to adult (Neves 1993).

Habitat requirements

The habitat requirements of the snuffbox are summarized from Parmalee and Bogan (1998). The snuffbox is found in small to medium-sized creeks to larger rivers and in lakes. It occurs in swift currents of riffles and shoals and wave-washed lakeshores over gravel and sand with occasional cobble and boulders, and generally burrows deep into the substrate except when spawning or attracting a host.

Habitat criteria used in the past to explain the spatial patchiness of mussels (e.g., water depth, current speed, sediment grain size) are poor predictors of where mussels occur in streams (Strayer 1999a). Mussels occur chiefly in flow refuges, relatively stable areas that display little movement of substrate particles during flood events and where shear stress is low (Vannote and Minshall 1982, Layzer and Madison 1995, Strayer 1999a, Johnson and Brown 2000, Hastie et al. 2001). Flow refuges conceivably allow relatively immobile mussels to remain in the same general location their entire lives.

Historical and current range

Methods

The distributional history of the snuffbox, detailed in tabular form in Appendix I, forms the basis of the status of snuffbox populations used in this report. The appendix is divided by major drainage (i.e., upper and lower Great Lakes sub-basins; upper Mississippi River sub-basin [above Ohio River confluence]; lower Missouri River system; Ohio, Cumberland, and Tennessee River systems; lower Mississippi River sub-basin [below Ohio River confluence]; White River system), counties, and states of occurrence. In addition, the authority of each record and the year of the record are given. Collection information was compiled from published scientific articles, grey literature, museum records, personal communications with mussel experts and other individuals, and occasionally my personal observations. I depicted collections for live (L) individuals or fresh dead (FD) specimens simply by stating the sampling year (e.g., 1999), or they are labeled as either relict (R) or dead (D) when shell condition was unspecified (e.g., 1999 R, 1999 D). Shells labeled R may originally have been reported as either weathered dead (or weathered dry) or subfossil. FD shells still have flesh attached to the valves, and/or retain a luster to their nacre, and/or their periostracum is non-peeling, all indicating relatively recent death (generally <1 year) (Buchanan 1980). R shells have lost the luster to their nacre, have peeling or are absent periostracum, may be brittle, worn, and likely have been dead more than a year (Buchanan 1980, Zanatta et al. 2002). Generally, FD shells indicate the continued presence of the species at a site (Metcalf 1980). The presence of R shells only, along with repeated failure to find L animals or FD shells, likely signifies that a population is extirpated (Watters and Dunn 1993-94).

Distribution of the snuffbox is mapped in Figure 1. Symbols differentiate extant from extirpated occurrences. There is only one symbol per stream per county of occurrence due to scale constraints.

Snuffbox populations I consider extant are annotated in the section on “Current and historical populations, and population trends.” Individual populations are generally considered extant if L individuals and/or FD specimens have been collected since ~1985 unless more recent sampling efforts indicate otherwise. Information in the extant population accounts includes drainage relationship, collection history, relative abundance, population trends, current status, landuse, and threats to the snuffbox. Densities are in English units. Age estimations are understood to indicate the enumeration of external growth rings and size refers to length. Current population status summarizes size, linear extent, trend, evidence of recruitment (presence of subadults[1]), and a rough estimate of viability. I characterized populations as being relatively large (generally distributed and common in >10 river miles [RM]), medium (sporadic and generally uncommon throughout a stream or common only in a restricted reach [<3 miles]), or small (rare and restricted to at most a few sites). In most cases, data is not available to make rigorous assessments of population size or viability, and finding subadults during routine qualitative sampling is rare (W.R. Haag, U.S. Forest Service [USFS], pers. comm., 2006), so most streams have scant data for these population parameters. I have made viability assessments based on evidence of recent recruitment (generally, subadults are considered individuals ≤1.5 inches and/or ≤4 years) or the presence of individuals in multiple age classes, population size, and spatial extent of the population (occupying a significant linear reach of stream). Even small populations with undetectable levels of recruitment may be viable and survive for decades. It is understood that streams with populations I consider extant may already be extirpated, while others currently considered extirpated may continue to harbor this species.

Appendix II lists surveys in historical streams from the past several decades that have failed to detect L/FD snuffbox populations. The format is similar to Appendix I but includes the year and number of sites surveyed in each stream or stream system. These data provide justification that certain stream populations may be extirpated, although it is possible some populations may be rediscovered.

Appendix III includes a summary of snuffbox populations I consider extant. This appendix is arranged by Service region and stream of occurrence; states; year of last observation; and objective estimates on whether the population is recruiting, potential viability, relative population size, and relative population trend.

Historical range

[1] Subadults are older and larger than newly-metamorphosed juveniles, which are too small to routinely sample.

Historically, the snuffbox occurred in portions of the Great Lakes and Mississippi River basins (Appendix I). Records are known from 208 streams/lakes in 18 states, 1 Canadian province, and 4 Service regions (Appendix II). The major watersheds of historical streams and lakes of occurrence include the Upper Great Lakes sub-basin (Lake Michigan drainage) (15 streams and lakes), Lower Great Lakes sub-basin (Lakes Huron, Erie, and Ontario drainages (32), Upper Mississippi River sub-basin (17), Lower Missouri River system (4), Ohio River system (107), Cumberland River system (7), Tennessee River system (18), Lower Mississippi River sub-basin (1), and White River system (7). Snuffbox populations occurred in Alabama, Arkansas, Illinois, Indiana, Iowa, Kansas, Kentucky, Michigan, Minnesota, Mississippi, Missouri, New York, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia, and Wisconsin, and in Ontario, Canada. These states comprise Service Regions 3 (Midwest), 4 (Southeast), 5 (Northeast), and 6 (Great Plains). Although no older records may occur where the snuffbox was recently discovered (e.g., Little Mahoning Creek, discovered in 1991), these populations are considered historical.

Rangewide (but incomplete) dot distribution maps for the snuffbox were depicted in Johnson (1978) and Roe (no date). Nebraska and Oklahoma were also considered in its range (Aughey 1877; Simpson 1900, 1914; Scammon 1906; Baker 1928; Burch 1975; Roe no date; NatureServe (http://www.natureserve.org/explorer/servlet/NatureServe?loadTemplate=tabular_report.wmt&paging=home&save=all&sourceTemplate=reviewMiddle.wmt). However, there are no valid records for this species from either Nebraska (Hoke 1996, 2000) or Oklahoma (Isely 1924, Branson 1984), so these states are considered outside of the historical range of this species (Williams et al. 1993). NatureServe also listed Shade Creek (River?), Sinking Creek (both Ohio River system), Deer Creek, Little Vermilion River (both Wabash River system), and Current River (White River system) as having snuffbox records. I found no other references for these populations in the literature, museums, nor from contacts with various experts, so they're excluded from this review. Historically, it may also have occurred in Georgia; it is known from a South Chickamauga Creek, Tennessee, museum record (five specimens) collected approximately two miles upstream from where this stream crosses the Georgia line.

Current distribution

I consider snuffbox populations to be extant in 73 streams in 14 states, 1 Canadian province, and 3 Service regions (Appendix III). However, it is probable that the species persists in some of the 135 streams/lakes where it is considered extirpated in this report or from other streams. Extant occurrences broken down into major watersheds include the Upper Great Lakes sub-basin (7 streams), Lower Great Lakes sub-basin (10), Upper Mississippi River sub-basin (4), Lower Missouri River system (0), Ohio River system (41), Cumberland River system (1), Tennessee River system (5), Lower Mississippi River sub-basin (1), and White River system (4). Multiple streams may comprise single snuffbox population segments, essentially decreasing the number of extant populations. Extant populations are generally separated and genetically isolated from each other by barriers such as impoundments or riverine reaches of unsuitable and otherwise unoccupied habitat.

Extant populations by state

Extant stream populations (numbers in parentheses) occur in the following 14 states and 1 Canadian province:

Alabama (1) □ Paint Rock River

Arkansas (3) □ Buffalo River, Spring River, Strawberry River

Illinois (2) □ Kankakee River, Embarras River

Indiana (7) □ Pigeon River, Salamonie River, Tippecanoe River, Sugar Creek, Buck Creek, Muscatatuck River, Graham Creek

Kentucky (10) □ Tygarts Creek, Kinniconick Creek, Licking River, Slate Creek, Middle Fork Kentucky River, Red Bird River, Red River, Rolling Fork Salt River, Green River, Buck Creek

Michigan (9) □ Grand River, Maple River, Pine River, Belle River, Clinton River, Huron River, Davis Creek, South Ore Creek, Portage River

Minnesota (1) □ St. Croix River

Missouri (4) □ Meramec River, Bourbeuse River, St. Francis River, Black River

Ohio (13) Grand River, Ohio River, Muskingum River, Walhonding River, Killbuck Creek, Olentangy River, Big Darby Creek, Little Darby Creek, Salt Creek, Scioto Brush Creek, South Fork Scioto Brush Creek, Little Miami River, Stillwater River

Pennsylvania (10) Allegheny River, French Creek, West Branch French Creek, Le Boeuf Creek, Muddy Creek, Conneaut Outlet, Little Mahoning Creek, Dunkard Creek, Shenango River, Little Shenango River

Tennessee (4) Clinch River, Powell River, Elk River, Duck River

Virginia (2) Clinch River, Powell River

West Virginia (5) Ohio River, Dunkard Creek, Middle Island Creek, North Fork Hughes River, Elk River

Wisconsin (5) St. Croix River, Wolf River, Embarrass River, Little Wolf River, Willow Creek

Ontario (2) Ausable River, Sydenham River

Snuffbox populations appear to be extirpated from Iowa, Kansas, Mississippi, and New York.

Current and historical populations, and population trends

Historically, the snuffbox was widespread and locally common in many streams/lakes in the Mississippi River and Great Lakes Basins. It was considered to be "the most successful member of the genus…[and] the most widely distributed and most generally abundant" (Johnson 1978). The snuffbox is the only taxon among the 28 currently recognized taxa in the genus *Epioblasma* that is neither federally endangered under the Act nor extinct (Neves et al. 1997, Butler and Biggins 2004).

Basic information on relative abundance can be gathered from the size and number of museum lots of the snuffbox. The vast majority of these collections are small in size (personal observation [pers. obs.] from hundreds of museum records I examined or had access to through museum databases). The literature also hints at relatively abundant snuffbox populations in the early 1900s (e.g., upper Scioto River [Higgins 1858], upper Ohio River and Beaver River [Rhoads 1899], White [Indiana] and Wabash Rivers [Call 1900], Allegheny River [Ortmann

1909a], Cumberland River [Wilson and Clark 1914], and Huron River [van der Schalie 1938]). Its status was changing to uncommon or rare by mid-century in many regions (e.g., Indiana streams [Goodrich and van der Schalie [1944], lower Great Lakes sub-basin [Strayer 1980], Midwest [Cummings and Mayer 1992], Canada [Metcalfe-Smith et al. 1998], and rangewide [Taylor 1983, NatureServe [http://www.natureserve.org/explorer/servlet/NatureServe?sourceTemplate=tabular_report.wmt&loadTemplate=species_RptComprehensive.wmt&selectedReport=RptComprehensive.wmt&summaryView=tabular_report.wmt&elKey=112023&paging=home&save=true&startIndex=1&nextStartIndex=1&reset=false&offPageSelectedElKey=112023&offPageSelectedElType=species&offPageYesNo=true&post_processes=&radiobutton=radiobutton&selectedIndexes=112023]).

Collectively, museum or literature data (generally pre-1980) documented sizable, at least localized, snuffbox populations in many streams/lakes (e.g., Lake Erie; Grand [Michigan], Belle, Clinton, Huron, Portage [Michigan], Niagara, Kaskaskia, Ohio, Allegheny, Beaver, Muskingum, Tuscarawas, Henry Fork, Scioto, Olentangy, South Fork Kentucky, Green, Wabash, White [Indiana], Cumberland, Holston, Nolichucky, Clinch, Powell, Elk, Duck Rivers; Le Boeuf, Middle Island, Tygarts, Big Walnut, Big Darby, Deer, Slate, Cedar Creeks). Many other sizable populations likely occurred but historical data is wanting. Most of the historically documented sizable populations are now considered extirpated (e.g., Lake Erie; Niagara, Kaskaskia, Tuscarawas, Henry Fork, Scioto, South Fork Kentucky, Holston, Nolichucky Rivers; Big Walnut, Deer, Cedar Creeks) or are small (e.g., Belle, Ohio, Muskingum, Olentangy, Green, Powell, Duck Rivers; Le Boeuf, Middle Island, Tygarts, Big Darby, Slate Creeks). Among the ~35 streams that historically had sizable populations, ~25 streams have either lost their snuffbox population or it is nearing extirpation.

The snuffbox was added to the Service's C2 candidate list of species under review for addition to the list of Endangered and Threatened Wildlife under the Act in 1991 (Service 1991) but dropped in 1996 when this list was reduced to those species the Service had formerly elevated to candidate status (formerly C1 species) (Service 1996). The American Malacological Union and

American Fisheries Society consider the snuffbox to be threatened (Williams et al. 1993). The Natural Heritage program database maintained by NatureServe ranks it a G3 species (very rare and local throughout its range). The species is considered endangered from 11 of the 18 states of historical occurrence (Arkansas, Illinois, Indiana, Kentucky, Michigan, Missouri, Mississippi, Ohio, Pennsylvania, Virginia, and Wisconsin), 3 states consider it threatened (Minnesota, Tennessee[2], and West Virginia), and 1 state has assigned it an uncategorized conservation status (Alabama). It is officially designated as endangered in Canada under their Species at Risk Act (Metcalfe-Smith et al. 2003, http://www.speciesatrisk.gc.ca/search/speciesDetails_e.cfm?SpeciesID=670).

This species was last reported L/FD 40 or more years ago in ~40% of the streams/lakes of historical occurrence (e.g., Lakes Michigan, Huron, Erie; Fox, Muskegon, Kalamazoo, St. Joseph, Saginaw, Tittabawassee, Chippewa, North Branch Clinton, Portage [Ohio], Sandusky, Grand [Ontario], Niagara, Mississippi, Wisconsin, Cedar, Illinois, Des Plaines, Sangamon, Kaskaskia, Castor, Wakarusa, Marais des Cygnes, South Grand, Little Niangua, Monongahela, Beaver, Mahoning, Tuscarawas, Mohican, Lake Fork Mohican, Hocking, Scioto, Great Miami, South Fork Kentucky, Blue, Barren, Wabash, Mississinewa, Eel, Little Wabash, White [Indiana], East Fork White, Flatrock, West Fork White, Cumberland, Obey, Caney Fork, Red [Kentucky/ Tennessee], Tennessee, Holston, South Fork Holston, Little, Sequatchie, Flint, White [Arkansas] Rivers; Otter, Buffalo, Crooked, Pymatuning, Slippery Rock, Connoquenessing, Sugar [Ohio], Whetstone, Big Walnut, Alum, Yellowbud, Deer, Paint, Little Salt, Goose, Cow, Station Camp, Russell, Drakes, West Fork Drakes, Big Beaver, Sugar, Beaver, Lick, South Chickamauga, Richland, Bear, Cedar Creeks). It may have disappeared several decades ago from other poorly sampled streams as well (e.g., Cass, Maumee, Auglaize, Rock, Mazon, Salt Rivers; Swan Creek). In some streams the only records are archaeological (e.g., Crawfish, Pond Rivers). The snuffbox has been extirpated from entire major drainages (e.g., lower Missouri River system) or is on the verge of becoming so (e.g., Cumberland River system).

[2] The conservation status given for Tennessee was determined not by the state but by Parmalee and Bogan (1998).

The compilation of distributional information herein indicates a significant reduction in range of the snuffbox over the past several decades. Long-term collection histories (e.g., OSUM records in the Scioto River system) depict this downward trend and indicate approximate time spans when the snuffbox became extirpated. It has been eliminated from ~65% of the total number of streams/lakes from which it was historically known (73 streams currently compared to 208 streams/lakes historically). Available records indicate that 24 of 73, or 33%, of streams considered to harbor extant populations of the snuffbox are represented by one or two recent L/FD individuals (e.g., Embarrass, Little Wolf, Maple, Pigeon, Kankakee, Meramec, Ohio, Muskingum, Olentangy, Stillwater, Green, Powell, Duck, Black Rivers; Little Mahoning, Middle Island, Big Darby, Little Darby, Salt, South Fork Scioto Brush, Slate, Buck [Indiana], Graham, Buck [Kentucky] Creeks). Several streams from which this species was historically known have nearly had their entire mussel fauna decimated (e.g., Detroit River [Schloesser et al. 1998, 2006], Des Plaines River [Starrett 1971, Cummings and Mayer 1997], Monongahela River [Rhoads 1899, Ortmann 1909b, Tolin 1987], Scioto River [Stansbery 1962], upper Cumberland River [Cicerello et al. 1991], Little South Fork [Anderson et al. 1991, Layzer and Anderson 1992, Warren and Haag 2005], Caney Fork [Layzer et al. 1993], Holston River [Ahlstedt 1991b], and lower South Fork Holston River [Parmalee and Polhemus 2004]).

Following is an annotated summary of the status of snuffbox populations I consider extant.

Upper Great Lakes sub-basin

The snuffbox was formerly known from 15 streams/lakes in the upper Great Lakes sub-basin, including Lake Michigan and its tributary streams. The Fox River system in Wisconsin, particularly its major tributary the Wolf River (and its tributaries), had a widespread and locally abundant population. The species is thought to be extant in seven sub-basin streams. However, all but the Wolf and Grand Rivers have populations considered marginal.

Wolf River

The Wolf River is the major tributary of the Fox River draining a large portion of northeastern Wisconsin and flowing southward to join the Fox at Lake Butte Des Morts near Oshkosh. Snuffbox records are known from Shawano, Waupaca, and Outagamie Counties. A composite total of 298 L and 19 D snuffbox were located from 1988-95 (D.J. Heath, Wisconsin Department of Natural Resources [WIDNR], pers. comm., 2002). Among 38 individuals measured, 2 were recently recruited (≤0.8 inches). A total of 262 of 529 total L individuals collected south of Shawano were relocated in 1995 for a development project (Dunn et al. 2000; J. Lee, ESI, pers. comm., 2003). Live individuals (0.5-2.3 inches, 2-18 years) were translocated within a mile of the development site (J. Lee, ESI, pers. comm., 2003). The sex ratio appeared skewed (~6:1 male-biased) for the July collections. The snuffbox was considered common ("a lot of FD specimens" being found) in 1999 downstream of Shawano Dam (B.E. Fisher, Indiana Department of Natural Resources [INDNR], pers. comm., 2003). A single L individual (~2.2 inches) was found during qualitative sampling at a proposed bridge replacement site (State Route 22) on the south side of Shawano in 2006 (ESI 2006). The much larger area quantitatively sampled in 1995 at the State Route 29 crossing 0.3 miles downstream of the 2006 site (35,521 feet [ft]^2, versus 61 ft^2 quantitatively and 5490 ft^2 semi-quantitatively surveyed in the latter study) may account for the huge discrepancy in snuffbox numbers between the two studies, although habitat quality or temporal variation may also be factors (ESI 2006). A single tagged R shell was recovered in 2006 by quantitatively resampling one of two 807 ft^2 grid where 107 snuffbox were translocated in 1995 (C. Howard, ESI, pers. comm., 2007). A total of 121 ft^2 were sampled in the grid.

The snuffbox is known from a 30 RM reach of the Wolf (J. Schlangen, Wisconsin Natural Heritage Inventory [WNHI], pers. comm., 2005). It is one of the few stronghold populations but appears to exhibit a low level of recruitment. Only 4 of 257 individuals downstream of Shawano were <6 years in the mid-1990s (J. Lee, ESI, pers. comm., 2003). Despite not having sieved substrates to locate small subadults, the population may soon be in decline (H. Dunn, ESI, pers. comm., 2003). A male-biased population may also be indicative of decline. The lack of L snuffbox in the translocation grid in 2006 may suggest that the population failed to recruit and died out over the 11-year period (C. Howard, ESI, pers. comm., 2007).

The watershed is highly forested and silvicultural activities contribute sediments to the stream. A bridge replacement project on the south side of Shawano may threaten the large snuffbox bed located just downstream (ESI 2006). The zebra mussel has invaded the river, with a 0.7% infestation rate on unionids sampled in 2006 (ESI 2006). Other threats include municipal runoff and a series of dams in the watershed that fragment habitat.

Embarrass River

A western tributary of the lower Wolf River, the Embarrass River is located in Shawano, Waupaca, and Outagamie Counties, and parallels the western bank of the Wolf before joining it at New London. A population of the snuffbox is located in the headwaters below a small dam at Pella. Records exist for three L and two D individuals during 1987-88 and a single D specimen in 1995 (D.J. Heath, WIDNR, pers. comm., 2002; J. Schlangen and W.A. Smith, WNHI, pers. comm., 2003, 2005). Very little is known regarding this population making further comments on its status conjectural at best. See the Wolf River account for general threats.

Little Wolf River

The Little Wolf River is a western tributary of the lower Wolf River in Waupaca County. The snuffbox is known from a single L specimen collected in 1988 at RM 14 below the Mill Pond dam at Manawa (J. Schlangen and W.A. Smith, WNHI, pers. comm., 2003, 2005). Five D specimens were found during 1999 at RM 2 where shells were abundant in a muskrat midden (D.J. Heath, WIDNR, pers. comm., 2006). Nothing else is known regarding this population. See the Wolf River account for general threats.

Willow Creek

Willow Creek flows in an easterly direction into Lake Poygan, a large flow-through lake of the Wolf River system, in Waushara County. The snuffbox is known from a single 2001 observation of two L females (J. Schlangen, WNHI, pers. comm., 2005). Nothing else is available on the status of this population. See the Wolf River account for general threats.

Grand River

The Grand River, a major Lake Michigan tributary, represents the largest lotic watershed in Michigan and is located in the southwestern portion of the state. Numerous museum collections from the 260-mile river date back several decades and indicate that the snuffbox was relatively abundant historically. Twenty-one L snuffbox were found at three Ionia County sites (six males, 2.1-2.6 inches; six males, six females, and an undetermined subadult, 1.5-2.7; and two males, 1.4 and 1.9) during transect sampling among six sites surveyed in 1999 (P.J. Badra, Michigan Natural Features Inventory [MNFI], pers. comm., 2002). Three L individuals (two males and a female) were found at two sites and a FD specimen at another site (all in Ionia County) among five sites sampled in 2001 (P.J. Badra, MNFI, pers. comm., 2002). A total of 14 L (6 male, 8 female) individuals were found at one site with D shells at another site <0.25 miles upstream among eight sites sampled in 2002 (Badra and Goforth 2003). They occurred at a density of $0.01/ft^2$, had a mean length of 2.2 inches, and were collected below the confluence of the Flat River in Kent County. This species is sporadically distributed in ~25 RMs of the middle Grand approximately between the confluences of the Flat and Maple Rivers. The medium-sized population appears to be experiencing a low level of viability with recruitment noted in 1999.

The most significant threats to mussels in Michigan were reported to be zebra mussels and alteration of hydrology from dams (Badra and Goforth 2003). Zebra mussels were reported at the same site where snuffbox occurred L in 2002, in addition to the alien round goby at a site downstream (Badra and Goforth 2003). At least seven dams, three of them hydroelectric, fragment mussel habitat both upstream and downstream of the snuffbox reach. There is a long history of water quality abuse in the system from early industries and mills. Large sections of the Grand are in urban areas (e.g., Grand Rapids, Lansing) and subject to the effects of municipal runoff and point source impacts. Two-thirds of the watershed is designated agricultural and 22% of the pesticide loadings into the entire Lake Michigan sub-basin originate in the Grand River system (Hester 1995). Sedimentation is also a concern (Badra and Goforth 2003).

Maple River

The Maple is a northeastern tributary of the Grand River draining south-central Michigan. A single snuffbox record (1 L individual) is known from 2001 in southern Gratiot County ~20 RMs upstream of the Grand (P.J. Badra, MNFI, pers. comm., 2002). Portions of the Maple and several tributaries have been channelized. Very little development occurs in the watershed, although agricultural activities contribute sedimentation (Badra and Goforth 2003).

Pigeon River

The Pigeon River is a headwater tributary of the St. Joseph River system of Lake Michigan, flowing in a westerly direction across northern-most Indiana, crossing the state border to its confluence in southwestern Michigan. There is a dearth of mussel data from the Pigeon, better sampling efforts having taken place in the St. Joseph (Wenninger 1921, Dolley 1933, van der Schalie 1936). A "single, very large/old" FD specimen was found in 1998 among thousands of shells in LaGrange County (B.E. Fisher, INDNR, pers. comm., 2003). The same site was sampled in 1996 without evidence of this species and R shells were found at three of nine sites sampled in 2004 (B.E. Fisher, INDNR, pers. comm., 2003, 2005). The snuffbox reach covered >10 RMs in north-central LaGrange County. The species is very rare and its viability status is unknown. A series of four lowhead dams fragment habitat in the snuffbox reach, but specific threats are few; substrate quality is good, sedimentation levels are low, and riparian zones are mostly intact (B.E. Fisher, INDNR, pers. comm., 2005).

Lower Great Lakes sub-basin

Thirty-two of the total streams/lakes the snuffbox was recorded from historically are in the lower Great Lakes sub-basin, including several chains-of-lakes, springs, and channels in some systems (e.g., Clinton, Huron Rivers). Historically, sizable populations occurred in some streams (e.g., Lake Erie; Belle, Clinton, Huron, Portage, Niagara Rivers). The species had become "characteristically uncommon" by the 1970s (Strayer 1980). A pre-zebra mussel decline of unionids in Lake Erie was noted (Mackie et al 1980) and the snuffbox appeared extirpated by the late 1960s. The Lake St. Clair population persisted until ~1983 (Nalepa and Gauvin 1988, Nalepa 1994, Nalepa et al. 1996), which was the year the zebra mussel is thought to have invaded (Schloesser et al. 1998). Records of L/FD snuffbox from the Detroit River were available until 1994 (Schloesser et al. 1998); the mussel fauna has been devastated by zebra mussels (Schloesser et al. 1998; P.J. Marangelo, D.R. Pearsall, The Nature Conservancy [TNC], pers. comm., 2005). Other snuffbox populations in the sub-basin may also have suffered from zebra mussels. It is considered extant in 10 streams, including a stronghold population in the Sydenham River and sizable but reach-limited populations in the Clinton River and Davis Creek. A single FD valve was reported in 1998 from 24 sites sampled in the Thames River, but the species is considered extant in Canada only in the Ausable and Sydenham Rivers (Morris and Burridge 2006); no evidence of the snuffbox was found at 16 Thames sites in 2004 (D.J. McGoldrick, EC, pers. comm., 2005).

Ausable River

The Ausable River is a southeastern tributary of Lake Huron, draining southwestern Ontario, Canada. A total of 25 sites have been surveyed in recent years (D.J. McGoldrick, EC, pers. comm., 2005). The snuffbox was not found at four sites sampled in 1993 (Di Maio and Corkum 1995), but single FD specimens were found at sites 52 RMs apart in 1998 and 1999 (J.L. Metcalfe-Smith, EC, pers. comm., 2003; *contra* Metcalfe-Smith et al. 2003). A single L subadult (~2 years) with a byssus and three FD specimens were located at a third site in the lower river in 2003 (D.J. McGoldrick, EC; D.T. Zanatta, ROM, pers. comm., 2005). A single FD valve was located at this site in 2004. Twenty-six L individuals were found at four of seven sites during 2006 quantitative sampling (D.J. McGoldrick, EC, pers. comm., 2007). Size ranged from 0.8-1.5 inches indicating recent recruitment. The population is sizable, occurs over 23 RMs in the lower river based on 2006 data (D.J. McGoldrick and J.L. Metcalfe-Smith, EC, pers. comm., 2005), and is viable.

Threats primarily include siltation and nutrient over-enrichment (85% of the watershed is in agriculture and 70% has been tile drained), while channel alterations and instability, altered flow regimes, contaminants, thermal alteration, and zebra mussels constitute secondary threats (Ausable River Recovery Team 2004). Common host fish for the snuffbox (e.g., logperch, rainbow darter) are very rare in the system and may contribute to snuffbox imperilment.

Pine River

A tributary of the St. Clair River, the Pine River flows south and is located in St. Clair County, southeastern Michigan. The snuffbox was considered "rare" (<1/hour [h] sampling effort, Trdan and Hoeh 1985) at one of six sampled sites during 1982-83 (1 L individual; P.J. Badra, MNFI, pers. comm., 2002). Single L individuals, including a subadult (<1 year), were located at the site in 1984 and 1985, respectively (P.J. Badra, MNFI, pers. comm., 2002). No evidence of this species was found during a 1997 revisit of this site. Single L individuals were also reported from two other sites in 1985 and 1986, the 1985 specimen possibly being a subadult (P.J. Badra, MNFI, pers. comm., 2002). L individuals were collected from three sites <4 RMs apart in 2002 (Badra and Goforth 2003). Although apparently stable, the snuffbox population is small, very restricted in range, and has a low level of viability. Located in an agricultural watershed (Hoeh and Trdan 1985), the snuffbox is threatened by sedimentation and runoff.

Belle River

The Belle River is another tributary of the St. Clair River in St. Clair County, flowing in a southeasterly direction in southeastern Michigan. Records for the snuffbox date to the early 1960s, but all L/FD records over the past 40 years have been from the same lower main stem site. Historically, a sizable population was found in the Belle (OSUM 20936-65 specimens, 1965). The species was "rare" (<1/h effort) at four sites sampled during 1982-83 (Trdan and Hoeh 1985). Two L/FD and several R specimens were found in 1994 (P.J. Badra, MNFI, pers. comm., 2002). Quantitative sampling at three sites produced 12 L individuals (0.04/ft^2) in 1999 (R. Sherman Mulcrone, University of Michigan Museum of Zoology [UMMZ], pers. comm., 2005). Nine individuals were recently recruited (1 age <2, 8 age 3-4). A single L snuffbox (1.9 inch male) and D shells were found at 3 of 11 sites sampled in 2002 (Badra and Goforth 2003). All three sites were in the lower main stem over a 12 RM reach. The population has declined to the point of being small but with evidence of recruitment and viability. The Belle is located in a primarily agricultural watershed (Hoeh and Trdan 1985), and impacted by sedimentation and runoff.

Clinton River

The Clinton River is an eastward flowing chain-of-lakes tributary of Lake St. Clair in southeastern Michigan. Twelve L snuffbox were found at 4 highly developed sites west of Pontiac of 76 sites in the drainage surveyed during 1977-78 (Strayer 1980). A total of 804 L individuals (1.1-2.6 inches) were found in 1992 using a suction dredge (Trdan and Hoeh 1993). The snuffbox was the most abundant mussel species at the site and had a relative abundance of 38.1% (Trdan and Hoeh 1993). Sampling produced 7 and 12 L individuals during the spring and fall of 1995, respectively (P.J. Badra, MNFI, pers. comm., 2002). Sixteen L snuffbox were located on the shoreline of Cass Lake in 1996 at a density of $0.05/ft^2$ for an estimated population size of 2200 (P.J. Badra, MNFI, pers. comm., 2002). Recently recruited individuals (3 age 2, 20 age 3-4) were noted at three of four sites sampled in 1998-99 (Sherman Mulcrone 2004). A total of 28 L individuals were found at five sites surveyed in 2001 (D.R. Pearsall, TNC, pers. comm., 2005). Quadrats produced five L and nine L individuals at these sites in 2001 and seven L and six L individuals in 2003, respectively (P.J. Marangelo and D.R. Pearsall, TNC, pers. comm., 2005). Two L snuffbox <0.8 inches were found in 2003 and 39% (13) of the individuals were ≤3 years and 85% were <7 years. The snuffbox remains the dominant mussel at these sites (relative abundance 28.1%), but total numbers of all species were very low (96 L total from both sites and years). The snuffbox population, in decline since the early 1990s, is recruiting and viable despite being limited to ~10 RMs and lakeshore in the western suburbs of Pontiac primarily between Cass and Loon Lakes.

Threats in the Clinton were summarized by Strayer (1980). The mussel fauna in the main stem downstream of Pontiac was apparently wiped out by pollution between 1933 and 1977. Municipal pollution and general developmental activities continue to threaten the snuffbox.

System streams have been channelized and some paved with concrete. Water withdrawals are a major concern (R. Sherman Mulcrone, UMMZ, pers. comm., 2005). The summer 2003 flows were the lowest in 40 years of U.S. Geological Survey (USGS) stream gauge data (P.J. Marangelo, TNC, pers. comm., 2005). Zebra mussels, recorded since 1994, may not pose a significant threat (P.J. Marangelo, TNC, pers. comm., 2005). Unionids fouled by zebra mussels declined from 56 to 22% at one site and 11 to 4% at another site between 2001 and 2003, respectively (P.J. Marangelo, TNC, pers. comm., 2005). The recent decline of the zebra mussel may bode well for the snuffbox, but development will continue to threaten its existence.

Sydenham River:

The Sydenham (or East Sydenham or East Branch Sydenham) River is a large southeasterly flowing eastern tributary of Lake St. Clair in extreme southwestern Ontario, Canada. It represents the most diverse stream in Canada for mussels with 34 historical species (Clarke 1973, 1977, 1992); only 4 species are extirpated from the system (Metcalfe-Smith et al. 2003). The snuffbox was reported in the mid-1960s and early 1970s by Clarke (1973) but was overlooked during surveys in 1985 (Mackie and Topping 1988, except D shells) and 1991 (Clarke 1992), prompting the latter to declare that this species might have become extirpated. A total of 10 L/FD individuals were found from 4 of 12 sites, including the 3 1960s sites during 1997-99 sampling (Metcalfe-Smith et al. 2003). The snuffbox was recorded at a rate of 0.22/h effort during 1997-98 (Metcalfe-Smith et al. 2000a). More recent sampling produced 57 L/FD individuals from 21 collections (some individuals may have been counted multiple times) at six sites during 2000-02. The increase in numbers relative to historical collections may be attributed to more intensive sampling methods than to improving population size (Metcalfe-Smith et al. 2003) thus making population trend assessments problematic (Morris and Burridge 2006). This stronghold population is recruiting (D.T. Zanatta, ROM, pers. comm., 2006), viable, and is currently known from ~30 RMs of the middle Sydenham (http://www.speciesatrisk.gc.ca/search/speciesDetails_e.cfm?SpeciesID=670).

Eighty-four percent of the watershed is agricultural, primarily in row crops (Metcalfe-Smith et al.

2003). Siltation, nutrient over-enrichment, exposure to agricultural pesticides and fertilizers, and runoff from highways, municipal, and industrial sources are threats (West et al. 2000). The drainage system of ditches around towns in the watershed also contributes sediment and runoff (Mackie and Topping 1987). Zebra mussels do not currently occur in the Sydenham reach harboring the extant snuffbox population, but they do occur in the lowermost main stem near Lake St. Clair (D.A. Woolnough, Trent University, pers. comm., 2002) and bear monitoring.

Huron River

The Huron River is a major tributary of western Lake Erie draining a significant portion of southeastern Michigan. It is a complex system of flow-through chains-of-lakes and tributaries. The snuffbox was found at 12 of ~48 river sites and 4 of several dozen lake sites surveyed during 1930-33; it was considered "abundant" at 2 unspecified Livingston County sites (van der Schalie 1938). Nineteen D specimens were found in 1996 in the Proud Lake area of southwestern Oakland County (P.J. Badra, MNFI, pers. comm., 2002); however, it was not sampled in Proud Lake State Recreation Area in 1998 (Sherman Mulcrone 2004). It was considered "common" in a roughly two-mile reach upstream of Davis Creek, southeastern Livingston County, during a 2001 float trip assessing mussel habitat (P.J. Marangelo, TNC, pers. comm., 2005). The species was also found L (1-2 individuals) in a third reach downstream of Portage Lake in 1995 (P.J. Marangelo, TNC, pers. comm., 2005; presumably also Nichols et al. 2000) but is believed to have become extirpated there by 2002 (P.J. Marangelo, TNC, pers. comm., 2005). The snuffbox is considered extant in two disjunct upper main stem reaches. The Huron population is probably recruiting and viable, with individuals in the middle Huron River reach considered a single population segment with that in Davis Creek.

The Huron River main stem has 11 major dams that have disrupted mussel habitat for decades (http://www.questoutdoors.net/locs/michigan/huron_mi/). The zebra mussel invaded the system in the early 1990s, with densities in the river reach below Portage Lake averaging 3,255/ft^2 by fall 1996 (Nichols et al. 2000). Zebra mussel densities on individual unionid mussels increased from <1 to 245, respectively, from spring 1995 until winter 1998. Mortality rates for the 16 unionid species at the site increased from 2-3% on encrusted unionids in late 1996 to 10-11% of biofouled individuals by 1997 (Nichols et al. 2000). Herbicide treatments in lakes threaten mussels by reducing their foods (P.J. Marangelo, TNC, pers. comm., 2005). Zebra mussels and herbicide treatments in Portage Lake (on a tributary, Portage River) are thought to have eliminated the mussel fauna in the Huron in northern Washtenaw County and adjacent Livingston County (P.J. Marangelo, TNC, pers. comm., 2005). Other threats to the snuffbox include developmental activities, sedimentation, and agricultural runoff.

Davis Creek

Davis Creek is a chain-of-lakes in the upper Huron River system, primarily in southeastern Livingston County. The first record for the system was from Sandy Bottom Lake in 1931 (van der Schalie 1938). A sizable population quantitatively determined at a density of $0.17/ft^2$ was found during 1992-93 downstream of Sandy Bottom Lake (Sherman 1994). Additional sampling produced two age 0 (<1 y) and two age 1 subadults at three sites during 1998-99 (Sherman Mulcrone 2004). The species was reported as being “common” over the ~0.5 miles upstream from the Huron River confluence in 2001 (P.J. Marangelo, TNC, pers. comm., 2005). Twelve L individuals (including 10 apparently gravid females) were located in four h of sampling effort upstream of where the earlier sampling occurred (P.J. Marangelo, TNC, pers. comm., 2005). Twenty-two L individuals were found in two h of effort in 2005 (D.T. Zanatta, ROM, pers. comm., 2005). The size of 20 individuals ranged from 1.3-2.3 inches (6 <1.5 inches). The sex ratio was 5:1 male-biased. The population appears to be sizable and is experiencing recent recruitment. Davis Creek was considered to be “the most abundant population” relative to others observed in the Clinch River, St. Croix River, Sydenham River, and French Creek over the past few years (D.T. Zanatta, ROM, pers. comm., 2005). However, it currently appears to be limited to the lower 3 RMs, comprising a single population with one of the extant Huron River population segments in this area. Were it not for the restricted reach from which it is known, the middle Huron River/Davis Creek population (collectively forming a non-linear 5 RM reach) might rank as a stronghold population.

Herbicide applications, general runoff, and zebra mussels threaten the snuffbox. The Detroit metropolitan area watershed is increasingly being subjected to developmental activities (Huron River Watershed Council [HRWC] 2003; P.J. Marangelo, TNC, pers. comm., 2005). Zebra mussels may have contributed to the extirpation of this species from Sandy Bottom Lake (P.J. Marangelo, TNC, pers. comm., 2005). Cattle have been observed in the stream above the snuffbox site (R. Sherman Mulcrone, UMMZ, pers. comm., 2007). Past activities with the potential for residual impacts include what was once the largest sand and gravel mine in the U.S., industrial pollution, and 11 "drains" created in headwater areas to convert wetlands to agricultural lands (HRWC 2003).

South Ore Creek

This is a northern tributary of the Huron River, forming a southward flowing chain-of-lakes draining southeastern Livingston County. The snuffbox was discovered in 1999 just upstream of Ore Lake, which is approximately at the Huron River confluence (Sherman Mulcrone 2004). Three subadult snuffbox (two age 2, one age 3-4) were recorded. Despite the lack of additional information, the small population appears to be viable based on recent recruitment. Threats are similar to those in other portions of the Huron River system in addition to nutrient over-enrichment from a wastewater treatment plant (WWTP) (R. Sherman Mulcrone, UMMZ, pers. comm., 2007).

Portage River

The Portage River (or Portage Creek) is a chain-of-lakes in the northwestern portion of the Huron River system. The snuffbox was found L at two of three sites collected upstream of Portage Lake in the 1930s (van der Schalie 1938); two UMMZ records (18 and 21 specimens) suggest former abundance (P.J. Badra, MNFI, pers. comm., 2002). It was reported as "rare" (<1 specimen/h) in the lower river during 1976-78 (Strayer 1979). At least 22 L individuals (only "small" individuals reported; 2 < age 2, 20 age 3-4) were located in 1998 at one of three sites upstream of Little Portage Lake/Portage Lake (Sherman Mulcrone 2004). The localized population appears medium-sized and viable. The zebra mussel, herbicide applications, sedimentation, and agricultural runoff are threats. The upper stream (Portage Creek) has been channelized.

Grand River

The Grand is a 99 RM tributary of Lake Erie, flowing north then west to its confluence northeast of Cleveland, Ohio. Several museum snuffbox records date back to the 1800s. Fourteen L snuffbox (among 4045 total mussels) were found in 1995 at an undisclosed number of sites in a reach (RM 9-31) among 95 sites float surveyed between 1995 and 2002 (Huehner et al. 2005). Dozens of FD snuffbox were found washed up on the banks in the vicinity of the Interstate 90 crossing in Lake County following a major flood in 2006 (M.A. Hoggarth, Otterbein College [OC], pers. comm., 2006). The species is known from ~12 RMs downstream of Harpersfield Dam (~RM 31) (Huehner et al. 2005; G. Zimmerman, EnviroScience, Inc. [EI], pers. comm., 2002). The sizable population was considered recruiting based on the 1995 Huehner et al. (2005) survey (G. Zimmerman, EI, pers. comm., 2002).

The watershed is in woodlands, fields, and wetlands, but riverine habitat has been "relatively unaffected by dredging, dams, pollution, and zebra mussels" (Huehner et al. 2005). There appears to be little development except in Painesville (a suburb of Cleveland) near the mouth. The snuffbox section is designated Wild and Scenic by the State of Ohio (Huehner et al. 2005).

Upper Mississippi River sub-basin

The snuffbox was historically known from 17 streams in the upper Mississippi River sub-basin. Records exist for Mississippi River Pools (MRPs) 3-4, 5a-6, and 14-16 (Kelner no date) with early surveys summarized by van der Schalie and van der Schalie (1950). It was reported L in the upper river in 1920s (Grier 1922, 1926) but not from subsequent surveys (e.g., 254 sites upstream of the Ohio River during 1930-31 [Ellis 1931], MRPs 5-7 and 9 in 1965 [Finke 1966], MRPs 3-11 during 1977-79 [Thiel 1981]) and is extirpated (Havlik and Sauer 2000). Only 4 of 17 historical populations remain, but they include two of the largest rangewide (St. Croix and Bourbeuse Rivers). Three populations, including the St. Croix, appear to be declining, *St. Croix River*

The St. Croix River is a major south-flowing tributary of the upper Mississippi River and forming the border between southeastern Minnesota and northwestern Wisconsin. A total of 371 L individuals were observed from 1988 to 2000; 91 (25%) were subadults <0.8 inches (D.J. Heath, WIDNR, pers. comm., 2002). Relative abundance ranged from 1.9-4.6% between 1988 and 2004 at Interstate Park (RM 51.8-52.8) (WIDNR 2004). Other studies have reported 54 L snuffbox from two sites (~RM 50 and ~RM 48) (Hornbach et al. 1996), and 9 L in 1992 at Interstate Park, including three individuals <0.9 inches (Hornbach 1992).

The long-term health of the entire St. Croix mussel community may be in jeopardy. Subadult densities declined at eight sites between 1992 and 2002 (Hornbach et al. (2003). Snuffbox density at Interstate Park declined significantly from 0.06 ft^2 in 1988 to 0.01 ft^2 by 2004 and L/D ratios from 4.0 to 0.33 (WIDNR 2004). The St. Croix snuffbox population occurs from the Northern States Power Dam (NSPD) at RM 54.2 to RM 36.8 (D.J. Heath, WIDNR, pers. comm., 2005), represents its northernmost occurrence, and remains one of the most significant population's rangewide.

Mussel declines may be due to a variety of impacts. Sediment ammonia concentrations in the St. Croix regularly reach levels sub-lethal or even lethal to mussels (Newton et al. 2003). Nearly 1% of the unionids were infested with zebra mussels in 2001 (Kelner and Davis 2002), and zebra mussels have recently invaded the Interstate Park site. Altered stream flows from hydropower generation may impact recruitment (Layzer and Madison 1995, Hardison and Layzer 2001, Layzer and Scott 2006) below NSPD. The proximity of the St. Croix to the expanding Minneapolis/St. Paul metropolitan area makes it vulnerable to developmental activities (Vaughan 1997). The St. Croix National Scenic Riverway, part of the National Park Service (NPS), affords a level of protection.

Kankakee River

The Kankakee River is a major westward-flowing upper Illinois River tributary with its headwaters in northwest Indiana and northeast Illinois. The snuffbox was reported a century ago (Baker 1906), but surveys in 1911 (43 sites, Wilson and Clark 1913), 1978 (13 sites, Suloway 1981), 1975-2000 (18 samples from an unknown number of Will County, Illinois, sites; Sietman et al. 2001), and 1999 (4 sites, Stinson et al. 2000) failed to find it. It was considered extirpated from the Kankakee by Cummings et al (1988), but single FD specimens in Illinois (Will County in 1988, Kankakee County in 1991) were subsequently found. Only R shells have been found since 1991. The Kankakee population, if extant, appears small, localized, and of unknown viability.

The entire Indiana portion of the river, in addition to some tributaries (e.g., Yellow River), were channelized around a century ago destroying much mussel habitat (Wilson and Clark 1913) and converted a 250 RM reach to an 82 RM ditch (Gammon 2005). This resulted in a significant sand sedimentation load, particularly in eastern Kankakee County (Suloway 1981). Several lowhead dams were constructed decades ago, five around Kankakee (Wilson and Clark (1913). Gravel mining (Fuller 1974) and fertilizer and pesticide runoff (Suloway 1981) may still pose threats.

Meramec River

The Meramec River is a 236-mile tributary that flows northeasterly into the Mississippi River downstream of St. Louis and drains the northeastern slope of the Ozark Plateaus in east-central Missouri. This northeasterly-flowing stream is located on the. Early species lists failed to report the snuffbox (Grier 1915, Utterback 1917). It was found FD at 3 of 70 sites with R shells at 2 other sites sampled from 1977-78 (Buchanan 1980). Forty-two sites, including 26 of Buchanan's (1980) sites, were sampled in 1997, with FD specimens at RM 33.5, 48.8, and 59.8; and 1 L individual at RM 39.8 (Roberts and Bruenderman 2000). The L specimen (2.4 inches, ~6 years) was reported from a reach where a die-off (perhaps attributable to disease) was reported in 1978 (Buchanan 1986). There was an obvious decline of mussels in the system based on catch-per-unit-effort data from sites surveyed ~1978 (39.7 L individuals/h effort) and the same sites resurveyed in 1997 (21.8/h) using similar sampling techniques (Roberts and Bruenderman 2000). The Meramec snuffbox population is rare, sporadically distributed (~26 RMs), and of unknown viability. The lower river drains the rapidly urbanizing St. Louis metropolitan area. Other threats are summarized under the Bourbeuse River account.

Bourbeuse River

The Bourbeuse River is a 149-mile northeasterly-flowing, northern tributary of the Meramec River joining it at RM 68. The snuffbox, considered "locally abundant" by Oesch (1984), was historically known from 19 sites over the length of the stream (RM 137 downstream) (S.E. McMurray, Missouri Department of Conservation [MDC], pers. comm., 2005). It was found L/FD at 12 of 37 sites with R shells from 3 more sites during 1977-78 (Buchanan 1980); 16 L individuals were found at 8 sites (S.E. McMurray, MDC, pers. comm., 2005). The snuffbox was found L/FD at 3 of 26 sites in 1997, including 14 L at RM 66.3, 2 L at RM 73.7, and FD shells at RM 1.4 (Roberts and Bruenderman 2000). Two sites yielded 15 L (RM 66.3) and 6 L (RM 53.9) in 2001, 13 L at RM 66.3 in 2002 (two collection dates), and 1 L at RM 70.6 in 2003 (S.E. McMurray, MDC, pers. comm., 2005). A total of 116 L individuals were reported at 10 mostly unsampled sites and FD specimens from another site from RM 16-56 in 2005 (S.E. McMurray, MDC, pers. comm., 2005, 2006). Ninety-eight L individuals were found at three sites resampled a total of eight times in 2006.

The snuffbox is currently distributed over ~60 RMs upstream of RM 16 plus a disjunct site at the mouth. Although it was considered to have "greatly declined" by the late 1990s (Roberts and Bruenderman 2000), post-2000 sampling indicates that the population is recruiting, viable, and improving (S.E. McMurray, MDC, pers. comm., 2006). The Bourbeuse, one of the few stronghold snuffbox populations rangewide, has been augmented with laboratory propagated juveniles since 2002 (S.E. McMurray, MDC, pers. comm., 2006).

Sixty percent of the Meramec River watershed is forested, 20% in crops, and 20% in pastures and other uses (Buchanan 1980). Threats to the mussel fauna were documented by Buchanan

(1980) and Roberts and Bruenderman (2000), including a die-off in 1979 in the best snuffbox reach (Buchanan 1986). Loss of riparian zones, gravel mining, substrate instability, channel degradation, and nutrient over-enrichment are major threats. Excessive sedimentation and mussel declines were observed at some snuffbox sites (e.g., RM 73.7). A lowhead dam at RM 11.6 isolates snuffbox population segments in the Bourbeuse. Zebra mussels, first reported from the lower Meramec in 1999, could spread into snuffbox habitat. The snuffbox is linearly distributed in the Bourbeuse and Meramec Rivers making the population susceptible to stochastic events.

Lower Missouri River system

The snuffbox was historically known from four streams in this system. The highly disjunct occurrences suggest that it was more widespread historically. All populations in the system are considered extirpated (S.B. Bruenderman, Kentucky Division of Water, pers. comm., 2003).

Ohio River system

Half of the water body occurrences for the snuffbox rangewide are known from the Ohio River system, which collectively represented the largest block of available habitat for this species. Sizable populations historically occurred in at least a dozen streams. Only French Creek is considered to have a stronghold population, although nine others are also significant. Currently, it is known from 40 of the 107 streams of historical occurrence.

Ohio River

The Ohio River is the largest eastern tributary of the Mississippi with its confluence marking the divide between the upper and lower portions of the latter system. Numerous historical records are known from throughout the river. Recently, single FD and L specimens have been reported from just below Belleville L&D, Ohio and West Virginia, in 1995 and 2001, respectively (ESI 2002). It is possible that OSUM 60726 is the specimen that ESI (1996, 2002) reported in 1995 (and collected since ~1980), but the single valve was categorized by OSUM as R, not FD. Having persisted in this highly modified river may indicate that the small population exhibits a low level of viability.

Barge navigation activities generally threaten the Ohio River snuffbox population. Navigational improvements on the Ohio began in 1830 (U.S. Army Corps of Engineers [Corps] 1981). Presently, 17 “high-level” L&Ds replaced 53 L&Ds constructed between 1878 and 1929. Nearly the entire 981 RM length (all except the lowermost portion near the Mississippi River confluence) is impounded. Riverine habitat in the Ohio River has deteriorated since the new L&Ds were built. The older structures (wicket dams) hinged on the bottom and were designed to fold lower during high flows so as not to impede the flooding river and barge traffic (nor the movement of fishes). The zebra mussel is prevalent in the Ohio River below Belleville L&D, although population size fluctuates greatly. A recent decrease in unionid density and increase in mortality in the local mussel beds was at least partially attributed to zebra mussels (ESI 2002). A chemical spill that caused a major mussel kill in the Ohio in 1999 may have impacted the snuffbox population (W.A. Tolin, Service retired, pers. comm., 2002).

Allegheny River

The 325-mile Allegheny River drains northwestern Pennsylvania and a small portion of adjacent New York flowing south before joining the Monongahela River at Pittsburgh to form the Ohio River. Snuffbox collections are sporadically known since ~1900 in Pennsylvania from Forest County downstream to Armstrong County. This species was found L (unknown number) in 1991 (Bogan and Davis 1992a), two FD (1.7 and 2.0 inches) in 1996 (museum record), one L from 1998 to 2001 (Villella and Smith 2002a), and two L in 2001 (Villella and Smith 2002b). The snuffbox is known from three disjunct sites over a 42 RM reach centered in Venango County. Its occurrence in the lower Allegheny River and lower French Creek could be considered a single population segment. The viability status of the small population is unknown.

The destruction of the mussel fauna in western Pennsylvania was reported by Ortmann (1909c).

Nine locks and dams (L&Ds) constructed on 72 RMs of the lower Allegheny from Armstrong County to Pittsburgh disrupted historical mussel habitat and snuffbox sites. Kinzua Dam (1965) on the upper main stem destroyed potential habitat. Current threats include channel maintenance activities, sedimentation, bridge replacement projects, silvicultural activities, accelerating oil and gas extraction, and refinery effluents (T. Proch, Pennsylvania Department of Environmental Protection [PDEP]; R.M. Anderson, Service, pers. comm., 2002). Although water quality has improved since the early 1900s, issues remain. Zebra mussels are dense in Chautauqua Lake, New York (S.A. Ahlstedt, USGS retired, pers. comm., 2002), and a single specimen was found in 2006 downstream of the French Creek confluence (R. Villella, USGS, pers. comm., 2006).

French Creek

French Creek is a major tributary of the middle Allegheny River with its headwaters in western New York and flowing south into northwestern Pennsylvania. It is known from the length of the stream in Pennsylvania in Erie, Crawford, Mercer, and Venango Counties. Most records date from ~1970 (Dennis 1971). The snuffbox was found L/FD in Erie (11 and 14 individuals) and Crawford (20 and 31 individuals) Counties in 1991-91 (museum records). Quantitative data from four Venango County sites in 1998-99 (data combined from both years over a 6,271 ft^2 area at each site) yielded 33, 289, 104, and 33 L individuals, for estimated densities of 0.005/ft^2, 0.040/ft^2, 0.014/ft^2, and 0.005/ft^2, respectively (Villella and Smith 2002a; R.R. Evans, Kentucky State Nature Preserves Commission [KSNPC], pers. comm., 2003).

Snuffbox collections made during 2002-04 from qualitative (2003), quantitative (2004), and muskrat midden (2002 and 2004) samples were summarized by Smith (2005). L/FD specimens were found at 19 sties throughout the stream. A total of 53 L individuals were found at 15 of 29 sites in 2003. Quantitative sampling in 2004 yielded 117 L/4 FD individuals at nine of the qualitative sites, including four additional sites where no L individuals were previously sampled qualitatively. Densities ranged from 0.001-0.024/ft^2. Snuffbox abundance at the nine sites was estimated to be from 21 to 854 (SE = 21.0-180.2). Size for L individuals over both years and sampling methods (0.4-2.6 inches) indicated that multiple year classes were represented including subadults under 1.2 inches at five sites. Samples from 14 muskrat middens yielded 35 FD specimens in 2002 and 13 FD specimens (1.2-2.2 inches) at 4 middens in 2004.

The French Creek snuffbox population is considered large and viable (G. Zimmerman, EI; R.R. Evans, KSNPC, pers. comm., 2003), it appears stable, and may represent the best stronghold population rangewide. It stretches for ~80 RMs from ~RM 10 upstream. The population encompasses several of its tributary population segments as well, making it relatively secure when compared to most of the other stronghold populations (e.g., Sydenham, Bourbeuse, Clinch Rivers) which are linearly distributed and more susceptible to stochastic events.

Threats to the snuffbox in French Creek include nutrients from agriculture, aging septic systems, sedimentation, municipal runoff and effluents, and oil and gas development wastes (e.g., brines, organics) (T. Proch, PDEP, pers. comm., 2002; R.R. Evans, KSNPC, pers. comm., 2003). Zebra mussels, known from Edinboro Lake on a headwater tributary in Erie County (R.M. Anderson, Service, pers. comm., 2002), were reported at five sites from Crawford County downstream in 2004, but only 10 L individuals were located during quantitative sampling (Smith 2005). Union City Lake on the upper main stem operates as a retarding basin to temporarily store and slowly release flood waters. The two best snuffbox sites from the survey of Smith (2005) were above this dam and therefore isolated from the downstream population.

West Branch French Creek

West Branch of French Creek follows a southerly course to its parent stream in Erie County, Pennsylvania. The only record for the snuffbox dates from 1993, but the number of specimens and shell condition are unknown (R.R. Evans, KSNPC, pers. comm., 2003). Union City Lake isolates the upper French Creek/West Branch French Creek population segment from the main French Creek population. The snuffbox was not found at three sites sampled in 2006 (T.A. Smith, Western Pennsylvania Conservancy [WPC], pers. comm., 2006). If extant, this population appears to be very small and of unknown viability. Threats are similar to those in French Creek.

Le Boeuf Creek

This is a small western tributary of upper French Creek flowing in a southerly direction just west of West Branch French Creek in Erie County, Pennsylvania. The first snuffbox collections were made 100 years ago (Ortmann 1909a). Two FD and 6 R shells were reported in 1988 (R.R. Evans, KSNPC, pers. comm., 2003), and 1 L, 16 FD, and 8 R specimens were found in 1991 (A.E. Bogan, North Carolina State Museum of Natural Sciences [NCSMNS], pers. comm., 2005). Three L individuals (1.3-2.3 inches) were found at a site in 2006 (T.A. Smith, WPC, pers. comm., 2006). The snuffbox population has recently recruited and exhibits some level of viability but appears to be very limited in extent. Threats are similar to those outlined for French Creek.

Muddy Creek

Muddy Creek is an eastern tributary of upper French Creek in Crawford County, Pennsylvania. The snuffbox was not discovered until the summer of 2003 having been overlooked by Dennis (1971). Forty-two L individuals were reported from 11 of 20 lower sites (P. Morrison, Service, pers. comm., 2005; N.L. Kline, Service, pers. comm., 2006). Low numbers were found at most sites, but 18 L individuals were collected from a site near the mouth. Relative abundance was 1.4% among 22 L species. The population is medium-sized, occurs along 8 RMs of the lower main stem, and viable as recent subadults were recorded (P. Morrison, Service, pers. comm., 2005). This occurrence is considered to be part of the more extensive French Creek snuffbox population. It primarily occurs on public land managed by the Service's Erie National Wildlife Refuge but is still threatened by sedimentation, agricultural runoff, and developmental pressures.

Conneaut Outlet

This stream forms the outlet to Conneaut Lake, flowing in a southeasterly direction until its confluence with middle French Creek, Crawford County, Pennsylvania. The snuffbox was first reported by Ortmann (1909a). Although not reported at a site sampled by Bogan and Davis (1992b) in 1990, the species was rediscovered L in 1997 but without collection details (G.

Zimmerman, EI, pers. comm., 2002). No specimens were found at a site sampled in 2006 (T.A. Smith, WPC, pers. comm., 2006). The snuffbox is considered rare and its viability is unknown. See French Creek account for general threats.

Little Mahoning Creek

Little Mahoning Creek is a tributary of Mahoning Creek, a lower eastern tributary of the Allegheny River northeast of Pittsburgh. The snuffbox was discovered in 1991 when sampling produced two FD and one R specimens at 1 of 12 sites in the system (A.E. Bogan, NCSMNS, pers. comm., 2005). Viability is unknown. The lower main stem is impounded by a reservoir on Mahoning Creek. Threats include coal mining and agricultural activities.

Dunkard Creek

Dunkard Creek is an easterly flowing, western tributary of the middle Monongahela River, straddling the Pennsylvania/West Virginia line. Snuffbox records are known for both states and date to several 1969-74 museum collections. Small numbers of specimens (unknown condition) were found at 4 of 14 sites during 1993-94 sampling in Pennsylvania (Bogan 1993; R.R. Evans, KSNPC, pers. comm., 2003). Eight specimens (unknown condition) were collected at a West Virginia site in 1997. The small population appears to have declined in recent decades and its current status and viability is uncertain. Threats include an increase in coal mining, agricultural runoff, and wastewater effluents (Bogan 1993; (J.L. Clayton, West Virginia Division of Natural Resources [WVDNR], pers. comm., 2000; R.R. Evans, KSNPC, pers. comm., 2002, 2005).

Shenango River

The Shenango is a large tributary in the Beaver River system, a northern tributary of the upper Ohio River in west-central Pennsylvania. The snuffbox was reported from four sites on the Shenango in 1908 (Ortmann 1919), but no specimens were found at two sites sampled ~1970 (Dennis 1971). It was considered “occasional” in occurrence (versus “rare” or “common”) at three of six Mercer County sites surveyed during 1983-84 (Bursey 1987). Six L individuals were collected from 3 of 16 sites sampled in 2001-02 between Jamestown and New Hamburg (~25

RMs); R shells were found at 7 other sites (R.R. Evans, KSNPC, pers. comm., 2003). Relative abundance was 1.68% and density 0.002 ft^2 (R.R. Evans, KSNPC, pers. comm., 2005). This upper reach is considered the best habitat in the Shenango. It was also reported L from another Mercer County site in 2002 (G. Zimmerman, EI, pers. comm., 2002) and 2003 (museum record). The population is small, has declined, and its viability is unknown (G. Zimmerman, EI, pers. comm., 2002).

Two large reservoirs (Pymatuning Dam 1934 and Shenango River Dam 1966) limit the snuffbox population and have destroyed ~50% of the 75-mile river. Domestic and industrial pollution and fertilizer and pesticide runoff was implicated as causes of the mussel decline (Bursey 1987), while excessive sedimentation, wastewater effluents, and possibly sediment toxicity are considered current threats to the disjunct mussel fauna (R.R. Evans, KSNPC, pers. comm., 2005).

Little Shenango River

The Little Shenango River is a small tributary of the upper Shenango River, Mercer County, Pennsylvania. This population was not located during limited surveys (e.g., Dennis 1971, Bursey 1987), but a single FD museum record from 1991 exists. The species was reported to be relatively abundant in the lower portion in 2002 (G. Zimmerman, EI, pers. comm., 2002). The Shenango River/Little Shenango River is a single, non-linear population segment. Viability of the small population is unknown. The Little Shenango watershed is not as developed as is the Shenango, but sedimentation, degraded water quality, and possibly sediment toxicity are concerns (R.R. Evans, KSNPC, pers. comm., 2005).

Middle Island Creek

This is a small tributary of the Ohio River in northwestern West Virginia. The first snuffbox records were made at six sites in 1969 (26 FD specimens in museum records, *contra* Taylor and Spurlock 1981) when it was locally common (13 FD specimens at a site) in Doddridge, Tyler, and Pleasants Counties. The snuffbox was found at two of six sites in Tyler County in 1980 and the overall mussel population was considered to be “thriving” (Taylor and Spurlock 1981). The last record was for a single L individual collected in Tyler County in 2001 (G. Zimmerman, EI, pers. comm., 2002). The snuffbox has declined, is currently rare, and its viability is questionable. Water quality was considered good by Taylor and Spurlock (1981). Landuse is in forest, with scattered towns and sparse industry. At least one mill dam persists on the stream.

Muskingum River

The Muskingum is a large southerly-flowing, northern tributary of the upper Ohio River draining a significant portion of east-central Ohio. The largest drainage in Ohio, it is formed by the confluence of the Tuscarawas and Walhonding Rivers in Coshocton County. The snuffbox, which has a long collection history dating to the early 1800s (Watters and Dunn 1993-94), occurred along the entire main stem and was locally abundant (e.g., OSUM 47308-29 FD specimens). Two L individuals and two FD shells were found in 1979, but no L/FD snuffbox were found in surveys conducted on five beds in 1979-81 (Stansbery and King 1983) and ~65 sites in 1992-93 (Watters and Dunn 1993-94). A single L specimen was located during sampling for a construction project in 2005 near Dresden (R.W. Taylor, Marshall University, pers. comm., 2006). Viability status is unknown.

Eleven L&Ds have been constructed on the Muskingum from Zanesville downstream (R. Sanders, Ohio Department of Natural Resources, pers. comm., 2002). The snuffbox population appears to have been eliminated from this modified reach and is restricted upstream. Sediment loads, other agricultural runoff, oil and gas development, and straight pipes in its major tributary systems may adversely impact mussels in the main stem. The snuffbox also occurs in two headwater tributaries, but the three population units are linearly distributed making them more susceptible to a stochastic event.

Walhonding River

The Walhonding River is a short (23.3 RMs), east flowing tributary of the Muskingum River in central Ohio, forming the latter river at its confluence with the Tuscarawas River, and formed by the confluence of the Mohican and Kokosing Rivers. Historical sampling, including OSUM records from the 1960s (14 FD from five sites), indicates that the snuffbox occurred throughout the river. Eight L/one FD snuffbox were found at 3 of 19 sites during a 1991-93 survey; three additional sites produced R shells (Hoggarth 1995-96). Overall, mussel habitat was considered good and the stream supported populations of 33 of 38 historical species of occurrence (Hoggarth 1995-96). The extant snuffbox reach (RM 1.8-6.8) is downstream from Killbuck Creek. The population has apparently declined in range and size by the early 1990s and possibly since; a once productive site ~0.25 miles downstream of the Killbuck Creek confluence yielded only a few mussels of very common species in 2006 (S.A. Ahlstedt, USGS retired, pers. comm., 2006; pers. obs.). The Walhonding population is considered small and of unknown viability.

Threats were summarized by Hoggarth (1995-96) and M.A. Hoggarth (OC, pers. comm., 2003). Mohawk Dam (~RM 17.5) was built on the main stem in 1936 and operates as a retarding basin to temporarily control flood waters. A low head dam (~RM 9) impounds a 0.5 mile reach of stream and gravel mining occurs in the riparian zone below this dam. Developmental and agricultural pressures occur, particularly upstream of Mohawk Dam, and vast acreages of corn and soybeans are common in the lower floodplain (pers. obs.). The Mohican has a high sediment load, while the Kokosing flows much clearer, although intensive agriculture on the lower Kokosing eventually may change water quality in that stream. Scores of summer homes (i.e., mostly stationary travel trailers) are located on the banks of the river below Mohawk Dam (pers. obs.) and some may discharge untreated wastes directly into the river via straight pipes or indirectly via leaky septic fields. A profusion of filamentous algae in 2006 suggests nutrient over-enrichment and excessive amounts of sediment in the lower river partially originates from heavily-sedimented Killbuck Creek (pers. obs.).

Killbuck Creek

This is a large tributary of the lower Walhonding River, flowing south from southern Medina County to Coshocton County and entering the latter at ~RM 7. The 1994 discovery of the last known population of a congener, the endangered catspaw, *Epioblasma obliquata obliquata*

(Rafinesque, 1820) (Hoggarth et al. 1995), prompted a 33-site survey during 1995-96 (Hoggarth 1997). Collectively, 21 L/5 FD snuffbox were found at eight sites from ~RM 15 to the mouth (Hoggarth 1997). No evidence of this species was detected at the upstream-most site of occurrence in 2004 (S.A. Ahlstedt, USGS retired, pers. comm., 2004). Four L adult snuffbox at two sites <3 RMs apart were found during spring 2006 sampling at several sites, while nine L individuals (2.4-3.1 inches) and a single FD specimen (2.8 inches) were collected near RM 13 during fall 2006 sampling at five sites (including most of the spring sites) (S.A. Ahlstedt, USGS retired, pers. comm., 2006). The snuffbox population segment in these two streams was generally distributed over a linear 22 RM reach making it more susceptible to a stochastic event. Its occurrence has become more sporadic in 10 years. A shrinking distribution, declining population size, and lack of recent evidence of recruitment suggest that the population may be losing viability and trending towards extirpation.

Observations on habitat conditions and the state of the mussel community were made a decade apart (Hoggarth et al. 1995, Hoggarth 1997; M.A. Hoggarth, pers. comm., 2006). By 2006, sedimentation had dramatically increased and good mussel habitat had become sporadic. Large habitat patches have interstitial spaces clogged with sediment. Excessive mud binds gravel and cobble together to form a cement-like armored bottom (pers. obs), obliterating juvenile habitat and making it difficult for *Epioblasma* species to vertically migrate. Overall mussel abundance has declined and unionid recruitment has become very low and limited to environmentally tolerant species (pers. obs.). The Asian clam (*Corbicula fluminea*) was present in the 1990s, but no more than 77 were recorded at a given site (Hoggarth 1997). They currently occur in extremely-high densities (>100/ft^2 but unmeasured, pers. obs.) at the best snuffbox/catspaw site (~RM 13), and muskrats have switched diets there from unionids to Asian clams. Unstable substrates and excessive sediment levels at other sites have reduced habitat for all bivalves making both mussels and clams uncommon (pers. obs.). Sloughing stream banks and high debris dams were common in 2006 and cattle were observed in unfenced riparian areas in the snuffbox reach (S.A. Ahlstedt, USGS retired, pers. comm., 2006). In addition to collapsing banks, sources of sedimentation include silvicultural activities (G. Zimmerman, EI, pers. comm., 2006) and extensive row cropping in the lower watershed (primarily corn and soybeans, pers. obs.). Channelization and urbanization impacted mussels from northern Coshocton County upstream (Hoggarth 1997). Oil and gas development is also located in the watershed and may accelerate given high recent prices.

North Fork Hughes River

The North Fork Hughes River is a westerly flowing tributary of the Hughes River in the lower Little Kanawha River system in northwestern West Virginia. The snuffbox was found at one of six North Fork sites sampled (numbers and shell condition not noted) during a 1981-82 survey of the Little Kanawha River system (Schmidt et al. 1983). A total of 41 L adult (all were eroded) individuals (23 reported as gravid) were reported at 5 of 31 sites located over a <1.5 mile reach in North Fork State Park, Richie County, sampled in 1993 (J. Lee, ESI, pers. comm., 2003). At least 10 L individuals were found at a site in the park in 1997 (B. Sietman, Minnesota Department of Natural Resources, pers. comm., 2003) and a single FD specimen was collected at an additional site downstream in 2001 (J. Lee, ESI, pers. comm., 2003). This small snuffbox population is declining, currently restricted to <4 RMs, but may continue to be viable.

Threats in the Little Kanawha River system, summarized by Schmidt et al. (1983), primarily included oil and gas exploration and inadequate wastewater treatment (no WWTPs were located in the watershed during the survey), with secondary threats being coal mining (coal fines were noted in most streams) and silvicultural activities. A dam recently built a mile upstream of the short snuffbox reach may adversely affect this tenuous population.

Elk River

The Elk River is a major 181 RM tributary in the lower Kanawha River system draining central West Virginia flowing west to the Kanawha at Charleston. The snuffbox was overlooked during a 1978-79 survey of 15 sites and museum search (Taylor and Hughart 1981). R shells were recorded at 3 of 21 sites (including most of Taylor and Hughart’s sites) below Sutton Reservoir during a 1991-92 survey (Clayton 1994). Two L/one FD specimens were collected in 1991, three L in 1992, two L in 1994, and three L in 1995 in eastern Kanawha County, the smallest being 1.5

inches and ~5 years (ESI personnel, pers. comm., 2003). Portions of the Elk below Sutton Reservoir have been surveyed since 2002 (B. Douglas, Service, pers. comm., 2005). Collectively, 16 L individuals were sampled at eight sites (1-5 per site) in a 13 RM reach in Kanawha County in 2002 and 4 L individuals were found at four sites in 2004 over a 16.8 RM reach further upstream in northeastern Kanawha and Clay Counties. The medium-sized population extends over 30 RMs, is viable, and has improved since the 1970s.

Landuse is primarily in forest, agriculture, and occasional towns. Primary threats include silvicultural activities, coal mining, and natural gas exploration and production (Wood and Raley 2000). Riparian and floodplain roads and development raise concerns with contaminant runoff. Straight piping, sedimentation (especially from Big Sandy Creek in northeastern Kanawha County), and localized channel alterations are also threats (R. Winterringer, ESI, pers. comm., 2005). Sutton Dam impounds ~15 RMs and impacts tailwater habitat.

Tygarts Creek

Tygarts Creek is a small north-flowing southern tributary of the Ohio River in northeastern Kentucky. Thirteen snuffbox were reported from 1 of 5 sites (an unknown number of other sites were visited) sampled in 1977 (Taylor 1980). FD specimens are also known from 1981 and 1987 (R.R. Cicerello, KSNPC retired, pers. comm., 2003). Nine L individuals (8 male, 1 female; W.R. Haag, USFS, pers. comm., 2006) and 36 FD specimens (OSUM 29086) were found at two sites, respectively, in 1988, while 1 L/2 FD were reported from at least two sites in 1995 (R.R. Cicerello, KSNPC retired, pers. comm., 2003). R specimens were sampled at two of eight sites in 1998 (R.R. Cicerello, KSNPC retired, pers. comm., 2006). The mussel population appeared "healthy, stable and replenishing itself" in 1977 (Taylor 1980), but the small snuffbox population, if extant, has recently declined. Threats include sedimentation from agriculture, municipal wastes, septic tank drains, quarries, and silvicultural activities (Burr and Warren 1986).

Scioto River system

The Scioto River system, central and south central Ohio, is a major northern tributary of the upper Ohio River. The system was one of the most routinely-sampled watersheds for mussels (mostly OSUM records) and historically harbored a large and thoroughly dispersed snuffbox population in the main stem and 16 tributaries. The system was either exceptional for its snuffbox population or it provided a general historical perspective of what researchers may have found if other systems had been as thoroughly sampled. Sizable populations were noted in at least the Olentangy River, Big Darby Creek, and Big Walnut Creek. Development associated with the Columbus metropolitan area, located in the heart of the watershed, has taken a major toll on the aquatic fauna. The mussel fauna was heavily impacted by the 1850s (Higgins 1858), when pollutants included wastes from sawmills, breweries, and slaughterhouses (Stansbery 1962). Only six fish species were found in the Scioto River 100 years ago (Trautman 1981). Currently, 90-95% of the normal summer-fall flow in the river consists of WWTP discharges (Yoder et al. 2005). Museum records indicate that the snuffbox had completely disappeared from the main stem by the 1970s. A series of reservoirs around Columbus disrupted habitat and eliminated or reduced populations (e.g., Olentangy, Scioto Rivers; Alum, Big Walnut, Deer Creeks). Currently, remnant populations remain in six streams making the snuffbox precariously close to extirpation throughout this once rich system.

Olentangy River

The Olentangy is a major headwater tributary of the Scioto River, draining central Ohio and flowing south to its confluence in Franklin County. OSUM snuffbox records date to the 1870s, although most are from the 1950s and 1960s. The snuffbox was reported from 15 of 31 main stem sites collected during a 1960-61 survey, when it appeared "fairly common" in the lower river (Stein 1963). Vouchers housed at OSUM validate actual numbers collected (e.g., OSUM 4911-17, OSUM 4602-23). A single L individual in southern Delaware County and two FD specimens in eastern Marion County were found among 30 sites in 1989, with R shells at 7 other sites (Hoggarth 1990). The small population has declined (Hoggarth 1990) and viability is unknown.

The snuffbox was eliminated from the lower Olentangy by developmental activities, highway construction, sedimentation, and channelization; Columbus metropolitan area suburbs dominate the lower watershed and the Delaware WWTP empties into the river (Stein 1964, 1973). Ten mostly low-head dams are known from throughout the stream (http://www.ohiodnr.com/water/dsafety/lowhead_dams/lowhead_ locations_map.htm). Agricultural and developmental sources of sedimentation continue to be a threat (Hoggarth 1990).

Big Darby Creek

Big Darby Creek is one of the major tributaries draining the northwestern portion of the Scioto River system in central Ohio. The Big Darby Creek system has more species of mussels (41) than any stream its size in North America (Watters 1994). Dozens of large OSUM lots of snuffbox date to the late 1950s; six Pickaway County collections near Orient in 1962 alone had 250 L/FD specimens. Surveys of 42 main stem sites in 1986 and 49 sites (the same 42 sites plus 7 more) in 1990 were conducted by Watters (1990, 1994). Combining the data from both years, 80 L/FD snuffbox were collected at 22 sites, with R shells from 5 other sites (Watters 1994). The population in 1990 occurred in a reach from ~RM 11.5-42.5. The snuffbox was recruiting (Watters 1994); four individuals during both 1986 (L) and 1990 (L/FD) were 2-5 years. The overall population trend over the past 40 years has been downward. Between 1986 and 1990, the number of L/FD specimens was reduced from 54 to 16 and its distribution declined from 17 to 8 sites. Two FD specimens were found at sites in Franklin (1996) and Pickaway (2000) Counties, and three other sites produced R specimens (OSUM records). This historically large snuffbox population has declined to marginal status and its viability is questionable.

Threats include riparian deforestation, agricultural runoff, sedimentation, sand and gravel mining, heavy metals, and nutrient over-enrichment (agricultural and lawn care fertilizers) (Watters 1994, http://www.nature.org/wherewework/northamerica/states/ohio/bigdarby/habitat/art18288.html). American Rivers, a conservation organization, named Big Darby Creek to its annual 2004 top 10 list of the most endangered rivers in the country, citing unplanned development and suburban sprawl as major threats (Williams 2004).

Little Darby Creek

Little Darby Creek is the major tributary in the Big Darby Creek system, flowing in a southeasterly direction to its confluence in southwestern Franklin County. The 25 OSUM lots for this species are small (<5 specimens per lot), date to the early 1960s, and represent lower main stem sites in Madison County. One L/five FD specimens from 4 of 20 sites were found during 1963-65 with a R shell from another site (Stein 1966, OSUM records). Two FD specimens were reported from the same Union County site Stein (1966) found it L in 1964 during a survey of 14 main stem sites in 1986 and 20 sites (the same 14 sites plus 6 more) in 1990 (Watters 1990, 1994). This site yielded only R specimens in 1990, as did three other sites over both years (Watters 1990, 1994). However, the two Union County FD specimens (OSUM 1266) were recorded as "weathered" (= R) in the museum's database. Upon reexamining the specimens, they are considered to be "closer" to R than to FD (G.T. Watters, OSUM, pers. comm., 2006), indicating that no FD snuffbox specimens were found in either year of sampling. However, single FD and R specimens were collected in 1999 from the same Union County site (OSUM 66740). Overall, the snuffbox was historically known from 35 RMs. The well documented collection history illustrates the steady decline of a snuffbox population nearing extirpation.

Threats, summarized by Watters (1990), include developmental activities associated with the Columbus metropolitan area, agricultural runoff particularly from cattle access to the stream, and general sources of sedimentation. The reach below West Jefferson was considered a "dead zone" due to the lack of L/FD mussels; two point-source discharges, including a WWTP, occur downstream of the town. A lowhead dam at the mouth was removed in 1990, restoring free-flowing status to the lower main stem and removing a barrier to mussel and host fish movements.

Salt Creek

Salt Creek is an eastern tributary in the Scioto River system, south-central Ohio. All records

(OSUM) were collected in the lower main stem (Ross County) beginning in 1958. A single L individual from 1987 represents the last known record. The mussels in the system "have been heavily impacted, apparently by [the towns of] Adelphi and Laurelville, and only isolated populations remain," in addition to being impacted by runoff from silvicultural activities and highway construction (Watters 1992). Habitat is also "disturbed by nonpoint sources, especially by row cropping that has increasingly encroached on the riparian zone" (Yoder et al. 2005).

Scioto Brush Creek

This is a small western tributary of the lower Scioto River in Scioto County, south-central Ohio. The snuffbox was discovered in the 1960s (Watters 1988a). Three L/FD specimens from 2 sites and R shells from 2 other sites were collected during a 1987 survey covering 11 sites (Watters 1988a, 1992). The snuffbox population, collectively known sporadically from five sites along the lower two-thirds of stream, is small and its viability unknown. This stream was considered "fairly pristine," but there was "evidence of some [mussel] die-off below [the town of] Otway" Watters (1988a, 1992), possibly indicating municipal discharges or runoff.

South Fork Scioto Brush Creek

South Fork is a small tributary of Scioto Brush Creek, in the lower Scioto River system. A single snuffbox was found among five sites sampled in 1987 (Watters 1988a, 1992). The population, whose viability status is uncertain, can be considered a single population unit with that in its parent stream. Specific threats are unknown.

Kinniconick Creek

Kinniconick Creek is a small southern tributary of the Ohio River in northeastern Kentucky. It was reported L (without numbers) from 4 of 15 sites sampled in 1982 with R shells from an additional 2 sites (Warren et al. 1984). Single FD and L snuffbox were collected in 2001 and 2004, respectively, from sampling efforts at several sites (R.R. Cicerello, KSNPC retired, pers. comm., 2004), and a single FD specimen was found while resurveying four sites in 2005 (R.R. Cicerello, KSNPC retired, pers. comm., 2005). The snuffbox has declined in the past few decades, is considered rare, and its viability status is low at best. Threats in this remote watershed include sedimentation and other runoff from agricultural and silvicultural sources.

Little Miami River

The Little Miami River is a northern tributary of the Ohio River in southwestern Ohio, flowing south into the latter at the eastern fringe of the Cincinnati metropolitan area. Snuffbox records date from the mid-1800s, but most collections are from the past several decades. Seven FD specimens were found at 4 of 46 main stem sites (105 total system sites) surveyed during 1990-91, with 10 R shells at 6 other sites (Hoggarth 1992). The FD specimens were found in ~20 RMs mostly in Warren County. Current viability status of the small population is unknown.

The "fragile nature" of the unionid community was summarized by Hoggarth (1992). Only 30 of the 49 species historically known were considered extant. Sedimentation, agricultural runoff, and developmental activities are threats. Localized reaches were severely impacted and the "fauna is in jeopardy of drastic reduction" if trends continue (Hoggarth 1992). American Rivers named the Little Miami River to its 2005 annual top 10 list of the most endangered rivers in the country citing WWTP expansions, new transportation infrastructure, and sewage pollution as major threats (http://www.americanrivers.org/site/PageServer?pagename=AMR_MERprogress). Yoder et al. (2005) also implicated WWTPs near treatment capacity as impacting the system.

Licking River

The Licking River is a southern tributary of the Ohio River in northeastern Kentucky, flowing in a northwesterly direction to its confluence across from Cincinnati. The snuffbox occurred at 13 of 60 historical main stem sites below Cave Run Reservoir (CRR) compiled by Laudermilk (1993) and a preimpoundment site in the reservoir footprint (Clinger 1974). The population extended ~50 RMs. All collections are small (≤6 L/FD specimens) (E.L. Laudermilk, KSNPC, pers. comm., 1993). Single L and FD specimens were found at 2 sites and R shells were reported from 7 other sites among 49 sites sampled in 1991 (Laudermilk 1993; E.L. Laudermilk, KSNPC, pers. comm., 1993). Single L and FD snuffbox were collected in 1999 (R.R. Cicerello, KSNPC retired, pers. comm., 2003) and a single L individual found in 2006 (M. McGregor, Kentucky Department of Fish and Wildlife Resource [KDFWR], pers. comm., 2006). The snuffbox has become very rare, sporadic in occurrence, and its viability is questionable. Constructed in 1974, CRR impounded 38 RMs of the upper Licking (Burr and Warren 1986), destroyed snuffbox habitat, and spikes in cold tailwater releases continue to impact the river (McMurray et al. 1999). Other threats include sedimentation, agricultural runoff, and sewage pollution (Burr and Warren 1986).

Slate Creek

Slate Creek is a southern tributary of the Licking River below Cave Run Dam in east-central Kentucky. Historically, the snuffbox was considered "extremely abundant throughout the stream" by Taylor and Spurlock (1983) and collectively known from 6 of 10 sites (Laudermilk 1993). It was reported from five of six sites in 1981 (Taylor and Spurlock 1983) with museum lots of 14 and 29 specimens. Seventeen D specimens were recorded from a site in 1987 (R.R. Cicerello, KSNPC retired, pers. comm., 2003). A single FD and seven R specimens were found at three of five sites sampled in 1991 (E.L. Laudermilk, KSNPC, pers. comm., 1993), when it was considered "occasional" in distribution (Laudermilk 1993). Twelve L individuals were found (unknown number of sites) in 1992 (R.R. Cicerello, KSNPC retired, pers. comm., 2003). Subsequent sampling has produced no additional L/FD specimens; two of three sites and four of eight sites yielded only R snuffbox in 2001 and 2002, respectively (R.R. Cicerello, KSNPC retired, pers. comm., 2005). The fact that recent recruitment was observed for at least seven species (R.R. Cicerello, KSNPC retired, pers. comm., 2005) makes the snuffbox die-off perplexing. The snuffbox population has crashed. If extant, it is marginal at best with questionable viability.

Threats include sedimentation, agricultural runoff, and several mill dams which continue to impound stream habitat. During summer low flow conditions in 2002, at least one site had cattle in the stream and several sites had zero flow, algal blooms, and other manifestations of nutrient over-enrichment (R.R. Cicerello, KSNPC retired, pers. comm., 2005).

Stillwater River

The Stillwater River is a 67 RM western tributary of the Great Miami River draining southwestern Ohio. The species was collectively known from eight sites throughout the river (Watters 1988a, OSUM records). One FD specimen below Englewood Dam in Montgomery County was found among 18 sites surveyed in 1987 with R shells from 5 other sites (Watters 1988a). No other information on the small population is available and its viability is unknown. Englewood Reservoir, constructed ~1920, is a retarding basin designed to retain and slowly release flood waters (D. Johnson, Miami Conservancy District, pers. comm., 2002). A long middle reach of the stream was considered a "dead zone" (Watters 1988a), possibly attributed to residential runoff and industrial outfalls from several towns. The location of the population in the northwestern fringes of the Dayton metropolitan area is an ongoing concern.

Middle Fork Kentucky River

The Middle Fork is one of three headwater tributaries (with the North and South Forks) forming the Kentucky River, flowing in a northerly then westerly direction and draining a portion of southeastern Kentucky. The snuffbox was first reported in 1966. Three L individuals and a R shell were found at three sites in 1996 and a single L individual was collected from another site in 1997 (R.R. Cicerello, KSNPC retired, pers. comm., 2003). All sites occur within a 10-RM reach above Buckhorn Reservoir in Leslie County. The small population has unknown viability. Buckhorn Reservoir, which impounds ~10 RMs of the Middle Fork, likely destroyed snuffbox habitat and contributes to adverse conditions for mussels downstream (R.R. Cicerello, KSNPC retired, pers. comm., 2003). Other threats include coal mining, oil exploration, and impacts associated with population growth in the narrow stream valleys (Burr and Warren 1986).

Red Bird River

The Red Bird River is a north-flowing headwater tributary of the South Fork Kentucky River in Clay County, southeastern Kentucky, forming the latter at its confluence with Goose Creek. Ten FD specimens were recorded from two sites in 1988 and three L/one FD snuffbox were collected from four sites in 1995 (R.R. Cicerello, KSNPC retired, pers. comm., 2003). The small population is sporadic in the lower ~20 RMs and viability is unknown (R.R. Cicerello, KSNPC retired, pers. comm., 2003, 2006). Threats in the system (except a reservoir) are similar to those in the Middle Fork.

Red River

The Red (or North Fork Red) River is a westerly-flowing tributary of the upper Kentucky River in eastern Kentucky. No L snuffbox were found in surveys of the 9 RM reach of the Wild River section during surveys of 1980, 1986, and 1991 (Houp 1980, 1993), but two FD/one L snuffbox were found at three sites in 1988, while 5 L individuals were found in 1996 (R.R. Cicerello, KSNPC retired, pers. comm., 2006). Mostly males have been found since 2002 and are being held in captivity for culture efforts (M. McGregor, KDFWR, pers. comm., 2002). A small population persists over an ~10 RM reach in the lower section of the Red River Gorge Geological Area of the Daniel Boone National Forest (NF) in Menifee, Wolfe, and Powell Counties (R.R. Cicerello, KSNPC retired, pers. comm., 2006). Viability is unknown. Threats include coal mining, and sedimentation from silvicultural and agricultural activities (Houp 1993). The mussel community was thought to be changing to one favoring habitat generalists and host fish generalists due to increasing sedimentation (Houp 1993), both trends counter to the well-being of the snuffbox.

Rolling Fork Salt River

The Rolling Fork is a major southern tributary of the Salt River in central Kentucky, flowing in a northwesterly direction to join the Salt near its mouth. The snuffbox was first reported in 1958 (Rosewater 1959). Seven FD specimens and a single L subadult were collected in 1988 from four sites in Larue, Marion, and Nelson Counties (R.R. Cicerello, KSNPC retired, pers. comm., 2003; W.R. Haag, USFS, pers. comm., 2006). A survey of 12 main stem and 30 tributary sites in the Rolling Fork system in 1998-99 yielded no evidence of the snuffbox, prompting an investigator to consider it extirpated (Akers 2000), but occasional specimens may still be found (M. McGregor, KDFWR, pers. comm., 2006). The species is sporadically distributed over ~40 RMs of the upper river (R.R. Cicerello, KSNPC retired, pers. comm., 2006). The viability status of this small population is unknown. Most of the watershed is in agriculture. Threats include sedimentation, and agricultural and municipal runoff (Burr and Warren 1986).

Green River

A major southern tributary of the lower Ohio River, the Green River flows in a westerly direction and drains west-central Kentucky. The Green historically had one of the highest number of mussel species known from a single site outside of the Tennessee River (47 species at Munfordville, Hart County) (Stansbery 1965a). The snuffbox was recorded from five of seven sites in the 1920s, and considered "[n]ot abundant, but apparently well distributed over the system" by Ortmann (1926). Large museum collections of snuffbox from Munfordville during 1961-66 include OSUM 5353-25 specimens, OSUM 6313-22, OSUM 11844-134, OSUM 12726-18, OSUM 16551-31, OSUM 16614-46, and OSUM 17517-17, but only 6 R shells (OSUM 44922) were reported there in 1967. Ten L individuals were found among 1,235 mussels collected in 1969 from a 103 RM reach between Mammoth Cave National Park (MCNP) and Green River Lake Dam (GRLD); no L snuffbox were found brailing and diving in the remaining 203 RMs to the mouth (Williams 1969). Only "occasional empty shells" were recorded during a 17-site survey in 1981 (Clarke 1981b). Five L/FD specimens were collected at 4 of 42 sites during 1987-89 sampling in MCNP (Cicerello and Hannan 1990). Three L/six FD snuffbox were reported in the upper Green from 1984-90 (R.R. Cicerello, KSNPC retired, pers. comm., 2003). R shells were found at 2 of 40 sites during 1996-98 sampling upstream of MCNP (Cicerello 1999). A single L individual was collected in Taylor County in 2000 (J.B. Layzer, USGS, pers. comm., 2006), but no evidence of the snuffbox was reported at 6 sites in 1999, 14 in 2000, 28 in 2001, and 15 in 2003 (R.R. Cicerello, KSNPC retired, pers. comm., 2005). Once abundant and occurring over ~200 RMs, it has become exceedingly rare since the 1960s, current viability is unknown, and it may be nearing extirpation from the entire Green River system (formerly known from eight tributaries).

A series of six L&Ds was constructed on the lower half of the Green decades ago and extend upstream to the western boundary of MCNP. The upper two L&Ds destroyed snuffbox habitat, particularly L&D 6, which flooded the western portion of MCNP. Similarly, ~30 RMs of habitat was eliminated with the closure of GRLD in 1969. Various nonpoint source pollutants (e.g., sedimentation, pesticides, fertilizers) continue to impact the system and a resurgence of oil and gas exploration may threaten the snuffbox.

Wabash River system

The Wabash River is the second largest sub-basin within the Ohio River system, the watershed of the 350-mile river encompassing much of Indiana, west-central Ohio, and southeastern Illinois. Approximately 75 species were known from the river (Cummings et al. 1987, Cummings and Mayer 1988). The main stem and at least 27 streams had one of the largest snuffbox population segments. Although considered "abundant" in the Wabash and White Rivers by Call (1900), by the 1940s the snuffbox had declined to where it was "seldom in large numbers" in Indiana (Goodrich and van der Schalie 1944). It persisted in the main stem until at least the 1960s. Researchers attributed a corresponding loss of darter diversity to siltation from soil erosion, sewage, coal mine drainage, and wastes from canneries, paper mills, and dairy-product factories (Gerking 1945). A long history of the progressive degradation of the Wabash was presented by Gammon (2005). Among dozens of historical quotations in Gammon's paper, Thomas (1819) stated that "[t]he freshwater clam or muscle is so plenty, as to be gathered and burnt for lime." Its current status consists of seven highly fragmented, small populations mostly near extirpation (B.E. Fisher, INDNR, pers. comm., 2003).

Salamonie River

The Salamonie River is a southern tributary of the upper Wabash River, flowing in a northwesterly direction and draining east-central Indiana. Two historical museum records were found. Nine sites were surveyed during 1993-94 without finding any evidence of the snuffbox, and only 11 L individuals of two mussel species total (ESI 1995a). The snuffbox was rediscovered in 2004 above Salamonie Reservoir, where two L (male and female) individuals at one site and FD shells including a very small subadult were found at another site two miles away (B.E. Fisher, INDNR, pers. comm., 2005). No specimens were found at a site three miles upstream. The small population is considered to be recruiting and viable at some level. Salamonie Reservoir, constructed in the 1960s, impounds ~14 RMs of what may historically have been main stem snuffbox habitat. Agriculture is intensive in the drainage and runoff from croplands likely impacts the snuffbox population.

Tippecanoe River

The largest tributary of the upper Wabash River system, the Tippecanoe River drains north-central Indiana and flows westerly then southerly before joining the Wabash near Lafayette. Nearly all records of the snuffbox were made in the past 20 years. Single FD specimens were found in the lower main stem among 16 sites sampled in 1987 (Cummings et al. 1987, Cummings and Berlocher 1990) and 30 sites in 1991-92 (ESI 1993), the latter survey producing 48 L/FD mussel species. One L/32+ FD specimens were found at a site at the upper end of Freeman Reservoir during a 1993 drawdown that may have contributed to their demise (B.E. Fisher, INDNR, pers. comm., 2000). A single FD specimen was found below Shafer Reservoir among 13 sites sampled in 2003 (ESI 2003a). The viability status of this declining population is unknown it but appears close to extirpation (B.E. Fisher, INDNR, pers. comm., 2003).

Threats include nutrient over-enrichment, cattle access, and sedimentation (Cummings and Berlocher 1990, ESI 1993). Suitable habitat in the lower river has been compromised by two major reservoirs (Shafer and Freeman). Mussel populations below the impoundments were primarily comprised of species indicative of slow water and soft substrate habitats, in turn suggesting that riffle habitats are impacted by tailwater conditions such as temporary exposure during low flow releases. The zebra mussel is known from all of the glacial lakes in the headwaters of the system, the two lower main stem reservoirs, and are scattered throughout the main stem but in low numbers (B.E. Fisher, INDNR, pers. comm., 2001, 2006).

Embarras River

This river is a southerly flowing western tributary of the lower Wabash River, flowing in a southerly direction in southeastern Illinois. A series of museum lots represent collections dating to 1956 and yielded the snuffbox from nine main stem and two tributary sites. A total of 9 L/15 FD specimens were collected at 4 of 25 sites in 1986 (including 21 sites sampled in 1956) in Coles and Douglas Counties (Cummings et al. 1988a). Although overall mussel abundance at the 21 sites sampled in each study dropped 86%, the snuffbox was one of only five species that showed relatively stable population size over the 30-year period (Cummings et al. 1988a). Additional L/FD snuffbox from museum collections were recorded from single sites in 1988 (7 specimens), 1990 (4), 1991 (1), and 1994 (2). Three L/eight FD snuffbox were found at two sites in 1992 and one L/three FD were found at three of six sites surveyed during 2001-02 with R shells from two other sites. Since 1986, the small snuffbox population occurs sporadically at six sites over ~50 RMs of the upper river, appears viable, but has declined to some extent.

Threats to mussel populations in west-central Illinois include agricultural runoff from croplands and other activities, restricted riparian zones, poorly-treated wastewater discharges, and headwater channelization (Cummings et al. 1998). Lake Charleston is a small reservoir that isolates the two downstream-most snuffbox sites. The snuffbox population may be threatened by the zebra mussel from an infested upstream reservoir, Walnut Point (Schneider et al. 1998).

Sugar Creek

Sugar Creek is a tributary in the upper East Fork White River system, draining central Indiana east and south of Indianapolis. It flows south to join the Big Blue River in forming the Driftwood River. A single L individual from 1 site, FD specimens from 7 sites (including 11 FD from a twice-collected site), and R shells from an additional 8 sites were reported among 27 sites sampled in 1990 (Harmon 1992, 1998). The snuffbox population sporadically occurred over ~35 RMs to near the mouth in Johnson County. Only R shells were found while resampling some of Harmon's (1992, 1998) sites in 1995, 1998, and 2001 (B.E. Fisher, INDNR, pers. comm., 2003). It is questionable if the population remains extant. Agricultural runoff from croplands is a threat, primarily in the headwaters of this currently rural watershed. The lower main stem below the confluence of Youngs Creek is affected by WWTP effluents from the city of Franklin.

Buck Creek

Buck Creek is a southerly-flowing western tributary of Sugar Creek in the upper East Fork White River system east of Indianapolis. The snuffbox was found FD near the mouth and R specimens at an upstream site in 1990 (Harmon 1992, 1998). Similar to the parent stream population, the snuffbox may already be extirpated in Buck Creek (B.E. Fisher, INDNR, pers. comm., 2003). The watershed primarily is in intensive rowcrop agriculture making sedimentation and chemical runoff concerns. Some portions of the system have been channelized in the past. Its proximity to Indianapolis has led to increasing development of the upper portions of the watershed.

Muscatatuck River

The Muscatatuck River is a large westerly-flowing tributary of the upper East Fork White River in southeastern Indiana. The snuffbox was first reported from the stream by Daniels (1903). FD specimens (unknown number) were recorded at a site downstream from Graham Creek sampled in 1988 by Harmon (1989), who considered it "occasional" in abundance. Nothing else is known regarding its status. Threats in the rural watershed likely include sedimentation and agricultural runoff.

Graham Creek

Graham Creek flows southwesterly to join Big Creek in forming the Muscatatuck River in the East Fork White River system in southeastern Indiana. The species was found FD (numbers unknown) at 6 of 11 sites over ~10 RMs of the lower stream in Jennings County in 1988 (Harmon 1989) and a single FD specimen was found in 1990 (Harmon 1998). Viability status of the small population is unknown. The watershed primarily is forested, particularly in the headwaters. Agricultural lands are located along the lower main stem making sedimentation and runoff potential impacts.

Cumberland River system

Snuffbox populations are known from the main stem Cumberland River and six tributaries. With few exceptions most main stem records were made prior to the 1920s when it was locally common. It represented 22% of the relative abundance among 25 species at Goodall Island, Smith County, Tennessee (Wilson and Clark 1914). The snuffbox is considered extirpated from the main stem, where a specimen (~27 years) was last collected in 1982-83 (Koch 1983). Currently, a single tributary population may be extant placing the species on the threshold of extirpation from the entire river system.

Buck Creek

Buck Creek is a southerly-flowing northern tributary of the upper Cumberland River below Cumberland Falls in southeastern Kentucky. Three D valves were found at a site in 1981 (Clarke 1981b), and two L/one FD snuffbox were reported from 3 of 24 sites during 1983-84 (Schuster et al. 1989, unpublished data). It was also reported L (no number given) from a lower main stem site among seven sites sampled from 1987-90 (Layzer and Anderson 1992). A recent survey found only R shells at 3 of 23 sites (Hagman 2000). If extant, the declining snuffbox population in Buck Creek is very tenuous and its viability is threatened. Agricultural activities and localized gravel mining are the principle threats in the stream (Schuster et al. 1989). Wolf Creek Dam on the main stem Cumberland impounds ~12 RMs of lower Buck Creek.

Tennessee River system

The Tennessee River is the largest tributary of the Ohio River draining seven southeastern states and joining the Ohio near its mouth in western Kentucky. The snuffbox originally was known from all but the lower section of river and 17 of its tributaries. Hundreds of miles of large river habitat on the main stem have been lost under nine reservoirs with additional dams on tributaries (e.g., Clinch, Holston, Elk Rivers) (Tennessee Valley Authority [TVA] 1971). The loss of mussel resources has been substantial (Watters 2000). Muscle Shoals, the 53 RM reach in northwestern Alabama, historically harbored 69 mussel species, the most diverse mussel fauna ever known (Garner and McGregor 2001). The construction of three dams (Wilson in 1925, Wheeler in 1930, Pickwick Landing in 1940) inundated most of the mussel beds, leaving 13 RMs of flooded shoal but flowing riverine habitat. No L snuffbox have been reported at Muscle Shoals for ~100 years (Garner and McGregor 2001), and it is believed to be extirpated from the entire Tennessee River (Ahlstedt and McDonough 1995-96). It persists in only five tributaries. The Clinch River maintains a stronghold population and highly restricted populations persist in the other streams.

Clinch River

The 350-mile Clinch River is a major tributary of the upper Tennessee River originating in southwestern Virginia and flowing in a southwesterly direction to its confluence near Knoxville in northeastern Tennessee. No other river in North America has extant populations for more federally endangered (15) and candidate (4) species of mussels than does the upper Clinch above Norris Reservoir. The snuffbox was reported from 9 of 26 sites by Ortmann (1918). Museum records from Hancock County, Tennessee, during 1965-71 documented a very large population (OSUM 16772-39 L/FD specimens, OSUM 18553-89, OSUM 19315-80, OSUM 20379-159, OSUM 24559-36, OSUM 23285-140, OSUM 28135-42, OSUM 26966-28).

Collectively, 85 L individuals were found from 30 of 141 sites (RM 170-235) upstream of Norris Reservoir during 1978-83 (Ahlstedt (1991b). Quantitative sampling conducted at ≤14 fixed sites in 1979, 1983, 1988, 1994, 1999, and 2004 never produced densities >0.029/ft^2 at 4 sites with nine L individuals found at 3 of 6 sites in 2004 (including seven individuals 0.8-1.8 inches at RM 184 and one adult at ~RM 235 in Virginia) (Ahlstedt and Tuberville 1997, Ahlstedt et al. 2005). Some 77 FD specimens at five Hancock County sites (including 43 and 27 specimens at two sites) were collected in 2001 (S.A. Ahlstedt, USGS retired, pers. comm., 2003). A single L female (1.0 inch, ~8 years) was the only evidence of snuffbox found during the qualitative phase of qualitative/quantitative (~500 quadrats) sampling at Clinchport, Virginia (RM 213), in 2006 (M.J. Pinder, VDGIF, pers. comm., 2006). The snuffbox is generally distributed from ~RM 170-195 in Hancock County, then is very sporadic in Virginia (~RM 213-235) where it has recently declined (S.A. Ahlstedt, USGS retired, pers. comm., 2003). The snuffbox population is recruiting, viable, and currently stable although decreased from 40 years ago. The Clinch ranks among the five stronghold snuffbox populations rangewide.

Threats were outlined by Ahlstedt (1991b), Ahlstedt and Rashleigh (1996), and Ahlstedt and Tuberville (1997). Reservoir construction and hypolimnetic releases have taken a major toll on the mussel fauna. Norris Dam (built in 1936), Melton Hill Dam (1963), and Watts Bar Dam (Tennessee River main stem, 1942) impound ~70, ~20, and ~15 miles, respectively, of the lower half of the Clinch. Further, Norris Reservoir isolated the Clinch from its major tributary, Powell

River. Accelerating coal mining activities in the headwaters are increasingly impacting the mussel fauna (Jones and Neves 2004), and coal washing and blackwater events from slurry pond spills has resulted in increased coal fines in river sediments (S.A. Ahlstedt, USGS retired, pers. comm., 2005). Known mussel toxicants (e.g., polycyclic aromatic hydrocarbons [PAHs)], heavy metals) contaminate river sediments (Robison et al. 1996, Ahlstedt and Tuberville 1997). A coal-fired power plant is planned for the upper Clinch in Virginia that will increase mining in the upper watershed (R. Hylton, Service, pers. comm., 2006). Agricultural runoff is a concern, and has been implicated in mussel declines in a Virginia tributary, Copper Creek (Fraley and Ahlstedt 2000). Periodic chemical spills (detailed in the threats section) have a long and devastating history on the mussel fauna above Norris Reservoir (Cairns et al. 1971).

Powell River

The Powell River is the major tributary of the upper Clinch River flowing in a southwesterly direction parallel to and northwest of the Clinch in southwestern Virginia and northeastern Tennessee. The snuffbox was reported at 3 of 8 sites by Ortmann (1918), 5 of 18 sites during 1973-78 by Dennis (1981), 4 of 20 sites from 1975-78 by Ahlstedt and Brown (1980), and 4 of 15 Virginia sites in 1988-89 by Wolcott and Neves (1994). Large collections attest to former abundance including museum lots from 1967 (OSUM 19399-39 specimens, OSUM 22423-19, OSUM 19560-16) and 49 L individuals reported from 15 of 78 sites sampled in 1979, including 2 Lee County, Virginia, sites with 10 and 17 individuals (Ahlstedt 1991a). Quantitative sampling at ≤19 sites conducted periodically during 1979-2004 produced densities ≤0.0037/ft^2 at 6 sites (Ahlstedt and Tuberville 1997) with 0.0009/ft^2 recorded in 1999 in Virginia and only R shells at 6 sites in 2004 (Ahlstedt et al. 2005; N.L. Eckert, VDGIF, pers. comm., 2006). The species was last found L/FD in Tennessee during 1989-90 (Hubbs et al. 1991). The population has declined, viability is questionable, and its extirpation may be imminent (S.A. Ahlstedt, USGS retired, pers. comm., 2004).

The construction of Norris Reservoir on the Clinch River in 1936 inundated ~60 miles of the lowermost Powell and isolated the snuffbox population in each river. Headwater coal mining activities have been more of a concern than in the Clinch (Ahlstedt and Tuberville 1997). Slurry pond spills in the 1990s have been implicated in fish kills (L.M. Koch, Service, pers. comm., 1998) and fines from coal processing are commonly found in river sediments (Kitchel et al. 1981). Nutrient over-enrichment and urban runoff are secondary threats (Soucek et al. 2003).

Paint Rock River

The Paint Rock River is a southerly-flowing, northern tributary of the southern bend of the Tennessee River in northeastern Alabama and adjacent Tennessee. The snuffbox was first reported from one of six main stem sites by Ortmann (1925). No evidence was found in two surveys of 5 sites during 1965-67 (Isom and Yokley 1973) and 25 sites in 1980 (Ahlstedt 1991a). Twelve L/FD specimens were found at 4 sites between RMs 13 and 21 among 18 sites sampled in 1991 (Ahlstedt 1995-96a). The species was again absent from 10 upper main stem sites surveyed in 2002 (Godwin 2002). Four FD specimens of varying sizes were found in the lower river at two sites in 2002 (S.J. Fraley, North Carolina Wildlife Resources Commission [NCWRC], pers. comm., 2003; J.M. Smith, NCSMNS, pers. comm., 2005). A 1.3 inch FD specimen in 2003, nine FD specimens (1-2 inches) in 2004 (three of the four specimens <1.1 inches were ~3 years; pers. obs.), and 3 FD specimens in 2006 (two specimens were ~4-5 years) were collected at ~RM 31 (P.L. Freeman, TNC, pers. comm., 2005, 2006). One L female/11 FD specimens (1.1-1.9 inches, 8 males, 3 females) were found at another site (~RM 21) in 2005 (M.M. Gangloff, Auburn University Museum, pers. comm., 2007), and 2 L/16 FD (10 of them subadults ~3-4 years; pers. obs.) were collected at ~ RM 31 in 2007. The medium-sized snuffbox population exists between RMs 13-31, and is recruiting, viable, and appears to have improved since 1980.

A summary of major threats was provided by Ahlstedt (1995-96a). Destructive flood control measures (e.g., channelization, desnagging, streambank clearing) primarily conducted in the 1960s contributed to unstable riverine habitat. The rural watershed has threats that are non-point and agricultural in nature (e.g., sedimentation, chemical runoff, nutrient over-enrichment, cattle access to streams, row-cropping in riparian areas).

Elk River

This is a large (200 RMs) northern tributary flowing in a southwesterly direction in the southern bend of the Tennessee River in south-central Tennessee and north-central Alabama. Snuffbox collections have been sporadic. It was found at 2 of 9 sites in the mid-1960s (Isom et al. (1973), and a single L individual was found among 108 sites sampled in 1980 (Ahlstedt 1983). Single specimens were also reported from 4 sites sampled in the lower river in 1997 (Madison and Layzer 1998) and 16 sites sampled in 1999 (Service 1999). A very large FD specimen was found at RM 51 among four sites sampled in 2001 (Hubbs 2002, pers. obs.). Single L/FD snuffbox were found at a site in Giles County during qualitative, but not quantitative, sampling at five sites in 2005 (Ahlstedt et al. 2006); one specimen was ~4-5 years (C.F. Saylor, TVA, pers. comm., 2005). The small snuffbox population has recently recruited, exhibits some level of viability, and its numbers appear to have been relatively stable in recent history.

Impoundments have played a major role in the demise of the Elk River mussel fauna. Three large reservoirs have inundated 80 RMs (~40%) of its length). Foremost among current threats are flow releases from the headwater Tim's Ford Dam (TFD) built in 1970. Hydropeaking and hypolimnetic discharges have disrupted habitat and decimated mussel populations (Service 1999, Hubbs 2002). Thirty-five species were reported downstream of the TFD site in the mid-1960s (Isom et al. 1973), but no mussels were found within 8 RMs of the dam in 1980 (Ahlstedt 1983). Habitat conditions are marginal and mussel populations remain low even in the lower river (Hubbs 2002; J.T. Garner, Alabama Department of Conservation and Natural Resources [ADCNR], pers. comm., 2001). If tailwater temperatures were increased and flow discharges ameliorated, the Elk could become a high-priority stream for mussel reintroduction efforts (S.A. Ahlstedt, USGS retired, pers. comm., 2005). Other negative factors in the Elk include instream gravel mining, agricultural runoff, and general sedimentation impacts (Ahlstedt 1983, Service 1999).

Duck River

The Duck River is the downstream-most large tributary of the Tennessee River draining south-central Tennessee and flowing 285 RMs west to its confluence near the head of Kentucky Reservoir. Collectively, 54 of 76 historical mussel species are extant in the Duck (Ahlstedt et al.

2004, Gangloff and Folkerts 2006), which represents one of the most biodiverse streams its size in the world. The snuffbox historically occurred throughout the Duck and was locally common based on museum records 40-50 years ago (13-20+ L/FD specimens). It was recorded from 5 of 11 sites in the early 1920s (Ortmann 1924), 3 of 5 sites in the early 1930s (van der Schalie 1973), and 3 of 12 sites in the mid-1960s (Isom and Yokley 1968a), but was absent in surveys from RM 180 downstream (Dennis 1985) and 18 sites (Ahlstedt 1981) in the mid-1970s. Two L individuals were collected from 2 of 99 sites surveyed in 1979 but none in quadrats at 22 sites (Ahlstedt 1991a). A single L individual (~8 years) was discovered in Maury County among 72 sites sampled during 2000-03 (Ahlstedt et al. 2004), but none were found at 11 lower sites surveyed in 2000 (Schilling and Williams 2002). The snuffbox is very rare and its viability is uncertain.

The mussel fauna in the Duck River has rebounded in recent years (Ahlstedt et al. 2004), but the snuffbox population has not. Two major reservoirs (Kentucky and Normandy) destroyed ~25 RMs of the main stem. Among 25 historical lowhead dams (Ahlstedt et al. 2004), 3 (Shelbyville, RM 221; Lillard Mill, RM 179; and Columbia, RM 132) continue to fragment habitat in the best river reach. Built but never closed, TVAs Columbia Dam would have destroyed the last known occurrence of the snuffbox. Current threats include habitat disturbance, destruction, or fragmentation; altered species composition; modifications in natural flow regimes, particularly water withdrawals; and nutrient, contaminant, and sediment loading (TNC 2003).

Lower Mississippi River sub-basin

The snuffbox is known from a single stream in this sub-basin outside of the White River system.

St Francis River

The St. Francis River is a major tributary of the lower Mississippi with its headwaters in southeastern Missouri and flowing south into northeastern Arkansas. No Arkansas records are available for this 450-mile river (Bates and Dennis 1983, Ahlstedt and Jenkinson 1991, Jenkinson and Ahlstedt 1993-94), but snuffbox records exist for Butler, Wayne, and Stoddard

Counties, Missouri, where it was considered “locally abundant” (Oesch 1984). The species is known from above Wappapello Reservoir with the exception of a single 1969 record (S.E. McMurray, MDC, pers. comm., 2005) being absent from Missouri surveys below Wappapello Dam at 7 sites in 1983 (Bates and Dennis 1983) and 25 sites in 1986 (Ahlstedt and Jenkinson 1991). Twelve L snuffbox were sampled at 3 of 55 sites in 2002 (Hutson and Barnhart 2004). They ranged from 0.9-2.5 inches with five individuals aged at ≤4 years and the largest specimen ~11 years. Eleven and 20 L individuals were found during collections at RM 172.1 in 2005 and 2006, respectively (S.E. McMurray, MDC, pers. comm., 2006). The snuffbox is restricted to a 10-mile reach (RM 172.1-182.0) on the northeastern edge of the Ozark Plateaus in the vicinity of Sam A. Baker State Park, Wayne County (Hutson and Barnhart 2004). The population is most likely stable as opposed to improving *contra* Hutson and Barnhart (2004) who overlooked some museum collections. This medium-sized snuffbox population is viable but restricted in distribution.

Threats and management recommendations in the system were detailed by Hutson and Barnhart (2004). Wappapello Reservoir periodically inundates ~30 RMs of the upper river. Past mining activities (e.g., smelting, tailings ponds) have resulted in continuing heavy metal (e.g., lead, iron, nickel, copper, cobalt, zinc, cadmium, chromium) contamination of surface waters upstream of the snuffbox reach. Eight National Pollution Discharge Elimination System (NPDES) discharges are permitted in the upper part of the watershed. The headwaters of Wappapello Reservoir and the confluence with Big Creek (with habitat degradation primarily from mining activities) effectively limit its downstream distribution. Sedimentation and various agricultural practices are also concerns. Below the dam the river enters the Mississippi Embayment and has been drastically altered for flood control (Bates and Dennis 1983).

White River system

The 690-RM White River is a large tributary system of the western bank of the Mississippi River. A snuffbox population once occurred in the main stem and six of its larger tributaries. Highly restricted populations persist in four streams.

Buffalo River

The Buffalo River is a large eastward-flowing tributary of the middle White River in north-central Arkansas. The snuffbox was overlooked during surveys in 1910 (26 sites, Meek and Clark 1912) and 1995 (40 sites, Harris 1996), but two L individuals were found at a single site among 60 sites surveyed throughout the river in 2006 (M.W. Matthews, Arkansas State University, pers. comm., 2007). The small population occurs in the lower river in Marion County but its viability is unknown. Pollutants from developmental activities associated with resort subdivisions outside the park boundaries and excessive canoe traffic threaten Buffalo mussels (M.E. Gordon, pers. comm., 2003). A proposed impoundment on Bear Creek in Searcy County may reduce flows. A large portion of the Buffalo is designated a National River in the NPS system.

Black River:

The Black River is the largest tributary in the White River system, draining much of southeastern Missouri and northeastern Arkansas before flowing in a southerly direction into the White near Newport, Arkansas. A long, but sporadic, collection history for the snuffbox appears in the 300-RM Black. Pre-1980 records exist for sites in Lawrence County, Arkansas, and Butler County, Missouri, where the species is thought to be extant only near the headwaters in the Ozark Plateaus. A single L male (1.5 inches, ~4 years) was collected at RM 65.5, Wayne County, among 51 Missouri sites sampled in 2002 (Hutson and Barnhart 2004). The species has become extirpated from the lower river on the Mississippi Embayment including Arkansas. The snuffbox appears rare but viable at some level.

Threats to the mussel fauna in the upper Black River, described by Hutson and Barnhart (2004), included numerous public and private WWTPs, instream gravel mining, and general sedimentation from poorly-developed riparian corridors. Leakage or catastrophic failure of tailings pond dams from past lead mining have the potential to devastate riverine habitat and resident mussel populations and heavy metals in stream sediments continue to threaten this species (Schmitt and Finger 1982). Historically, hundreds of miles of the main stem and tributaries were channelized and scores of ditches dug to drain the watershed on the Mississippi Embayment.

Spring River

The Spring River is a large tributary of the Black River that drains the eastern Ozark Plateaus in south-central Missouri and northeastern Arkansas. Based on pre-1986 records, the snuffbox was known in low numbers from at least four sites in ~20 RMs of the lowermost main stem in Arkansas downstream of the South Fork Spring River confluence (Harris and Gordon 1987). A single L adult male was found in Lawrence County in 2005, and represents the first L specimen found in Arkansas in >20 years (C.L. Davidson, Service, pers. comm., 2005). Further, 53 FD (44 male, 9 female) snuffbox were collected in four large muskrat middens (C.L. Davidson, Service, pers. comm., 2005). The extent of the population is not known, but it is probably limited to a relatively few miles in the lower main stem in Lawrence and Randolph Counties, appears sizable, has improved in status, and is likely viable based on relative population size. It is threatened by developmental activities associated with retirement villages, general sedimentation, and agricultural runoff.

Strawberry River

The Strawberry River is a western tributary of the Black River draining a portion of the southeastern Ozark Plateaus in northeastern Arkansas. The only snuffbox records were from ~1983 and 1997 in the middle main stem in Sharp County (W.R. Posey, Jr., Arkansas Game and Fish Commission, pers. comm., 2003). No other details on these collections or the status of the population are known. Considering the dearth of records, the snuffbox appears to be very rare in the Strawberry and of unknown viability. Threats were outlined by TNC (2004). The watershed is composed of forests and agricultural lands in cattle production. Increased sedimentation and nutrient over-enrichment are the primary stresses to the diverse mussel fauna (39 species). Sources of sedimentation were determined to be incompatible agricultural practices, road maintenance activities, and riparian conversion. Lesser threats were gravel mining and construction activities.

Summary of current and historical populations, and population trends

The snuffbox has declined rangewide and appears to be extant in 73 of 208 streams and lakes of historical occurrence (a 65% decline). Since multiple streams essentially may comprise single snuffbox population segments (e.g., French Creek system), the actual number of extant populations is somewhat less. Some multiple stream population segments are linearly distributed (e.g., Muskingum River/Walhonding River/Killbuck Creek), thus making the entire population susceptible to single stochastic events. Extant populations with few exceptions are highly fragmented and restricted to short reaches. In addition to the 135 streams where the snuffbox is considered extirpated, other poorly sampled or unsampled stream populations of this species that were never discovered undoubtedly have been lost. For instance, snuffbox records are known from several headwater tributaries of stream systems but not from the parent stream where undocumented populations almost certainly occurred (e.g., known from Nippersink Creek but not Fox River, known from Little Mahoning Creek but not Mahoning Creek, known from Nolichucky River but not French Broad River).

To conceptualize the relative status of extant populations, they have been grouped into three general categories: 1) *stronghold populations*—sizable populations generally distributed over a significant and more or less contiguous length of stream (≥30 RMs), with ample evidence of recent recruitment, and currently considered viable; 2) *significant populations*—small generally restricted populations with limited levels of recent recruitment and viability, and susceptible to extirpatation in the foreseeable future[3]; and 3) *marginal populations*—very small and highly restricted populations, with no evidence of recent recruitment, of questionable viability, and that may be on the verge of extirpation in the immediate future (if not already extirpated). Following are the results of this scheme (individual streams within multi-stream population segments are treated separately).

1) *Stronghold populations (5 streams)*: Wolf River, Sydenham River, Bourbeuse River, French Creek, and Clinch River.
2) *Significant populations (24)*: Grand River (Michigan), Ausable River, Belle River,

Clinton River, Huron River, Davis Creek, South Ore Creek, Portage River, Grand River (Ohio), St. Croix River, Muddy Creek, Dunkard Creek, Little Shenango River, Walhonding River, North Fork Hughes River, Elk River (West Virginia), Red River, Salamonie River, Embarras River (Illinois), Paint Rock River, Elk River (Tennessee), St. Francis River, Black River, and Spring River.

3) *Marginal populations (44)*: Embarrass River (Wisconsin), Little Wolf River, Willow Creek, Maple River, Pigeon River, Pine River, Kankakee River, Meramec River, Ohio River, Allegheny River, West Branch French Creek, Le Boeuf Creek, Conneaut Outlet, Little Mahoning Creek, Shenango River, Middle Island Creek, Muskingum River, Killbuck Creek, Tygarts Creek, Olentangy River, Big Darby Creek, Little Darby Creek, Salt Creek, Scioto Brush Creek, South Fork Scioto Brush Creek, Kinniconick Creek, Little Miami River, Licking River, Slate Creek, Stillwater River, Middle Fork Kentucky River, Red Bird River, Rolling Fork Salt River, Green River, Tippecanoe River, Sugar Creek, Buck Creek (Indiana), Muscatatuck River, Graham Creek, Buck Creek (Kentucky), Powell River, Duck River, Buffalo River, and Strawberry River.

All of the streams with stronghold and significant populations are crucial for maintaining the snuffbox and eventually recovering the species. Many marginal populations are also important for recovery because they may: 1) represent the last populations in entire river systems (e.g., Buck Creek, Kentucky, Cumberland River system), 2) still be viable, 3) respond favorably to positive habitat improvements (e.g., Green, Duck Rivers) or augmentations, or 4) represent distinct genetic populations. Other populations considered marginal may actually be extirpated.

Very few snuffbox populations have displayed evidence of recent stability (e.g., Pine, Clinch [Tennessee portion only], Elk [Tennessee], St. Francis Rivers; French Creek), let alone improvement (e.g., Bourbeuse, Elk [West Virginia], Paint Rock, Spring Rivers) (Appendix III). Available information indicates that numerous streams have declining populations, including the Wolf River, one of five stronghold populations. Other extant populations considered in decline are numerous (e.g., Clinton, St. Croix, Meramec, Walhonding, North Fork Hughes, Olentangy,

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[3] This approach has the effect of including streams in Category 2 having a broad range of population quality.

Green, Tippecanoe, Embarras [Illinois], Clinch [Virginia portion only], Powell Rivers; Dunkard, Middle Island, Killbuck, Big Darby, Little Darby, Tygarts, Kinniconick, Slate, Sugar, Graham, Buck [Kentucky] Creeks). Population declines in other streams appear likely although recent trend data is lacking. Further, the available status information indicates that snuffbox population extirpations have regularly occurred in various streams in each of the past several decades. Additional extirpations will occur if this downward population trend is not arrested or reversed. Considering the prevalence and magnitude of current threats, and diminished population sizes and restricted distributions in many streams, no extant snuffbox population anywhere is completely safe from suffering population declines and potential extirpations at some point in the future. The snuffbox is already believed extirpated from Iowa, Kansas, Mississippi, and New York, while its continued existence in several other states (e.g., Alabama, Arkansas, Illinois, Virginia) is extremely perilous.

Sixty-five percent of the historical streams of occurrence have lost their populations of this species. Realistically, much more than 65% of the habitat historically available for this species no longer supports its populations. Habitat losses measured in the thousands of miles have occurred rangewide. This loss is readily apparent in larger rivers from which it is considered extirpated (e.g., Mississippi, Wisconsin, Rock, Illinois, Kaskaskia, Scioto, Wabash, East Fork White, West Fork White, Cumberland, Tennessee, Holston, White [Arkansas] Rivers), in addition to thousands of miles of habitat in scores of smaller streams. Reductions in range have also occurred within those large rivers having small and very restricted extant populations (e.g., >99% of the 981 RM length of the Ohio River main stem, >95% of the 150 RM upper Green River, >95% of the 150 RM upper Duck River, >90% of the 225 RM upper St. Francis River, >95% of the 300 RM Black River). Even in one of the stronghold populations, the Clinch River, the snuffbox is restricted to ~15% of the 350 RM main stem. Considering that the species may not have been generally distributed throughout the length of the aforementioned streams, the level of range reduction and habitat loss from this perspective is nevertheless profound and easily measures several thousand linear miles. Accordingly, the elimination of this species from scores of streams and thousands of miles of stream reaches indicates catastrophic population losses and a precipitous decline in overall abundance. It would not be unreasonable to estimate that total range reduction and overall population losses for the snuffbox each approximate, if not exceed, 90%.

Given this compilation of current distribution, abundance, and status trend information, the level of population decline of the snuffbox is clear. The following section reinforces the elevated level of imperilment of this species by adding threat factors to the equation.

Summary of status and threats

A. The present or threatened destruction, modification, or curtailment of its habitat or range.

The vast majority of mussel declines in the Mississippi River and Great Lakes Basins are the result of habitat loss and degradation (Stansbery 1971, Neves 1993). Juvenile mussels appear to be more susceptible to environmental perturbation than are adults (Yeager et al. 1994). A strong correlation between populations of the snuffbox and its host fish (logperch) suggests that host specialists are vulnerable to both habitat degradation and fish host declines also attributed to degraded habitats (Sherman Mulcrone 2004). The chief causes of the general decline of mussels include impoundments, channelization, chemical contaminants, mining, sedimentation, and developmental activities (Neves 1991, 1993; Williams et al. 1993; Richter et al. 1997; Neves et al. 1997; Watters 2000). Humankind is placing enormous pressure on mussel populations by increasing demands on freshwater ecosystems (Naiman and Turner 2000, Strayer et al. 2004, Strayer 2006). Bourgeoning human populations will invariably increase the likelihood that many of the factors in this section will continue to impact snuffbox populations.

Impoundments

The most egregious manifestation of habitat alteration in riverine ecosystems is attributed to impoundments (Yeager 1993). Historical population losses due to impoundments have probably contributed more to the decline and imperilment of the snuffbox than any other single factor.

The impacts of impoundments on warmwater streams was evaluated by Yeager (1993), while the specific effects of impoundments on freshwater mollusks was reviewed by Suloway et al. (1981a), Williams et al. (1992), Neves et al. (1997), and Watters (2000).

Dams interrupt most of a river's ecological processes by eliminating productive riffle and shoal habitats; modifying flood pulses; controlling impounded water elevations; altering water flow, sediments, nutrients, and energy inputs and outputs; increasing depth; decreasing habitat heterogeneity; decreasing stability due to subsequent sedimentation; blocking host fish passage; and isolating mussel populations from fish hosts (Williams et al. 1992, Yeager 1993, Neves et al. 1997, Khym and Layzer 2000, Watters 2000). Even small lowhead or mill dams can have some of these effects on mussels by reducing species richness and eveness, and blocking host fish movements (Watters 1996, Dean et al. 2002). Sediment accumulations behind dams of all sizes adversely modify habitat and preclude the occurrence of nearly all riverine mussels and many of their host fishes. The reproductive process of riverine mussels is generally disrupted by impoundments. The snuffbox does not occur in reservoirs lacking riverine characteristics and it is unable to successfully reproduce and recruit under reservoir conditions. It rarely persists in large rivers with dams (e.g., Ohio River) and then only in sections retaining riverine characteristics (generally tailwaters).

In addition, dams can also seriously alter downstream water quality and riverine habitat, and negatively impact or eliminate tailwater mussel populations (Allan and Flecker 1993, Neves et al. 1997, Watters 2000). These changes include thermal alterations immediately below dams; changes in channel characteristics, habitat availability, and flow regime; daily discharge fluctuations from hydropeaking (flow releases during peak electricity generating times); increased sediment loads from bank sloughing; and altered host fish communities. Hypolimnetic releases (cold water released from the bottom of deep reservoirs) from large non-navigational dams; scouring of the river bed from highly fluctuating, turbulent tailwater flows; and bank slumping due to rapid water level rises during discharge periods have also been implicated in the demise of mussel faunas (Gordon 1982, Miller et al. 1984, Layzer et al. 1993, McMurray et al. 1999, Vaughn and Taylor 1999). Many miles are needed to ameliorate hypolimnetic tailwater effects before allowing rivers to create conditions suitable for population recolonization (Vaughn and Taylor 1999). There is no evidence that the snuffbox can successfully reproduce and recruit in hypolimnetic tailwater conditions.

Seasonally altered flow regimes in tailwaters, even when thermally conducive for riverine mussel populations, may preclude successful recruitment. Temporal discharges during peaking operations of hydroelectric facilities may affect mussels in several ways (Layzer and Scott 2006). Daily peaking operations may negatively affect fertilization rates by diluting sperm concentrations. Peak discharges during times of glochidial release can force host fishes into habitats with few mussels thus lowering infestation rates. Conversely, if host fishes that become infested during minimum flows are forced to seek hydraulic refugia, that habitat may be unsuitable for newly excysted juveniles. Furthermore, increases in dam discharge during spring and early summer (when many mussel glochidia are dropping off their host fish) may result in shear forces sufficiently high to prevent the newly-metamorphosed juveniles from successfully settling into suitable habitat (Layzer and Madison 1995, Hardison and Layzer 2001). A study of the geomorphic effects of lowhead overflow dams in southeastern Kansas concluded that the impacts downstream were substantial and manifest in channel widening, channel erosion associated with plungepools, and formation of unstable gravel bars (Juracek 1999). These factors all act to decrease mussel habitat.

The significant loss of mussel species from the Cumberlandian Region (Cumberland and Tennessee River systems) due to impoundments was summarized by Watters (2000). Approximately 90% of the 562-mile length of the Cumberland River downstream of Cumberland Falls is either directly impounded by Corps structures (three L&Ds and Wolf Creek Dam [WCD]) or otherwise impacted by cold tailwater releases from WCD and Corps dams on tributaries. WCD also eliminated historical snuffbox populations in the impounded reaches of some Cumberland River tributaries (e.g., Buck, Beaver Creeks; Little South Fork). Corps impoundments on Cumberland River tributaries (e.g., Obey River, Caney Fork) have inundated ~100 RMs of additional potential riverine habitat for the snuffbox. Collectively, hypolimnetic releases from WCD (upper Cumberland River), Dale Hollow (Obey River), and Center Hill

(Caney Fork) Dams also impact ~200 RMs of riverine habitat in the Cumberland River system. From dams alone, larger river snuffbox habitat has virtually been eliminated from the entire Cumberland River system.

Over 2,300 RMs (~20%) of the Tennessee River and its tributaries were impounded behind 36 TVA dams by 1971 (TVA 1971). These include nine main stem and several other dams on snuffbox tributary streams (e.g., Holston, South Fork Holston, Clinch, Elk, Duck Rivers; Bear, Cedar Creeks). Further, main stem impoundments have eliminated historical snuffbox populations and habitat in the impounded lower portions of tributary streams (e.g., Powell, Little, Sequatchie, Paint Rock, Flint, Elk, Duck Rivers; South Chickamauga, Bear Creeks).

Snuffbox streams of all sizes have been impounded leaving isolated patches of suitable habitat. Included are streams with navigational L&Ds (e.g., Mississippi, Illinois, Des Plaines, Ohio, Allegheny, Monongahela, Muskingum, Kentucky, Green, White [Arkansas] Rivers), major dams (e.g., Kalamazoo, Tittabawassee, St. Croix, Wisconsin, Illinois, Sangamon, Kaskaskia, Wakarusa, Marais des Cygnes, Shenango, Walhonding, Elk [West Virginia], Scioto, Little Miami, Licking, Middle Fork Kentucky, Salt, Green, Nolin, Barren, Wabash, Salamonie, Mississinewa, Eel, Tippecanoe, Duck, St. Francis, White, Black Rivers; Nippersink, Pymatuning, Sugar [Ohio], Big Walnut, Alum, Fall Creeks), and hundreds of lowhead dams (e.g., Wolf, Little Wolf, Muskegon, Grand [Michigan], Maple, Kalamazoo, St. Joseph, Pigeon, Cass, Pine, Belle, Clinton, Huron, Maumee, Auglaize, Sandusky, Grand [Ohio], Wisconsin, Rock, Des Plaines, Kankakee, Mahoning, Tuscarawas, Walhonding, Hocking, Scioto, Olentangy, Great Miami, Wabash, Eel, Mississinewa, East Fork White, West Fork White, Flatrock, Duck Rivers; Swan, Tonawanda, Middle Island, Big Walnut, Alum, Big Darby, Little Darby, Slate, Sugar, Richland Creeks). The Duck River alone had at least 25 mill dams (Ahlstedt et al. 2004). The Huron River in southeastern Michigan has 11 major dams, and over 90 dams in the system overall, or 1 dam for every 10 square miles of the ~900 square mile watershed (http://www.quest outdoors.net/locs/ michigan/huron_mi/). Other streams with at least 10 lowhead dams include the Olentangy (10), Great Miami (14) (http://www.ohiodnr.com/water/dsafety/lowhead_dams/lowhead_locations_ map.htm), and West Fork White (12) (http://www.indianaoutfitters.com/white_river_w.html) Rivers. Many of these dams have contributed to the reduction or loss of snuffbox habitat and populations.

Beaver dam ponds change streams from lotic to lentic conditions thereby disrupting habitat for mussels (Rudzite 2005) and fishes (Collen and Gibson 2001). Beaver dams on streams affect hydrological parameters (e.g., elevated water temperatures and nitrogen levels), shift fish communities to larger bodied, lentic-tolerant forms, block fish movements, and sedimentation buildup impairs substrates, particularly spawning habitats (Collen and Gibson 2001, Rudzite 2005). The beaver is distributed throughout the range of the snuffbox but is not anywhere considered a significant threat.

Channelization

Dredging and channelization activities have profoundly altered riverine habitats nationwide, and their specific effects on freshwater mollusks were reviewed by Hartfield (1993), Neves et al. (1997), and Watters (2000). Channelization impacts many physical (e.g., accelerated erosion, increased bedload, reduced depth, decreased habitat diversity, geomorphic instability, riparian canopy loss) and biological (e.g., decreased aquatic biodiversity, changed species composition and abundance, decreased biomass, reduced growth rates) characteristics of streams (Hartfield 1993, Hubbard et al. 1993). Channel construction for navigation has been shown to increased flood heights (Belt 1975), and is partially attributed to a decrease in stream length and increase in gradient (Hubbard et al. 1993). Flood events may thus be exacerbated, conveying into streams large quantities of sediment, potentially with adsorbed contaminants. Channel maintenance may result in profound impacts downstream (Stansbery 1970), including increased turbidity that may impede sight-feeding host fishes and disrupted attractant mechanisms mussels use to lure fish hosts (Hartfield and Hartfield 1996), and sedimentation that smothered juvenile mussels (Ellis 1936).

Channel maintenance operations for barge navigation have impacted habitat for the snuffbox in several large rivers. Impacts associated with barge traffic, which include construction of fleeting areas, mooring cells, docking facilities, and propeller wash, also disrupt habitat. Navigation maintenance activities may continue to adversely affect this species in the upper Ohio River. Hundreds of miles of snuffbox streams (e.g., Grand, Kankakee, Sangamon, Kaskaskia, Olentangy, Salamonie, Mississinewa, Eel, Vermilion, North Fork Vermilion, Embarras, Paint Rock, St. Francis Rivers; Tonawanda, Killbuck, Chickamauga, Bear Creeks) were dredged and channelized decades ago, and some populations have been eliminated. The entire length of the Kankakee River in Indiana was channelized by 1917 (http://www.in.gov/dnr/outdoor/canoe/kankakee.htm). In addition, hundreds of drains (formed from ditching low-gradient creeks and swales) were created around 100 years ago in Illinois, Michigan, and other Midwestern states. Stream channelizations were ill-conceived attempts ostensibly to reduce flooding, drain low-lying areas, and "improve" storm flow runoff.

Contaminants

Contaminants contained in point and non-point discharges can degrade water and substrate quality and adversely impact mussel populations. Although chemical spills and other point sources of contaminants may directly result in mussel mortality, widespread decreases in density and diversity may result in part from the subtle, pervasive effects of chronic, low-level contamination (Naimo 1995). The effects of heavy metals, ammonia, and other contaminants on freshwater mussels were reviewed by Mellinger (1972), Fuller (1974), Havlik and Marking (1987), Naimo (1995), Keller and Lydy (1997), Neves et al. (1997), and Newton (2003) while a series of papers appeared in Farris and Van Hassel (2006).

The effects of contaminants (e.g., metals, chlorine, ammonia) are profound on juvenile mussels (Robison et al. 1996, Bartsch et al. 2003, Augspurger et al. 2003, Mummert et al. 2003), which may readily ingest contaminants adsorbed to sediment particles while pedal feeding (Newton 2003), and on glochidia, which are very sensitive to some toxicants (Goudreau et al. 1993, Jacobson et al. 1997). Several of these studies were conducted on the Clinch River (Goudreau et al. 1993, Robison et al. 1996, Jacobson et al. 1997), which has a stronghold snuffbox population.

Mussels are very intolerant of heavy metals (Keller and Zam 1991, Havlik and Marking 1987), and even at low levels, certain heavy metals may inhibit glochidial attachment to fish hosts (Huebner and Pynnönen 1992). Cadmium appears to be the heavy metal most toxic to mussels (Havlik and Marking 1987), although chromium, copper, mercury, and zinc also negatively affect biological processes (Naimo 1995, Keller and Zam 1991, Jacobson et al. 1997, Keller and Lydy 1997, Valenti et al. 2005).

Among pollutants, ammonia warrants priority attention for its effects on mussels. It has been shown to be lethal to juveniles at concentrations as low as 0.7 parts per million (ppm) total ammonia nitrogen, normalized to pH 8 (range = 0.7-19.7 ppm) and lethal to glochidia at concentrations as low as 2.4 ppm total ammonia nitrogen, normalized to pH 8 (range = 2.4-10.4 ppm) (Augspurger et al. 2003). The un-ionized form of ammonia (NH_3) is usually attributed as being the most toxic to aquatic organisms (Mummert et al. 2003), although the ammonium ion form (NH_4^+) may contribute to toxicity under certain conditions (Newton 2003). Documented toxic effects of ammonia on freshwater bivalves include reduced survival (Augspurger et al. 2003, Mummert et al. 2003, Newton et al. 2003), reduced growth (Zischke and Arthur 1987, Newton et al. 2003) and reduced reproduction (Zischke and Arthur 1987, Hickey and Martin 1999). Ammonia has also been shown to cause a shift in glucose metabolism (Chetty and Indira 1995) and to alter the metabolic utilization of total lipids, phospholipids, and cholesterol (Chetty and Indira 1994).

Sources of ammonia are agricultural (e.g., animal feedlots, nitrogenous fertilizers), municipal (e.g., effluents of out-dated WWTPs), and industrial (e.g., waste products) as well as from precipitation and natural processes (e.g., decomposition of organic nitrogen) (Goudreau et al. 1993, Hickey and Martin 1999, Augspurger et al. 2003, Newton 2003). Atmospheric deposition is one of the most rapidly growing sources of anthropogenic nitrogen entering aquatic ecosystems and livestock are the largest global source of atmospheric ammonia (Robarge et al. 2002). Agricultural sources of ammonia may be highly variable over time (Hickey and Martin 1999), confounding concentration readings. Toxic effects of ammonia are more pronounced at higher pH and water temperature because the level of the un-ionized form increases as a percentage of total ammonia (Mummert et al. 2003, Newton 2003). Therefore, this contaminant may become more problematic for juvenile mussels during low flow, high temperature periods (Newton et al. 2003, Cherry et al. 2005, Cooper et al. 2005). In stream systems, ammonia frequently is at its highest concentrations in interstitial spaces where juvenile mussels live and feed (Whiteman et al. 1996, Hickey and Martin 1999, Augspurger et al. 2003, Cooper et al. 2005), and may occur at levels that exceed water quality standards (Frazier et al. 1996). U.S. Environmental Protection Agency (EPA) established ammonia water quality criteria (WQC) (EPA 1985) may not be protective of mussels (Augspurger et al. 2003, Sharpe 2005). Ammonia is considered a limiting factor for survival and recovery of some mussel populations due to its high level of toxicity and because the highest concentrations occur in their microhabitats (Augspurger et al. 2003).

Other common contaminants associated with households and urban areas, particularly those from industrial and municipal effluents, may include heavy metals, chlorine, phosphorus, and numerous other toxic compounds. Numerous pharmaceuticals, hormones, and other organic wastewater contaminants (OWCs) were detected downstream from urban areas and livestock production (Kolpin et al. 2002). These OWCs (82 of the 95 they tested for) originated from a wide range of residential, industrial, and agricultural sources, and some are known to have deleterious effects upon aquatic organisms. Wastewater is discharged through NPDES permitted (and some non-permitted) sites throughout the country. Elimination sites are ubiquitous in watersheds with snuffbox populations, providing ample opportunities for pollutants to impact the species (e.g., >250 NPDES sites in the Meramec River system, Roberts and Bruenderman [2000]).

Agricultural sources of chemical contaminants are considerable and include two broad categories: nutrients and pesticides (Frick et al. 1998). Stream ecosystems are impacted when nutrients (e.g., nitrogen, phosphorus) are added at concentrations that cannot be assimilated, resulting in over-enrichment, a condition exacerbated by low-flow conditions. Nutrient over-enrichment results primarily from runoff from livestock farms, feedlots, and fertilizers from row crops (Peterjohn and Correll 1984). Various OWCs may also be associated with livestock concentrations (Kolpin et al. 2002). Nutrient levels tend to be more prevalent in streams with grassy versus wooded riparian buffers (Morris and Corkum 1996), stressing the importance of forested buffer zones for filtering nutrients (Peterjohn and Correll 1984). Nitrate concentrations are high in surface waters downstream of agricultural areas (Mueller et al. 1995), and they act as endocrine disruptors in vertebrates (Guillette and Edwards 2005), although their effects on mussels is untested. Excessive nitrogen concentrations were thought to be detrimental to juvenile (Rudzite 2005) as well as the adult (Bauer 1988) freshwater pearl mussel, *Margaritifera margaritifera* (Linnaeus, 1758), a species highly specialized to low-nutrient waters. There was a negative correlation between growth and eutrophication, longevity was reduced as the concentration of nitrates increased (Bauer 1992), and there was a positive linear relationship between mortality and nitrate concentration (Bauer 1988). Juvenile mussels utilizing interstitial habitats are also particularly affected by depleted dissolved oxygen (DO) levels resulting from nutrient over-enrichment (Sparks and Strayer 1998). Increased risks from bacterial and protozoan infections to eggs and glochidia may also pose a threat (Fuller 1974).

Pesticide runoff from row crops commonly ends up in streams where the effects may be profound (Fuller 1974, Havlik and Marking 1987). Commonly-used pesticides have been implicated in a North Carolina mussel die-off (Fleming et al. 1995). Organochlorine pesticides are still detected in streams and aquatic organism's decades after their use has been banned, and may still be found at levels that often exceed chronic exposure criteria for the protection of aquatic life (Buell and Couch 1995, Frick et al. 1998). Fertilizers and pesticides are also commonly used in developed areas. These contaminants collectively have the potential to impact all snuffbox populations.

Chemical spills occur often and are devastating for isolated populations of rare, relatively immobile species with limited potential for recolonization, such as mussels (Wheeler et al. 2005). Numerous streams throughout the range of the snuffbox have experienced mussel and fish kills from toxic chemical spills, especially in the upper Tennessee River system in Virginia (Cairns et al. 1971; Neves 1986, 1991; Jones et al. 2001; Schmerfeld 2006). Chronic mercury contamination from a chemical plant on the North Fork Holston River, Virginia, destroyed a diverse mussel fauna (Brown et al. 2005) including a snuffbox population. Catastrophic pollution events, coupled with pervasive sources of contaminants (e.g., municipal and industrial pollution, coal-processing wastes), have contributed to the decline of the snuffbox and other species in the Clinch (Neves 1991). An alkaline fly ash pond spill in 1967 and a sulfuric acid spill in 1970 on the Clinch River at Carbo, Virginia, caused a massive mussel kill for up to 12 RMs downstream from a power plant (Cairns et al. 1971). Natural recolonization has not occurred in the impacted river reach (Ahlstedt 1991a), possibly due to persistent copper contamination from the power plant at Carbo (Wilcove and Bean 1994). Sediment from the upper Clinch River was found to be toxic to juvenile mussels (Ahlstedt and Tuberville 1997), who surmised that the presence of toxins in the Clinch River "could explain some of the decline and lack of recruitment of mussels in the Virginia portion of the Clinch."

One recent major spill in the upper Clinch River, Virginia, eliminated ~18,000 mussel individuals of several species (Jones et al. 2001, Schmerfeld 2006). The death toll included ~750 individuals of three federally listed species (Schmerfeld 2006). A catastrophic spill in 1999 impacted ~10 RMs of the Ohio River and resulted in the loss of an estimated one million mussels, including two federally listed species (W.A. Tolin, Service retired, pers. comm., 2002). Chemical spills will invariably continue to occur and have the potential to reduce or eliminate snuffbox populations.

Mining

The mining of various commodities have adversely impacted many mussel populations (Neves 1993, Williams et al. 1993). Among mining activities, the extraction of coal has a long and well-documented history of affecting mussels (Ortmann 1909c, Kitchel et al. 1981); effects on mussels were reviewed by Neves et al. (1997). Various impacts have been identified, particularly acid mine drainage (AMD) (Soucek et al. 2003). The low pH associated with AMD can reduce glochidial encystment rates (Huebner and Pynnönen 1992) therefore affecting recruitment. Acid-soluble metals that may be toxic to mussels (e.g., copper, zinc) are mobilized by AMD (Soucek et al. 2003). Powell River mussel populations were inversely correlated with coal fines, which decreased filtration times and increased movements in laboratory-held mussels (Kitchel et al. 1981). Sedimentation runoff from mines may clog interstitial spaces (Branson and Batch 1972).

Mussels also appear to be among the most sensitive test organisms to PAHs (Weinstein 2001, Weinstein and Polk 2001), which are associated with fossil fuels. Although most PAHs are relatively non-toxic in acute toxicity tests (Veith et al. 1983), an important subset of PAHs, termed ultraviolet (UV)-induced PAHs, are several orders of magnitude more toxic in the presence of sunlight (Weinstein 2002). In the absence of UV, PAHs are not acutely toxic to test glochidia (Weinstein 2002). Some organisms (e.g., fish) can repair UV-induced PAH biological damage at night when not exposed to sunlight (Oris and Giesy 1986). Exposure of paper pondshell, *Utterbackia imbecillis* (Say, 1829) glochidia over various photoperiods to fluoranthene, a common UV-induced PAH, indicated that glochidia suffered cumulative damage during light periods with no evidence of biological repair during dark periods (Weinstein 2002). Mussels that lack the ability to repair this damage will therefore be more susceptible to UV-induced toxicity of PAHs in the environment than those organisms with this ability (Weinstein 2002).

Coal mining activities have affected many snuffbox populations (e.g., upper Ohio River system in western Pennsylvania, West Virginia, southeastern Ohio, and eastern Kentucky; lower Ohio and Mississippi River systems in southeastern Illinois and western Kentucky; upper Cumberland River system in southeastern Kentucky and northeastern Tennessee; upper Tennessee River system in southwestern Virginia) (Ortmann 1909c, Neel and Allen 1964, Kitchel et al. 1981, Anderson et al. 1991, Gordon 1991, Bogan and Davis 1992c, Layzer and Anderson 1992, Ahlstedt and Tuberville 1997, Milam et al. 2000, Warren and Haag 2005). Acid mine drainage was implicated in the mussel die-off in the Little South Fork (Anderson et al. 1991, Layzer and Anderson, 1992, Ahlstedt and Saylor 1995-96, Warren and Haag 2005). Tailings pond failures have impacted aquatic resources (e.g., Powell River, Virginia; L.M. Koch, Service, pers. comm., 1996). A decline of the snuffbox and other imperiled mussels in the Powell was blamed coal mining impacts (Ahlstedt and Tuberville 1997). Increased mining activities in the upper Clinch River system is resulting in “blackwater” and “graywater” events (Jones and Neves 2004). Anecdotal evidence suggests that coal fines are increasing in the Clinch reach harboring a stronghold snuffbox population (S.A. Ahlstedt, USGS retired, pers. comm., 2004, 2006). A coal-fired power plant planned for the upper Clinch, Virginia, will by law burn only Virginia coal (R. Hylton, Service, pers. comm., 2006), which would further increase mining in the Clinch/Powell watersheds. An acceleration of mining in western Pennsylvania could also threaten snuffbox populations.

Other mining activities that may impact snuffbox populations include metals (e.g., lead, cadmium, zinc) in Missouri. Mining has been implicated in the decline of mussels from the upper St. Francis River (Hutson and Barnhart 2004). Lead and barite mining is common in the Big River, a Meramec River tributary. A tailings-pond blowout discharged 81,000 $yards^3$ of mine tailings in 1977 that impacted ~80 RMs (Buchanan 1980, Roberts and Bruenderman 2000). High levels of heavy metals detected in the system (Schmitt et al. 1986, Roberts and Bruenderman 2000) may continue to hinder stream recovery. Forty-five tailings ponds and numerous tailings piles remain in the watershed (Roberts and Bruenderman 2000).

Oil and gas production may have contributed to the decline of this species in certain drainages (e.g., Sangamon River in the upper Mississippi River system; Slippery Rock and Connoquenessing Creeks in the upper Ohio River system; Green, Kentucky, Salamonie, and Mississinewa Rivers in the lower Ohio River system) (Ortmann 1909c, Schanzle and Cummings 1991, ESI 1995, Cicerello 1999). Pollutants include brines, high levels of potassium, and numerous organic compounds (Imlay 1971). Increasing demand can be expected to accelerate oil and gas exploration in certain snuffbox streams.

Instream and alluvial gravel mining has been implicated in the destruction of mussel populations (Hartfield 1993, Brown and Curole 1997). Negative impacts include stream channel modifications (e.g., altered habitat, disrupted flow patterns, channel incision, sediment transport), water quality modifications (e.g., increased turbidity, reduced light penetration, increased temperature), macroinvertebrate population changes (e.g., elimination, habitat disruption, increased sedimentation), and changes in fish populations (e.g., impacts to spawning and nursery habitat, food web disruptions) (Yokley 1977, Kanehl and Lyons 1992, Kondolf 1994, Roell 1999). The Corps retains regulatory oversight for gravel mining, but many mining operations do not fall under Corps purview (Roberts and Bruenderman 2000). Gravel mining may continue to be a localized threat to snuffbox populations (e.g., Kankakee, Bourbeuse, Walhonding, Elk [Tennessee], Strawberry Rivers; Big Darby, Buck [Kentucky] Creeks).

Sedimentation

Excessive sedimentation affects an estimated 46% of all U.S. streams (Judy et al. 1984) and has been implicated in the decline of mussel populations (Kunz 1898, Ellis 1936, Marking and Bills 1979, Vannote and Minshall 1982, Dennis 1985, Wolcott and Neves 1990, Brim Box 1999, Fraley and Ahlstedt 2000, Poole and Downing 2004). Biological effects, relationships to land-use practices, and remediation measures were reviewed by Waters (1995), Brim Box and Mossa (1999), and Henley et al. (2000). Specific biological impacts include reduced feeding and respiratory efficiency from clogged gills, disrupted metabolic processes, reduced growth rates, limited burrowing activity, and physical smothering (Ellis 1936, Stansbery 1971, Imlay 1972, Marking and Bills 1979, Vannote and Minshall 1982, Waters 1995). Primary productivity reduction is an indirect impact that affects mussel foods (Kanehl and Lyons 1992). Studies tend to indicate that excessive sediment level impacts are sublethal with detrimental effects not immediately apparent (Brim Box and Mossa 1999). Physical effects include altered suspended and bed material loads, and bed sediment composition associated with increased sediment production and run-off; clogged interstitial habitats and reduced interstitial flow rates and DO levels; changed channels in form, position, and degree of stability; altered depth or width/depth ratio that affects light penetration and flow regime; aggraded (filling) or degraded (scouring) channels; and changed channel positions that dewater mussel beds (Vannote and Minshall 1982, Gordon et al. 1992, Kanehl and Lyons 1992, Brim Box and Mossa 1999).

Sedimentation reduces crucial habitats for juvenile mussels by clogging interstitial spaces (Gordon et al. 1992). Sediment runoff may also act as a vector for delivering nutrients, pesticides, and other contaminants to streams (Salomons 1987). Because sediments adsorb many contaminants that partition into pore water (Newton 2003), juvenile ingestion of silt particles or interstitial pore water while feeding could increase exposure to sediment-bound contaminants

(Yeager et al. 1994). Some snuffbox populations may exhibit recruitment impairment due to these mechanisms.

Non-point agricultural activities are the most significant source of sediments in streams (Waters 1995, Henley et al. 2000) and the leading stressor-source combination for mussels (Richter et al. 1997). Agriculture (including both sediment and chemical run-off) affects 72% of the impaired stream miles in the country (Neves et al. 1997). Riverbank croplands and unrestricted stream access by livestock are significant threats to many snuffbox populations. Grazing may reduce infiltration rates, decrease filtering capacity of pollutants (thereby increasing contaminated sediment run-off), and trampling and eventual elimination of riparian vegetation reduces bank resistance to erosion and contributes to increased water temperatures (Armour et al. 1991, Trimble and Mendel 1995, Brim Box and Mossa 1999, Henley et al. 2000). The decline of Copper Creek (an upper Clinch River tributary) mussels from 1980 to 1998 was largely attributed to an increase in cattle grazing and loss of riparian vegetation (Fraley and Ahlstedt 2000).

Erosion from silvicultural activities is a relatively minor source of sedimentation (Henley et al. 2000), with impacts resulting more from logging roads than actual timber harvesting (Waters 1995, Brim Box and Mossa 1999). Annual runoff and/or peak flow volumes increase with timber harvests, particularly during the wet season (Allan 1995). This is partially due to the construction of logging roads, and vegetation removal tends to compact soils, reduce infiltration rates, and increase soil erosion. Increased flows and harvesting within streamside management zones may result in stream channel changes (Brim Box and Mossa 1999) that ultimately affect mussel beds.

Turbidity has been considered the most detrimental of water quality parameters affecting a third of all U.S. streams (Judy et al. 1984). The snuffbox may be indirectly affected when turbidity levels significantly reduce the amount of light available for photosynthesis and the production of foods (Kanehl and Lyons 1992). High turbidity levels may also impact sight-feeding fishes (Berkman and Rabeni 1987), such as darters, host fishes for the snuffbox.

Other Activities Affecting Mussels

Activities associated with urbanization can be detrimental to stream habitats (Couch and Hamilton 2002) and were summarized by Feminella and Walsh (2005). Developmental activities may impact streams and their mussel fauna where adequate streamside buffers are not maintained and erosion of impacted land is allowed to enter streams (Brainwood et al. 2006). Types of development may include highway construction, parking lots, building construction, general infrastructure (e.g., utilities, sewer systems), and recreation facilities (e.g., golf courses, race tracks). Factors impacting snuffbox populations in urban and suburban areas include lawn care chemicals (Conners and Black 2004), sedimentation, toxic effluents, domestic sewage, road salts, and general runoff.

Impervious surfaces are detrimental to mussel habitat by altering various hydrological factors including increased volumes of flow, annual flow rates, peak flows and duration, and temperature; decreased base flow; and changes in sediment loadings (Galli 1991, EPA 1997, DeWalle et al. 2000, Myers-Kinzie et al. 2002). These factors result in flooding, erosion, channel widening, altered streambeds, channel instability, riparian and instream habitat loss, and loss of fish populations (EPA 1997). As little as 10% of a watershed being impervious can cause channel instability and a host of other stream habitat effects (Booth 1991, Booth and Reinelt 1993). Impervious surfaces may reduce sediment input into streams but result in channel instability by accelerating stormwater runoff, which increases bank erosion and bed scouring (Brim Box and Mossa 1999). Stream channels become highly unstable as they respond to increased flows by incising which increases shear stress and bed mobilization (Doyle et al. 2000). Hydrological variability influences the distribution of mussels in streams, with distinct communities associated with hydrologically flashy and hydrologically stable streams (Di Maio and Corkum 1995). High shear stress, peak flows, and substrate movement limits mussel communities, reduces abundance (particularly for juveniles), and animals become increasingly dislodged downstream (Layzer and Madison 1995, Myers-Kinzie et al. 2002, Gangloff and Feminella 2006). Recruitment is also significantly reduced in high discharge years (Howard and Cuffey 2006).

Most snuffbox streams have been impacted by general developmental activities and increased impervious surface levels. Michigan populations occur in rapidly developing watersheds (e.g., Grand, Clinton, Huron, Portage Rivers; Davis Creek). The Huron and Clinton River systems were at risk of water quality decline due to impervious surfaces ranging from 5-15% (Madsen and Shriberg 2005). The St. Croix, lower Meramec, Little Miami, and Stillwater Rivers, and upper Scioto River system are also increasingly threatened by rapidly developing metropolitan areas.

No snuffbox streams are exempt from bridges, highways, and associated development. Effects were reviewed by Wheeler et al. (2005). Categories of impacts for three phases of existence include primary effects (construction), secondary effects (post-construction), and indirect effects (development associated with highway presence) (Angermeier et al. 2005). Culverts act as barriers to fish passage (Wheeler et al. 2005), particularly by increasing flow velocity (Warren and Pardew 1998). Stream channels become destabilized when culverted or improperly bridged by interrupting the transport of woody debris, substrate, and water (Wheeler et al. 2005).

Anthropogenic activities act insidiously to lower water tables, making snuffbox and other mussel populations susceptible to depressed flow levels. Water withdrawals for irrigation, municipal, and industrial water supplies are an increasing concern due to expanding human populations. U.S. water consumption doubled from 1960 to 2000 and will continue to increase (Naiman and Turner 2000). Droughts may also be a threat (Ahlstedt and Tuberville 1997), especially in small streams. Decreases in flow velocity and DO were highly correlated to mussel mortality (Johnson et al. 2001). These stochastic events may be exacerbated by water withdrawals. Decreased stream flows are not a new phenomenon; deforestation a century ago in southern Indiana was blamed for low flow in streams and impacts to aquatic life (Culbertson 1909).

Other factors may play roles in the demise of snuffbox populations. Host fish declines may be an indirect impact by contributing to reduced recruitment (Watters 1996, Khym and Layzer 2000). Factors associated with climate change likely to affect regional mussel populations include changes in stream temperature regimes and precipitation levels that may indirectly result in reduced habitat and declines in host fish stocks (Hastie et al. 2003). Remedial (e.g., flood control structures) and preventative (e.g., more renewable energy from hydroelectric facilities to reduce greenhouse gas emissions) measures to address climate change issues may impact snuffbox populations in the future (Hastie et al. 2003).

B. Overutilization for commercial, recreational, scientific, or educational purposes.

The snuffbox was not included in lists of commercially valuable pearling and button mussels in the Clinch nor the Holston Rivers, Tennessee (Böpple and Coker 1912), despite its historical abundance but likely due to its small size. Localized declines from use as bait by fishermen has been noted (e.g., Cumberland River, Wilson and Clark 1914). Despite the alarm generated over exploitation events in historical (e.g., Anthony and Downing 2001) or recent (e.g., Hastie 2006) times, the collective impact from human harvest is minuscule compared to habitat alteration. It is unlikely that exploitation activities have ever eliminated any snuffbox populations. The species may be increasingly sought by collectors, and localized populations could become impacted and possibly extirpated by unregulated overcollecting. However, overcollecting is not currently a threat.

C. Disease or predation.

The occurrence of diseases in mussels is virtually unknown (Grizzle and Brunner 2007). Mussel die-offs have been documented in snuffbox streams (Neves 1986). Some researchers believe that disease may be a factor, although the ultimate cause is unknown (Buchanan 1986, Neves 1986). Mussel parasites include water mites, trematodes, oligochaetes, leeches, copepods, bacteria, and protozoa (Grizzle and Brunner 2007). Generally, parasites are not suspected of being a major limiting factor (Oesch 1984), but a recent study provides contrary evidence. Reproductive output and physiological condition were negatively correlated with mite and trematode abundance, respectively (Gangloff and Feminella 2004). Anthropogenic factors that reduce fitness may make mussels more susceptible to parasites (W.F. Henley, Virginia Polytechnic Institute and

State University [VPI], pers. comm., 2005). Introduced bivalves that become established in continental waters may carry diseases and parasites potentially devastating to the fauna (Strayer 1999b).

Native Americans consumed large quantities of mussels (Morrison 1942, Parmalee and Klippel 1974, Parmalee et al. 1982); however, the snuffbox represents insignificant portions of their middens (Bogan 1990). The muskrat is cited as the most prevalent predator (Kunz 1898, Hanson et al. 1989). Muskrat predation may limit the recovery potential of endangered mussels or contribute to local extirpations of previously stressed populations according to Neves and Odum (1989), who nevertheless considered it primarily a seasonal or localized threat. It ranked fourth among 12 species in a St. Croix River muskrat midden, occurring nearly four times more abundant than in quantitative samples (Tyrrell and Hornbach 1998). Numbers were too low to determine electivity indices or statistics.

Trends in muskrat predation on unionids appear to be ambiguous. Some studies indicate size selectivity for smaller species and individuals (e.g., van der Schalie 1938, Tyrrell and Hornbach 1998) while others do not (e.g., Convey et al. 1989, Hanson et al. 1989, Neves and Odum 1989). Mussels were a favorite winter food in Michigan (van der Schalie 1938), but winter exhibited the lowest level of mussel predation in Virginia (Neves and Odum 1989). The recent absence of middens in many southern streams may indicate a decline in muskrats (pers. obs.). The apparent decline of muskrats may partially be attributed to predation by river otter (Greer 1955), which is widely being reintroduced (Serfass et al. 1998).

Other mammals (e.g., raccoon, mink, river otter, striped skunk, hog, rat), hellbender, turtles, aquatic birds, and fishes (e.g., freshwater drum, redear sunfish) feed on mussels (Kunz 1898, Meek and Clark 1912, Trautman 1981, Neck 1986, Tyrrell and Hornbach 1998). Hydra, non-biting midge larvae, dragonfly larvae, crayfish, and especially flatworms are invertebrate predators on newly-metamorphosed juveniles (Zimmerman et al. 2003, Klocker and Strayer 2004; R.J. Neves, USGS, pers. comm., 2002). The overall threat posed by these predators on the snuffbox is not considered significant.

D. The inadequacy of existing regulatory mechanisms.

Most states with extant snuffbox populations prohibit the taking of mussels for scientific purposes without a state collecting permit. However, enforcement of this permit requirement is difficult, and state regulations do not generally protect mussels from other threats. Existing authorities available to protect riverine ecosystems (e.g., Clean Water Act [CWA], administered by the Corps and EPA), are not being fully utilized or enforced, which has contributed to habitat degradation and aquatic resource losses. Additionally, current WQC for ammonia (EPA 1985) may not be protective of mussels (Augspurger et al. 2003, Sharpe 2005). EPA is currently re-evaluating its WQC for ammonia to determine if it is protective of mussels (http://www.epa.gov/waterscience /criteria/ammonia/). Although ammonia loadings have been significantly reduced with the implementation of advanced treatment technology at many WWTPs (Yoder et al. 2005), it is still a major concern at outdated facilities. While WQC for chlorine (EPA 1984) may be adequate for acute exposure of mussels (C. Kane, Service, pers. comm., 2006), long-term exposure of juveniles may result in sublethal impairment of growth (Valenti et al. 2006). Further, *Epioblasma* spp. juveniles appeared to be the most intolerant taxa among mussels tested (Valenti et al. 2006). WQC must become more stringent and pollution-prevention controls more effective for point-source pollution (e.g., WWTP effluents) to have a decreasing influence on riverine habitat quality (Newton 2003).

The snuffbox coexists with other federally listed mussels in >25 streams, but listing under the Act would provide additional layers of protection. Federal permits would be required to take the species, and Federal agencies would be required to consult with the Service when activities they fund, authorize, or carry out may adversely affect the species. The snuffbox is designated as endangered in Canada (Metcalfe-Smith et al. 2003), and has been assigned conservation status in 14 of the 18 states of historical occurrence. The level of protection it receives from state-listing varies, but state regulations fall short of that afforded by the Act.

E. Other natural or manmade factors affecting its continued existence.

Population Fragmentation and Isolation

The majority of snuffbox populations are small and geographically isolated due primarily to impoundments but also toxic effluents and contaminated sediments. Small isolated populations are more susceptible to extirpation due to the lack of recolonization potential (Sjögren 1991) and stochastic events (e.g., toxic spills, catastrophic drought). High levels of isolation make natural repopulation of any extirpated population impossible without human intervention.

The Scioto River system provides a good example of the phenomena of population fragmentation and isolation. Historically, the species was widespread and locally abundant in the main stem and at least 16 tributaries. The Scioto River became highly contaminated over a century ago (Trautman 1981, Yoder et al. 2005) and the snuffbox eventually died out there. The six population segments that persisted became increasingly isolated due to impoundments and other factors; all are very small, highly fragmented, and appear to be trending towards extirpation.

Genetic Considerations

Genetic considerations for managing imperiled mussels and for captive propagation were reviewed by Neves (1997) and Jones et al. (2006), respectively. Many snuffbox populations are potentially below the effective population size (EPS) required to maintain genetic heterogeneity and population viability (Soulé 1980). Isolated populations eventually die out when population size drops below the EPS or threshold level of sustainability. Evidence of recruitment in many snuffbox populations is scant making recruitment reduction or outright failure suspect. These populations may be experiencing the bottleneck effect of not attaining EPS. Small, isolated, below EPS-threshold populations of short-lived species (e.g., most host fishes) theoretically die out within a decade or so, while below-threshold populations of long-lived species (e.g., snuffbox) might take decades to die out even given years of total recruitment failure. Without historical barriers to genetic interchange, small isolated populations could be slowly expiring, a phenomenon termed the extinction debt (Tilman et al. 1994). Even given the totally improbable absence of anthropogenic threats, we may lose disjunct populations to below-threshold EPS. However, evidence indicates that general degradation continues to decrease habitat patch size and to act insidiously in the decline of snuffbox populations.

Snuffbox rarity makes maintaining adequate heterogeneity problematic for resource managers. Neves (1997) warned that "[i]f we let conservation genetics become the goal rather than the guidelines for restoring and recovering mussel populations, then we will be doomed to failure with rare species." Habitat alteration, not lack of genetic variability, is the driving force of population extirpation (Caro and Laurenson 1994, Neves 1997). Nevertheless, genetics issues should be considered in maintaining high levels of heterozygosity during snuffbox recovery efforts. Treating disjunct occurrences of this wide-ranging species as a metapopulation would facilitate conservation management while increasing recovery options (e.g., translocating adults, introducing infected host fishes and propagated juveniles) to establish and maintain viable populations (Neves 1997). Due to small population size and probable reduction of genetic diversity within populations, efforts should be made to maximize genetic heterogeneity to avoid both inbreeding (Templeton and Read 1984) and outbreeding depression (Avise and Hamrick 1996) whenever feasible in propagation and translocation efforts (Jones et al. 2006).

Alien Species

The complexity of the issue of alien (i.e., nonnative) species invaders is summed up by Naiman and Turner (2000), who write, "[t]he homogenization of the world's fauna and flora is an increasingly perplexing issue with multiple, synergistic consequences." The zebra mussel (*Dreissena polymorpha*) represents the most notable current alien species threat to the snuffbox. Species declines and extirpations have occurred with the attachment of huge numbers to live native mussels (e.g., Schloesser and Nalepa 1994; Schloesser et al. 1998, 2006; Havlik 2001, Kelner and Davis 2002) and more may be expected (Ricciardi et al. 1998). Zebra mussels impact native mussels primarily by direct fouling of unionid shells (Martel et al. 2001), which impedes locomotion (both laterally and vertically), interferes with normal valve movements, deforms valve margins, depletes food resources to levels too low to support reproduction or even survival, and increases waste products (Strayer 1999b). Heavy infestations may also overly stress animals by reducing their energy stores, reducing growth rates, and making them less fit for survival (Payne and Miller 2002). Other impacts to native mussels may include filtering their sperm and glochidia from the water column. Habitat for native mussels may be degraded by large deposits of zebra mussel pseudofeces (undigested waste material passed out of the incurrent siphon) (Vaughan 1997). An indirect impact has been the proliferation of aquatic macrophytes from increased water clarity in lakes, which in turn has prompted managers to increase the use of herbicides that may threaten mussels via food reduction (P.J. Marangelo, TNC, pers. comm., 2005).

A source population (e.g., reservoir) appears instrumental in the maintenance of zebra mussel populations (Schneider et al. 1998, Stoeckel et al. 2003). Where zebra mussels maintain high densities, extant snuffbox populations may be impacted and invasions of additional snuffbox streams are likely. However, zebra mussels are not always serious threats (e.g., Clinton River, P.J. Marangelo, TNC; Tippecanoe River, B.E. Fisher, INDNR; French Creek, T.A. Smith, WPC, pers. comm., 2005). Significant but highly fluctuating zebra mussel populations remain largely restricted to navigational waterways, although smaller streams have also had their mussel faunas virtually eliminated by them (Martel et al. 2001). At least two of the stronghold snuffbox populations (e.g., Wolf River, French Creek) presently have low numbers of zebra mussels that warrant close monitoring.

The Asian clam has spread throughout the Mississippi River Basin since its introduction into the basin in the mid-1900s. Asian clams compete with native mussels, especially juveniles, for food, nutrients, and space (Neves and Widlak 1987, Leff et al. 1990) and may ingest unionid sperm, glochidia, and newly-metamorphosed juveniles (Strayer 1999b, Yeager et al. 2001). Dense Asian clam populations actively disturb sediments that may reduce habitat for juvenile unionids (Strayer 1999b). In laboratory experiments, clam density and juvenile mussel mortality were positively correlated, mussel growth rates were reduced with the presence of clams, and juvenile mussels were displaced in greater numbers downstream in laboratory tests with clams (Yeager et al. 2001). Unionized ammonia released from Asian clam decomposition following periodic die-offs may result in concentrations high enough to exceed acute tolerance levels of juvenile mussels (Cherry et al. 2005, Cooper et al. 2005). Temperature and clam density are directly correlated with ammonia production, and low DO associated with Asian clam dieoffs could exacerbate juvenile stress (Cherry et al. 2005, Cooper et al. 2005). The effects of clam die-offs are most prevalent during summer low flows and high water temperatures (Cherry et al. 2005, Cooper et al. 2005). Outside of the deleterious impacts of dense Asian clam populations on survival and growth of newly-metamorphosed juvenile unionids and recruitment (Yeager et al. 2001), interactions appear to be unsatisfactorily revealed (Vaughn and Spooner 2006).

Asian clam densities vary widely in the absence of native mussels or in patches with sparse mussel concentrations, but clam density is never high in dense mussel beds indicating that the clam is unable to successfully invade small-scale habitat patches with high unionid biomass (Vaughn and Spooner 2006). The invading clam therefore appears to preferentially invade sites where mussels are already in decline (Strayer 1999b, Vaughn and Spooner 2006) and does not appear be a causative factor in the decline of mussels in dense beds. However, a clam population that thrives in previously stressed, sparse mussel populations might exacerbate unionid imperilment through competition and impeding mussel population expansion (Vaughn and Spooner 2006).

The black carp (*Mylopharyngodon piceus*) is native to eastern Asia and a potential snuffbox threat (Strayer 1999b). Nico et al. (2005) prepared a risk assessment of this species and summarized all known aspects of its ecology, life history, and intentional introduction (since the 1970s) into North America. A molluscivore, the black carp has been known to feed on unionids and is proposed for widespread use by aquaculturists to control snails, the intermediate host of a trematode (flatworm) parasite infesting catfish in culture ponds. They are the largest of the Asian carp species, reaching five feet in length and achieving a weight in excess of 150 pounds (Nico et al. 2005). Foraging rates for a 4-year fish average three or four pounds a day, indicating that a single individual could consume 10 tons of native mollusks over its lifetime (MICRA 2005). Several black carp escaped from an aquaculture facility in Missouri during a flood in 1994 and a fish was caught a few years later in southern Illinois. The escape of nonsterile black carp is considered imminent by conservation biologists. A notice of intent to list the fish as an injurious species of wildlife was published by the Service in July 2002 but no final decision has been made (MICRA 2003, 2005).

The round goby (*Neogobius melanostomus*)is another alien fish species released into the Great Lakes that is well established and likely to spread through the Mississippi River system (Strayer 1999b). This species is an aggressive competitor of similar sized benthic fishes (e.g., sculpins, darters) as well as a voracious carnivore despite its size (<10 inches in length), preying on a variety of foods, including small mussels and fishes that could serve as glochidial hosts (Strayer 1999b, Janssen and Jude 2001). Round gobies may therefore have important indirect effects on the snuffbox through negative impacts to their host fishes.

Additional alien species will invariably become established in coming years (Strayer 1999b). These include *Limnoperna fortunei*, a biofouling mussel from southeast Asia that has already spread to Japan and South America, and "probably will have strong effects" on native unionids (Strayer 1999b). Alien species could carry diseases and parasites that may be devastating to the native biota. Because of our ignorance of mollusk diseases and parasites, "it is imprudent to conclude that alien diseases and parasites are unimportant" (Strayer 1999b).

Current protective status under state/provincial/tribal/Federal laws and regulations

The snuffbox was first given unofficial conservation status by Stansbery (1970, 1971). TNC considers it to be a G2G3 species. This species is state-listed in 13 of the 14 states (except Tennessee) that are thought to harbor extant populations, but the level of protection it receives varies. The American Malacological Society and American Fisheries Society consider it threatened (Williams et al. 1993). The snuffbox is protected from harvest in stream segments protected as mussel sanctuaries (e.g., Clinch, Powell, Duck Rivers) or from entire states (e.g., Indiana, Wisconsin).

Summary of land ownership and existing habitat protection

The vast majority of snuffbox populations border private lands. Sporadic parcels of public land (e.g., state parks, recreational, and wildlife management areas; state forests; NF, NPS) that occur along some snuffbox streams and in their watersheds implement various landuse restrictions but collectively accounts for <10% of the total. Because of this ratio, public ownership confers little direct benefit to mussel populations (Neves 1993). Portions of several snuffbox watersheds occur in NFs with established riparian buffers (e.g., Allegheny River, Allegheny NF, Pennsylvania; Middle Fork Kentucky, Red Bird, and Red Rivers, Daniel Boone NF, Kentucky; Black and St. Francis Rivers, Mark Twain NF, Missouri; Clinch River, Jefferson NF, Virginia). The St. Croix, Green, and Buffalo Rivers flow through NPS lands.

Past, current, and anticipated conservation activities undertaken for the benefit of the species or its habitat

Several non-governmental organizations (NGOs) play various roles in conserving rivers (e.g., TNC, World Wildlife Fund, American Rivers, Izaak Walton League, local watershed groups). The most significant NGO in river conservation and restoration has been TNC, which has made several high-diversity snuffbox streams bioreserves (e.g., Licking, Green, Tippecanoe, Clinch/Powell, Paint Rock, Strawberry Rivers; French, Big/Little Darby, Buck [Kentucky] Creeks). These groups typically have few riparian inholdings, but they have collectively conducted innovative community-based projects on multiple scales that address aquatic species and habitat needs. Since disturbed riparian habitats have been associated with lack of mussel recruitment and depleted populations (Brainwood et al. 2006), TNC and other NGOs prioritize projects with riparian landowners to help restore and protect streams and riparian zones.

Various funding sources are available for habitat restoration efforts. The Service's Partners for Fish and Wildlife program has funded millions of dollars in grants to private landowners to enhance riparian habitat in many snuffbox streams. Passage of the Partners for Fish and Wildlife Act in 2006 will dedicate tens of millions of dollars in annual funding for five years. Other funding sources include CWA Section 319, U.S. Department of Agriculture Natural Resource

Conservation Service programs (e.g., Conservation Security Program [CSP], Environmental Quality Incentives Program, Wildlife Habitat Improvement Program, Conservation Reserve Enhancement Program [CREP]), Private Stewardship grants, National Fish and Wildlife Foundation grants, state wildlife grants, and numerous other Federal and State programs. A CREP grant of $110 million will take up to 100,000 acres of riparian lands out of agricultural production in the upper Green River. CSP grants to agricultural landowners for the conservation and improvement of natural resources have been made in several priority watersheds (e.g., Maple, Little Kanawha, Elk [Tennessee] Rivers; French Creek). TNC bioreserve staff, such as the Strawberry River which is on the CWA Section 303(d) list for sedimentation impairment (TNC 2004), often procure Section 319 grants for sediment remediation activities.

Several settlements from large chemical spills have recently been negotiated in the upper Tennessee River system in southwestern Virginia (e.g., Schmerfeld 2006). Settlements are used to fund recovery projects (e.g., developing propagation technology, augmenting extant populations, reintroducing extirpated populations) designed to restore mussel populations.

Ontario's Freshwater Mussel Recovery Team has developed a Proposed Recovery Strategy for the snuffbox and four other endangered mussels in Canada (http://www.sararegistry.gc.ca). The document outlines goals and strategies needed to restore these species. Resource managers are developing strategies to restore mussel populations at the watershed level. A Sydenham River Recovery Strategy for conserving imperiled species and addressing threats has been developed (http://www.dfo-mpo.gc.ca/species-especes/species/species_recoveryPlanning_Sydenham_e.asp). Resource managers are developing a population reintroduction and augmentation (R/A) strategy for the snuffbox and 56 other federally listed and imperiled mussels in the Cumberlandian Region. This document includes prioritized lists of imperiled species, suitable streams, and R/A activities.

Relocation of a mussel community is often used to minimize the impact of specific developmental projects (e.g., highway crossings, channel dredging, barge mooring cell construction) on mussel resources (Dunn and Sietman 1997, Havlik 1997, Dunn et al. 2000). This technique, however, may provide at best limited benefit for overall species conservation and recovery because of a no-net-gain in population status; failed relocation attempts often result in increased mortality of the translocated population (Dunn and Sietman 1997, Havlik 1997). The snuffbox and other species of concern receive no regulatory protection under the Act; however, the Service strongly encourages Federal agencies and others to consider these species when planning and implementing projects where listed species co-occur.

Service biologists are initiating Safe Harbor Agreements (for listed species) and Candidate Conservation Agreements with Assurances (for candidate species) with private landowners to conserve aquatic resources. Snuffbox populations occurring with listed and candidate species targeted for these protection measures will benefit as well. The Ohio River Valley Ecosystem (ORVE) team's Mollusk Subgroup, which has made imperiled mussels a high priority resource for conservation, determined the need for and is conducting this status assessment.

Groundwork for a proposed national fish and wildlife refuge on the Clinch River has been established. This non-traditional refuge is planned to be slowly implemented over time and be comprised of some Federal inholdings and cooperatively managed private lands.

Public outreach/environmental education staff are prevalent among the Service, other agencies, and NGOs. Specialists educate the general public of the benefits of water and habitat quality, while promoting an aquatic ecosystem and community-based watershed restoration management approach. Aquatic issues form a major part of outreach efforts in the Southern Appalachian Ecosystem, comprising the headwaters of the Tennessee River system. Representative projects have included posters and videos highlighting mussels, a riparian restoration and conservation video for streamside landowners, endangered species pamphlets, a children's book focusing on the plight of imperiled mussels, and mussel outreach/education kits for educators.

Reservoir releases from dams have been modified in recent years improving water quality and habitat conditions in TVA (Scott et al. 1996, Ahlstedt et al. 2004) and other (Poff et al. 2003) tailwaters. Improvements have enabled partners to attempt the reintroduction of extirpated federally listed and other imperiled species (Layzer and Scott 2006). Several nonessential experimental populations, a recovery tool legislated for federally listed species under Section 10(j) of the Act, are in various stages of planning and implementation in some TVA tailwaters and other streams. Although current reintroduction efforts in TVA tailwaters have focused almost entirely on listed species, activities are expanding to include other imperiled taxa. TNC staff with the Green River Bioreserve contracted with the Corps to modify flow releases from the GRRD to improve seasonal flow patterns and instream habitat. Favorable flows have contributed to increased mussel recruitment levels and helped ameliorate the effects of a drought (J.B. Layzer, USGS, pers. comm., 2005).

Developers can minimize runoff and stream habitat degradation by employing techniques of low-impact development outlined by Madsen and Shriberg (2005). These include preventing rather than mitigating runoff, conserving natural landscape features that retain stormwater and filter pollutants, directing runoff from impervious surfaces to rain gardens, establishing buffers, and adopting no-net-runoff standards. Large scale smart growth ideals for protecting water resources are also described.

The St. Croix River Research Rendezvous is an annual meeting of biologists and conservationists dedicated to managing biodiversity the St. Croix River and its diverse mussel fauna. Participants annually present their research, which are abstracted in *Ellipsaria*, the newsletter of the Freshwater Mollusk Conservation Society. Recent research subjects involving mussels included sediment contamination, juvenile toxicity, status surveys, population dynamics, and zebra mussel control. Vaughan (1997) outlined various measures implemented for mussel conservation in the St. Croix River.

Several streams with extant snuffbox populations have been designated National Wild and

Scenic Rivers (e.g., Wolf, St. Croix, Allegheny, Little Miami, Red [Kentucky], Buffalo Rivers; Big/Little Darby Creeks) or have similar state status (e.g., Huron River/Davis Creek; Grand [Ohio], Olentangy, Stillwater Rivers). National or State designation typically insures that streams are maintained as free-flowing and limits riparian zone development to compatible activities (e.g., restrictions on zoning and land alterations from development, mining, silvicultural activities).

Management actions (species, habitat, or people management) needed

Management actions needed to conserve unionid mussels (Neves 1993, 1997, 1999; Kay 1995; Neves et al. 1997; Shute et al. 1997; Bogan 1998, 2006; Seddon et al. 1998; Lydeard et al. 2004; Strayer et al. 2004) and freshwater ecosystems (e.g., Saunders et al. 2002, Wishart and Davies 2003, Strayer 2006) are well documented. However, the national strategy for the conservation of mussels, compiled by the National Native Mussel Conservation Committee (NNMCC) (1998), includes the most detailed information on managing and recovering North America's imperiled mussel fauna. Similar guidelines are included in recovery plans for listed mussels in general (e.g., Butler and Biggins 2004) or the snuffbox in particular in Canada (Morris and Burridge 2006). Specific actions for the management of the snuffbox are outlined in this section.

Extant snuffbox populations should continue to be protected with Federal and State laws and regulations that address the species' habitat. WWTPs in snuffbox drainages should be converted to state-of-the-art facilities for reducing ammonia, chlorine, pharmaceuticals, and other pollutants. Implementation of pollution controls to meet CWA goals can be achieved (Yoder et al. 2005), but water quality improvements may not be adequate to protect all aquatic life forms. WQC of pollutants that are not protective of mussels should be lowered. Management recommendations to reduce sand and gravel mining impacts (Roell 1999) should be implemented wherever aggregate mining is occurring in snuffbox habitat. Unfortunately, conservationists must understand that merely protecting disjunct mussel populations through regulatory actions may not curb their downward trend (Obermeyer et al. 1997).

The overall conservation status of the snuffbox would improve if more extant populations could be maintained at viable levels and if historical populations were reintroduced. Certain snuffbox populations might benefit from augmentation, particularly in those streams where active recruitment has been documented for congeners and other species and threats appear manageable (e.g., Allegheny, Green, Duck Rivers). R/A efforts can be achieved through various translocation options (e.g., release of cultured juveniles, infected host fishes, adult mussels where a large donor population exists).

Streams, stream reaches, and watersheds should be prioritized for protection based on a variety of factors, with emphasis on conserving the best snuffbox populations and stream reaches as opposed to restoring habitats. These factors may include high endemicity; high diversity of imperiled species; biogeographic history of rare species; highly fragmented habitats; cost effectiveness and ease of preservation, management, recovery, and restoration; landowner complexity; watershed size; existing land-use patterns; imminent threats; public accessibility; those systems exhibiting low resilience to disturbance; and likelihood for success.

Stakeholder support, particularly members of local communities (e.g., agricultural, silvicultural, mining, construction, and other developmental interests; key individuals; riparian landowners), will be essential in meeting snuffbox recovery goals. Without involved partnerships with those who live, work, and have a direct influence on habitat quality, recovery efforts will be doomed.

Significant levels of habitat can be restored and protected through watershed-scale, community-based riparian habitat restoration projects initiated in snuffbox streams. Maintaining vegetated riparian buffers is a proven method of reducing stream sedimentation and runoff of chemicals and nutrients (Osborne and Kovacic 1993). Buffers and other best management practices should be implemented along all snuffbox streams. Stress analyses, which determine the entire suite of stressors to the species and its habitat, locate the sources of the various stressors, and outline management activities to eliminate or at least minimize each stressor, should be undertaken in at least those watersheds with significant snuffbox populations (Freeman et al. 2002).

Dam removal has become an increasingly common management option in restoring riverine habitat (e.g., http://www.dnr.state.oh.us/water/dsafety/lowhead_dams/removed_dams_list.htm). Removal should be considered if issues regarding bed load sediments and potential contaminants are thoroughly addressed during the planning stage and where dams are not thought to provide stabilizing tailwater mussel habitat (Gangloff 2005).

Research, surveys, and monitoring needed

Much research is needed if we are to preserve and restore populations of imperiled mussels like the snuffbox (NNMCC 1998, Garner 1999, Lydeard et al. 2004, Strayer et al. 2004). Snuffbox life history information is sparse, so additional studies will be needed for recovery. Habitat (e.g., relevant physical, biological, chemical components), sensitivity to general threats, effects of genetic bottlenecks from population isolation, population viability analysis (Beissinger and McCullough 2002), and feeding ecology and nutritional needs are subjects to investigate. Specific needs are detailed below.

The effects of toxicants on various mussel life stages are a critical need. "Unionid toxicology could benefit from the approaches used in the marine bivalve literature to help ascertain the importance of different routes of contaminant exposure (surface water, pore water, sediments, and food)," according to Newton (2003). Pharmaceutical chemicals are a growing source of concern for mussels. Modifying drug delivery methodologies could reduce concentrations in wastewater effluents and WWTPs could be designed to remove harmful pharmaceuticals.

Efforts to propagate and translocate laboratory-reared progeny were summarized by Neves and Ahlstedt (2001) and Neves (2004). Propagation technology should be developed and perfected for the snuffbox that adheres to policy established by the Service for propagation of federally listed species (Service and National Marine Fisheries Service 2000) and the 10 genetic guidelines recommended by Jones et al. (2006). Since most snuffbox populations are too small for the culling and direct translocation of adults, the propagation of significant numbers of juveniles will make R/A efforts more feasible. This species has been the focus of propagation activities at several culture facilities (Center for Mollusk Conservation, Kentucky, M. McGregor, KDFWR, pers. comm., 2002; Lost Valley Fish Hatchery, Missouri, S.E. McMurray, MDC, pers. comm., 2006; Columbus Zoo, Ohio, G.T. Watters, OSUM, pers. comm., 2006; Freshwater Mollusk Conservation Center, Virginia, R. Mair, VPI, pers. comm., 2005; and Aquatic Wildlife Conservation Center [AWCC], Virginia, M.J. Pinder, Virginia Department of Game and Inland Fisheries [VDGIF], pers. comm., 2005). Other facilities that are in the planning stage (e.g., Tennessee, D.W. Hubbs, TWRA, pers. comm., 2006) or existing (e.g., Alabama Aquatic Biodiversity Center, P.D. Johnson, ADCNR, pers. comm., 2006) may be involved in future snuffbox propagation efforts. AWCC has been successful at naturally spawning snuffbox in captivity (M.J. Pinder, VDGIF, pers. comm., 2005). Snuffbox populations in the Bourbeuse, Clinch, and Powell Rivers have been augmented with cultured juveniles (S.E. McMurray, MDC; N.L. Eckert, VDGIF; J.W. Jones, Service; pers. comm., 2007).

An artificial culture medium for propagating juvenile mussels is being researched (M. McGregor, KDFWR, pers. comm., 2006). Logistical issues associated with the complex host fish stage of the life cycle can be circumvented during laboratory culture, if successful, while greatly accelerating the time necessary to produce significant numbers of an imperiled species like the snuffbox.

In addition to focusing efforts on threats contributing to snuffbox declines, research should target beneficial factors that promote the maintenance of healthy viable populations. There is evidence that minimum flow releases from impoundments have been associated with relatively high levels of mussel recruitment in two regulated rivers, the Duck (Ahlstedt et al. 2004) and Green (J.B. Layzer, USGS, pers. comm., 2004). Physical (e.g., fluvial geomorphology, habitat stability, well-oxygenated interstitial habitat) and biological (e.g., food quality and quantity, host fish abundance and seasonality, mussel density needed to assure high fertilization rates, demographic and genetic characteristics, EPS) factors positively correlated with population size should be investigated (Strayer et al. 2004). A thorough understanding of these factors is crucial not only for maintaining existing populations but ultimately in establishing reintroduced ones.

Sets of biological, ecological, and habitat parameters will need to be developed to determine if extant snuffbox populations will be suitable for R/A efforts. Habitats must be identified that provide environmental factors critical for survival and recovery for reintroductions to be successful. Reintroduction stream criteria will include habitat suitability, substrate stability, presence of host fishes, controllable site threats, and any other limiting factor that might decrease the likelihood of long-term benefits from population reintroduction efforts. While hydropeaking tailwaters are potential reintroduction sites, they pose an additional set of conditions that must be thoroughly considered (Layzer and Scott 2006). Regarding augmentation, this is important for separating those populations that are more readily protected, capable of maintaining viability, and possessing significant recovery potential (i.e., likely to remain stable or improve over time) from those considered suffering from overwhelming and uncontrollable threats, incapable of maintaining viability, and displaying insignificant recovery potential (i.e., likely to decline over time). Prioritized populations and potential augmentation sites for this task will be selected based on present population size, demographic composition, population trend data, potential site threats, habitat suitability, and any other limiting factor that might decrease the likelihood of long-term benefits from population augmentation efforts. R/A activities should not be conducted at totally unprotected sites or at sites with significant uncontrollable threats. By following these guidelines, managers will be identifying streams and stream segments that promote long-term snuffbox population stability.

A genetics study on the snuffbox has been conducted with tissue samples from several of the largest populations (e.g., Sydenham, St. Croix, Bourbeuse, Clinch, St. Francis Rivers; Davis, French Creeks) (D.T. Zanatta, ROM, pers. comm., 2006). The results indicated that populations should not be mixed management actions. Further, the St. Francis and possibly the Clinch River populations may represent evolutionarily significant units, the former being unique enough to potentially represent a distinct taxonomic entity. Thorough studies on anatomy, biology, ecology, and possibly other evidence should be presented before taxonomic decisions are made.

Developing and implementing cryogenic techniques to preserve snuffbox genetic material until such time as conditions are suitable for reintroduction may be beneficial to its recovery. If a population were lost to a catastrophic event, such as a toxic chemical spill, a repository of cryogenic material could allow for the eventual reestablishment of the population.

Survey work to search for new snuffbox populations, presumed extirpated populations, and to assess the status of other populations would be beneficial for updating its conservation status, conservation management, and recovery efforts. These streams should be prioritized in order of importance given limited funding resources.

A monitoring program should be developed and implemented to evaluate conservation and recovery efforts and monitor snuffbox population levels and habitat conditions. Further, viability of extant, newly discovered, reintroduced, and augmented populations should be assessed on a regular basis, particularly those populations considered most critical for its recovery. A comprehensive Geographic Information System (GIS) or other databases to incorporate information on the species' distribution, population demographics, various threats identified during monitoring activities, and to track recovery accomplishments should be established. A GIS database is being incorporated for the Bear Creek mussel population (S.W. McGregor, Geological Survey of Alabama, pers. comm., 2005).

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See Appendix IV.

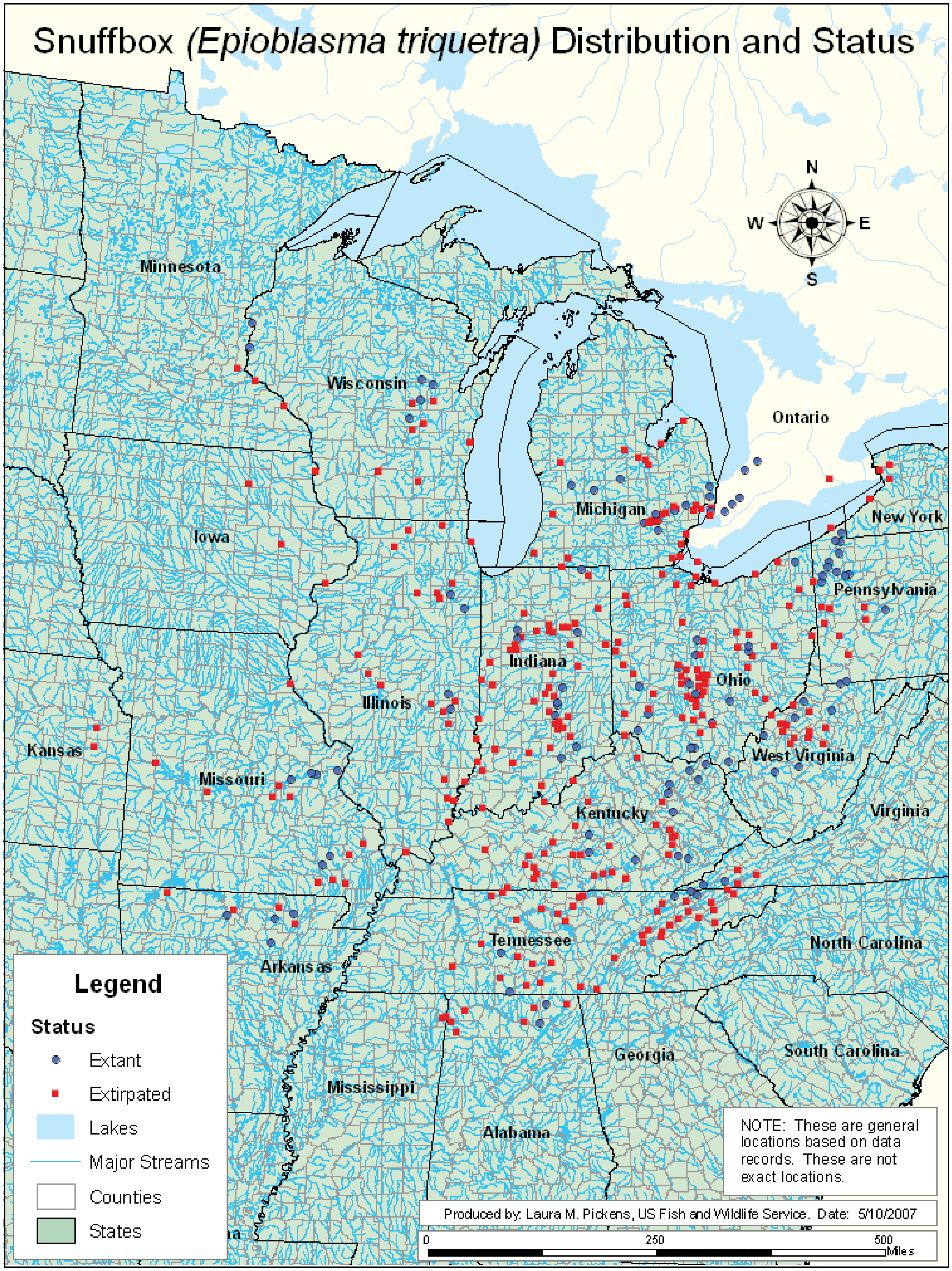
Site specific location information should be attached as a separate appendix so this information easily can be removed if the document is distributed outside of the Service. The inclusion of maps is strongly encouraged.

Copies of the most important references should be provided.

FIGURE 1

Snuffbox (*Epioblasma triquetra*) Distribution and Status

Distribution map of the snuffbox displaying its historical and current range.



Snuffbox (Epioblasma triquetra) Distribution and Status
Minnesota
Wisconsin
Iowa
Michigan
Ontario
New York
Pennsylvania
Indiana
Ohio
Illinois
Kansas
Missouri
West Virginia
Kentucky
Virginia
Tennessee
North Carolina
Arkansas
Georgia
South Carolina
Mississippi
Alabama
N
W
E
S
Legend
Status
Extant
Extirpated
Lakes
Major Streams
Counties
States
NOTE: These are general locations based on data records. These are not exact locations.
Produced by: Laura M. Pickens, US Fish and Wildlife Service. Date: 5/10/2007
0
250
500
Miles

APPENDIX I

Snuffbox (*Epioblasma triquetra*) Distributional History

Occurrence by stream (main stem working downstream, then tributaries), county, and state; authority (primary literature and other records); and chronology of occurrence (last record first)

Stream Number-Stream, County, State	Authority	Date
Upper Great Lakes sub-basin		
1-Lake Michigan, ? County, MI	NMNH 40734	?
2-Fox River, Green Lake County, WI	INHS 20534	1931
Fox River, Winnebago County, WI	Baker (1928), Johnson (1978), D.J. Heath (WIDNR, pers. comm., 2002) UMMZ 21636	1920 ?
3-Wolf River, Shawano/Waupaca Counties, WI	ESI (2006) B.E. Fisher (INDNR, pers. comm., 2005) Dunn & Sietman (1997), Dunn et al. (2000), J. Lee (ESI, pers. comm., 2003), BMNH 14841 D.J. Heath (WIDNR, pers. comm., 2002) Havlik (1997)	2006 1999 1995-97 1988-95 1993
Wolf River, Outagamie County, WI	W.A. Smith (WNHI, pers. comm., 2003)	?
4-Embarrass River, Shawano County, WI	D.J. Heath (WIDNR, pers. comm., 2002)	1995 D, 1988, 1987
5-Little Wolf River, Waupaca County, WI	D.J. Heath (WIDNR, pers. comm., 2006) W.A. Smith (WNHI, pers. comm., 2003)	1999 D 1988
6-Waupaca River, Waupaca County, WI	D.J. Heath (WIDNR, pers. comm., 2002)	1994 R
7-Willow Creek, Waushara County, WI	W.A. Smith (WNHI, pers. comm., 2003)	2001
8-Sheboygan River, Sheboygan County, WI	D.J. Heath (WIDNR, pers. comm., 2002)	1999 R
9-Muskegon River, Newaygo County, MI	Carman & Badra (2003), Carman & Goforth (2003) van der Schalie (1941) Johnson (1978), UMMZ ?	2002 R 1940 ?
10-Grand River, Ionia County, MI	P.J. Badra (MNFI, pers. comm., 2002) UMMZ 160483	2001, 1999 1942
Grand River, Kent County, MI	P.J. Badra (MNFI, pers. comm., 2002) UMMZ 91394 Johnson (1978); ANSP 341439; BMNH 2548; FLMNH 64362(12), 64363, 180568; FMNH 195125; MCZ 236774; NMNH 25373, 84436, 124424; OSUM 33008	2002, 1960s <1950 ?
Grand River, ? County, MI	MFM 1932 INHS 20524, 20525	1940 <1921

	ANSP 48386, 56387(13); FLMNH 4114; FMNH 23057, 50468	?
11-Maple River, Gratiot County, MI	P.J. Badra (MNFI, pers. comm., 2002)	2001
12-Kalamazoo River, Allegan County, MI	INHS 18730	1996 R
13-St. Joseph River, St. Joseph County, MI	P.J. Badra (MNFI, pers. comm., 2002) van der Schalie (1936), Johnson (1978), UMMZ 58915	2001 R 1930
St. Joseph River, Berrien County, MI	P.J. Badra (MNFI, pers. comm., 2002) UMMZ 154029 FLMNH 180569	2001 R 1930? ?
St. Joseph River, ? County, MI	UMMZ 91389 FMNH 23059	? R ?
St. Joseph River, Elkhart/St. Joseph Counties, IN	UMMZ 91299	?
14-Pigeon River, Lagrange County, IN	B.E. Fisher (INDNR, pers. comm., 2000, 2005)	2004 R, 1998
15-Turkey Creek, Lagrange County, IN	FMNH 89649	?
Lower Great Lakes sub-basin		
16-Lake Huron, Huron County, MI	OSUM 12366 Goodrich & van der Schalie (1932), UMMZ 51842 UMMZ 41105	1964 1931 R ?
Lake Huron, Tuscola County, MI	P.J. Badra (MNFI, pers. comm., 2002)	1940
Lake Huron, ? County, MI	Goodrich (1932), Johnson (1978)	<1932
Lake Huron, ONT	La Rocque & Oughton (1937)	<1937
17-Saginaw River, Saginaw County, MI	OSUM 19110	1965 R
18-Cass River, Saginaw County, MI	UMMZ 54988	?
19-Tittabawassee River, Saginaw County, MI	OSUM 15696	1965 R
20-Chippewa River, Midland County, MI	UMMZ 128416, 128438	1937
21-Ausable River, ONT	D.J. McGoldrick (EC, pers. comm., 2005, 2007) J.L. Metcalfe-Smith (EC, pers. comm., 2003) UMMZ 178600	2006, 2003-04 1998, 1950, 1929 ?
22-St. Clair River, St. Clair County, MI	OSUM 16007	1965 R
23-Pine River, St. Clair County, MI	Badra & Goforth (2003) P.J. Badra (MNFI, pers. comm., 2002) Hoeh & Trdan (1985)	2002 1984-85 1982
24-Belle River, St. Clair County, MI	Badra & Goforth (2003) Sherman Mulcrone (2004) UMMZ 255064(R), 255078(R),	2002 1999 1994

	255102(2), 255111(R) Hoeh & Trdan (1985) OSUM 45684 OSUM 20936(65) OSUM 13918	 1982-83 1978 1965 1960-64
25-Lake St. Clair, ? County, MI	Goodrich (1932), Goodrich & van der Schalie (1932), Johnson (1978) UMMZ 91388	<1932 ? R
Lake St. Clair, ONT	J.L. Metcalfe-Smith (EC, pers. comm., 2003) La Rocque & Oughton (1937)	1983 <1937
26-Clinton River, Oakland County, MI	P.J. Marangelo & D.R. Pearsall (TNC, pers. comm., 2005) Sherman Mulcrone (2004) P.J. Badra (MNFI, pers. comm., 2002) Trdan & Hoeh (1993), W.R. Hoeh (KSU, pers. comm., 1992) UMMZ 250147, 250159, 250160 Strayer (1980) UMMZ 56908(13)	2003, 2001 1998-99 1995, 1988, 1986, 1981, 1978, 1933 1992 1981 R 1977-78 R, <1935 ?
Clinton River, Macomb County, MI	Strayer (1980) UMMZ 58643, 56917	<1935 ?
[1] Three Mile Lake (Clinton River), Oakland County, MI	UMMZ 91386	<1950?
Sylvan Lake (Clinton River), Oakland County, MI	UMMZ 250168	1981 R
Cass Lake (Clinton River), Oakland County, MI	P.J. Badra (MNFI, pers. comm., 2002)	1996
Spring (Clinton River), Oakland County, MI	P.J. Badra (MNFI, pers. comm., 2002)	1995
27-North Branch Clinton River, Macomb County, MI	Strayer (1980) OSUM 21457 UMMZ 56867	1977-78 R, <1935 1966 ?
28-Sydenham River, ONT	J.L. Metcalfe-Smith (EC, pers. comm., 2003) Woolnough (2002) Metcalfe-Smith et al. (2003) Mackie & Topping (1988), Clarke (1992) Clarke (1973), Johnson (1978) MFM 15868 OSUM 19211	1996-2002, 1963-67 2001 1997-99 1985 D 1973 1967 1965
29-Thames River, ONT	J.L. Metcalfe-Smith (EC, pers. comm., 2003) Clarke (1981a) UMMZ 91304	1998, 1997 R, 1935, 1894 <1981 ?
30-Detroit River, Wayne County, MI/ONT	J.L. Metcalfe-Smith (EC, pers. comm., 2003)	1994, 1992

	P.J. Badra (MNFI, pers. comm., 2002) Schloesser et al. (1998, 2006) Trdan & Hoeh (1993) OSUM 53226(2), UMMZ 250323(2) La Rocque & Oughton (1937) UMMZ 7493 Johnson 1978	1988, 1983-84, 1930, 1920 1994 D, 1992, 1987 1988 1983 <1937 1908 <1823
31-Huron River, Oakland County, MI	UMMZ 60059 van der Schalie (1938) UMMZ 60060 Johnson (1978)	1934 1930-33 1931 ?
Huron River, Livingston County, MI	P.J. Marangelo & D.R. Pearsall (TNC, pers. comm., 2005) P.J. Badra (MNFI, pers. comm., 2002) van der Schalie (1938) UMMZ 60049(15), 60050, 60051, 60052 UMMZ 60048(36), 60054, 60055(11) UMMZ 10472 Johnson (1978); FLMNH 180563; FMNH 20234, 90278, 185581(>25)	2001 1951 1931-32 1932 1931 1920 ?
Huron River, Washtenaw County, MI	P.J. Marangelo (TNC, pers. comm., 2005) UMMZ 197202 LACM 49-264.7 FLMNH 20404	1995 1958 1949 ?
Huron River, Monroe County, MI	UMMZ 60043 UMMZ 60042 UMMZ 91413 Johnson (1978)	1933 R 1931 R <1931 R ?
Proud Lake Channel (Huron River), Oakland County, MI	P.J. Badra (MNFI, pers. comm., 2002)	1996 D
Zukey Lake (Huron River), Livingston County, MI	UMMZ 180039 or 190039	1951
Strawberry Lake (Huron River), Livingston County, MI	ANSP 56556, UMMZ 91390	?
Base Line Lake (Huron River), Livingston County, MI	UMMZ 91395 van der Schalie (1938), UMMZ 60046 UMMZ 60045	<1950 R 1930-33 1931 R
32-Davis Creek, Livingston County, MI	D.T. Zanatta (ROM, pers. comm., 2005) P.J. Marangelo & D.R. Pearsall (TNC, pers. comm., 2005) Sherman Mulcrone (2004)	2005 2001 1998-99
Sandy Bottom Lake (Davis Creek), Livingston County, MI	van der Schalie (1938), P.J. Badra (MNFI, pers. comm., 2002)	1931
33-South Ore Creek, Livingston County, MI	Sherman Mulcrone (2004)	1999
34-Portage River, Livingston County, MI	Sherman Mulcrone (2004) UMMZ 60056(18)	1998 1931

	UMMZ 60058	?
Portage River, Washtenaw County, MI	Strayer (1979) ANSP 320806 P.J. Badra (MNFI, pers. comm., 2002)	1976-78 1962 1931
Portage Lake (Portage River), Livingston County, MI	UMMZ 60047	1930s?
Portage Lake (Portage River), Washtenaw County, MI	UMMZ 60044 UMMZ 10473	1930s? 1917
[2] 35-Little Portage River, ? County, MI	van der Schalie (1975)	<1975
36-Lake Erie, Monroe County, MI	OSUM 52733 UMMZ 91393 P.J. Badra (MNFI, pers. comm., 2002) UMMZ 45000 Johnson (1978); CM 61.5021, 61.7871; MCZ 236773; UMMZ 91387	1981 R <1950 1930 1928 ?
Lake Erie, ONT	J.L. Metcalfe-Smith (EC, pers. comm., 2003) OSUM 53192 OSUM 46026, 46111 OSUM 18668, 20617 OSUM 10986 OSUM 9483 Brown et al. (1938) La Rocque & Oughton (1937) NMNH 347304 Johnson (1978); NMNH 360117; MCZ ?; UMMZ 42213, 67157, 91331, 91338, 91344, 91348, 91349, 186264	2001 R, 1963, 1961, 1956, 1934-35, 1894, 1885 1982 R 1978 R 1967 1963 R 1960 1937 <1937 1890 ?
Lake Erie, Ottawa County, OH	OSUM 46092 OSUM 17773, 27675 OSUM 27623, 27770 OSUM 27656, 27725 OSUM 10986 OSUM 4752, 4800 OSUM 3962, 8710, 17542 OSUM 3803 OSUM 649, 651, 655, 1284, 3306 MFM 1688 Brown et al. (1938), OSUM 28168 OSUM 10361, 45927 Clark & Wilson (1913), Johnson (1978), OSUM 68300 UMMZ 128776	1977 R 1967 1966 1964 1963 R 1961 1960 1958 1954 1950 R 1937 1927 1908 R ?
Lake Erie, Erie County, OH	OSUM 68366 CM 61.11100 CM 61.11099 UMMZ 91339	1800s 1906 1900 ?
[3] Lake Erie?, Cuyahoga County, OH	ANSP 323948, 355311	?

Lake Erie, ? County, OH	UMMZ 54361	?
Lake Erie, Erie County, PA	CM 61.4901 Johnson (1978)	1910 ?
Lake Erie, Chautauqua/Erie Counties, NY	Strayer et al. (1991)	<1895
Lake Erie, ? County, ? State/Province	Walker (1913) INHS 1670	<1913 ?
37-Otter Creek, Monroe County, MI	UMMZ 68872	<1950
38-Maumee River, Allen County, IN	Goodrich & van der Schalie (1944)	<1944
Maumee River, Paulding County, OH	Clark (1987a)	1939
Maumee River, Defiance County, OH	D.L. Strayer (IES, pers. comm., 2006) Clark (1987a) UMMZ 248940	1977 R 1941 ?
Maumee River, Henry County, OH	Clark (1987a)	1949
39-Auglaize River, ? County, OH	Johnson (1978), MCZ 236771, UMMZ 91328	?
40-Swan Creek, Lucas County, OH	J. Grabarkiewicz (EI, pers. comm., 2006) Ortmann (1919); CM 61.7870, 61.9202 Johnson (1978), UMMZ 91340	2006 R <1919 ?
41-Portage River, ? County, OH	OSUM 2800	1953
42-Sandusky River, Wyandot County, OH	OSUM 46236	1936
Sandusky River, Sandusky County, OH	Johnson (1978), CM 61.7869, UMMZ 91397	?
43-Grand River, Lake County, OH	M.A. Hoggarth (OC, pers. comm., 2006) OSUM 61958 OSUM 57908 OSUM 40144 OSUM 40075 ANSP 227537 Johnson (1978), MCZ 236781 OSUM 68306 UMMZ 150207	2006 1997 R 1995 R 1977 1975 1949 <1941 <1877 ?
Grand River, Ashtabula County, OH	G. Zimmerman (EI, pers. comm., 2002), Huehner et al. (2005)	1995
44-Grand River, ONT	J.L. Metcalfe-Smith (EC, pers. comm., 2003) Robertson & Blakeslee (1948), La Rocque and Oughton (1937) Whiteaves (1896) Kidd (1973)	1966, 1935 1936 1894-95 1885
45-Buffalo Creek, Erie County, NY	Strayer & Jirka (1997)	<1950
46-Niagara River, Erie/Niagara Counties, NY/ONT	Strayer et al. (1991), Strayer & Jirka (1997) J.L. Metcalfe-Smith (EC, pers. comm.,	<1948 1906

	2003) NMNH 152989	?
47-Tonawanda Creek, Erie/Niagara Counties, NY	Marangelo & Strayer (2000)	1998 R
Upper Mississippi River sub-basin		
48-Mississippi River, Dakota/Washington Counties, MN	B. Sietman (MNDNR, pers. comm., 2003), BMNH 12109	2000 R
Mississippi River, Goodhue County, MN; Pierce County, WI	Grier (1922)	1920
Mississippi River, Wabasha/Winona Counties, MN; Buffalo/ Pepin/Trempealeau Counties, WI	Grier (1926) Grier (1922)	1925 1920
Mississippi River, Allamakee/Clayton Counties, IA; Crawford County, WI	D.J. Heath (WIDNR, pers. comm., 2002) OSUM 48045 Havlik & Marking (1980)	~1982 R 1979 R 1976 R
Mississippi River, Rock Island County, IL; Muscatine/Scott Counties, IA	Johnson (1978), MCZ 6161 UMMZ uncat.; NMNH 124430, 477036, 510198 ANSP 56558, NMNH 124455 MCZ 228687; NMNH 124430, 124455, 159357, 477036, 510198; UMMZ 91300	~1900 ~1895 ~1865 ?
Mississippi River, ? County, IL	Cummings & Mayer (1997)	?
St. Croix River, Chisago County, MN; Polk County, WI	WIDNR (2004) BMNH 13441(2), 13465(4), 13510(1) BMNH 9492(1) BMNH 7633(3), 7767(1), 8114(1), 8132(1), 8204(2), 8886(1), 8888(1), 8898(1), 8928(1), 9001(1); MCZ 316071(2) INHS 27006(13) Tyrrell & Hornbach (1998) BMNH 5701(?), 10467(6), 10873(2), 10958(2), 11084(1), 11105(1), 11253(1), 11748(8), 11759(4); OSUM 29019(4) Hornbach (2001)	1996-2004, 1990, 1988, 1987 2001 1998 1995 1994 1993 1987 >1980
St. Croix River, Washington County, MN; St. Croix County, WI	BMNH 12845(1)	2001
[4] 50-Wisconsin River, Columbia/Dane/Iowa/Sauk Counties, WI	Baker (1928) Johnson (1978), UMMZ 91329	~1900 ?
51-Rock River, Winnebago County, IL	INHS 27132	2002 R
Rock River, Ogle County, IL	INHS 18821	1996 R
52-Crawfish River, Jefferson County, WI	D.J. Heath (WIDNR, pers. comm., 2002), OSUM 52793	A
53-Cedar (Red Cedar) River, Chickasaw County, IA	FLMNH 125081	?
Cedar (Red Cedar) River, Linn County, IA	NMNH 477035	1882

54-Illinois River, Grundy County, IL	INHS 18710	1996 R
Illinois River, LaSalle County, IL	INHS 20315 Starrett (1971), Johnson (1978)	<1921 <1874
Illinois River, Fulton/Mason Counties, IL	Starrett (1971), Johnson (1978), INHS 20313	1911
Illinois River, ? County, IL	CHAS 1875, FMNH 57508	?
55-Des Plaines River, Will County, IL	OSUM 10362	1800s
56-Kankakee River, Kankakee County, IL	INHS 16238 INHS 12635(1) INHS 11568	1994 R 1991 1987 R
Kankakee River, Will County, IL	INHS 23988 INHS 12042, 12605 INHS 5819(1) OSUM 49400 ILSM 674831, 679103 Baker (1906), Suloway (1981)	1999 R 1991 R 1988 1981 R 1955 <1906
Kankakee River, ? County, IL	Parmalee (1967), Johnson (1978)	<1967
57-Nippersink Creek, McHenry County, IL	Schanzle et al. (2004), INHS 20037	1997 R
58-Mazon River, Grundy County, IL	FMNH 90163	?
59-Sangamon River, Sangamon County, IL	NMNH uncat.	1921
Sangamon River, Menard County, IL	INHS 1667 ANSP 56557	<1919 ?
Sangamon River, ? County, IL	UMMZ 50	?
60-Meramec River, Jefferson/St. Louis Counties, MO	Roberts & Bruenderman (2000) FMNH 312153 S.B. Bruenderman (KDW, pers. comm., 2003), S.E. McMurray (MDC, pers. comm., 2005) Buchanan (1980), OSUM 40457 FMNH 312163 FMNH 312157 FMNH 312155	1997 1988 1983, 1980-81, 1967 1977-78 1975 1967 1965
Meramec River, Franklin County, MO	Roberts & Bruenderman (2000) S.B. Bruenderman (KDW, pers. comm., 2003), S.E. McMurray (MDC, pers. comm., 2005) Buchanan (1980)	1997 1981 R, 1975-76, 1969-71 1977-78
Meramec River, Crawford County, MO	FMNH 312167 OSUM 13889	1970 1964
61-Bourbeuse River, Phelps County, MO	Buchanan (1980), S.B. Bruenderman (KDW, pers. comm., 2003), S.E. McMurray (MDC, pers. comm., 2005)	1977-78
Bourbeuse River, Gasconade County, MO	FMNH 312159 Buchanan (1980), S.B. Bruenderman	1987 1977-78

	(KDW, pers. comm., 2003), S.E. McMurray (MDC, pers. comm., 2005) Johnson (1978), MCZ 268287, OSUM 13944	 1964
Bourbeuse River, Franklin County, MO	S.B. Bruenderman (KDW, pers. comm., 2003), S.E. McMurray (MDC, pers. comm., 2005) Barnhart (1998), Barnhart et al. (1998) Roberts & Bruenderman (2000) FMNH 312154 Buchanan (1980), OSUM 42665	2005-06, 2001-03, 1979, 1972, 1968-69 1997-98 1997 1979 1977-78
62-Kaskaskia River, Moultrie County, IL	Suloway et al. (1981a), INHS 16890(14)	1956
63-Whitewater River, Cape Girardeau County, MO	S.E. McMurray (MDC, pers. comm., 2005)	1974
64-Castor River, Bollinger County, MO	S.B. Bruenderman (KDW, pers. comm., 2003)	1982 R, 1978 R
Lower Missouri River system		
65-Wakarusa River, Douglas County, KS	Murray & Leonard (1962), Johnson (1978), NMNH 743156	1909
66-Marais des Cygnes River, Franklin County, KS	Scammon (1906), Johnson (1978)	<1906
67-South Grand River, Henry County, MO	Oesch (1984), S.E. McMurray (MDC, pers. comm., 2005)	1978
68-Little Niangua River, Camden County, MO	Oesch (1984), S.E. McMurray (MDC, pers. comm., 2005)	1978
Ohio River system		
69-Ohio River, Allegheny County, PA	CM 61.1580, 61.1581 Rhoads (1899), Ortmann (1909a), ANSP 75987 CM 61.2037	1905 1898 ?
Ohio River, Beaver County, PA	Rhoads (1899), Ortmann (1909a), ANSP 75960	1898
Ohio River, Jefferson County, OH; Hancock County, WV	Johnson (1978), MCZ uncat.	1861
Ohio River, Washington County, OH; Wood County, WV	OSUM 19262 CM 46976	1879 ?
Ohio River, Meigs County, OH; Jackson County, WV	ESI (2002) OSUM 60726 CM 61.5562 CM 61.4903	2001, 1995 1995 R 1911 1910
Ohio River, Boone/Campbell/Kenton Counties, KY; Hamilton County, OH	Johnson (1978), MCZ 6158(12) OSUM 57421 OSUM 68307 OSUM 69465 Call (1900) OSUM 10355, 67950	~1900 <1889 <1844 1838 <1831 1800s

	Schuster (1988); FLMNH 64349, 269106; NMNH 26162, 26164, 84429 (17); UMMZ 232552	?
Ohio River, Jefferson/Oldham Counties, KY; Clark/Floyd Counties, IN [Type Locality]	Johnson (1978), ANSP 20231 (lectotype)	~1831
Ohio River, Meade County, KY; Harrison County, IN	Rafinesque (1820)	<1820
Ohio River, Henderson County, KY; Vanderburgh/Warrick Counties, IN	Bogan (1990)	A
Ohio River, Ballard/McCracken Counties, KY; Alexander/Massac/Pulaski Counties, IL	INHS 6729	1988 R
Ohio River, ? County, ?	INHS 1668, 1669 Johnson (1978) NMNH 25830; OSUM 10359, 58877 ANSP 56553(15), 188260, 366124; FLMNH 64357, 64366; FMNH 90161; NMNH 25576, 25935; UMMZ 58737	<1919 <1831 1800s ?
70-Allegheny River, Forest County, PA	Villella & Smith (2002b)	2001
Allegheny River, Venango County, PA	Villella & Smith (2002a) NCSMNS 6291(2)	1998-99 1996
Allegheny River, Armstrong County, PA	CM 61.9203 FLMNH 64370 CM 61.4902 CM 61.3967, 61.3968, 61.3972, 61.3973, 61.3974; FLMNH 64358 Ortmann (1909a, 1912, 1913); CM 61.3351, 61.3358(20), 61.3360; MCZ 89494 Ortmann (1911); CM 61.2912, 61.2914, 61.2983, 61.2984, 61.2985 Johnson (1978), MCZ 192483, NMNH 251414, UMMZ 62142	1917 1913 1910 1909 1908 1907 ?
71-French Creek, Erie County, PA	Smith (2005) G. Zimmerman (EI, pers. comm., 2002) OSUM 31282(14), 31722(1), 31754(R) ANSP 396777(11)	2003-04 2002 1992 1991
French Creek, Crawford County, PA	Smith (2005) NCSMNS 27228(1) G. Zimmerman (EI, pers. comm., 2002) FMNH 282623, 282652 NCSMNS 6362(7), 6471(6), 6498(3), 6511(1) ANSP A18373(1) ANSP 396177(20), 396291(3), 396322(31), 396897(R) ANSP 372579(6), 397153(R) OSUM 40547 OSUM 34930 Ortmann (1909a); CM 61.3353, 61.3975 FLMNH 64359	2002-04 2002 D 2002, 1997-98 1998 R 1996 D 1993 1991 1988 1977 1973 1908-09 ~1900?

French Creek, Mercer County, PA	Smith (2005)	2002-04
French Creek, Venango County, PA	Smith (2005) Villella & Smith (2002a), R.R. Evans (KSNPC, pers. comm., 2003) OSUM 57169(1) ANSP A18374(1) Ortmann (1909a), CM 61.3354 Johnson (1978)	2002-04 1998-99 1994 1993 1908 ?
French Creek, ? County, PA	Dennis (1985, 1971) FLMNH 226030	~1970 ?
72-West Branch French Creek, Erie County, PA	R.R. Evans (KSNPC, pers. comm., 2003)	1993
73-Le Boeuf Creek, Erie County, PA	T.A. Smith (WPC, pers. comm., 2006) ANSP 394714(11), A.E. Bogan (NCSMNS, pers. comm., 2005) R.R. Evans (KSNPC, pers. comm., 2003) Ortmann (1909a), CM 61.3228 Johnson (1978)	2006 1991 1988 <1908 ?
74-Muddy Creek, Crawford County, PA	P. Morrison (Service, pers. comm., 2003)	2003
75-Conneaut Outlet, Crawford County, PA	G. Zimmerman (EI, pers. comm., 2002) Ortmann (1909a); CM 61.3227, 61.3966 CM 61.3352 Johnson (1978)	1997 1909 1908 ?
76-Little Mahoning Creek, Indiana County, PA	A.E. Bogan (NCSMNS, pers. comm., 2005)	1991
77-Crooked Creek, Armstrong County, PA	CM 61.3971 Ortmann (1913), CM 61.2911	1909 1907
78-Monongahela River, Washington/Westmoreland Counties, PA	Ortmann (1913)	<1897
79-Dunkard Creek, Monongalia County, WV	NCSMNS 30283(8) Zeto (1982), OSUM 50689(1) ANSP 397333, 397336; OSUM 22914	1997 D 1980 1969
Dunkard Creek, Greene County, PA	R.R. Evans (KSNPC, pers. comm., 2003) OSUM 35825 ANSP 397338 CM 61.4900 Johnson (1978); MCZ 276632; OSUM 23547, 24936	1993-94 1974 1970 1969 1910 ?
80-West Fork River, Lewis County, WV	Johnson (1978), CM 61.5970	1912
West Fork River, Harrison County, WV	Zeto (1982) CM 61.5971 Ortmann (1913), CM 61.5560 Johnson (1978), CM 61.2035	1980 1912 1911 ?
81-Beaver River, Lawrence County, PA	Rhoads (1899), Ortmann (1909a), ANSP 75951, CM 61.2863(13), FLMNH 64371 NMNH 152076; UMMZ 62140, 91350	1897-98 ?
82-Shenango River, Mercer County, PA	CM 65865	2003

	R.R. Evans (KSNPC, pers. comm., 2003) ANSP 394822 Bursey (1987) Ortmann (1909a, 1919); CM 61.2913, 61.3355, 61.3359, 61.4097 Johnson (1978), UMMZ 62141	2001-02 1991 R 1984 1907-09 ?
Shenango River, Lawrence County, PA	CM 61.4904 CM 61.3970	1910 1909
Shenango River, ? County, PA	ANSP 366103	?
83-Little Shenango River, Mercer County, PA	G. Zimmerman (EI, pers. comm., 2002) ANSP 396269(1), A.E. Bogan (NCSMNS, pers. comm., 2005)	2002 1991
84-Pymatuning Creek, Mercer County, PA	Ortmann (1909a, 1919); Johnson (1978); CM 61.3356, 61.3965, 61.3969	1908-09
85-Slippery Rock Creek, Lawrence County, PA	MFM 1459 Ortmann (1919)	1950 <1919
86-Connoquenessing Creek, Lawrence County, PA	CM 61.11379	1922
87-Mahoning River, Portage County, OH	Johnson (1978), MCZ 236777	<1951?
Mahoning River, Trumbull County, OH	INHS 20526 NMNH 124439	<1921 ?
Mahoning River, ? County, OH	OSUM 68309 FMNH 90166, 299175, 299176; MCZ 236776; UMMZ 91302	<1877 ?
Mahoning River, Lawrence County, PA	CM 61.3357 CM 61.2141	1908 1907
88-Middle Island Creek, Doddridge County, WV	ANSP 397649	1969
Middle Island Creek, Tyler County, WV	G. Zimmerman (EI, pers. comm., 2002) Taylor & Spurlock (1981) OSUM 49559 ANSP 397569; OSUM 22853, 22884(13)	2001 1980 1980 R 1969
Middle Island Creek, Pleasants County, WV	OSUM 22833, 22866	1969
89-Muskingum River, Coshocton County, OH	OSUM 44876, 44956, 45069	1979
Muskingum River, Muskingum County, OH	R. Taylor (MU, pers. comm., 2005) OSUM 47397(R), 47480(2), 47631(R), 47647(R), 47765(R), 48264(R), 48703(R), 48929(R), 48950(R) OSUM 45114, 45288, 45336, 45596 OSUM 37585 OSUM 5608	2005 1980 1979 1975 1961
Muskingum River, Morgan County, OH	OSUM 49722 OSUM 43991 OSUM 10357	1980 R 1929 1927
Muskingum River, Washington County, OH	OSUM 50891 OSUM 7196	1980 R 1963 R

	OSUM 6456, 6733 OSUM 46433 OSUM 44257, 46954 OSUM 45925	1962 1934 1930 1927
Muskingum River, ? County, OH	Bates (1970) OSUM 9042 OSUM 47305, 47306, 47307, 47308(29)	1967-70 <1860 1825-35
90-Tuscarawas River, Tuscarawas County, OH	ANSP 56559 CM 61.11106 CM 61.11104 CM 61.11105 CM 61.11103, MCZ 114420(40) CM 61.11102, OSUM 10360 Johnson (1978) CM 61.11101(11); MCZ 169961; UMMZ 62965(10), 63000	1891 ~1890 1887 1885 1884 1883 ?
Tuscarawas River, ? County, OH	CM 61.1372	?
91-Sugar Creek, Stark County, OH	CM 61.11107	1895
Sugar Creek, Tuscarawas County, OH	CM 61.11106	~1890
92-Walhonding River, Coshocton County, OH	OSUM 60766(1), 60825(R), 60844(R), 60876(R), 60886(R), 60939(R) OSUM 18089, 19902, 20072 OSUM 6153, 6220 OSUM 11022 OSUM 4136, 4174	1991 1967 1962 1961 1960
93-Mohican River, Coshocton County, OH	Johnson (1978), MCZ 268046 OSUM 11112	1965 R 1963
94-Lake Fork Mohican River, Holmes County, OH	OSUM 10356	1927
95-Killbuck Creek, Holmes County, OH	OSUM 65641	1995 R
Killbuck Creek, Coshocton County, OH	S.A. Ahlstedt (USGS retired, pers. comm., 2006) Hoggarth (1997); OSUM 65683(1), 65754(R) OSUM 56649(5), 56660(1)	2006 1995 1994
96-Little Kanawha River, Braxton County, WV	Johnson (1978), CM 61.5561	1911
Little Kanawha River, Gilmer County, WV	Schmidt et al. (1983)	1981-82
Little Kanawha River, Calhoun County, WV	Schmidt et al. (1983) Johnson (1978), CM 61.2036	1981-82 ?
Little Kanawha River, Wirt County, WV	Schmidt et al. (1983)	1981-82
97-Leading Creek, Gilmer County, WV	Schmidt et al. (1983)	1981-82
98-Cedar Creek, Gilmer County, WV	Schmidt et al. (1983)	1981-82
99-Henry Fork, Calhoun/Roane Counties, WV	Schmidt et al. (1983), OSUM 53488(10)	1982
100-Hughes River, Wirt County, WV	Schmidt et al. (1983)	1981-82

Hughes River, Wood County, WV	OSUM 14537	1930
101-North Fork Hughes River, Richie County, WV	J. Lee (ESI, pers. comm., 2003) B. Sietman (MNDNR, pers. comm., 2003) OSUM 31579 Schmidt et al. (1983), OSUM 53377(1) Johnson (1978), CM 61.5969	2001, 1993 1997 1993 R 1982 1912
102-South Fork Hughes River, Richie/Wirt Counties, WV	Schmidt et al. (1983)	1981-82
103-Hocking River, Hocking County, OH	Watters (1988a, 1992), OSUM 46748	1930
104-Elk River, Clay County, WV	R. Winterringer (ESI, pers. comm., 2005) Clayton (1994) OSUM 43895	2004 1991-92 R 1970
Elk River, Kanawha County, WV	R. Winterringer (ESI, pers. comm., 2005) W.A. Tolin (Service retired, pers. comm., 2002) Dunn & Sietman (1997), J. Lee (ESI, pers. comm., 2003) Clayton (1994) OSUM 44290, 44635	2004 2002 1994-95, 1991-92 1991-92 R 1970
105-Tygarts Creek, Carter County, KY	P.W. Shute (TVA, pers. comm., 2003) EKU 755 OSUM 29086(36) OSUM 30869(1) Zeto (1979); OSUM 43479, 48769	1995 1991 R 1988 1987 1978 R
Tygarts Creek, Greenup County, KY	R.R. Cicerello (KSNPC retired, pers. comm., 2003) W.R. Haag (USFS, pers. comm., 2006) INHS 12855 OSUM 50836(2) Zeto (1979), MUMC 1158 Taylor (1980)	1995, 1987 1988 1989 R 1981 1978 1977
Tygarts Creek, ? County, KY	R.R. Cicerello (KSNPC retired, pers. comm., 2006)	1998 R
106-Scioto River, Franklin County, OH	OSUM 67382 OSUM 13097 OSUM 5679 OSUM 9357 OSUM 9599 OSUM 68051 OSUM 57815 Johnson (1978); CM 61.11108; FMNH 14293(>25), 90171; MCZ 53103; NMNH 25460, 29928; UMMZ 43078	1999 R 1964 R 1961 1960 1959 R ~1850 1800s ?
Scioto River, Pickaway County, OH	OSUM 67167, 67245, 67349 OSUM 61342 OSUM 58901 OSUM 56521, 66416 OSUM 31881 OSUM 1906 OSUM 5710 OSUM 5661, 13164 OSUM 13332, 13382	1999 R 1997 R 1995 R 1994 R 1993 R 1986 R 1962 1961 1960

	OSUM 13359 Johnson (1978), MCZ 228688, UMMZ 91296	1959 R ?
Scioto River, Ross County, OH	OSUM 68305 UMMZ 43852 Stansbery (1965b), Peacock et al. (2005)	<1886 ? A
Scioto River, Pike County, OH	OSUM 8598	1963
Scioto River, ? County, OH	OSUM 25264 OSUM 9788 Johnson (1978) OSUM 68052 ANSP 56555, 267784; FLMNH 187940, 269107; FMNH 90168, 120567; NMNH 58256; UMMZ 51, 205500	<1970 <1963 <1914 1800s ?
107-Olentangy River, Marion County, OH	OSUM 66889(2), 68982(R), 69074(R), 69158(R), 69298(R) OSUM 63750 Stein (1963); OSUM 4977, 5052 Stein (1963); OSUM 16867, 16876, 16924 OSUM 10358	1989 1978 R 1961 1960 1927
Olentangy River, Delaware County, OH	OSUM 69184, 69387 OSUM 36155 Stein (1963); OSUM 4536, 4651 Stein (1963); OSUM 4234, 7013 MFM 2197 OSUM 46855 INHS 20527 MCZ 254884 OSUM 58865 OSUM 57646, 58876(12) Johnson (1978), ANSP 366104, MCZ 236783, UMMZ 91301	1989 R 1974 1961 1960 1951 R 1930 <1921 ~1900 1876 1800s ?
Olentangy River, Franklin County, OH	OSUM 60945 OSUM 30503 OSUM 18246 OSUM 14311 OSUM 5734, 5764 Stein (1963); OSUM 4441, 4467, 4548, 4602(23), 4936, 4911(17), 4962, 4990 Stein (1963); OSUM 4284, 4335, 5928, 13574, 16890, 16964 OSUM 3815, 4214, 4224, 4348, 4384, 4393, 5920, 6704 OSUM 3578(10), 4322, 4357, 4373 UMMZ 57067	1997 R 1990 R 1967 1965 1962 1961 1960 1959 1958 ?
Olentangy River, ? County, OH	ANSP 133867	1923 R
108-Whetstone Creek, Morrow County, OH	OSUM 5779	1962
109-Big Walnut Creek, Franklin County, OH	OSUM 66531 OSUM 65632 OSUM 7887 OSUM 6863(10) OSUM 4513, 5075	1999 R 1998 R 1963 1962 1961

	OSUM 4001, 16969 OSUM 9940, 10470, 10635, 11460(12), 11610, 11800, 13198 OSUM 10712 UMMZ 91327	1960 1959 1927 ?
Big Walnut Creek, Pickaway County, OH	OSUM 66585 OSUM 4048	1999 R 1960
110-Alum Creek, Delaware County, OH	OSUM 26153 OSUM 60860 OSUM 62420 OSUM 17857 OSUM 5967, 6008 OSUM 4568 OSUM 9677 OSUM 9233, 9255, 9810	1971 1970 R 1969 1967 1962 1961 1960 1959
Alum Creek, Franklin County, OH	OSUM 56960 OSUM 62324 OSUM 7466, 7487	1994 R 1969 R 1959 R
111-Blacklick Creek, Franklin County, OH	OSUM 31689	1993 R
112-Walnut Creek, Franklin County, OH	OSUM 61854	1994 R
Walnut Creek, Pickaway County, OH	OSUM 32398, 56032, 56062, 56111, 56317, 56333, 56362, 56946	1994 R
113-Big Darby Creek, Union County, OH	OSUM 66779 Watters (1994) OSUM 7705 OSUM 3877, 8741	1999 R 1990 or 1986 1963 1960
Big Darby Creek, Madison County, OH	OSUM 69809 Watters (1994) OSUM 9698	2001 R 1990 or 1986 1963
Big Darby Creek, Franklin County, OH	OSUM 58208(1) NCSMNS 30287(2) Watters (1994) OSUM 1439(1), 1441(1), 1455(R), 1466(2), 1485(R) OSUM 67652(6), 67844(2) OSUM 67665(1) OSUM 46835 OSUM 47909 OSUM 39662 OSUM 63520 OSUM 32947, 33309 OSUM 26754(11), 27217(33) MFM 15728 OSUM 14770 OSUM 8249(13), 9710, 9735 OSUM 4489, 5530, 6497, 8318 OSUM 4408 OSUM 8041, 8134	1996 1991 D 1990 or 1986 1986 1983 1982 1980 R 1979 1977 1976 R 1972 1971 1967 1965 1963 1961 1960 1959

	OSUM 3578, 7757	1958
	OSUM 3542, 3552	1957
	OSUM 3120, 3189	1956
Big Darby Creek, Pickaway County, OH	OSUM 69502(1), 69521(R), 69869(R)	2000
	OSUM 31520	1993 R
	Watters (1994)	1990 or
		1986
	OSUM 1406(4), 1420(3), 1432(1),	1986
	1433(1), 1446(1)	
	OSUM 67961(1)	1985
	OSUM 67790(2), 67956(2)	1984
	OSUM 1413(1), 53037(R), 53175(R),	1983
	53447(R), 67531(4), 67947(2), 67986(3)	
	OSUM 54675(R), 67593(1)	1982
	OSUM 51793	1981 R
	OSUM 43254	1978
	OSUM 41386	1977 R
	OSUM 38737	1976
	OSUM 32928, 33829, 40790	1972
	OSUM 26493, 26625	1971
	OSUM 25735(10), 25971	1970
	NCSMNS 30288	1970 D
	OSUM 15212	1966
	MFM 15886, OSUM 14085	1965
	Johnson (1978); MCZ 268234; OSUM	1964
	12210, 12332, 12794, 24210	
	OSUM 7225, 7260, 7729, 7808, 8413,	1963
	8701, 9181	
	OSUM 5881(27), 6022(29), 6100(10),	1962
	6347, 6755, 7446(18), 7525(130),	
	8505(36)	1961
	OSUM 4870, 6908	1960
	OSUM 8159, 8761, 8854, 16911	1959
	OSUM 7945(11), 7963, 8093, 8117, 8190,	
	8297, 8356, 8380	1958
	OSUM 3659(15), 3676, 3756, 7739,	
	7768(12)	1957
	OSUM 3569(12), 7134, 7843(10), 27909	1956
	OSUM 3133(30), 8051, 8057	1939
	FMNH 191098	?
	FLMNH 187862	
114-Little Darby Creek, Union County, OH	OSUM 66740(1)	1999
	Watters (1990)	1990 R
	Watters (1990), OSUM 1266	[5]1986 R
	OSUM 12318	1964
Little Darby Creek, Madison County, OH	OSUM 69832	2001 R
	OSUM 66742, 67725, 68675	2000 R
	Watters (1994)	1990 R
	OSUM 30082	1987 R
	Watters (1990); OSUM 1377, 1384, 55842	1986 R
	OSUM 51745	1982 R
	OSUM 49822	1981 R
	OSUM 47348	1980
	OSUM 43609	1979
	OSUM 42040	1978
	OSUM 40059, 41404	1977
	OSUM 36595	1975

	OSUM 14105 OSUM 11479 OSUM 7654, 8004, 8202	1965 1964 1963
Little Darby Creek, Franklin County, OH	OSUM 68400	1989 R
115-Yellowbud Creek, Pickaway County, OH	OSUM 26466	1971
116-Deer Creek, Madison County, OH	OSUM 50506, 63854, 64115 OSUM 61239, 61270	1981 R 1968
Deer Creek, Fayette County, OH	OSUM 64501 MFM 12685(10) OSUM 5700	1981 R 1965 R 1961
Deer Creek, Pickaway County, OH	OSUM 66272 OSUM 64324(2) OSUM 41965 OSUM 63238, 63313, 63385, 63546 OSUM 62314	1999 R 1981 1978 1975 1969 R
Deer Creek, Ross County, OH	OSUM 65483 OSUM 58790	1998 R 1996 R
117-Paint Creek, Highland County, OH	OSUM 33236	1972
Paint Creek, Ross County, OH	OSUM 62158 OSUM 20986 OSUM 21012 UMMZ 155947	1997 R 1968 1967 ?
118-Salt Creek, Ross County, OH	Watters (1988a, 1992), OSUM 65090(1) Watters (1988a) Watters (1988a), OSUM 22756 Watters (1988a), OSUM 8582 Watters (1988a), OSUM 7095	1987 1975 <1970 1963 1958
119-Little Salt Creek, Ross County, OH	Watters (1988a), OSUM 22756	1964
120-Scioto Brush Creek, Scioto County, OH	Watters (1988a, 1992); OSUM 59450(1), 59471(R), 59512(2), 60033(R) (Watters 1988a), OSUM 25136 (Watters 1988a), OSUM 12350	1987 1966 1964
121-South Fork Scioto Brush Creek, Scioto County, OH	(Watters 1988a, 1992), OSUM 59432(1)	1987
122-Kinniconick Creek, Lewis County, KY	R.R. Cicerello (KSNPC retired, pers. comm., 2003, 2004, 2005) INHS 12941(8) INHS 6953(3) Schuster (1988); EKU 30(5), 467(R) Warren et al. (1984), MFM 15885(?)	2004-05, 2001, 1995, 1989-90 1989 1987 1986 1982
[6] 123-Little Miami River, Greene County, OH	Hoggarth (1992), OSUM 60180 Walter (1972)	1990 R 1951-64
Little Miami River, Warren County, OH	Hoggarth (1992), OSUM 60204(R), 60239(1), 60252(R), 60280(2), 60265(1), 60309(R) OSUM 48960	1990 1980 R

	OSUM 39324 OSUM 11563 Clark (1987b) Whiteaves (1863) UMMZ 165307	1976 1961 R 1935-46 <1863 ?
Little Miami River, Clermont/Hamilton Counties, OH	Hoggarth (1992), OSUM 60435(2)	1991
Little Miami River, ? County, OH	Johnson (1978); MCZ 45352, 70845 FMNH 9401, 9406, 9536; UMMZ 91298	~1900 ?
[7] 124-Caesar Creek, Warren County, OH	Hoggarth (1992), OSUM 60538	1990 R
125-Licking River, Morgan County?, KY	R.R. Cicerello (KSNPC retired, pers. comm., 2003)	1966
Licking River, Bath/Fleming/Nicholas/Rowan Counties, KY	M. McGregor (KDFWR, pers. comm., 2006) J. Settles (EKPC, pers. comm., 2002) R.R. Cicerello (retired) & E.L. Laudermilk (KSNPC, pers. comm., 2001) Hardison & Layzer (2001) Laudermilk (1993) EKU 886, 922, 924, 932, 934, 937, 939, 950, 962, 972 Schuster (1988), EKU 25(1) OSUM 54696 MUMC 2093(?), 3017(?) Clinger (1974) OSUM 34308 EKU 98 FMNH 175430	2006 2002 R 1999, 1990-91, 1986-88, 1983 R, 1980, 1971, 1937 1995 1991 1991 R 1986 1983 R 1981 ~1972 1971 1969 ?
Licking River, Pendleton County, KY	ANSP 377082	1971
126-Slate Creek, Bath County, KY	R.R. Cicerello (KSNPC retired, pers. comm., 2001) Laudermilk (1993), E.L. Laudermilk (KSNPC, pers. comm., 1993) EKU 961, 964 MUMC 4387(?) Taylor & Spurlock (1983); ANSP 355330(14); MCZ 280774; MUMC 3110(?); OSUM 50309(6), 50314(29)	2001 R, 1992 1991, 1990 R, 1983 1991 R 1987 1981
Slate Creek, Montgomery County, KY	Schuster (1988), Laudermilk (1993)	1983
127-Great Miami River, Montgomery County, OH	Walter (1972)	1951-64
Great Miami River, ? County, OH	Johnson (1978), CM 61.7682	?
128-Stillwater River, Darke County, OH	Watters (1988a), OSUM 59982 OSUM 64890	1987 R 1983 R
Stillwater River, Miami County, OH	OSUM 59593	1987 R
Stillwater River, Montgomery County, OH	Watters (1988a); OSUM 59533(R), 59543(1) Walter (1972)	1987 <1972

	Watters (1988a), OSUM 16496	1965
129-Middle Fork Kentucky River, Leslie County, KY	R.R. Cicerello (KSNPC retired, pers. comm., 2003) EKU 427 Schuster (1988), EKU 69	1997, 1996, 1992 R, 1966 1983 R 1973
130-South Fork Kentucky River, Clay County, KY	Schuster (1988) Schuster (1988), EKU 45	1986 R 1970 R
South Fork Kentucky River, Owsley County, KY	EKU 65 Schuster (1988); EKU 44, 50, 586 MFM 13898 MFM 12855(15) Johnson (1980); MCZ 220344, 293421	1971 R 1970 1966 1965 1958
South Fork Kentucky River, Lee County, KY	Schuster (1988)	1971 R
131-Red Bird River, Clay County, KY	R.R. Cicerello (KSNPC retired, pers. comm., 2003) EKU 688 EKU 670 EKU 64	1995, 1988 1992 R 1991 R 1986 R
132-Goose Creek, Clay County, KY	Schuster (1988), EKU 46 MFM 13873	1970 1966
133-Cow Creek, Owsley County, KY	Schuster (1988), EKU 68	1971 R
134-Station Camp Creek, Estill County, KY	MFM 16111	1967
135-Red River, Menifee/Wolfe Counties, KY	R.R. Cicerello (KSNPC retired, pers. comm., 2003, 2006)	?
Red River, Powell County, KY	M. McGregor (KDFWR, pers. comm., 2002) R.R. Cicerello (KSNPC retired, pers. comm., 2001, 2003) Schuster (1988), EKU 19, MFM 16087	2002 1996, 1988 1967
136-Salt River, Spencer County, KY	R.R. Cicerello (KSNPC retired, pers. comm., 2003)	1982 R
137-Rolling Fork Salt River, Marion County, KY	Madison & Layzer (1998) EKU 771 W.R. Haag (USFS, pers. comm., 2006), R.R. Cicerello (KSNPC retired, pers. comm., 2003, 2006); EKU 767(2), 770(R) EKU 779(1) Rosewater (1959), Johnson (1978), MCZ 220162	1996 R 1989 1988 1986 1958
Rolling Fork Salt River, Larue/Nelson County, KY	R.R. Cicerello (KSNPC retired, pers. comm., 2003, 2006) EKU 768	1988 1988 R
138-Blue River, Harrison County, IN	B. Sietman (MNDNR, pers. comm., 2003)	1995 R
Blue River, ? County, IN	Daniels (1903)	<1903

139-Green River, Casey County, KY	Ortmann (1926) UMMZ 40732	1925 ?
Green River, Taylor County, KY	J.B. Layzer (TTU, pers. comm., 2006) R.R. Cicerello (KSNPC retired, pers. comm., 2003) OSUM 13620 Johnson (1978), MCZ 220157 Ortmann (1926) UMMZ 91346	2000 1989 1964 1958 1925 ?
Green River, Green County, KY	Cicerello (1999) R.R. Cicerello (KSNPC retired, pers. comm., 2003) OSUM 6554 Ortmann (1926) OSUM 67921, 67922, 67927 Johnson (1978), MCZ ?	1989, 1984 1988 1962 1925 1908 ?
Green River, Hart County, KY	Cicerello (1999), INHS 12894(3) Cicerello & Hannan (1990) Cicerello (1999), EKU 91(1) Schuster (1988), EKU 87 Clarke (1981b) OSUM 49890 OSUM 33294 ANSP 385967, OSUM 27338 OSUM 25559 EKU 396 OSUM 44922 OSUM 17517(17) ANSP 314014; NMNH 745416; OSUM 16614(46), 16551(31) ANSP 310000; MCZ 252040, 268180; MFM 11699(~20); OSUM 12726(18), 12776, 13488, 13607 OSUM 11844(134) OSUM 5353(25), 6313(22) Clench & van der Schalie (1944) MCZ 52616 Ortmann (1926) Johnson (1978); FMNH 156060; UMMZ 91345, 234203	1989 1987-88 1986 1983 R 1981 D 1981 R 1972 1971 1968 1968 R 1967 R 1966 1965 1964 1963 1961 1927 1926 1924-25 ?
Green River, Edmonson County, KY	J.B. Layzer (TTU, pers. comm., 2006) Cicerello (1999) R.R. Cicerello (KSNPC retired, pers. comm., 2003) Cicerello & Hannan (1990); INHS 12982(1), 15705(1) 15852(R) OSUM 5260 Ortmann (1926) OSUM 67926 Johnson (1978), MCZ 6156 Bogan (1990)	~2005 R 1996-98 R 1990 1988-89 1989 R 1961 1922 1908 ~1900 A
Green River, Butler/Warren Counties, KY	OSUM 42970 OSUM 33786 OSUM 26853	1978 R 1972 1971

	OSUM 44107 OSUM 21722, 44416, OSUM 67923 Patch (1976), Peacock et al. (2005)	1970 R 1969 1908 A
140-Russell Creek, Green County, KY	R.R. Cicerello (KSNPC retired, pers. comm., 2003) OSUM 68146 Cicerello (1999)	1982 R 1908 ?
141-Little Barren River, Green County, KY	W.R. Haag (USFS, pers. comm., 2006) R.R. Cicerello (KSNPC retired, pers. comm., 2003)	1987 R 1982 D
142-Nolin River, Grayson County, KY	R.R. Cicerello (KSNPC retired, pers. comm., 2003) Schuster (1988), EKU 416 MUMC 3042, 3060, Taylor (1983)	1993 R, 1981 R 1986 R 1981
143-Barren River, Allen/Barren Counties, KY	INHS 12732, 16968, 16083	1990 R
Barren River, Warren County, KY	Gordon & Sherman (1995) INHS 12818 W.R. Haag (USFS, pers. comm., 1988) Clarke (1981b) OSUM 19178 Ortmann (1926), Schuster (1988) OSUM 67924, 67925, 68071, 68072	1993 R 1990 R 1988 R 1981 D 1964 R 1924 1908
Barren River, ? County, KY	UMMZ 91347	?
144-Drakes Creek, Warren County, KY	ANSP 358892 MCZ 58372; UMMZ 42203, 45102	1983 R 1927
145-West Fork Drakes Creek, Warren County, KY	ANSP 358855 Johnson (1978), MCZ 58384, UMMZ 44651	1983 R 1927
146-Gasper River, Warren County, KY	R.R. Cicerello (KSNPC retired, pers. comm., 2003)	1993 R
147-Pond River, Hopkins County, KY	Peacock et al. (2005)	A
148-Wabash River, Mercer County, OH	OSUM 41150 OSUM 6933 Johnson (1978); MCZ 236785; UMMZ 156123, 156411, 156423	1977 R 1962 R ?
Wabash River, Wells County, IN	B.E. Fisher (INDNR, pers. comm., 2005)	2005 R
Wabash River, Huntington County, IN	Cummings et al. (1988b), INHS 5009	1988 R
Wabash River, Wabash County, IN	Cummings et al. (1988b); INHS 5078, 6325	1988 R
Wabash River, Miami County, IN	EI (2005) B.E. Fisher (INDNR, pers. comm., 2005) NMNH uncat.	2004 R 2002 R 1908
Wabash River, Cass County, IN	INHS 5066, 6237	1988 R

Wabash River, Carroll County, IN	EI (2005) INHS 8238 Cummings et al. (1988b); INHS 5177, 5209, 6662 NMNH 149374	2004 R 1989 R 1988 R <1919
Wabash River, Tippecanoe County, IN	EI (2005) Cummings et al. (1988b); INHS 6202, 6636 MCZ 268021 UMMZ uncat. UMMZ uncat. INHS 20519(12) NMNH uncat. OSUM 68421 MFM 1844 Johnson (1978), MCZ 89201(15) UMMZ 91334 MCZ 63314; UMMZ 150784, 227334, 231707	2004 R 1988 R 1964 1963 1941 <1918 1908 1907 1902 ~1900 1897 ?
Wabash River, Fountain County, IN	Cummings et al. (1988b); INHS 5103, 6143	1988 R
Wabash River, Clark County, IL; Vigo County, IN	INHS 20520(10) OSUM 68422	<1918 1907
Wabash River, Crawford County, IL; Sullivan County, IN	FMNH 282867 Peacock et al. (2005)	1991 R A
Wabash River, Lawrence County, IL; Knox County, IN	Bogan (1990), Peacock et al. (2005)	A
Wabash River, Wabash County, IL; Gibson County, IN	INHS 18873 FMNH 174825 OSUM 41430	1996 R 1966 A
Wabash River, White County, IL; Posey County, IN	INHS 13402 INHS 8437 Cummings et al. (1987), INHS 4754 NMNH 540392 NMNH 84435 ILSM 674830	1991 R 1989 R 1987 R 1904 R 1800s ?
Wabash River, ? County, IN	CHAS 1864, FMNH 90165, UMMZ 91330	?
Wabash River, ? County, IL/IN	OSUM 39004, 39005	1800s
149-Big Beaver Creek, Mercer County, OH	Johnson (1978), CM 61.6863	1913
150-Limberlost Creek, Jay County, IN	B.E. Fisher (INDNR, pers. comm., 2005)	2003-05 R
151-Salamonie River, Huntington County, IN	B.E. Fisher (INDNR, pers. comm., 2005)	2004
Salamonie River, Wabash County, IN	MFM 22675	1971 R
Salamonie River, ? County, IN	Johnson (1978), MCZ 236782	<1941 R
152-Mississinewa River, Grant County, IN	UMMZ 155921	1940
Mississinewa River, Miami County, IN	B.E. Fisher (INDNR, pers. comm., 2000)	2001 R

Mississinewa River, ? County, IN	UMMZ 91341	1887
153-Eel River, ? County, IN	Daniels (1903)	<1903
154-Tippecanoe River, Pulaski County, IN	EI (2005)	2003 R
Tippecanoe River, White County, IN	EI (2005) ESI (2003a) B.E. Fisher (INDNR, pers. comm., 2000) ESI (1993) Cummings & Berlocher (1990), INHS 4123(1) UMMZ 91332	2003 R 2003 1993, 1973 1991-92 1987 ?
Tippecanoe River, Carroll County, IN	B.E. Fisher (INDNR, pers. comm., 2000) OSUM 56494(R), 56549(R), 56633(1) INHS 6597 UMMZ 91333	1993 1992 1988 R ?
Tippecanoe River, Tippecanoe County, IN	EI (2005) ESI (1993), OSUM 56389 Cummings & Berlocher (1990), INHS 3610	2003 R 1992 R 1987 R
Tippecanoe River, ? County, IN	Daniels (1903)	<1903
155-North Fork Wildcat Creek, Tippecanoe County, IN	B.E. Fisher (INDNR, pers. comm., 2005)	2004 R
156-Vermilion River, Vermilion County, IL	INHS 9657	1990 R
Vermilion River, Vermillion County, IN	B.E. Fisher (INDNR, pers. comm., 2005)	2005 R
157-Sugar Creek, Parke County, IN	NMNH uncat. (2 lots)	1925 R
158-Embarras River, Douglas County, IL	INHS uncat. (1) INHS 25846(1), 26046(1), 26114(R) INHS 16216(2) INHS 13546(9) INHS 13387(1) INHS 10392(1), INHS uncat. (3) INHS 5808(7) Cummings et al. (1988a), INHS 2422(9) INHS 2396	2002 2001 1994 1992 1991 1990 1988 1986 1956 R
Embarras River, Coles County, IL	INHS 27162(1), 27215(R) INHS 25854 INHS 18661 INHS 13601(2) Cummings et al. (1988a), INHS 2498(1), 2545(13), 2561(R), 2800(1) INHS 2400, 2786 UMMZ 91326	2002 2001 R 1996 R 1992 1986 1956 ?
Embarras River, Cumberland County, IL	INHS 27365	2002 R
159-Little Embarras River, Coles County, IL	INHS 26033	2001 R
160-Kickapoo Creek, Coles County, IL	INHS 27215	2002 R
161-Little Wabash River, Wayne County, IL	Johnson (1978), MCZ 236784 OSUM 57348	<1947 1800s

Little Wabash River, White County, IL	INHS 20760	1997 R
162-White River, Gibson/Knox/Pike Counties, IN	FMNH 68291 MFM 1315 OSUM 50103 ANSP 125900, ANSP 56554; FLMNH 269103; FMNH 2538, 59199, 68291; INSM 1184; UMMZ 91297	<1960 1937 <1928 <1883 ?
163-East Fork White River, Bartholomew County, IN	INHS 11595	1990 R
East Fork White River, Jackson County, IN	Johnson (1978), MCZ 6160 UMMZ 91335	~1900 ?
East Fork White River, Lawrence County, IN	EI (2005)	2003 R
East Fork White River, Martin County, IN	INHS 12499 INHS 11408 OSUM 12028 UMMZ uncat. UMMZ 166234	1991 R 1990 R 1964 R 1946 ?
164-Driftwood River, Bartholomew County, IN	B.E. Fisher (INDNR, pers. comm., 2003)	1998 R
165-Sugar Creek, Hancock County, IN	Harmon (1992, 1998); INHS 10878(1), 10927(3), 10949(1); INSM 2118(?)	1990
Sugar Creek, Shelby County, IN	B.E. Fisher (INDNR, pers. comm., 2003) Harmon (1992, 1998); INHS 10977(R), 11011(R), 11049(2), 11088(1), 11096(R)	2001R, 1998 R 1990
Sugar Creek, Johnson County, IN	B.E. Fisher (INDNR, pers. comm., 2003) Harmon (1992, 1998); INHS 10919(1), 10993(R), 11029(1), 11049(2), 11065(1), 11114(R), 11131(R), 11149(R), 11192(R), 11254(1)	1998 R, 1995 R 1990
166-Buck Creek, Marion County, IN	Harmon (1992), INHS 10718	1990 R
Buck Creek, Shelby County, IN	Harmon (1992), INHS 10727(1)	1990
167-Youngs Creek, Johnson County, IN	B.E. Fisher (INDNR, pers. comm., 2003) Harmon (1992), INHS 10826	1995 R 1990 R
168-Flatrock River, Shelby County, IN	Richards (1998) INHS 17293 MFM 2170	1997 R 1994 R 1951
Flatrock River, Bartholomew County, IN	INHS 17309	1994 R
169-Clifty Creek, Bartholomew County, IN	INHS 17156, 17166	1994 R
170-Sand Creek, Jennings County, IN	INHS 15545, 15563, 15575	1993 R
171-Muscatatuck River, Jefferson County, IN	Harmon (1989)	1988
Muscatatuck River, ? County, IN	Daniels (1903)	<1903

172-Graham Creek, Jennings County, IN	INHS 10584(1) Harmon (1989), OSUM 29930	1990 1988 R
173-West Fork White River, Delaware County, IN	INHS 20517	<1921
West Fork White River, Hamilton County, IN	B.E. Fisher (INDNR, pers. comm., 2003)	2000 R
West Fork White River, Marion County, IN	B.E. Fisher (INDNR, pers. comm., 2003) Richards (1998) FMNH 89714 INHS 20518 INHS 20521 Johnson (1978), MCZ 236778 INSM 1057 Call (1900) INSM 1058 UMMZ 91337 INHS 20518	2000 R, 1893 1997 D 1939 <1921 <1918 1902 1900 <1900 ~1895 1882 ?
West Fork White River, Morgan County, IN	Richards (1998)	1997 D
174-Fall Creek, Marion County, IN	B.E. Fisher (INDNR, pers. comm., 2003, 2005 Henschen (1993)	2002 R, 1993 R
175-Black Creek, Knox County, IN	B.E. Fisher (INDNR, pers. comm., 2005)	2003 R
Cumberland River system		
176-Cumberland River, Wayne County, KY	Neel & Allen (1964), UMMZ 167123	1947
Cumberland River, Cumberland/Russell Counties, KY	Schuster (1988); EKU 95, 431 Neel & Allen (1964), FMNH 36047, NMNH 595003 Wilson & Clark (1914) UMMZ 91315, 91316, 167046, 167064, 167166, 168081, 172789, 173679	1982 R 1947-49 1911 ?
Cumberland River, Clay County, TN	Shoup et al. (1941) UMMZ 134826	1939 ?
Cumberland River, Jackson County, TN	Shoup et al. (1941) Wilson & Clark (1914), MCZ 236775 UMMZ 134851 Peacock et al. (2005)	1939 1911 ? A
Cumberland River, Smith County, TN	Parmalee et al. (1980) TVA (1976) Wilson & Clark (1914), Johnson (1978)	1977-79 1976 1911
Cumberland River, Sumner/Trousdale/Wilson Counties, TN	Koch (1983) MCZ 289407 TVA (1976)	1982-83 1977 1976
Cumberland River, Davidson County, TN	Johnson (1978), MCZ 6154 NMNH 477030	~1900 1891
Cumberland River, ? County, KY/TN	UMMZ 91325	?
	Hagman (2000)	1998-99 R

177-Buck Creek, Pulaski County, KY	Layzer & Anderson (1992) Schuster et al. (1989) EKU 208 EKU 112, 115, 129 Clarke (1981b)	1987-90 1978-84 1984 R 1983 R 1981
178-Little South Fork, McCreary/Wayne Counties, KY	M.E. Gordon (pers. comm., 1995) R.R. Cicerello (KSNPC retired, pers. comm., 2001) EKU 141	~1992 R 1988 R 1980 R
179-Beaver Creek, Russell County, KY	Neel & Allen (1964); Johnson (1978); FLMNH 28106; FMNH 29106; MCZ 159740; NMNH 592119; UMMZ 167046, 167090, 172739	1947-48
180-Obey River, Pickett County, TN	Shoup et al. (1941) Johnson (1978); FMNH 120273; MCZ 70968; NMNH 382414; UMMZ 49631, 58488	1939 ?
Obey River, Clay County, TN	UMMZ 134807 Wilson & Clark (1914), Johnson (1978), FLMNH 4113 UMMZ 91317	1939 ~1910? ?
Obey River, ? County, TN	MCZ 236778 UMMZ 206704	<1929 ?
181-Caney Fork, Dekalb/Putnam/Smith Counties, TN	Layzer et al. (1993) OSUM 29717 OSUM 50051 MFM 8764 ANSP 341121, 355303; FLMNH 226028; FMNH 23058; UMMZ 91396	1989 R 1988 R 1981 R 1961 R ?
182-Red River, Logan County, KY	INHS 12745 W.R. Haag (USFS, pers. comm., 2006)	1990 R 1988 R
Red River, Robertson County, TN	OSUM 23156 OSUM 16996, 17023, 17088	1969 1966
Red River, Montgomery County, TN	MFM 16203	1967
Tennessee River system		
183-Tennessee River, Knox County, TN	Johnson (1978), MCZ 6155 Pilsbry & Rhoads (1896) Lewis (1870) Hughes & Parmalee (1999)	~1900 1895 ~1870 A
Tennessee River, Loudon County, TN	Peacock et al. (2005)	A
[8] Tennessee River, Meigs/Rhea Counties, TN	Parmalee et al. (1982), Hughes & Parmalee (1999)	A
Tennessee River, Jackson County, AL	Ortmann (1925) UMMZ 91318 Bogan (1990), Peacock et al. (2005), Hughes & Parmalee (1999)	<1925 ~1900 A

Tennessee River, Limestone/Madison/Marshall/Morgan Counties, AL	MFM 2705 van der Schalie (1939) UMMZ 66442	1952 1931 ?
Tennessee River, Colbert/Lauderdale Counties, AL	Ortmann (1925) UMMZ 21314 FLMNH 64367 Hinkley (1906), INHS 20523 INHS 20522 Johnson (1978), CM 61.7684, FMNH 59200 EKU 881	<1925 ~1910 1909 1904 1894 ? A
Tennessee River, Decatur/Perry/Wayne Counties, TN	Hughes & Parmalee (1999)	A
184-Holston River, Hawkins County, TN	Ortmann (1918), CM 61.7601 Johnson (1978), MCZ 16777 UMMZ 91305	1914 1903 ?
Holston River, Grainger/Hamblen Counties, TN	Ortmann (1918); CM 61.6730, 61.7186 NMNH 677785, 678259; OSUM 35017	1913-14 1909
Holston River, Jefferson County, TN	MFM 10532	1963 R
Holston River, Knox County, TN	NCSMNS 7135 UMMZ 91336 Ortmann (1918); CM 61.6731, 61.7602, 61.8795 ANSP 68378 Johnson (1978); FMNH 59211, 90164; MCZ 46730, 63006, 70886, 236772; UMMZ 57104, 91311, 198097	1978 R <1940 1913-15 1895 ?
Holston River, ? County, TN	INHS 20529 MFM 912 ANSP 125904, 218971; FLMNH 41553, 269104; NMNH 25411, 26163, 656596; UMMZ 35127, 193352	<1921 ~1900 ?
185-North Fork Holston River, Washington County, VA	Neves (1995) Ortmann (1918), Johnson (1978), CM 61.6449	1991-95 R 1913
North Fork Holston River, Scott County, VA	W.H. Henley (VPI, pers. comm., 2005) ANSP 361284 Ortmann (1918), CM 61.6450 UMMZ 91321	2005 R 1984 R 1913, 1901 ~1900
North Fork Holston River, Hawkins/Sullivan Counties, TN	MFM 984 Ortmann (1918); CM 61.6452, 61.6726	1949 1913
186-South Fork Holston River, Sullivan County, TN	Ortmann (1918), Johnson (1978), CM 61.7185 FLMNH 64365 FMNH 23056	1914 ~1870? ?
187-Nolichucky River, Greene County, TN	ANSP 359453, 359458 MFM 11891(~20) MFM 8333	1980 R 1964 1959 R
Nolichucky River, Cocke/Hamblen Counties, TN	Ahlstedt (1991a)	1980

	ANSP 361148 Ortmann (1918), Johnson (1978), CM 61.6732	1977 1913
188-Lick Creek, Greene County, TN	MFM 14878	1964 R
189-Little River, Knox County, TN	Ortmann (1918) UMMZ 91310	<1918 ?
190-Clinch River, Wise County, VA	Johnson (1978), MCZ ?	?
Clinch River, Scott County, VA	M.J. Pinder (VDGIF, pers. comm., 2006) Ahlstedt et al. (2005) Hubbs et al. (1991) Dennis (1989) EKU 795 Ahlstedt (1991b) EKU 355 OSUM 49326(2), 54954(R) Ahlstedt & Tuberville (1997), MCZ 293625 OSUM 42467, 43399 LACM 76-83.12, ANSP 389172 ANSP A11269 EKU 296 OSUM 54927(43) OSUM 54840(11) OSUM 26878 ANSP 376934; OSUM 25621, 25778 MFM 15318(~35), 20664 MFM 18254 OSUM 17117 Johnson (1978); MCZ 268793, 268905, 268928; OSUM 16572, 16658, 16698, 16733 OSUM 12133 OSUM 10755, 10870, 11232, 11526 MFM 5473 MFM 3908 ANSP 149875 Ortmann (1918); CM 61.6461, 61.6727 OSUM 35079 ANSP 226965, CM 47006(12), FLMNH 226029, NCSMNS 7136, NMNH 133514, UMMZ 246110	2006 2004 1989-90 D 1987 1984 R 1978-83 1982 R 1981 1979 1978 R 1976 1975 1975 R 1974 1973 1971 1970 1969 1968 1966 1965 1964 1963 1955 1953 1929 1913 1909 ?
Clinch River, Hancock County, TN	J.W. Jones (Service, pers. comm., 2006) Ahlstedt et al. (2005) NCSMNS 29282(2), 29329(2), 29347(1) NCSMNS 29371(2) INHS 26435(2), 27552(2) Layzer & Crigger (2001) NCSMNS 5983(1), 6168(1) NCSMNS 6569(1), 6667(1) NCSMNS 30286(2), 30289(3), 30290(1), 30292(1) Layzer & Crigger (2001) Ahlstedt & Tuberville (1997) INHS 16643(2)	2005-06 2004, 1999 2002 D 2001 D 2001 1999 1999 D 1998 D 1997 D 1996 1994, 1979 1992

	Hubbs et al. (1991)	1989-90 D
	Ahlstedt (1991b)	1978-83
	Barr et al. (1993-94)	1981
	NMNH 791527, OSUM 30408(15)	1979
	NCSMNS 7131, 7137	1978 D
	OSUM 43191	1978 R
	ANSP 361215; OSUM 40234, 40249	1977
	ANSP 389175(10)	1976
	ANSP A11086, A11147	1974
	OSUM 33504	1972
	ANSP 376987, 377057; OSUM	1971
	26966(28)	1970
	ANSP 376890, CM 69088, MFM 21802,	
	OSUM 26249	1969
	OSUM 23285(140), 28135(42)	1968
	MFM 18210, 18292; OSUM 44078,	
	44153	1967
	LACM 76-577.2; MFM 16693; OSUM	
	18553(89), 19315(80), 20379(159),	
	24559(36), 26617(12)	1965
	Johnson (1978), MCZ 269002(10),	
	OSUM 16772(39)	1950
	MFM 1779	1930
	Johnson (1978), MCZ 236786	~1900
	UMMZ 91324	1899
	Ortmann (1918)	?
	FMNH 90169, UMMZ 91303	
Clinch River, Claiborne/Grainger Counties, TN	OSUM 43277	1978 R
	MFM 16580	1967
	MCZ 268961, OSUM 16798	1965
	Ortmann (1918); CM 61.6728, 61.8157,	1913-15
	61.8793	
	OSUM 35134	1909
Clinch River, Campbell/Union Counties, TN	Ortmann (1918), CM 61.8794	1915, 1899
Clinch River, Anderson/Knox Counties, TN	Johnson (1978), MCZ 46712	<1937
	Cahn (1936), Hickman (1937), INHS	1936
	20532, UMMZ 66871	
	Ortmann (1918); CM 61.7598, 61.7599,	1914-15,
	61.7600, 61.8796	1899
	UMMZ 91322	~1900
	UMMZ 67741	?
Clinch River, Loudon/Roane Counties, TN	Parmalee & Bogan (1986)	A
Clinch River, ? County, TN	ANSP 125903, UMMZ 91319	?
191-Powell River, Lee County, VA	Eckert et al. (2006)	2004 R
	Ahlstedt et al. (2005)	1999
	Hubbs et al. (1991)	1989-90
	Wolcott & Neves (1994)	1988-89
	Ahlstedt & Tuberville (1997)	1988, 1983,
		1979
	Barr et al. (1993-94)	1981
	Ahlstedt (1991a)	1979
	NCSMNS 30291(1)	1979 D
	INHS 16152	1978
	Dennis (1981, 1985)	1973-81

	Ahlstedt & Brown (1980) FMNH 23055, ANSP 341441, UMMZ 58525	1975-78 ?
Powell River, Hancock County, TN	Ahlstedt & Tuberville (1997) ANSP 358697(2) ANSP 359471(1) MMNS 2206(1), NCSMNS 6344(12) Ahlstedt (1991a), INHS 14308(21) NCSMNS 7620(18) Ahlstedt & Brown (1980) Dennis (1981) NCSMNS 7132, 7133, 7134 ANSP A10904 ANSP 389174	1988 1983 1981 1980 D 1979 1979 D 1975-78 1973-78 1977 D 1976 1975
Powell River, Claiborne County, TN	Hubbs et al. (1991) Ahlstedt & Tuberville (1997) EKU 505 ANSP 358679 EKU 356, 357, 393 Barr et al. (1993-94) Ahlstedt (1991a) Ahlstedt & Brown (1980) Dennis (1981) ANSP A10874 FMNH 312156 ANSP A9939, A9964 MCZ 288405, OSUM 20801 OSUM 19399(39), 19560(16), 22423(19) MFM 11440 Ortmann (1918); Johnson (1978); CM 61.6729, 61.8792 UMMZ 91320 UMMZ 47324	1989-90 1988, 1983, 1979 1984 R 1983 1982 R 1981 1979 1975-78 1973-78 1976 1972 1971 1968 1967 1964 1913-15, 1899 ~1900 ?
Powell River, Campbell County, TN	Ortmann (1918)	1899
Powell River, ? County, ?	INHS 14302	1979
192-South Chickamauga Creek, Hamilton County, TN	MFM 11941	1964
193-Sequatchie River, Marion County, TN	Gordon (1991) MFM 7942 MFM 7397	1991 R 1958 R 1957
194-Paint Rock River, Jackson County, AL	P.L. Freeman (TNC, pers. comm., 2006) Godwin (2002) OSUM 38312 MFM 17540, 17573 OSUM 20637 MFM 7481 Ortmann (1925), Johnson (1978), CM 61.6998 ANSP 103907, 103975 UMMZ 91307	2004-06 2002 1973 1968 1966 1957 <1925 1919 ?
Paint Rock River, Madison/Marshall Counties, AL	NCSMNS 27318(1), 27354(3) Ahlstedt (1995-96a); INHS 16510(2),	2002 1991

	16527(2), 16555(?) OSUM 30339, 30352 UMMZ 69005	 1983 R ?
Paint Rock River, ? County, AL	FMNH 90162, UMMZ 4454	?
195-Flint River, Madison County, AL	MFM 6038 Ortmann (1925), Johnson (1978), CM 61.6999, UMMZ 91308	1955 <1925
196-Elk River, Moore/Franklin Counties, TN	ANSP 361124 Isom et al. (1973), OSUM 19855, 21362 Isom et al. (1973), MFM 12876, OSUM 16166 MFM 11044 ANSP 103875	1973 R 1967 1965 1963 R ~1910
Elk River, Lincoln County, TN	Ahlstedt et al. (2006) Hubbs et al. (1991) Ahlstedt (1983) ANSP 361110 MCZ 274937 OSUM 19071 MFM 7327(~20) van der Schalie (1932) INHS 20530 Johnson (1978); MCZ 83994; NMNH 218126; UMMZ 52908(14), 91309	2005 1990 R 1980 1976 R 1967 R 1966 1957 1931 1892 ?
Elk River, Giles County, TN	Hubbs (2002) Service (1999) Madison & Layzer (1998)	2001 1999 1997
Elk River, ? County, TN	ANSP 345220	?
197-Richland Creek, Giles County, TN	Hubbs (2002) INHS 20528	2001 R 1892
198-Bear Creek, Franklin County, AL	Isom & Yokley (1968b), OSUM 16170 UMMZ 91313 Ortmann (1925) Johnson (1978), CM 61.7683, MCZ 236787	1965 <1925 ~1910 ?
Bear Creek, Tishomingo County, MS	MFM 17709 MMNS 1549 Isom & Yokley (1968b), OSUM 16202	1968 1967 1965
199-Cedar Creek, Franklin County, AL	ANSP 389173, OSUM 18758(81)	1966
Cedar Creek, Tishomingo County, MS	Isom & Yokley (1968b), OSUM 16172	1965
200-Duck River, Coffee County, TN	FMMUT 3407	1973
Duck River, Bedford County, TN	OSUM 21615 OSUM 33184 Ortmann (1924), CM 61.11492 Bogan (1990)	1966 1965 1922 A
Duck River, Marshall County, TN	Ahlstedt (1991a) INHS 14511	1979 1979 R

	FMMUT 3406 Isom & Yokley (1968a), OSUM 33920 OSUM 12070, 12244(13), 14863, 15147(13) MFM 6920 MFM 4327(~20) Johnson (1978), MCZ 98547 van der Schalie (1973), ANSP 157155 Ortmann (1924), CM 61.11664 MCZ 93770 Johnson (1978); FLMNH 64368; MCZ 93770; UMMZ 58332, 247585	1973 1965 1964 1956 1953 1933 1931 1923 1905 ?
Duck River, Maury County, TN	Ahlstedt et al. (2004) Madison et al. (1999) ANSP 391122(1) Ahlstedt (1991a) Isom & Yokley (1968a); OSUM 34042, 34156 UMMZ 128859 van der Schalie (1973) INHS 232 Ortmann (1924); CM 61.11264, 61.11493, 61.11665 INHS 4351 Johnson (1978), MCZ 6153 NMNH 477012 CM 61.7000, INHS 20531 Hinkley & Marsh (1885) FLMNH 269105; FMNH 90167, 90207; NMNH 512362; UMMZ 57255, 91306, 128859	2001 1998 R 1986 1979 1965 1937 1931 <1930 1921-23, <1921 <1919 ~1900 1891 1894 ~1885 ?
Duck River, Hickman County, TN	ANSP 359466	?
Duck River, ? County, TN	FMNH 9141, 90170; MFM 1841; UMMZ 22986, 91342	?
Lower Mississippi River Sub-basin		
201-St. Francis River, Wayne County, MO	S.E. McMurray (MDC, pers. comm., 2006) S.B. Bruenderman (KDW, pers. comm., 2003) OSUM 43099 FMNH 312162(12), 312165 FMNH 312170 FMNH 312164(14), 312168(10); OSUM 33798(14) FMNH 312158, 312160; OSUM 49632 FMNH 312169 FMNH 312161(12), 312166 Oesch (1984)	2006 2000, 1981 R 1973 1972 1971 1970 1969 1968 1967 >1965
St. Francis River, Butler/Stoddard Counties, MO	Oesch (1984), S.E. McMurray (MDC, pers. comm., 2005)	1969
White River System		
202-White River, Baxter/Marion Counties, AR	INHS 20322 Hinkley (1915)	<1921 1914

White River, Independence County, AR	Harris & Gordon (1987), Gordon (1982)	~1974 R
203-Kings River, Carroll County, AR	W.R. Posey, Jr. (AGFC, pers. comm., 2006)	2003 R
204-Buffalo River, Marion County, MO	M.W. Matthews (ASU, pers. comm., 2007)	2006
205-Black River, Wayne County, MO	Hutson & Barnhart (2004)	2002
Black River, Butler County, MO	Johnson (1978, 1980), UMMZ 81269 UMMZ 91343	1891 ?
Black River, Lawrence County, AR	Harris & Gordon (1987), Bates & Dennis (1983) OSUM 47694 NMNH 523001 FLMNH 226027	~1980 D 1978 R 1939 ?
206-Little Black River, Ripley County, MO	Buchanan (1987), S.E. McMurray (MDC, pers. comm., 2007)	1985
207-Spring River, Sharp County, AR	Harris & Gordon (1987)	~1983
Spring River, Lawrence/Randolph Counties, AR	C.L. Davidson (Service, pers. comm., 2005), W.R. Posey, Jr. (AGFC, pers. comm., 2003) Harris & Gordon (1987) OSUM 42701 OSUM 28033 INHS 11350 NMNH 738266	2005 1983-84 ~1983 1978 1966 1948 ?
208-Strawberry River, Sharp County, AR	W.R. Posey, Jr. (AGFC, pers. comm., 2003) Harris & Gordon (1987)	1997 ~1983

Footnotes:

[1] Three Mile Lake was not located but presumably is in the Clinton River system although the record may also be from the upper Huron River system.

[2] Little Portage River was not located but may represent Portage Creek, located in the headwaters of the Portage River chain-of-lakes, in Livingston County.

[3] The original label in both ANSP lots reads "Cleveland, Ohio." Lake Erie is the most plausible locality for these records, although the Cuyahoga River is also a possibility, even though the snuffbox is not known from this river.

[4] The Wisconsin River record for this species is questionable (Baker 1928). The lot from the Wright collection and acquired by Walker also contained *Truncilla donaciformis* (Lea 1828) and had two labels, one for this locality, the other stating "Mississippi River." Since no other records are known from the Wisconsin River, the specimens may actually come from the Mississippi River. The fact that valid records for the Mississippi River appear much further upstream than the mouth of the Wisconsin River makes this record reasonable.

[5] These two specimens were considered FD in Appendix C of Watters (1990) but R in the OSUM database. Upon reexamining the specimens, they are considered to be "closer" to R than to FD (G.T. Watters, OSUM, pers. comm., 2006).

[6] A single valve was found in the Little Miami River by Hoggarth (1992), noting that it was

“dead” (= FD) in the annotated site species lists in his appendix. However, in the museum’s database OSUM 60180, which represents this collection, states that the single valve is “weathered” (= R) (G.T. Watters, OSUM, pers. comm., 2002).

[7] A single valve was found in Caesar Creek by Hoggarth (1992), noting that it was “weathered” (= R) in the annotated site species lists in his appendix (Station 70, collected 20 August 1990) but FD in his Table 6. OSUM 60538 represents this collection, and contains a single “weathered” (= R) valve (G.T Watters, OSUM, pers. comm., 2002).

[8] It occurred in this Tennessee River reach according to Ahlstedt & McDonough (1995-96), who failed to give a specific authority. If they credit Ortmann (1918), which is probable given the time frame for its presence (1850-1918; Table 1), then they are in error as Ortmann did not report it from this reach of the Tennessee River. They report it as being extirpated from the Tennessee River main stem.

Codes and Acronyms:

< = collected before [date]; > = collected after [date]; ~ = circa [date] or approximately [number of specimens]; AGFC = Arkansas Game and Fish Commission; ANSP = Academy of Natural Sciences at Philadelphia (A [catalogue number] = alcohol specimens); ASU = Arkansas State University; BMNH = Bell Museum of Natural History, University of Minnesota; CHAS = Chicago Academy of Science; CM = Carnegie Museum; D = dead shell(s) of unspecified condition; EC = Environment Canada; EI = EnviroScience, Inc.; EKPC = East Kentucky Power Cooperative; EKU = Branley A. Branson Museum of Zoology, Eastern Kentucky University; ESI = Ecological Specialists, Inc.; FD = fresh dead shell(s); FMMUT = Frank McClung Museum, University of Tennessee; FLMNH = Florida Museum of Natural History; FMNH = Field Museum of Natural History; INDNR = Indiana Department of Natural Resources; IES = Institute of Ecosystem Studies; INHS = Illinois Natural History Survey; INSM = Indiana State Museum; ILSM = Illinois State Museum; KSU = Kent State University; KSNPC = Kentucky State Nature Preserves Commission; L = live; LACM = Los Angeles County Museum; MDC = Missouri Department of Conservation; MNDNR = Minnesota Department of Natural Resources; MFM = Museum of Fluviatile Mollusks; MMNS = Mississippi Museum of Natural Science; MNFI = Michigan Natural Features Inventory; MU = Marshall University; MUMC = Marshall University Malacological Collection; NCSMNS = North Carolina State Museum of Natural Sciences; NMNH = National Museum of Natural History; OC = Otterbein College; OSUM = Ohio State University Museum of Biological Diversity; R = relict shell(s); ROM = Royal Ontario Museum; Service = U.S. Fish and Wildlife Service; T = transplanted individuals; TNARI = Tennessee Aquarium Research Institute; TTU = Tennessee Technological University; TWRA = Tennessee Wildlife Resources Agency; UMMZ = University of Michigan Museum of Zoology; uncat. = uncatalogued museum lot; USFS = U.S. Forest Service; USGS = U.S. Geological Survey; WIDNR = Wisconsin Department of Natural Resources; WNHI = Wisconsin Natural Heritage Inventory; and WPC = Western Pennsylvania Conservancy. Standard two-letter postal codes are used for state abbreviations.

Other Notes:

1) Streams are numbered sequentially to aid in determining totals for extant versus extirpated stream populations.

2) A number in parentheses following the museum catalog number is the number of L/FD specimens represented in the collection, or the actual number of L/FD specimens found in the case of some INHS collections but not necessarily museum vouchered.
3) Numbers of L/FD specimens are given for all museum lots since 1980 and for lots of ≥10 L/FD specimens regardless of date. For museum collections since 1980, an R is added after the catalog number to denote where R shells only (no numbers) are vouchered.
4) "[E]astern Nebraska to Indian Territory [Oklahoma]" was included in the range of this species by Simpson (1914), but site specific records are unknown (Branson 1984). The snuffbox is not considered to be part of the Nebraska nor Oklahoma mussel faunas (Williams 1993).
5) Records from several small streams in the Meramec River system (e.g., Big River; Terre Bleue, Huzzah, Courtois Creeks; Dry Fork) from surveys conducted by Missouri Water Pollution Board (1964) were presented in Buchanan (1980). S.E. McMurray (MDC, pers. comm., 2005) also found snuffbox records for Cedar Creek and Little Dry Fork (instead of Buchanan's Dry Fork) in the report. McMurray discounted these records. The snuffbox was not found in any of these tributaries during subsequent survey efforts by mussel experts, suggesting that the records were misidentifications.
6) It was included in a list of species occurring in Symmes Creek, southeastern Ohio, by Watters (1992) but not in the report (Watters 1988a) upon which his former published paper is based.
7) The species was reported from various stream or lake drainages without giving county-specific locality data: Lake St. Clair drainage (La Rocque and Oughton 1937), Muskingum River (Stansbery 1974), Olentangy River (Stein 1964), Little Darby Creek (Stein 1966), Green River system (Price 1900), Wabash River system (Goodrich 1914), lower Cumberland River (Bates and Dennis 1985), Clinch River (Stansbery (1973), and various archeological sites (Bogan 1990).

APPENDIX II

Streams where the snuffbox (*Epioblasma triquetra*) is likely extirpated[1], based on no evidence of an extant population since last observed L/FD

Occurrence by stream (main stem working downstream, then tributaries) and state, authority (primary literature and other records), dates of survey, and number of sites surveyed

Stream, State(s)	Authority	Date[2]	Sites[3]
Upper Great Lakes Sub-basin			
Fox River, WI	Mathiak (1979)	1973-77	~6[4]
Waupaca River, WI	D.J. Heath (WIDNR, pers. comm., 2006)	1994 R	5
Sheboygan River, WI	D.J. Heath (WIDNR, pers. comm., 2002) Mathiak (1979)	1999 R 1973-77	15 2
Muskegon River, MI	Carman & Badra (2003), Carman & Goforth (2003)	2002 R	61
St. Joseph River, IN	B.E. Fisher (INDNR, pers. comm., 2005)	2004	3
Lower Great Lakes Sub-basin			
Cass River, MI	Badra & Goforth (2003)	2002	9
Tittabawassee River, MI	Hoeh & Trdan (1984)	1979-81	50
Lake St. Clair, MI/ONT	D.J. McGoldrick (EC, pers. comm., 2005) Zanatta et al. (2002) Nalepa & Gauvin (1988)	2003 1998-2001 1986	25 95 29
North Branch Clinton River, MI	Di Maio & Corkum (1995) Strayer (1980)	1993 1977-78 R	2 12 (28)
[5]Thames River, ONT	D.J. McGoldrick (EC, pers. comm., 2005) Morris (1996)	2004 1995	16 16 (30)
Detroit River, MI/ONT	Schloesser et al. (2006)	1997-98	6
Lake Erie (western)	Schloesser & Nalepa (1994), Nichols & Wilcox (1997), Schloesser et al. (1997)	1990s	?
Grand River, ONT	Metcalfe-Smith et al. (2000b) Mackie (1996) Kidd (1973)	1997-98 1995 1970-72	20 (24) 11 (70) 34 (68)
Maumee River, IN	Watters (1988b)	1988	4 (89)
Auglaize River, IN	Clark (1987a)	1938-47	20
Swan Creek, IN	J. Grabarkiewicz (EI, pers. comm., 2006) Clark (1987a)	2006 R 1939-50	5 3
Upper Mississippi River Sub-basin			
Mississippi River, IA/MN/WI	D.J. Heath (WIDNR, pers. comm., 2006) Thiel (1981)	>1980 1977-79	100s Pools 3-

	Finke (1966) Ellis (1931)	1965 1931	11 Pools 5-7, 9 Pools 4, 7-10
Wisconsin River, WI	D.J. Heath (WIDNR, pers. comm., 2002) Mathiak (1979)	1990s 1973-77	26 beds ~30[4]
Crawfish River, WI	Mathiak (1979)	1973-77	~20[4]
Cedar (Red Cedar) River, IA	Arbuckle (2000)	1998[6]	~20[4]
Illinois River, IL	Sietman et al. (2001) Starrett (1971)	1990-99 1966	~4[7] 262
Mazon River, IL	Sietman et al. (2001) K.S. Cummings (INHS, pers. comm., 2003)	1975-2000 1990-91	7[8] ?
Sangamon River, IL	Schanzle & Cummings (1991)	1987-89 1956-60	29 (57) (40)
Kaskaskia River, IL	Suloway et al. (1981a)	1978-79	19
Lower Missouri River system			
Marais des Cygnes River, MO	Combes & Edds (2005)	1999-2000	15
Little Niangua River, MO	ESI (2003b)	2001	12
Ohio River system			
Monongahela River, PA	Tolin (1987)	1985	?[9]
Crooked Creek, PA	Bogan & Davis (1992c) Bogan & Davis (1992b)	1992 1990	7 4
Hocking River, OH	Watters (1988a, 1992)	1987	12
Caesar Creek, OH	Hoggarth (1992)	1990-91	16
Great Miami River, OH	Clark (1987c)	1939-46	9
South Fork Kentucky River, KY	R.R. Cicerello (KSNPC retired, pers. comm., 2003)	~1990-2005	~20
Russell Creek, KY	Cicerello (2005) R.R. Cicerello (KSNPC retired, pers. comm., 2003)	2000-04 1982 R	7 2
Nolin River, KY	Cicerello (2005) R.R. Cicerello (KSNPC retired, pers. comm., 2003)	2001-04 1993 R	6 1
Barren River, KY	R.R. Cicerello (KSNPC retired, pers. comm., 2003) Gordon & Sherman (1995)	>1993 1993 R	~20 38
West Fork Drakes Creek, KY	Cicerello (2005)	2000-04	7
Pond River, KY	Gordon & Sherman (1995)	1993	6 (23)

Wabash River, IL/IN	EI (2005) Cummings et al. (1988b) Cummings et al. (1987) Clark (1976) Krumholz et al. (1970), Meyer (1974)	2003-04 1988 R 1987 R 1975 1966-67	5 26 27 8 ~33
Mississinewa River, IN	ESI (1995)	1993-94	17
Eel River, IN	Henschen (1987)	1986	28 (32)
Vermilion River, IL/IN	K.S. Cummings (INHS, pers. comm., 2003) Suloway et al. (1981b) Cummings et al. (1998)	>1990 1980 1950s	(~100) 2 (29) 1 (27)
Little Wabash River, IL	Cummings et al. (1989)	1988 1956	17 (30) 17
White River, IN	Krumholz et al. (1970), Meyer (1974)	1966-67	~4
East Fork White River, IN	EI (2005) Krumholz et al. (1970), Meyer (1974)	2003-04 1966-67	3 ~12
Driftwood River, IN	Harmon (1998)	1990-96	2
Youngs Creek, IN	Harmon (1992)	1990 R	5
Flatrock River, IN	Harmon (1998)	1990-96 R	12 (15)
Clifty Creek, IN	Harmon (1998)	1990-96 R	6
Sand Creek, IN	Harmon (1998)	1990-96 R	14
Cumberland River system			
Cumberland River, KY	Miller et al. (1984)	1982	7
Cumberland River, TN	D.W. Hubbs (TWRA, pers. comm., 2005) Ahlstedt (1995-96b)	2003-05 1992	51 8
Little South Fork, KY	Warren & Haag (2005) Anderson et al. (1991), Layzer & Anderson (1992) Ahlstedt & Saylor (1995-96) Starnes & Bogan (1982)	1997-98 1987-88 1984-85 1977-81	29 19 (20) 4 (6) 16
Beaver Creek, KY	Layzer & Anderson (1992)	1988-90	3 (4)
Obey River system, TN	Layzer & Anderson (1992)	1988	(14)
Caney Fork, TN	Layzer et al. (1993)	1989 R	5 (45)
Red River, KY	W.R. Haag (USFS, pers. comm., 2007) R.R. Cicerello (KSNPC retired, pers. comm., 2003)	1988 R 1982	10 (4) 3
Red River, TN	D.W. Hubbs (TWRA, pers. comm., 2005) Aquatic Resources Center (1993) Hatcher & Ahlstedt (1982)	2005 1990 1981	2 2? 4
Tennessee River system			

Tennessee River, AL	McGregor et al. (1998) J.T. Garner (ADCNR, pers. comm., 2003)	1998 >1990	24 ?[10]
Tennessee River, TN	D.W. Hubbs (TWRA, pers. comm., 2002) Gooch et al. (1979) Yokley (1972)	>1990 1978 1969-72	?[10] ?[11] 96
Holston River, TN	S.J. Fraley (NCWRC, pers. comm., 2002) Ahlstedt (1991b)	2002 1981	20 7
North Fork Holston River, TN/VA	W.F. Henley (VPI, pers. comm., 2006) Henley & Neves (1999) Ahlstedt & Saylor (1995-96) Hill et al. (1980) Stansbery & Clench (1974)	2004-05 R 1995 1985 1976 1968-71	18 19 7 (8) 20 13 (16)
[12]South Fork Holston River, TN/VA	Parmalee & Polhemus (2004) Stansbery & Clench (1978)	1986, 2003 1968-74	8 16 (26)
Nolichucky River, TN	Tennessee Valley Authority (2002)	2000	10
Sequatchie River, TN	Gordon (1991) Hatcher & Ahlstedt (1982)	1991 1980	28 10
Flint River, AL	McGregor & Shelton (1995)	1995	3 (21)
Richland Creek, TN	D.W. Hubbs (TWRA, pers. comm., 2001)	2001 R	2
Bear Creek, AL	McGregor & Garner (2004) Isom & Yokley (1968b	1996-2001 1965	22 (40) 1 (3)
Bear Creek, MS	R.L. Jones (MMNS, pers. comm., 2006) McGregor & Garner (2004) Isom & Yokley (1968b	1998-2006 1996-2001 1965	8 3 1
Cedar Creek, AL/MS	R.L. Jones (MMNS, pers. comm., 2006) McGregor & Garner (2004)	1998-2006 1996-2001	2 9 (10)
White River system			
White River, AR/MO	Harris (2002) Harris (1994, 1995) Gordon (1982)	2002 1994-95 1982	~3 14 RMs 13
Black River, AR	Rust (1993) Miller & Hartfield (1986) Bates & Dennis (1983)	~1992 1985 1982	48 beds 44 13
Little Black River, MO	S.E. McMurray (MDC, pers. comm., 2007)	2006, 1998, 1979-82	?, ?, ~10

Footnotes:

[1] The intent of this table is to present survey data from the past few decades that have failed to detect extant populations in historical streams of occurrence. This “negative” or absence of extant population data indicates additional survey work relative to data in Appendix I. These data provide justification that certain stream populations are extirpated, although it is possible some populations may be rediscovered.

[2] R shells are noted after the sampling date; otherwise, no evidence of the species was reported.

[3] Indicates the number of main stem sites sampled, with the number in parentheses representing

the total number of sites surveyed in the entire system in question.
[4] Sites sampled were estimated from low-scale dot-distribution drainage maps.
[5] Although a single FD valve was reported among 24 sites in 1998, it is considered extirpated (Metcalfe-Smith et al. 2003; J.L. Metcalfe-Smith, Environment Canada, pers. comm., 2003).
[6] Shell condition was not indicated in Arbuckle (2000). A composite list of live material collected throughout her study area was presented.
[7] Four Illinois River mussel beds were sampled in 1994, 1995, and 1999 (Sietman et al. 2001). In addition, they reported on 211 brail and 40 dive samples conducted in a reach (RM 158-231).
[8] This number refers to samples taken and not necessarily the number of sites sampled.
[9] An undisclosed number of sites were sampled in the lowermost 41.5 RMs (Tolin 1987).
[10] Investigators have made hundreds of dives at scores of sites in the tailwaters of Wilson Dam in Alabama and Pickwick Landing Dam in Tennessee since 1990.
[11] An undisclosed number of sites were sampled between RM125.9-206.7 in the Pickwick Landing Dam tailwaters (Gooch et al. 1979).
[12] Sites sampled by Stansbery and Clench (1978) were all in Virginia (although not known from the Virginia portion of the South Fork Holston River, it possibly occurred there historically), while sites sampled by Parmalee and Polhemus (2004) were all in Tennessee. No riverine habitat unaffected by impoundments remains in the Tennessee portion of the stream (Parmalee and Polhemus 2004).

Acronyms: ADCNR = Alabama Department of Conservation and Natural Resources; NCWRC = North Carolina Wildlife Resources Commission; and RM = river mile. Otherwise, see Appendix I codes and acronyms.

APPENDIX III

Snuffbox (*Epioblasma triquetra*) extant stream population[1] summary

By Service region and stream of occurrence; states; year of last observation; and objective estimates on whether the population is recruiting, potential viability, relative population size, and relative population trend

Service Region/Stream	State(s) (Region)	[2]Last Obs.	[3]Recruiting	[4]Potential Viability	[5]Population Size	[6]Population Trend
Region 3						
Wolf River	WI	2006	Yes	High	Large	Declining
Embarrass River	WI	1995	?	?	Small	?
Little Wolf River	WI	1999	?	?	Small	?
Willow Creek	WI	2001	?	?	Small	?
Grand River	MI	2002	Yes	High	Medium	?
Maple River	MI	2001	?	?	Small	?
Pigeon River	IN	1998	?	?	Small	?
Pine River	MI	2002	?	Low	Small	Stable
Belle River	MI	2002	Yes	High	Small	?
Clinton River	MI	2003	Yes	High	Large	Declining
Huron River	MI	2001	?	Low	Medium	?
Davis Creek	MI	2005	Yes	High	Medium	?
South Ore Creek	MI	1999	Yes	High	Small	?
Portage River	MI	1998	Yes	High	Medium	?
Grand River	OH	2006	Yes	High	Medium	?
St. Croix River	MN/WI	2004	Yes	High	Large	Declining
Kankakee River	IL	1991	?	?	Small	?
Meramec River	MO	1997	?	?	Small	Declining
Bourbeuse River	MO	2006	Yes	High	Large	Improving
Ohio River	OH (+R5)	2001	?	Low	Small	?
Muskingum River	OH	2005	?	?	Small	?
Walhonding River	OH	1991	?	?	Small	Declining
Killbuck Creek	OH	2006	?	?	Small	Declining

Olentangy River	OH	1989	?	?	Small	Declining
Big Darby Creek	OH	2000	?	?	Small	Declining
Little Darby Creek	OH	1999	?	?	Small	Declining
Salt Creek	OH	1987	?	?	Small	?
Scioto Brush Creek	OH	1987	?	?	Small	?
South Fork Scioto Brush Creek	OH	1987	?	?	Small	?
Little Miami River	OH	1991	?	?	Small	?
Stillwater River	OH	1987	?	?	Small	?
Salamonie River	IN	2004	Yes	Low	Small	?
Tippecanoe River	IN	2003	?	?	Small	Declining
Embarras River	IL	2002	Yes	Low	Small	Declining
Sugar Creek	IN	1990	?	?	Small	Declining
Buck Creek	IN	1990	?	?	Small	?
Muscatatuck River	IN	1988	?	?	Small	?
Graham Creek	IN	1990	?	?	Small	Declining
St. Francis River	MO	2006	Yes	High	Medium	Stable
Black River	MO	2002	Yes	Low	Small	?
Region 4						
Tygarts Creek	KY	1995	?	?	Small	Declining
Kinniconick Creek	KY	2005	?	Low	Small	Declining
Licking River	KY	2006	?	Low	Small	?
Slate Creek	KY	1992	?	?	Small	Declining
Middle Fork Kentucky River	KY	1997	?	?	Small	?
Red Bird River	KY	1995	?	?	Small	?
Red River	KY	~2002	?	?	Small	?
Rolling Fork Salt River	KY	~2005	?	?	Small	?
Green River	KY	2000	?	?	Small	Declining
Buck Creek	KY	1987-90	?	?	Small	Declining
Clinch River	TN (+R5)	2006	Yes	High	Large	Stable

Powell River	TN (+R5)	1989-90	?	?	Small	Declining
Paint Rock River	AL	2006	Yes	High	Medium	Improving
Elk River	TN	2005	Yes	Low	Small	Stable
Duck River	TN	2001	?	?	Small	?
Buffalo River	AR	2006	?	?	Small	?
Spring River	AR	2005	?	Low	Medium	Improving
Strawberry River	AR	1997	?	?	Small	?
Region 5						
Ohio River	WV (+R3)	2001	?	?	Small	?
Allegheny River	PA	2001	?	?	Small	?
French Creek	PA	2004	Yes	High	Large	Stable
West Branch French Creek	PA	1993	?	?	Small	?
Le Boeuf Creek	PA	2006	Yes	Low	Small	?
Muddy Creek	PA	2003	Yes	Low	Medium	?
Conneaut Outlet	PA	1997	?	?	Small	?
Little Mahoning Creek	PA	1991	?	?	Small	?
Dunkard Creek	PA/WV	1994/1997	?	?	Small	Declining
Shenango River	PA	2002	?	?	Small	?
Little Shenango River	PA	2002	?	?	Small	?
Middle Island Creek	WV	2001	?	?	Small	Declining
North Fork Hughes River	WV	2001	?	Low	Small	Declining
Elk River	WV	2004	?	Low	Medium	Improving
Clinch River	VA (+R4)	2006	Yes	High	Small	Declining
Powell River	VA (+R4)	1999	?	Low	Small	Declining
Canada						
Ausable River	ON	2006	Yes	High	Medium	?
Sydenham River	ON	2002	Yes	High	Large	?

Footnotes:

[1] A population is considered extant if L individuals and/or FD specimens have been located since ~1985. Multiple streams may essentially comprise single snuffbox population segments (e.g., Huron River/Davis Creek, Muskingum River/Walhonding River/Killbuck Creek).

[2] The last year in which L individuals and/or FD specimens were observed. Where an extant population occurs in two states, the year of last observation in each state is given.
[3] A population was considered to be recruiting if there was recent (within ~10 years) evidence of subadults (generally, individuals ≤1.5 inches long and/or ≤4 years). Population recruitment was assessed as yes or unknown (?).
[4] Data used to determine the viability of a mussel population is largely non-existent. Evidence of a population recruiting subadults and being comprised of different age classes suggests some level of viability. Level of viability was assessed as being high, low, or unknown (?).
[5] Population size is estimated to be relatively large, medium, or small.
[6] Population trend is estimated where adequate data is available over the past few decades. Trends are depicted as improving, stable, declining, or unknown (?).

Other Notes:
The snuffbox was historically known from 208 streams in 18 states, 1 Canadian province, and 4 Service regions (3, 4, 5, and 6). Currently, it is known from 73 streams in 14 states, 1 Canadian province, and 3 Service regions (3, 4, and 5). Region 3 has the most extant streams of occurrence with 40, while Region 4 has 18, and Region 5 has 16 occurrences. Some stream populations occur in multiple Service regions and two stream populations occur in Canada.

Codes:
Standard two-letter postal codes are used for state and provincial abbreviations. See Appendix I for abbreviations.

APPENDIX IV

List of primary individuals who provided status or other information for the snuffbox

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