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Post-Drought Survey Of Freshwater Mussels In The Saline And Smoky Hill Rivers With Emphasis On The Status Of The Cylindrical Papershell (Anodontoides Ferussacianus) And Effects Of Lowhead Dams On Growth Of The Pimpleback (Quadrula Pustulosa) In The Neosho River, Kansas

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POST-DROUGHT SURVEY OF FRESHWATER MUSSELS IN THE SALINE AND SMOKY HILL RIVERS WITH EMPHASIS ON THE STATUS OF THE CYLINDRICAL PAPERSHELL (*ANODONTOIDES FERUSSACIANUS*) AND EFFECTS OF LOWHEAD DAMS ON GROWTH OF THE PIMPLEBACK (*QUADRULA PUSTULOSA*) IN THE NEOSHO RIVER, KANSAS

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Andrew T. Karlin
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The Master of Science Degree

by

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ABSTRACT

Study 1:Post-drought survey of freshwater mussels in the Saline and Smoky Hill rivers with emphasis on the status of the Cylindrical Papershell (Anodontoides ferussacianus) *in Kansas.*

The Cylindrical Papershell (*Anodontoides ferussacianus*), considered a "Species in Need of Conservation" in Kansas, historically occurred across much of the state; however, recent studies suggest that the species is currently restricted to the upper Smoky Hill-Saline River Basin, and a survey emphasizing the status of the Cylindrical Papershell conducted in 2011 suggested its conservation status be elevated to endangered. Continuing drought since the completion of the 2011 survey raised concerns regarding the status of the Cylindrical Papershell. The objectives of this study were to evaluate possible drought-related changes in Cylindrical Papershell populations and to evaluate the status of this species in Kansas. Timed, tactile searches were conducted at 19 sites on the Saline River and 21 sites on the Smoky Hill River between July and August 2015. Thirty of these sites were revisited from the 2011 survey. In 2011, 24 live Cylindrical Papershell were observed among 11 sites. Declines in Cylindrical Papershell abundance were observed in 2015, with 10 individuals observed at 3 sites. The species occurred at low abundances across a limited geographic range comprised of highly fragmented habitat. Abundance of Cylindrical Papershell per site declined significantly ($t=5.19$, $df=10$, $p<0.001$) between 2011 and 2015.

Study 2: Effects of lowhead dams on growth of the Pimpleback (Quadrula pustulosa) *in the Neosho River, Kansas.*

In Kansas, few studies have investigated freshwater mussel growth rates or variables that might influence growth. Lowhead dams are reported to alter variables thought to influence freshwater mussel growth, including water temperature and primary productivity. Annuli deposited in freshwater mussel valves can be used to estimate age, growth, and recruitment. The objective of this study was to evaluate differences between individual growth characteristics of Pimpleback upstream and downstream of lowhead dams in the Neosho River, Kansas by comparing von Bertalanffy growth function parameters. Pimpleback mussels (*Quadrula pustulosa*) were collected near 3 lowhead dams in the Neosho River of southeastern Kansas and aged by counting internal annuli. Likelihood ratio tests were used to compare von Bertalanffy growth function parameters between upstream and downstream samples at each lowhead dam sampled. Results of likelihood ratio tests suggested no significant difference in growth between upstream and downstream samples.

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PREFACE

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STUDY 1:

POST-DROUGHT SURVEY OF FRESHWATER MUSSELS IN THE SALINE AND SMOKY HILL RIVERS WITH EMPHASIS ON THE STATUS OF THE CYLINDRICAL PAPERSHELL IN KANSAS

INTRODUCTION

In recent years, the imperiled status of freshwater mussels (Bivalvia: Unionoida) has become widely recognized. More than 70% of the nearly 300 recognized North American mussel species are considered endangered, threatened, or of conservation concern (Williams et al. 1993). Nearly 40 species have gone extinct during the last century (Haag 2012), and half of the extant species are likely to go extinct during this century if current trends continue (Ricciardi and Rasmussen 1999). The decline of mussels has been attributed to many factors. These include the historical harvest of freshwater mussels for the pearl-button and cultured-pearl industries (Fassler 1994; Anthony and Downing 2001), agricultural practices that degrade stream habitats (Richter et al. 1997; Strayer and Fetterman 1999; Poole and Downing 2004), physical and chemical alteration of streams and stream flows through impoundment and channelization (Williams et al. 1993; Haag 2012), introduction of invasive species such as the Asian Clam (*Corbicula fluminea*) (Strayer 1999) and Zebra Mussel (*Dreissena polymorpha*) (Ricciardi, Neeves, and Rasmussen 1998). Changing climates might also pose an imminent risk for this group (Haag 2012).

Contractions in the geographic distribution of many Kansas mussel species and trends of reduced species richness relative to historic conditions have been observed (Angelo et al. 2009). Approximately 40 unionid species approach or reach the western edge of their geographic distribution within the state of Kansas (Murray and Leonard 1962; Angelo et al. 2009). It has been suggested that peripheral populations near the edge of a species' distribution play an important role in the conservation of declining species. These populations are more likely to persist than central populations and should, therefore, be included in conservation plans (Channell 2004). Conservation of these species and suitable habitat is consistent with the goals of the Kansas State Wildlife Action Plan (Rohweder 2015) and the mission of the Kansas Department of Wildlife, Parks and Tourism (KDWPT).

The Cylindrical Papershell (*Anodontoides ferussacianus*) occurs throughout the northeastern United States and southeastern Canada, and reaches the southwestern limits of its distribution in Kansas. This species historically occurred over a large portion of the state, but a decline in its geographic distribution has been documented (Angelo et al. 2009) (Figure 1). The Cylindrical Papershell is considered a species in need of conservation (SINC) in Kansas, and recent studies suggest it now occurs as peripheral and isolated populations in the Saline and Smoky Hill rivers of Ellis and Russell counties (Bergman 1998; Angelo et al. 2009; Sowards et al. 2012, 2016).

The Cylindrical Papershell is relatively short-lived and fast-growing. Its lifespan in a Michigan stream ranged from 3 to 16 years, with an average lifespan of 9 years (Harrigan, Moerke, and Badra 2009). Investigations of Cylindrical Papershell lifespans have not been conducted within Kansas. Sowards et al. (2012) documented the rapid growth of Cylindrical Papershell in the Smoky Hill River, where 2 individuals grew 10 mm and 11 mm from June to August. The Cylindrical Papershell reproduces in August, and glochidia mature by September (Watters, Hoggarth, and Stansbery 2009). The glochidia are retained within the female until the following May (Watters, Hoggarth, and Stansbery 2009), when they are released in mucous strands that passively entangle potential host fish (Hove et al. 1995, 1997; Watters 1995). Though host suitability studies have not been conducted in Kansas, potential host fish within the state include White Sucker (*Catostomus commersonii*) (Fuller 1978), Bluegill (*Lepomis macrochirus*) (Watters 1995), Largemouth Bass (*Micropterus salmoides*) (Watters 1995; O'Dee and Watters 2000), Bluntnose Minnow (*Pimephales notatus*), Fathead Minnow (*Pimephales promelas*) (Fuller 1978), and Black Crappie (*Pomoxis nigromaculatus*) (Hove et al. 1995).

In 2011, Sowards et al. (2012, 2016) conducted an intensive mussel survey in the Saline and Smoky Hill rivers of Ellis and Russell counties, Kansas, and observed 24 live Cylindrical Papershell, with 9 and 15 in the Saline River and Smoky Hill River, respectively. Although no evidence of recent Cylindrical Papershell recruitment was observed in the Saline River, it was observed in the Smoky Hill River at a survey site west of Pfeifer (Sowards et al. 2012); however, this stream reach is subject to dewatering by the municipal water-well fields of Hays and Russell, Kansas, located near Schoenchen and Pfeifer, respectively. Due to the relatively short lifespan of the species, Sowards et al.

(2012) suggested a few years of little to no recruitment might greatly increase the probability of local extinction.

Persistent drought since completion of the 2011survey (Figure 2) raised questions regarding the current status of the Cylindrical Papershell. The data collected by Sowards et al. (2012, 2016) provided a point of comparison for documenting potential changes in freshwater mussel abundance and distribution in the upper reaches of these 2 rivers. The objectives of this study were to evaluate the conservation status of the Cylindrical Papershell in northwestern Kansas and evaluate possible post-drought changes in the composition of freshwater mussels in these segments of the Saline and Smoky Hill rivers.

METHODS

To meet the objectives of this study and allow for useful comparisons of pre-drought (2011) and post-drought (2015) mussel communities, the methods described by Sowards et al. (2012, 2016) were used with some modification. The study area in Kansas included the Saline and Smoky Hill rivers in Ellis and Russell counties, the Smoky Hill River in Logan and Trego counties, and Ladder Creek in Logan and Scott counties. Effort was focused in the Saline and Smoky Hill rivers of Ellis and Russell counties, as recent studies suggested this area supported the abundance and potentially the last remaining, populations of Cylindrical Papershell within Kansas (Figure 1) (Hoke 1997; Bergman 1998; Angelo et al. 2009; Sowards et al. 2012, 2016).

Survey sites were initially selected based on accessibility to locations surveyed in 2011 by Sowards et al. (2012, 2016). In an attempt to document extant Cylindrical Papershell populations, additional survey sites were selected by using Google Earth™ imagery of the Saline and Smoky Hill rivers to identify stream reaches that apparently maintained water throughout the drought. Locations in Logan and Scott counties were selected based on historical records of Cylindrical Papershell shell material (Angelo et al. 2009). Of the potential pool of sample sites, 40 were sampled, 19 in the Saline River in Ellis and Russell counties and 21 in the Smoky Hill River in Ellis, Russell, and Trego counties (Figure 3).

A qualitative survey consisting of a timed, tactile search of all wadeable habitats was conducted at each site. When possible, search effort as person-hours was replicated at sites also surveyed by Sowards et al. (2012, 2016). All live mussels encountered during the survey were held in a mesh bag until the timed search was complete. Mussels were identified to species, measured (length, height, and width to nearest mm), and returned to the stream. For live Cylindrical Papershell, a numbered, polyethylene tag was glued to each valve posterior to the umbo to ensure the individual, if recaptured during quantitative surveys, was represented only once in the survey total. Valves of dead Cylindrical Papershell were collected as voucher specimens to be housed at the Sternberg Museum of Natural History in Hays, Kansas. Photographs of the survey site were taken, and GPS coordinates for the upstream and downstream limits of the survey area were recorded. Relative abundances as catch per person hour (CPUE), species richness, and a Simpson Diversity Index were calculated for each site.

Quantitative surveys were conducted at 2 sites in the Saline River and 5 sites in the Smoky Hill River. Sites were selected based on those quantitatively surveyed in 2011 (Sowards et al. 2012, 2016) and on the relative abundance of live Cylindrical Papershell and overall diversity of live mussels observed during qualitative surveys in 2015. A 1,000-m^2 grid covering the wetted stream area was delineated at each site. Average wetted width, calculated from 10 wetted width measurements spaced 10 m apart, was used to determine the width of the 1,000-m^2 grid, and the quotient of 1,000 and the average wetted width was used to determine the length of the grid (Wolf and Stark 2008; Sowards et al. 2012). A random number generator was used to select forty 1-m^2 quadrats to be sampled from the 1,000-m^2 grid (Wolf and Stark 2008; Sowards et al. 2012). Environmental factors including stream depth, stream flow, and substrate type (Wentworth 1922) were measured at each quadrat. Substrate from each quadrat was excavated by hand to a depth of 10 cm and placed into a wire sieve with 5-mm mesh. Live mussels were processed as previously described for qualitative surveys. Density of live mussels as individuals per m^2, species richness, and a Simpson Diversity Index were calculated for each site. A 4.5-m straight seine with 3-mm mesh was used to sample potential host-fish populations at each site. Fish species observed were ranked by abundance.

Length-frequency histograms for each species were produced to better understand the status and age structure of mussel populations. Histograms for all species except Cylindrical Papershell were produced by using lengths of all individuals captured during qualitative and quantitative surveys. Individuals of these species might be represented twice in the histograms, as they were not marked during qualitative surveys, and were not identifiable as recaptured individuals if again observed during quantitative surveys.

Characteristics of mussel communities from this survey were compared to those from 2011 (Sowards et al. 2012, 2016) to discern possible changes. Because data collected during quantitative surveys were insufficient to use for analyses, paired t-tests were used to compare aspects of qualitative surveys from 2011 and 2015. These included per site search effort, species richness, total abundance of live mussels, and abundance of live Cylindrical Papershell and, the most commonly observed species, Mapleleaf (*Quadrula quadrula*). One-tailed tests were used for comparing species richness and for comparing abundance of Cylindrical Papershell. When necessary, data were transformed to meet normality assumptions of the paired t-test. Low abundances and non-normal data prevented analysis of most species observed. Data transformed included per site search effort [log(x)], species richness [log(x+1)], and abundance of live Cylindrical Papershell [log(x+1)]. Abundance data, length-frequency histograms, and changes in the distribution of the species were used to evaluate its status within the study area.

RESULTS

Qualitative, timed surveys at 19 sites in the Saline River were conducted from 14 July to 14 August 2015. During 45.2 hours of surveys, 34 live mussels representing 4 species were collected at 5 sites (Table 1). At each site, stream lengths surveyed ranged from 17 to 115 m, search effort from 1.0 to 4.9 hours, number of live mussels collected from 0 to 20 individuals, and CPUE from 0 to 9.76 individuals per person hour. The Simpson Diversity Index for the Saline River was 0.63. Lilliput (*Toxolasma parvus*) and Mapleleaf were the most commonly observed species and represented 55.88% and 23.53% of the composite sample, respectively. The Cylindrical Papershell occurred at a CPUE of 0.09 and represented 11.76% of the sample. Four Cylindrical Papershell were collected at site SR-16 (Figure 3).

Qualitative, timed surveys at 21 sites in the Smoky Hill River were conducted from 16 July to 14 August 2015. During 74.4 hours of surveys, 697 live mussels representing 5 species were collected at 18 sites (Table 1). Per site, length of stream surveyed ranged from 13 to 146 m, search effort from 1.0 to 5.8 hours, number of live mussels from 0 to 244 individuals, and CPUE from 0 to 34.86. The Simpson Diversity Index for the Smoky Hill River was 0.29. Mapleleaf and Pink Papershell (*Potamilus ohiensis*) were the most commonly collected species and represented 83.64% and 6.74% of the composite sample, respectively. The Cylindrical Papershell was collected at 4 sites (SH-17, SH-19, SH-21, and SH-22) and occurred at a CPUE of 0.13, representing 1.43% of the sample. Ten Cylindrical Papershell were collected in the Smoky Hill River, with 4 at site SH-21, 3 at site SH-22, 2 at site SH-17, and 1 at site SH-19 (Figure 3).

Due to limited accessibility, lack of surface water, and little evidence from Google Earth™ imagery of stream reaches that retained water through the drought, no timed or quantitative surveys were conducted in Logan or Scott counties. A qualitative survey was attempted in Ladder Creek upstream of Lake Scott in Scott County on 15 September 2015; however, approximately 1 m of silt, detritus, and tree limbs and branches covered the stream bottom and did not allow for a timed search. Instead, visual searches for mussel valves were conducted near Lake Scott in Scott County. A Giant Floater (*Pyganodon grandis*) weathered valve below the dam of Scott Lake was the only evidence of freshwater mussels observed in the area.

Quantitative surveys were conducted at 2 sites (SR-08 and SR-16; Figure 1) in the Saline River. In the 80 quadrats surveyed, 16 live mussels representing 3 species occurred at a density of 0.20 individuals per m^2 (Table 2). Lilliput was the most abundant species at a density of 0.15 individuals per m^2. The Cylindrical Papershell occurred at a density of 0.04 individuals per m^2. Three live Cylindrical Papershell were collected at site SR-16. No live mussels were observed at site SR-08.

Quantitative surveys were conducted at 5 sites (SH-11, SH-12, SH-17, SH-21, and SH-22; Figure 3) in the Smoky Hill River. In the 200 quadrats surveyed, 57 live mussels representing 7 species occurred at a density of 0.29 individuals per m^2 (Table 2). Lilliput was the most frequently collected species at a density of 0.14 individuals per m^2. Cylindrical Papershell occurred at a density of 0.01 individuals per m^2. Two live Cylindrical Papershell were observed at site SR-22, one of which represented a recapture from the qualitative survey.

Attempts were made to measure stream flow at quantitative survey sites; however, no flow was detectable in pool habitats, and areas with visible flow were too shallow to be measured with available equipment. Substrate at quantitative sites in the Saline River was composed of 67.5% sand, 17.5% fine material, 13.8% pebble, and 1.3% cobble. Substrate at quantitative sites in the Smoky Hill River was composed of 58.5% pebble, 16% sand, 13% cobble 6.5% boulder, and 6% fine material. Potential host fish were present at all quantitative survey sites. Three species were present at sites SH-11 (Bluegill, Largemouth Bass, and Fathead Minnow) and SH-21 (Bluegill, Largemouth Bass, and Bluntnose Minnow). Two species (Bluegill and Largemouth Bass) were present at sites SH-12 and SH-17. One species was present at sites SR-08 and SR-16 (Fathead Minnow) and at SH-22 (Bluegill).

During qualitative and quantitative surveys in the Saline River, valves of 5 species were collected: Cylindrical Papershell, White Heelsplitter (*Lasmigona complanata*), Fragile Papershell (*Leptodea fragilis*), Mapleleaf, and Lilliput. Fragile Papershell was represented only by dead valves. The greatest species richness of live mussels occurred at site SR-16, where 3 species (Cylindrical Papershell, Mapleleaf, and Lilliput) were observed. During qualitative and quantitative surveys in the Smoky Hill River, valves of 9 species were observed: Cylindrical Papershell, Fragile Papershell, Pondmussel (*Ligumia subrostrata*), Pink Papershell, Bleufer (*Potamilus purpuratus*), Giant Floater, Mapleleaf, Lilliput, and Paper Pondshell (*Utterbackia imbecillis*). Bleufer was represented only by dead valves. The greatest species richness of live mussels occurred at site SH-21, where 8 species were observed.

Eighteen live Cylindrical Papershell, 7 in the Saline River and 11 in the Smoky Hill River, were collected during the 2015 qualitative and quantitative surveys. Live Cylindrical Papershell were collected at 1 of 19 survey sites in the Saline River and at 4 of 20 survey sites in the Smoky Hill River. In the Saline River, the species was most abundant at site SR-16 (7 individuals). In the Smoky Hill River, Cylindrical Papershell was most abundant at sites SH-21 and SH-22 (4 individuals each). Length of individuals ranged from 55 to 78 mm in the Saline River, and 93 to 112 mm in the Smoky Hill River (Figure 5.1).

Thirty sites qualitatively surveyed by Sowards et al. (2012) were included in the 2015 survey. No live mussels were observed at 7 of these sites (SR-03, SR-05, SR-06, SR-10, SR-13, SH-01, and SH-02) in 2011 and 2015, and they were removed from further analyses. At the remaining 23 sites, per site search effort (person hours) did not differ significantly ($t=0.725$, $df=22$, $p=0.476$) between 2011 and 2015. Live mussel abundance increased at 7 sites and decreased at 16 sites, with no live mussels observed at 7 of these 16 sites in 2015. Abundance of live mussels per site did not differ significantly ($t=0.454$, $df=22$, $p=0.654$) between 2011 and 2015; however, species richness per site significantly decreased ($t=3.61$, $df=22$, $p<0.001$) between 2011 and 2015. Abundance of Mapleleaf, the most commonly observed species, did not differ significantly between 2011 and 2015 ($t=0.844$, $df=19$, $p=0.409$). Abundance of Cylindrical Papershell per site significantly decreased ($t=5.19$, $df=10$, $p<0.001$) between 2011 and 2015.

At the sites surveyed in both 2011 and 2015, Sowards et al. (2012, 2016) observed a total of 23 live Cylindrical Papershell among 11 sites, with 8 individuals among 5 sites in the Saline River and 15 individuals among 6 sites in the Smoky Hill River. In 2015, 10 Cylindrical Papershell were observed at 3 sites, with 7 individuals at 1 site in the Saline River and 3 individuals at 2 sites in the Smoky Hill River.

DISCUSSION

Consistent with the observations of Sowards et al. (2012, 2016), freshwater mussels were more abundant in the Smoky Hill River (697 live individuals) than in the Saline River (34 live individuals) in 2015. Live mussels were collected at 5 of 19 survey sites in the Saline River and 19 of 21 survey sites in the Smoky Hill River. Species richness in the Smoky Hill River (8) was greater than in the Saline River (4), but the Simpson Diversity Index for the Saline River (0.63) was greater than that for the Smoky Hill River (0.29) which was dominated by the Mapleleaf. As suggested by Sowards et al. (2012, 2016), the typically sandy substrates in the Saline River might be less conducive to mussel aggregations. During high stream flows, mussels in the Saline River might be less able to maintain their position in the predominately sand and silt substrates than mussels in the coarser and more heterogeneous substrates of the Smoky Hill River.

At sites surveyed during both 2011 and 2015, declines in the abundance (Figure 6) and distribution (Figure 4) of Cylindrical Papershell were observed relative to those reported by Sowards et al. (2012, 2016) prior to the drought. In 2015, the species was not collected at 8 of 11 sites at which it was detected by Sowards et al. (2012, 2016), and only 10 live Cylindrical Papershell were collected compared to 23 in 2011. Changes in the mussel communities were also observed between the surveys. Overall abundance of live mussels at these sites did not differ significantly between the pre-drought and post-drought surveys, but species richness of live mussels significantly declined.

Overall, 18 live Cylindrical Papershell were collected during the 2015 survey. Lengths of the 7 individuals in the Saline River ranged from 55 to 78 mm (Figure 5.1), which suggests relatively recent recruitment, given the short, average lifespans (Harrigan, Moerke, and Badra 2009) and rapid growth (Sowards et al. 2012) reported for this species. Lengths of the 11 individuals in the Smoky Hill River ranged from 93 to 112, providing no evidence of recent recruitment.

In the Saline River at site SR-16, the 7 live Cylindrical Papershell was the greatest abundance at any site surveyed. The only evidence of recent recruitment was observed here. This site was downstream from a low-water bridge with perched culverts and seemed to have retained adequate water throughout the drought. Surface water consisted of several shallow pools (<0.5 m deep) surrounded by dense vegetation and interconnected by shallow (often <0.1 m), narrow (often <1 m) braided runs. Substrates were predominately comprised of sand and fine material. Mapleleaf and Lilliput were also observed at the site, in addition to 9 fish species, of which Fathead Minnow was the only known potential host species. The high abundance of Cylindrical Papershell at site SR-16 might be influenced by 2 factors. The perched culverts of the low-water bridge could prevent host fish infested with glochidia from traveling farther upstream during periods of low stream flow. In addition, the low-water bridge and dense vegetation at this site might decrease water velocity during high flows, reducing scour and erosion and allowing mussels to maintain their positions in the fine substrate.

In the Smoky Hill River, the greatest abundances of live Cylindrical Papershell were observed at sites SH-21 and SH-22, with 4 individuals each. These were sites chosen by using Google Earth™ imagery based on presence of surface water during the drought. Cool, spring-like inflow was evident at both sites, and substrates were heterogeneous and comprised of coarse gravel, fine gravel, and sand. At site SH-21, all live Cylindrical Papershell were collected near the shallow margins of an isolated pool with a maximum depth of approximately 1.5 m. This site supported 8 live mussel species, the highest species richness of live mussels at any site surveyed. Eight fish species were also present, including 3 known potential host species (Bluegill, Largemouth Bass, and Bluntnose Minnow). Site SH-22 consisted of a large pool with a maximum depth of approximately 1.2 m. Three Cylindrical Papershell were collected near the shallow margins of the pool, and a fourth was collected near the middle of the pool at a depth of 0.6 m. This site supported 6 live mussel species and 4 fish species, with Largemouth Bass being the only known potential host species.

During the drought, the Saline and Smoky Hill rivers in much of Ellis and Russell counties were reduced to areas of low flows and isolated pools. During the 2015 survey, stream discharge in the Saline River at USGS site 06867000 near Russell ranged from 2.1 to 7.6 cubic feet per second (cfs), and stream discharge in the Smoky Hill River near Pfeifer at USGS site 06863000 remained at 0.0 cfs (Appendix 1). In the survey area, surface water and stream flows in the Smoky Hill River are subject to a greater degree of alteration by humans relative to surface water and stream flows than in the Saline River. Near the western edge of the survey area, Cedar Bluff Reservoir restricts stream flow in the Smoky Hill River except for seepage from the reservoir. Occasionally, water is released to recharge municipal well fields downstream in the study area. The last such release occurred during the spring of 2013.

Municipal well fields for Hays and Russell are located along the Smoky Hill River near Schoenchen and Pfeifer, respectively. Groundwater withdrawal by the wellfields seems to profoundly affect the presence of surface water in the Smoky Hill River in Ellis County, increasing habitat fragmentation during periods of low precipitation. This is evidenced by the absence of surface water near Schoenchen and Pfeifer, and the presence of surface water downstream from Schoenchen and Pfeifer during drought years (Figure 7), along with a decrease in stream discharge typically observed between the gaging stations upstream and downstream from Schoenchen.

Seep-springs or alluvial discharges were observed at or near most survey sites depicted in Figure 7 (SH-17, SH-21, SH-22, and SH-23), and these sites seemed to maintain adequate surface water during the drought. Seep-springs were also observed approximately 400 m north of the dry streambed near Pfeifer. These observations suggest the lack of water near Schoenchen and Pfeifer is largely influenced or potentially caused by lowering of the water table near the wellfields. If withdrawal rates were reduced, these reaches of the Smoky Hill River could potentially maintain surface water during periods of low precipitation, decreasing fragmentation. A lowhead dam near Pfeifer further fragments the habitat and prevents upstream dispersal of host fish potentially infested with glochidia (Figure 7).

During the early 1980s, the Cylindrical Papershell was described as one of the most abundant mussel species in the Smoky Hill River in Trego, Ellis, and Russell counties (Hoke 1997). In 2011, Sowards et al. (2012, 2016) observed the Cylindrical Papershell at low relative abundances and densities, and described the species as one of the least abundant mussel species; however, they were unable to document a marked decline or accurately compare their results to historical populations due to lack of abundance data in previous studies. Although quantitative survey data would be preferable for making comparisons, the relatively low abundances of mussels during quantitative surveys in 2011 (Sowards et al. 2012, 2016) and 2015 did not allow for reasonable comparisons. The qualitative survey data collected during this study did, however, allow for comparisons of Cylindrical Papershell populations in 2011 to those in 2015, because per site search effort did not differ significantly between the surveys. Drought conditions and reduced stream flows decreased the available habitat at most survey sites relative to the same sites in 2011. Consequently, similar search effort was concentrated within smaller stream areas in 2015.

The observed changes in the Cylindrical Papershell populations of the Saline and Smoky Hill rivers between 2011 and 2015 suggested a decline of the species during recent years. Similar declines have been observed in other areas near the edge of the species' distribution. Historically known to occur in Lake Winnipeg, Manitoba, Cylindrical Papershell was not observed during a recent survey of 90 sites in the lake (Pip 2000, 2006). Once the most common freshwater mussel species in Colorado, the Cylindrical Papershell has recently been observed at only 2 locations (Harrold and Guralnick 2010) and is currently considered a species of "State Special Concern." Similar concerns of possible declines throughout its distribution have led to the listing of the species as critically imperiled in Missouri, endangered in Vermont, threatened in Iowa, and imperiled in Pennsylvania and West Virginia.

Climate change could pose a substantial threat to the Cylindrical Papershell in Kansas. Climate has been suggested as a limiting factor in the distribution of the species, with Cylindrical Papershell becoming localized and rare south of 39° latitude (Cummings and Mayer 1992; Watters, Hoggarth, and Stansbery 2009; Haag 2012). The northern border of Ellis and Russell counties, Kansas, occurs at approximately 39.1° latitude. Increased mortality rates in the Cylindrical Papershell have been observed at 29°C (Salbenblatt and Edgar 1964; Edgar 1965), a temperature that might be met or exceeded in shallow and unshaded reaches of the Saline and Smoky Hill rivers within the study area. Additionally, elevated water temperature has been suggested to negatively affect physiological processes and increase metabolic rates of freshwater mussels, reducing energy available for survival, growth, and reproduction (Ganser, Newton, and Haro 2015).

Drought and low flows potentially increase the risk of predation upon freshwater mussels by predators such as Raccoon (*Procyon lotor*). During a severe drought in Texas in 2011, 73% of recently deceased *Potamilus amphichaenus*, a thin-shelled, state-threatened species, showed evidence of predation as bite or scratch marks (Walters and Ford 2013). Many of the dead Cylindrical Papershell valves collected during this study also exhibited evidence of predation, suggesting predation during low flows might pose another threat to the species.

CONCLUSIONS

Historically, the Cylindrical Papershell occurred across the northern half of Kansas (Angelo et al. 2009). As a result of widespread stream degradation, the distribution of the species in Kansas has been reduced during the past century (Angelo et al. 2009; Sowards et al. 2016). The species is now apparently restricted to the upper Smoky Hill-Saline River Basin in west-central Kansas, where a significant decline in the abundance of the species was observed between 2011 and 2015. During this study, the species occurred at low abundances across a limited geographic area comprised of highly fragmented streams.

Loss of surface water and stream flows, along with habitat fragmentation and degradation, are the primary factors that threaten the persistence of Cylindrical Papershell within Kansas. Continued monitoring of this species within the state is important, as similar declines have been observed in other areas of the species' range. These observations suggest that, with current climate trends and water consumption, the Cylindrical Papershell could be lost as a viable component of Kansas' ecosystems and warrant a change in the conservation status of the Cylindrical Papershell within Kansas to endangered. This change would afford regulatory measures, designation and protection of critical habitat, and increase priority of recovery efforts for the species. The data collected during this survey, along with the data collected by Sowards et al. (2012, 2016), can be used as points of comparison for future surveys in the area to increase our understanding of the mussel communities present in the dynamic systems of the Saline and Smoky Hill rivers in northwestern Kansas.

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Table 1. Qualitative survey data for live mussels collected at survey sites the Saline River (SR-##) and Smoky Hill River (SH-##) in Ellis, Russell, and Trego counties, Kansas during 2015.

Site	*Anodontoides ferussacianus*	*Lasmigona complanata*	*Leptodea fragilis*	*Potamilus ohiensis*	*Pyganodon grandis*	*Quadrula quadrula*	*Toxolasma parvus*	*Utterbackia imbecillis*	Total	CPUE	Species Richness	Simpson Diversity Index
SR-03	-	-	-	-	-	-	-	-	-	-	-	-
SR-04	-	-	-	-	-	1	19	-	20	9.76	2	0.01
SR-05	-	-	-	-	-	-	-	-	-	-	-	-
SR-06	-	-	-	-	-	-	-	-	-	-	-	-
SR-07	-	-	-	-	-	-	-	-	-	-	-	-
SR-08	-	-	-	-	-	1	-	-	1	0.33	1	0.00
SR-09	-	-	-	-	-	-	-	-	-	-	-	-
SR-10	-	-	-	-	-	-	-	-	-	-	-	-
SR-11	-	-	-	-	-	-	-	-	-	-	-	-
SR-12	-	-	-	-	-	-	-	-	-	-	-	-
SR-13	-	-	-	-	-	-	-	-	-	-	-	-
SR-14	-	-	-	-	-	-	-	-	-	-	-	-
SR-16	4	-	-	-	-	2	-	-	6	1.24	2	0.56
SR-17	-	-	-	-	-	-	-	-	-	-	-	-
SR-18	-	-	-	-	-	-	-	-	-	-	-	-
SR-19	-	3	-	-	-	2	-	-	5	1.43	2	0.60
SR-20	-	-	-	-	-	-	-	-	-	-	-	-
SR-21	-	-	-	-	-	-	-	-	-	-	-	-
SR-22	-	-	-	-	-	2	-	-	2	1.00	1	0.00
SH-01	-	-	-	-	-	-	-	-	-	-	-	-
SH-02	-	-	-	-	-	-	-	-	-	-	-	-
SH-03	-	-	2	1	-	34	-	-	37	18.50	3	0.15
SH-04	-	-	-	1	-	12	-	-	13	6.50	2	0.15
SH-06	-	-	1	-	-	30	-	-	31	15.50	2	0.06

Table 1. (Continued)

Site		*Anodontoides ferussacianus*	*Lasmigona complanata*	*Leptodea fragilis*	*Potamilus ohiensis*	*Pyganodon grandis*	*Quadrula quadrula*	*Toxolasma parvus*	*Utterbackia imbecillis*	Total	CPUE	Species Richness	Simpson Diversity Index
SH-09		-	-	-	-	-	9	-	-	9	4.50	1	0.00
SH-11		-	-	1	1	-	82	-	-	84	10.50	3	0.05
SH-12		-	-	-	-	-	9	-	-	9	3.60	1	0.00
SH-14		-	-	-	-	-	11	-	-	11	5.50	1	0.00
SH-15		-	-	-	-	-	8	-	-	8	4.00	1	0.00
SH-16		-	-	-	-	-	53	-	-	53	17.67	1	0.00
SH-17		2	-	-	1	3	3	-	-	9	2.25	4	0.81
SH-18		-	-	3	2	-	-	-	-	5	0.87	2	0.60
SH-19		1	-	17	16	-	61	-	-	95	13.57	4	0.53
SH-20		-	-	-	-	-	-	-	-	-	-	-	-
SH-21		4	-	5	6	1	19	-	1	36	9.00	6	0.68
SH-22		3	-	-	-	-	5	-	13	21	5.25	3	0.57
SH-23		-	-	-	2	-	9	-	-	11	2.75	2	0.33
SH-24		-	-	1	1	-	1	-	-	3	0.60	3	1.00
SH-25		-	-	5	1	-	233	1	3	243	34.71	5	0.08
SH-26		-	-	-	15	-	4	-		19	5.99	2	0.35
Saline River	Total	4	3	-	-	-	8	19	-	34	0.75	4	0.63
	CPUE	0.09	0.07	-	-	-	0.18	0.42	-	-	-	-	-
Smoky Hill River	Total	10	-	35	47	4	583	1	17	697	9.37	7	0.29
	CPUE	0.13	-	0.47	0.63	0.05	7.83	0.01	0.23	-	-	-	-
Combined	Total	14	3	35	47	4	591	20	17	731	6.11	8	0.34
	CPUE	0.12	0.03	0.29	0.39	0.03	4.94	0.17	0.14	-	-	-	-

Table 2. Quantitative survey data for live mussels collected at survey sites in the Saline River (SR-##) and Smoky Hill River (SH-##) in Ellis and Russell counties, Kansas during 2015.

Site		*Anodontoides ferussacianus*	*Leptodea fragilis*	*Ligumia subrostrata*	*Pyganodon grandis*	*Quadrula quadrula*	*Toxolasma parvus*	*Utterbackia imbecillis*	Total	Density (m^{-2})	Species Richness
SR-08		-	-	-	-	-	-	-	-	-	-
SR-16		3	-	-	-	1	12	-	16	0.40	3
SH-11		-	2	-	-	10	8	-	20	0.50	3
SH-12		-	-	-	-	3	19	-	22	0.55	2
SH-17		-	-	-	1	-	-	1	2	0.05	2
SH-21		-	-	1	-	5	1	-	7	0.18	3
SH-22		2	1	-	1	-	-	2	6	0.15	4
Saline River	Total	3	-	-	-	1	12	-	16	0.20	3
	Density (m^{-2})	0.04	0.00	0.00	0.00	0.01	0.15	0.00	-	-	-
Smoky Hill River	Total	2	3	1	2	18	28	3	57	0.29	7
	Density (m^{-2})	0.01	0.02	0.01	0.01	0.09	0.14	0.02	-	-	-
Combined	Total	5	3	1	2	19	40	3	73	0.26	7
	Density (m^{-2})	0.02	0.01	0.00	0.01	0.07	0.14	0.01	-	-	-

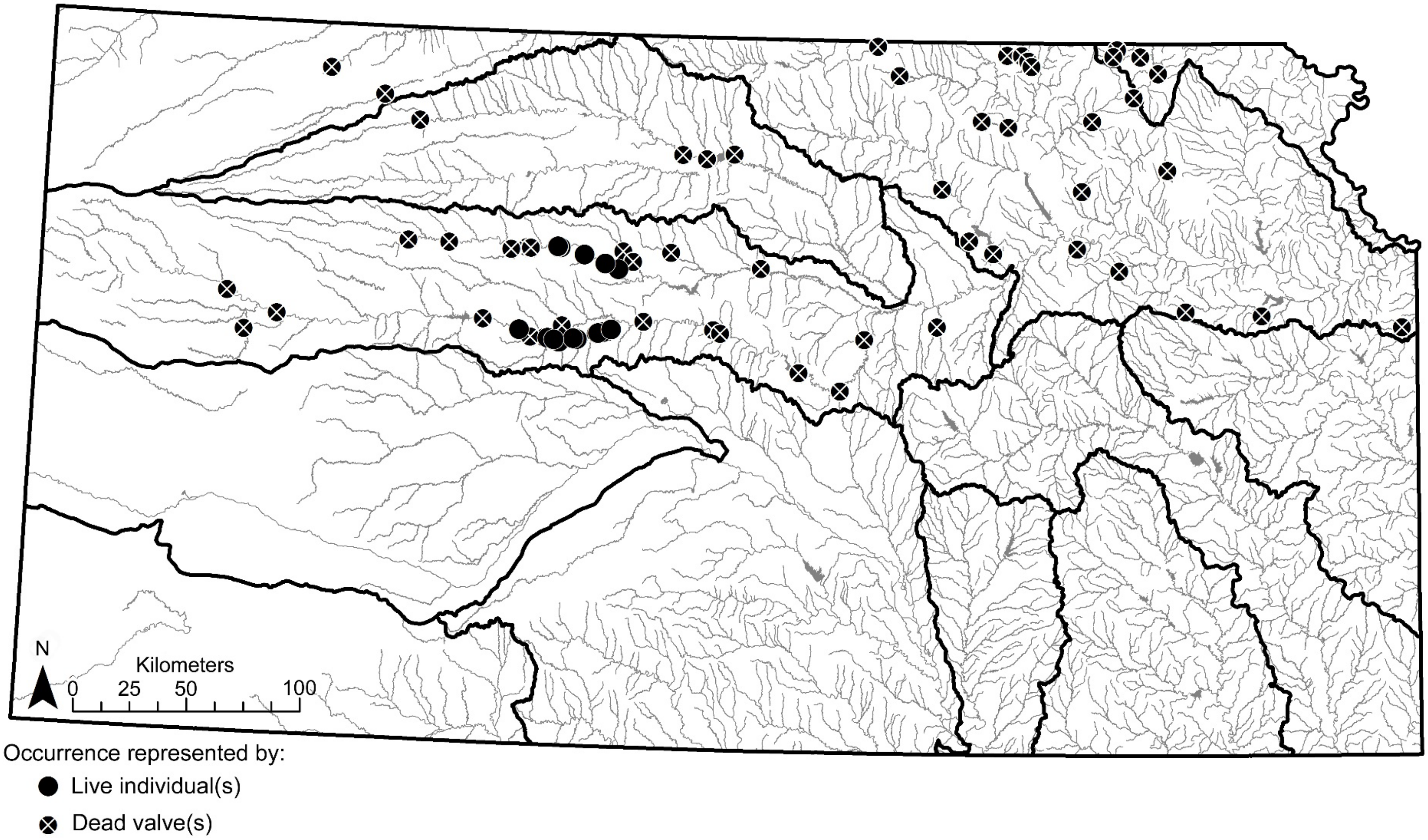

Figure 1. Documented occurrences of *Anodontoides ferussacianus* in Kansas through 2015. Modified from Angelo et al. 2009 and Sowards et al. 2012.

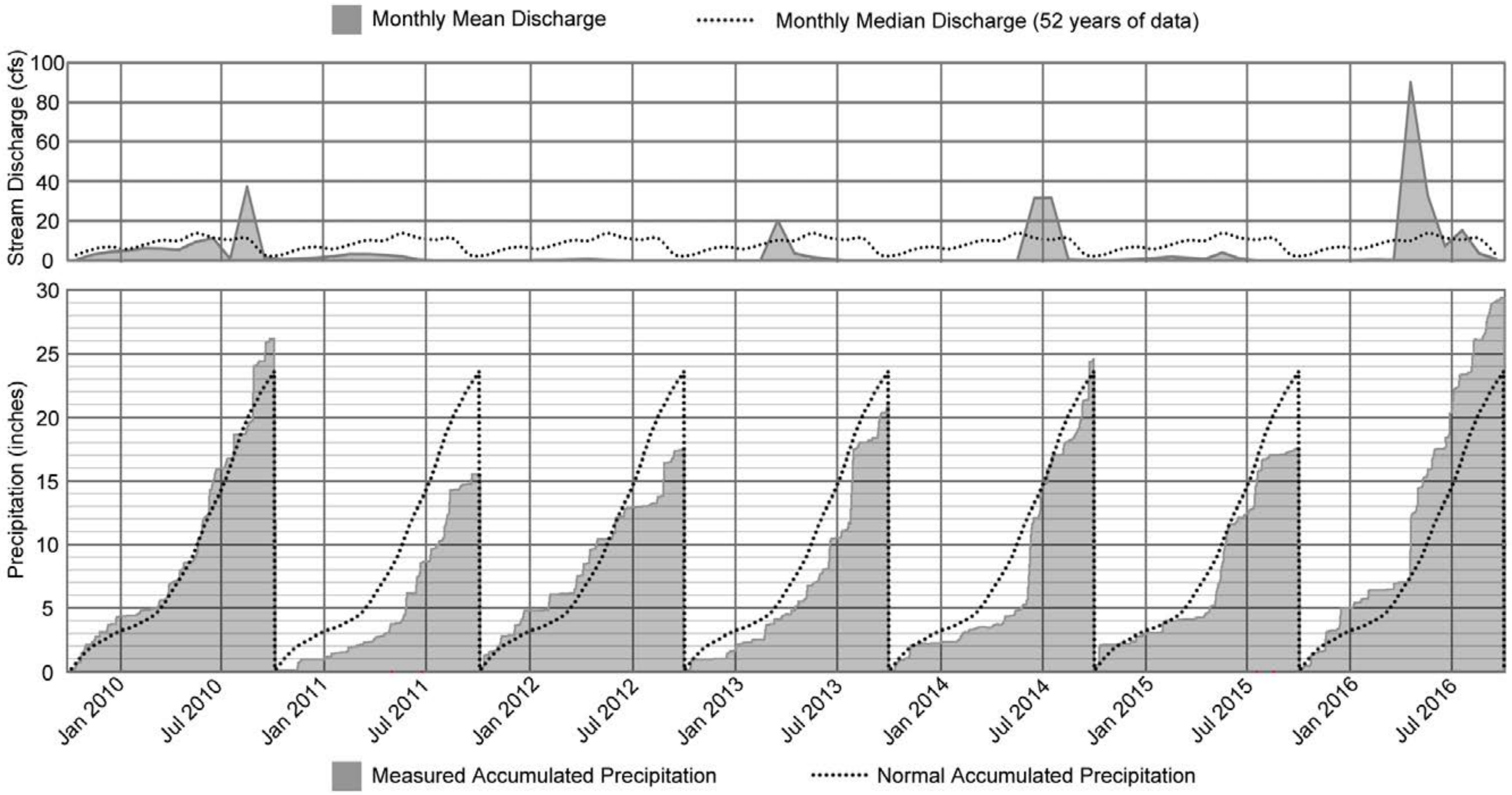

Figure 2. Graphic depiction of drought from 2011 to 2015. The lower graph depicts measured accumulated precipitation relative to normal accumulated precipitation near Hays, Kansas (NOAA NCDC Station Hays 1 S) per water year from 2010 to 2016. The upper graph depicts monthly mean stream discharge relative to monthly median discharge in the Smoky Hill River near Schoenchen, Kansas (USGS Station 06862700).
(Accumulation graph modified from the accumulation graph for Hays S 1 produced at http://scacis.rcc-acis.org/)

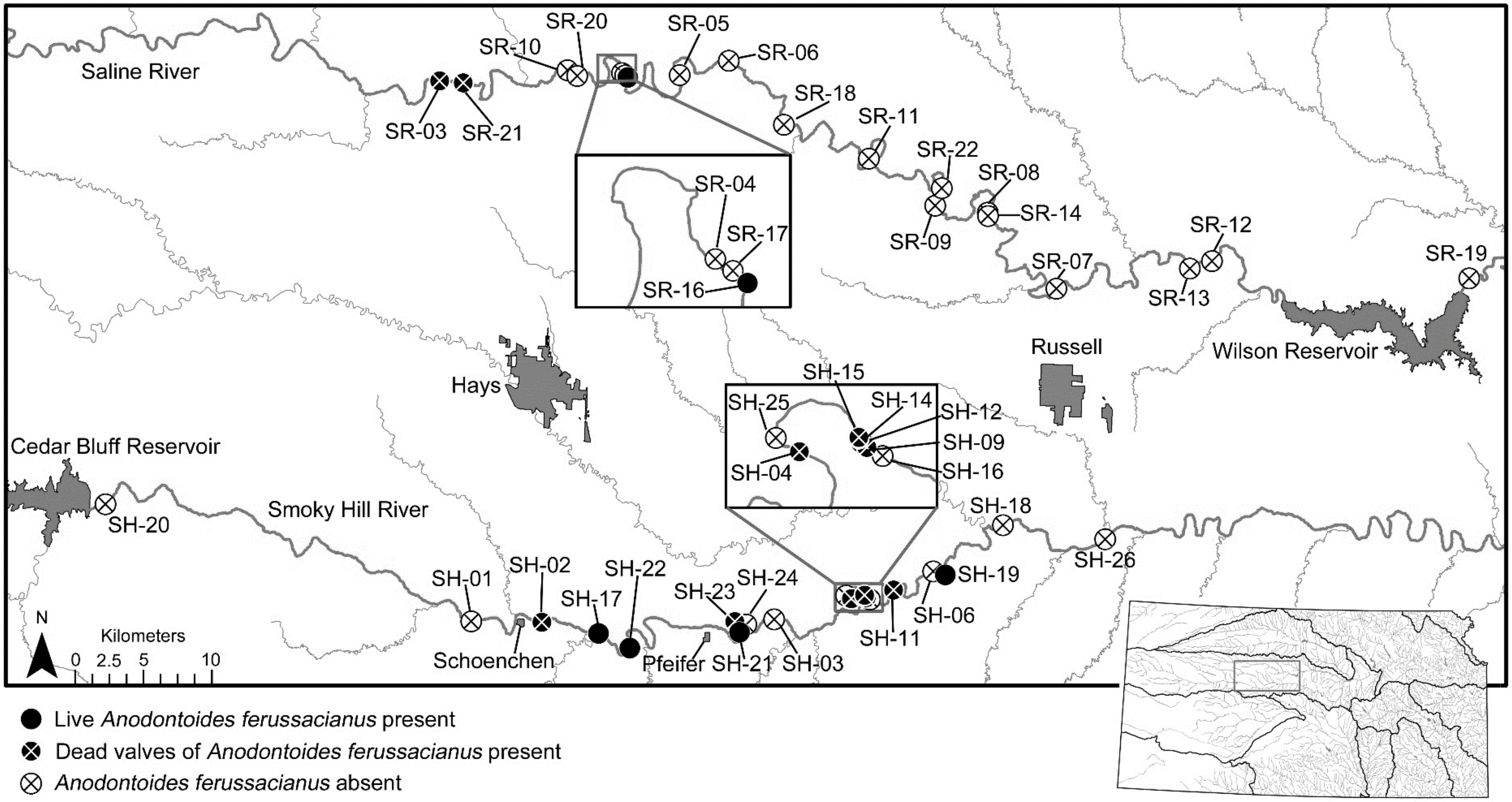

Figure 3. Survey area and sites sampled for freshwater mussels on the Saline and Smoky Hill rivers in Ellis, Russell, and Trego counties, Kansas during 2015.

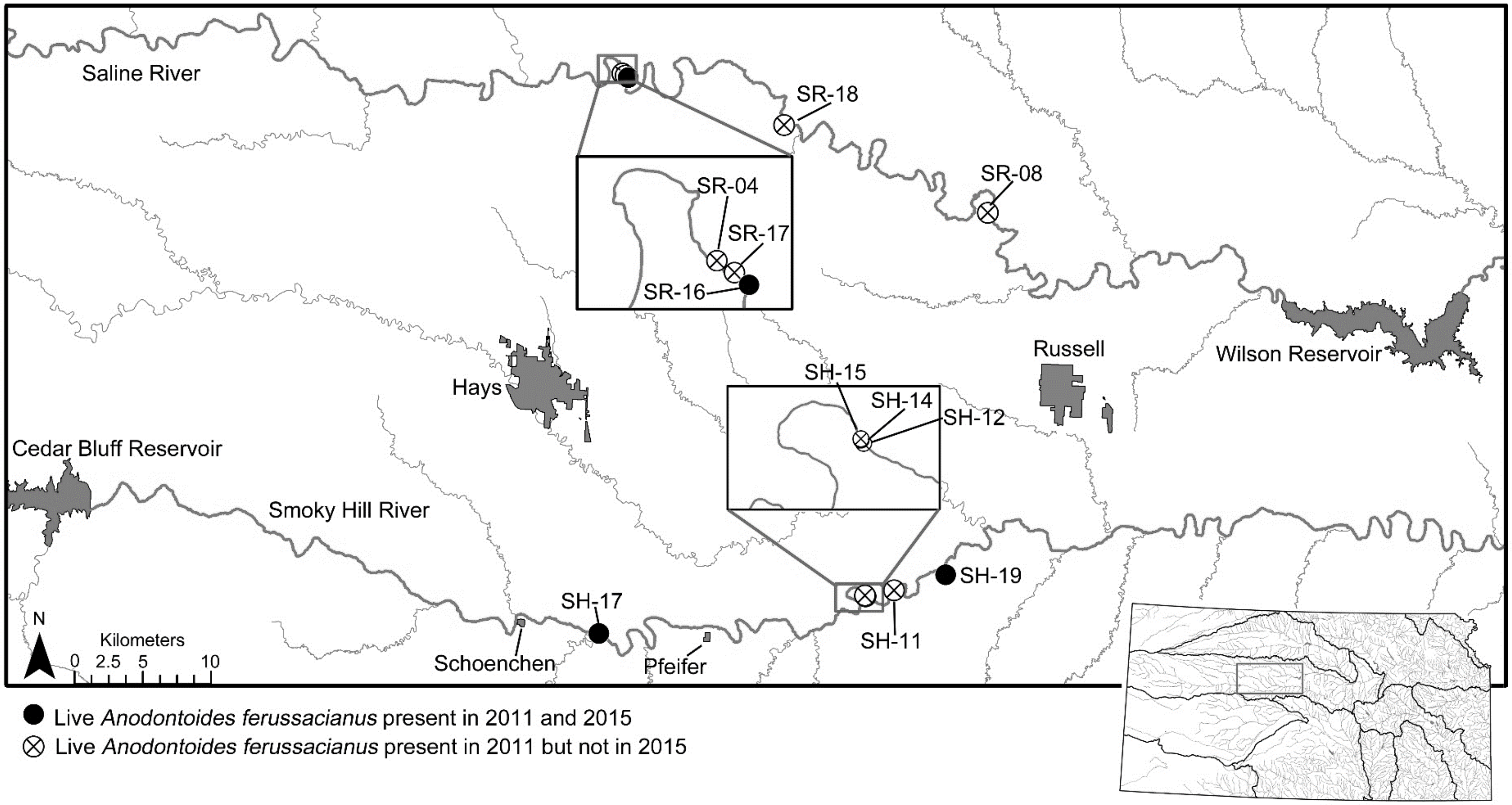

Figure 4. Change in occurrence of *Anodontoides ferussacianus* between the 2011 and 2015 surveys in the Saline and Smoky Hill rivers in Ellis and Russell counties, Kansas. In 2015, *A. ferussacianus* was not collected at 8 of 11 sites at which it was observed by Sowards et al. (2012).

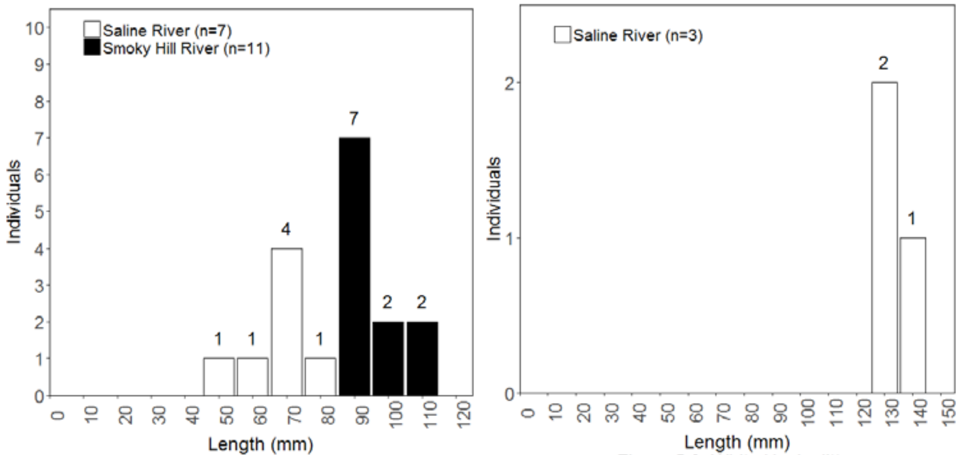

Figure 5.1. Cylindrical Papershell

Figure 5.2. White Heelsplitter

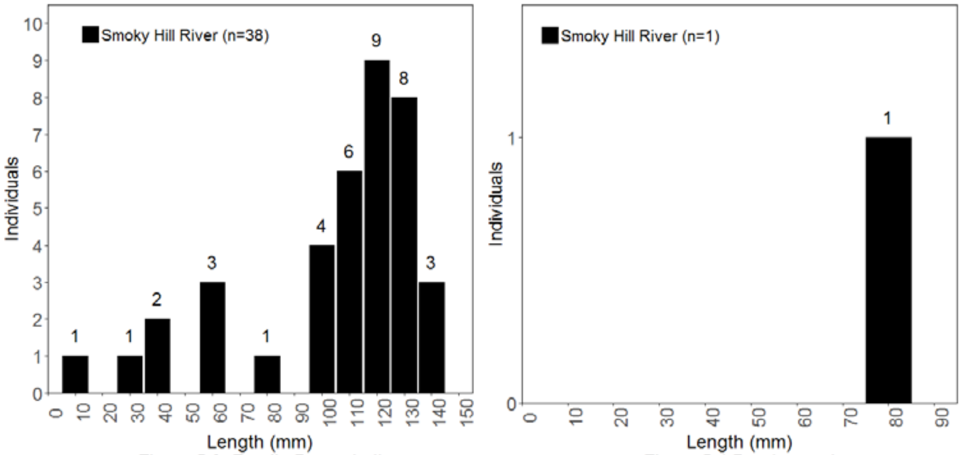

Figure 5.3. Fragile Papershell

Figure 5.4 Pondmussel

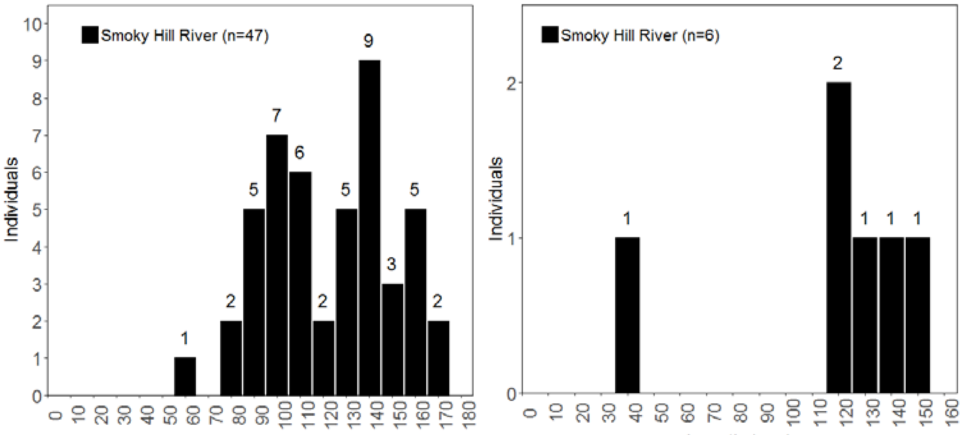

Figure 5.5. Pink Papershell

Figure 5.6. Giant Floater

Figure 5. Length-frequency histograms of live freshwater mussels collected in the Saline and Smoky Hill rivers in Ellis, Russell, and Trego counties, Kansas during 2015. Note: Axis ranges vary among figures.

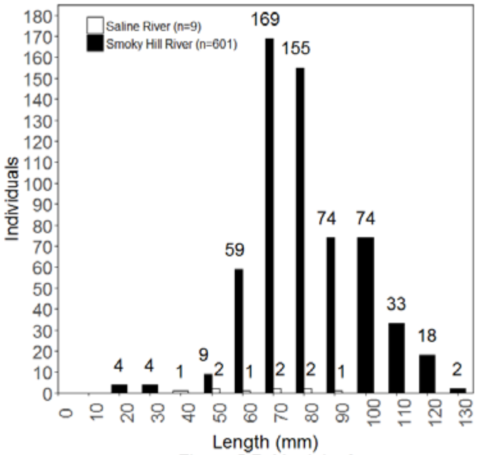

Figure 5.7. Mapleleaf

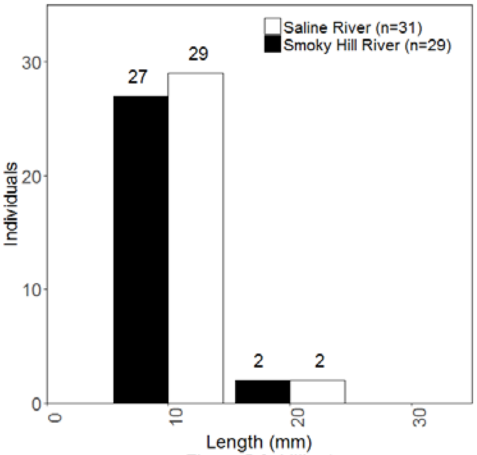

Figure 5.8. Lilliput

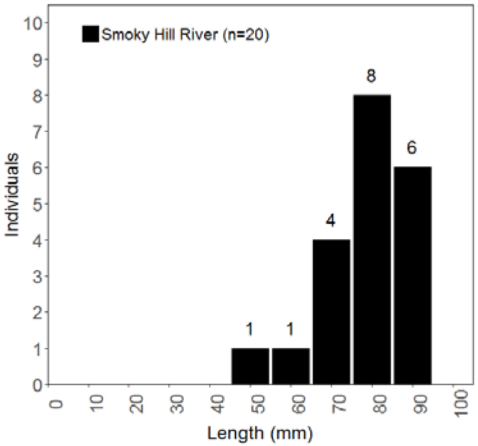

Figure 5.9. Paper Pondshell

Figure 5 (Continued). Length-frequency histograms of live freshwater mussels collected in the Saline and Smoky Hill rivers in Ellis, Russell, and Trego counties, Kansas during 2015. Note: Axis ranges vary among figures.

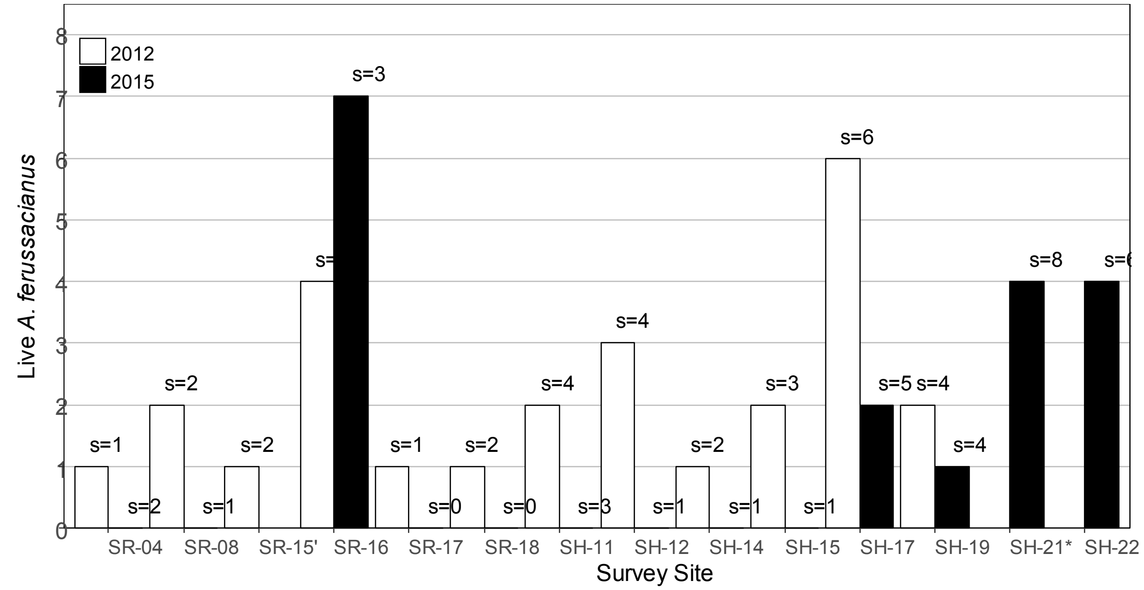

Figure 6. Change in abundance of *Anodontoides ferussacianus* and species richness (s) of live mussels at sites in the Saline River (SR-##) and Smoky Hill River (SH-##) in Ellis, Russell, and Trego counties, Kansas during 2011 (Sowards et al. 2012) and 2015. Apostrophes (‘) denote sites surveyed only in 2011, and asterisks (*) denote sites surveyed only in 2015.

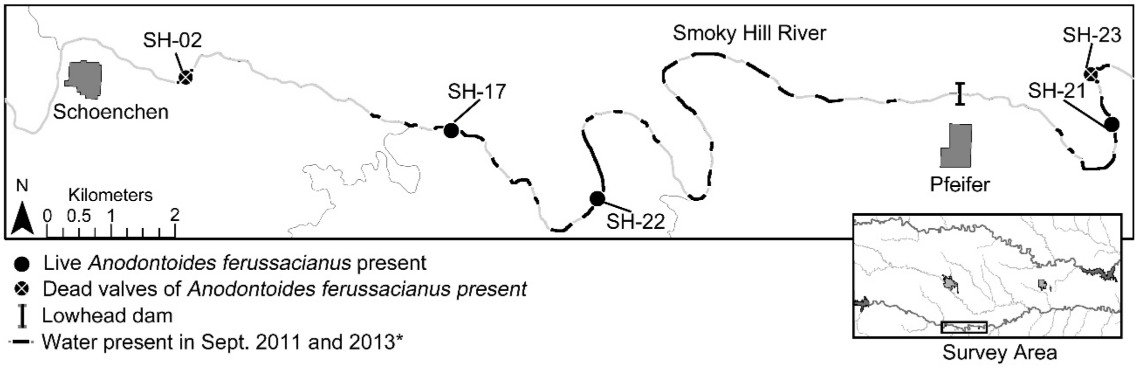

Figure 7. Habitat fragmentation in the Smoky Hill River. Municipal water-well fields for the cities of Hays and Russell, Kansas are located along the Smoky Hill River near Schoenchen and Pfeifer, respectively. *Estimated by using Google Earth™ Imagery.

Appendix 1. Information for qualitative sites surveyed for freshwater mussels in the Saline River (SR-##) and Smoky Hill River (SH-##) in Ellis, Russell, and Trego counties, Kansas during 2015.

Site	Upstream Boundary		Downstream Boundary		Site Length (m)	Date	Daily Mean Discharge (cfs)	Effort (person hours)
	Latitude	Longitude	Latitude	Longitude				
SR-03	39.09092	-99.42327	39.09077	-99.42264	57	7/14/2015	2.1	2.3
SR-04	39.10111	-99.25924	39.10083	-99.25865	60	7/14/2015	2.1	2.1
SR-05	39.10133	-99.20719	39.10152	-99.20726	22	7/17/2015	7.6	2.0
SR-06	39.11272	-99.16351	39.11255	-99.16322	31	7/17/2015	7.6	2.0
SR-07	38.96060	-98.86150	38.96102	-98.86140	48	7/21/2015	5.7	2.0
SR-08	39.01233	-98.92553	39.01213	-98.92544	24	7/20/2015	6.8	3.0
SR-09	39.01594	-98.97298	39.01553	-98.97276	49	7/20/2015	6.8	2.0
SR-10	39.10188	-99.30841	39.10148	-99.30844	45	7/14/2015	2.1	2.0
SR-11	39.04746	-99.03418	39.04849	-99.03410	115	7/20/2015	6.8	4.0
SR-12	38.98338	-98.72246	38.98342	-98.72227	17	7/21/2015	5.7	1.0
SR-13	38.97775	-98.74194	38.97790	-98.74150	42	7/21/2015	5.7	1.5
SR-14	39.01005	-98.92509	39.00958	-98.92480	58	7/20/2015	6.8	3.0
SR-16	39.09826	-99.25400	39.09795	-99.25404	35	7/14/2015	2.1	4.9
SR-17	39.09972	-99.25638	39.09964	-99.25576	54	7/14/2015	2.1	1.5
SR-18	39.06901	-99.11182	39.06886	-99.11113	62	7/20/2015	6.8	3.0
SR-19	38.97678	-98.49039	38.97702	-98.49004	40	7/21/2015	15.0	3.5
SR-20	39.09796	-99.29951	39.09822	-99.29913	44	8/6/2015	4.7	2.0
SR-21	39.09015	-99.40192	39.08960	-99.40151	71	8/6/2015	4.7	1.5
SR-22	39.02840	-98.96750	39.02797	-98.96796	62	8/14/2015	2.0	2.0
SH-01	38.71232	-99.37585	38.71239	-99.37529	49	7/16/2015	0.0	2.0
SH-02	38.71355	-99.31259	38.71325	-99.31303	51	7/16/2015	0.0	2.0
SH-03	38.72151	-99.10468	38.72149	-99.10423	39	8/3/2015	0.0	2.0
SH-04	38.73807	-99.03613	38.73817	-99.03659	41	7/30/2015	0.0	2.0
SH-06	38.75909	-98.96364	38.75942	-98.96281	81	8/3/2015	0.0	2.0
SH-09	38.73912	-99.02266	38.73887	-99.02226	45	7/30/2015	0.0	2.0
SH-11	38.74500	-98.99842	38.74525	-98.99697	129	7/23/2015	0.0	8.0
SH-12	38.74000	-99.02380	38.73960	-99.02360	48	7/30/2015	0.0	2.5
SH-14	38.74051	-99.02431	38.74017	-99.02402	45	7/30/2015	0.0	2.0
SH-15	38.74068	-99.02436	38.74132	-99.02496	88	8/4/2015	0.0	2.0
SH-16	38.73786	-99.01941	38.73750	-99.01871	73	8/3/2015	0.0	3.0
SH-17	38.70719	-99.26153	38.70714	-99.26029	108	7/22/2015	0.0	4.0
SH-18	38.79319	-98.90233	38.79399	-98.90217	90	8/14/2015	0.0	5.8
SH-19	38.75710	-98.95277	38.75780	-98.95135	146	7/23/2015	0.0	7.0
SH-20	38.78413	-99.70808	38.78415	-99.70793	13	7/16/2015	0.0	1.0
SH-21	38.71166	-99.13547	38.71148	-99.13532	24	7/22/2015	0.0	4.0
SH-22	38.69773	-99.23318	38.69802	-99.23273	51	8/12/2015	0.0	4.0
SH-23	38.71902	-99.13980	38.71962	-99.13914	88	8/12/2015	0.0	4.0
SH-24	38.71729	-99.12940	38.71695	-99.12904	49	8/12/2015	0.0	5.0
SH-25	38.74014	-99.04100	38.74141	-99.04098	141	8/12/2015	0.0	7.0
SH-26	38.78561	-98.81027	38.78597	-98.80946	81	8/14/2015	0.7	3.2

STUDY 2:

EFFECTS OF LOWHEAD DAMS ON GROWTH OF *QUADRULA PUSTULOSA* IN THE NEOSHO RIVER, KANSAS

INTRODUCTION

North American freshwater mussels (Bivalvia: Unionoida) have been increasingly studied in recent decades. Further studies focusing on the influence of habitat and environmental variables on mussel biology, ecology, and physiology are needed to increase our understanding of this imperiled (Williams et al. 1993) group of organisms and to aid in conservation decisions.

In Kansas, past studies have used the abundance of juvenile mussels as a measure of population health (Obermeyer 1996; Hoke 2005; Miller and Mosher 2008; Sowards et al. 2012). Wolf (2005) suggested discharges in the Fall and Marais des Cygnes rivers vary between recruitment and non-recruitment years. Age and growth studies can also provide valuable information on the health of freshwater mussel populations; however, few studies in the state have attempted to measure mussel growth or variables that might influence growth.

Methods used to obtain age and growth data for freshwater mussels include direct measurement of individuals and counts of external shell rings during mark-recapture studies (Negus 1966; Downing, Shostell, and Downing 1992), counts of external annuli, and counts of internal annuli deposited as a result of cyclical growth that alternates between cool and warm seasons in temperate regions (Neeves and Moyer 1988; Haag and

Commens-Carson 2008). However, the assumption of annuli production, both external and internal, has been questioned. A study conducted by Haag and Commens-Carson (2008) tested, and supported, the assumption of internal annuli production. Additionally, it was suggested that internal annuli allow for more accurate and reliable age estimates relative to external annuli, which often underestimate the age of older individuals (Haag and Commens-Carson 2008).

Lowhead dams are reported to negatively influence mussel assemblages and aquatic communities (Watters 1996; Dean et al. 2002; Tiemann et al. 2007; Gangloff et al. 2011). Lowhead dams on the Neosho River have been the subject of several previous studies (Dean et al. 2002; Tiemann et al. 2004, 2005), but relatively few studies have investigated the effects of lowhead dams on freshwater mussels in this river system. Dean et al. (2002) reported differences in the composition of mussel communities above and below lowhead dams in the upper Neosho River.

Factors thought to influence mussel growth include water temperature and the changing global climate (Kendall et al. 2010), availability of calcium and bicarbonate (Haag and Rypel 2011), primary productivity and nutrient availability (Morris and Corkum 1999), and stream discharge (Rypel et al. 2008, 2009; Dycus, Wisniewski, and Peterson 2015). Lowhead (small, top release) dams have been reported to affect several factors thought to influence the growth of freshwater mussels. Lowhead dams alter physical stream characteristics by increasing water temperatures directly downstream, producing an impoundment upstream, often for several kilometers, and disrupting sediment transport (Lessard and Hayes 2003; Singer and Gangloff 2011; Hoch 2012;

Fencl et al. 2015). It has been reported that this increase in temperature directly downstream of lowhead dams also increases growth rates in mussels (Hoch 2012; Singer and Gangloff 2011).

Studying the effect of lowhead dams on mussel growth could provide insights on the influence of stream fragmentation and changes in hydrology, and benefit our understanding of freshwater mussel growth in systems fragmented by lowhead dams and impoundments. A common mussel species with robust populations in the Neosho River (e.g. Pimpleback, *Quadrula pustulosa*) could serve as a surrogate for mussel species of greater conservation concern, for which adequate samples for any study of this nature would be not only improbable, but unethical. The collection of a surrogate species is readily justified by the information that could be gained and its potential applicability toward the conservation of this group of organisms.

The objective of this study was to compare growth characteristics of Pimpleback upstream and downstream of lowhead dams in the Neosho River, Kansas. Given the reported effects of lowhead dams on variables thought to influence individual growth rates of freshwater mussels, and the increasing stream discharge gradient along which sample dams were located, I hypothesize that growth differs between samples collected upstream and downstream of lowhead dams and among samples along a stream discharge gradient.

METHODS

Study area

The Neosho River of southeastern Kansas is a gravel bed stream that lies in the tallgrass prairie ecoregion and drains an area of approximately 16,300 km^2. The river originates in the Flint Hills near Council Grove, Kansas and flows southeast for approximately 440 km before reaching the Kansas-Oklahoma border (Figure 1). Predominant land cover in the basin is grassland (56.3%), cropland (31.5%), and woodland (8.5%) (Homer et al. 2015).

The Neosho River in Kansas historically supported 36 mussel species (Angelo et al. 2009). Recently, 31 species were documented (Angelo et al. 2009), of which 3 are listed as state endangered, 2 as threatened, and 10 as species in need of conservation (SINC). The Neosho River also supports populations of the federally threatened Rabbitsfoot (*Quadrula cylindrica*) and endangered Neosho Mucket (*Lampsilis rafinesqueana*).

In Kansas, the Neosho River has been altered by humans. Two federal reservoirs and 16 lowhead dams have been constructed along its length. The focal area of this study was the 275-km reach downstream from John Redmond Dam to the Kansas-Oklahoma border (Figure 1). The operation of John Redmond Dam, constructed in 1964, has changed flow regimes in this reach by decreasing peak-flow magnitudes and increasing low-flow magnitudes (Studley 1996). John Redmond Dam also reduces suspended sediment concentrations immediately downstream, but its influence is moderated by tributaries further downstream (Juracek 1999).

In the early to mid-1900s, 12 lowhead dams, typically 1 to 2 m tall, were constructed for water-supply purposes in this reach of river (Juracek 1999). The river channel began to bypass the lowhead dam near South Mound (upstream from Parsons) in 1995 (Juracek 1999), and completely bypassed the dam in the early to mid-2000s. At the time of this study, 11 functioning lowhead dams remained in the Neosho River within Kansas downstream of John Redmond Dam (Figure 1) and occurred at a frequency of 1 dam per 25 km of stream.

Species selection

The Pimpleback (*Quadrula pustulosa*) is locally abundant in the Neosho River (Obermeyer, 1996), and current populations are relatively stable as judged by their absence from threatened, endangered, or SINC lists within the state of Kansas. Probable host fishes for *Q. pustulosa* in Kansas include *Ictalurus punctatus* (Channel Catfish) (Howard 1913, 1914; Coker et al. 1921; Weiss and Layzer 1995), *Pomoxis annularis* (White Crappie) (Surber 1913; Coker et al. 1921), and *Pylodictis olivaris* (Flathead Catfish) (Howard 1913, 1914; Coker et al. 1921). These species are abundant across large geographic ranges, possibly possible variation in recruitment among sample sites caused by absence of host species.

The Pimpleback is sexually monomorphic, allowing for direct comparison of all individuals within populations. This species was compatible with available sectioning equipment, as maximum length of individuals rarely exceeds 100 mm. The relatively long lifespan of this species, documented as 48 years in the Little Tallahatchie River, Mississippi (Haag and Rypel 2011), can provide decades of growth information. This species has been successfully used in other age and growth studies (Wolf 2005; Haag and Commens-Carson 2008; Rypel, Haag, and Findlay 2008, 2009; Black et al. 2010; Haag and Rypel 2011). Haag and Commens-Carson (2008) validated the assumption of annual ring production in this species.

Site selection

Lowhead dams in the lower Neosho near Iola, Parsons, and Oswego were chosen based on abundance of Pimpleback and proximity to United States Geological Survey (USGS) gages with a minimum of 50 years of historical stream flow data for potential comparisons to mussel growth-increment chronologies (Figure 1). The lowhead dam near Oswego lacked historical streamflow data, but was the best replicate for upstream and downstream comparisons based on Pimpleback abundance (Figure 1). The upstream site at each dam was determined by the nearest accessible site with adequate Pimpleback abundance upstream from the area of impeded flow (Table 1).

It is necessary to note the large distance between the Parsons dam and the Parsons upstream site (PU), located in the Neosho Wildlife Area, relative to the distances between the Iola and Oswego upstream sites and their respective dams (Table 1). Five sites were sampled upstream from the Parsons dam, and the site chosen was the fifth and farthest upstream of the sites; however, it was the only site from which an adequate sample of Pimpleback could be collected. It is also necessary to note that the bypassed-lowhead dam discussed previously (Figure 1) is located between PU and the Parsons dam. It is expected, based on distance, that this site was located upstream of the area impounded by the bypassed dam while it was functional and, therefore, was considered an adequate upstream comparison for the Parsons dam.

Specimen collection and processing

Pimplebacks were collected via tactile and visual searches on 2-3 October 2016 and 17-18 October 2016 (Table 1). At each of the 6 sample locations, I attempted to collect 5 individuals per 10-mm length class for lengths less than 40 mm (e.g. 0-9 mm, 10-19 mm), and 5 individuals per 5-mm length class for lengths greater than or equal to 40 mm (e.g. 40-44 mm, 45-49 mm). Fresh-dead individuals (those still having flesh attached to the nacre) were initially targeted to reduce the number of live individuals collected. Live mussels were collected to fill remaining length classes. Flesh was removed from live individuals, and valves were marked with a unique identifier. Valves were taken to the lab for further processing.

Valves were measured to the nearest 0.01 mm by using digital calipers for length (greatest distance between anterior and posterior valve margins), height (greatest distance between the umbo and ventral valve margin), width (greatest lateral dimension), and ligament length. Mussel valves were sectioned with a Buehler® Isomet™ (Lake Bluff, IL) low-speed saw. Right valves were arbitrarily chosen for sectioning. Initial cuts were made along a plane that passed through the umbo and a depression in the pseudocardinal tooth (Figure 2). To ensure uniformity among cuts, an adjustable cutting jig was fabricated from a Meccano™ Maker System (Spinmaster Inc., Los Angeles, CA) (Figure 3). Hot-melt adhesive was used to temporarily adhere the valve to the cutting jig for the initial cut (Figure 3).

Upon completion of the initial cut, the cut surface on the anterior portion of the valve was polished with 400, 800, 1000, and 1500 grit wet/dry sand paper. The polished surface was adhered to a standard microscope slide with Loctite® Super Glue Liquid (Henkel Corp., USA). In some instances, the cut surface was too large for standard microscope slides, and pane glass was used as slides for these large specimens. Secondary cuts produced mussel thin-sections of 300-400 µm thickness. The cut surface was polished as described previously.

An Olympus SC100 camera mounted on an Olympus SZX16 stereomicroscope at 0.7× magnification was used to capture images of thin sections. A simple, illuminated, movable stage was fabricated by using plywood and polycarbonate sheeting. Images of each thin section were taken systematically at 5-mm intervals. A composite image of each thin section was produced by using the Stitching plugin (Preibisch, Saalfeld, and Tomancak 2009) in ImageJ (Figure 4).

Age estimation

Internal annuli were identified by viewing the composite images produced in ImageJ and viewing thin sections by using a stereomicroscope and transmitted light. Annuli were distinguished from disturbance rings by using the qualitative characteristics described by Haag and Commens-Carson (2008). The ObjectJ plugin in ImageJ was used to record age and measure annual growth increments for each thin section. Thin sections were aged in random order without knowledge of overall size. Age estimates were made by the same reader on 2 separate occasions, and were retained for analysis if the age estimates agreed (Singer and Gangloff 2011). If the age estimates differed, the thin section was aged a third time. The third estimate was retained for analysis if it agreed with either the first or second estimate. If the third estimate did not agree with the first or second estimate, the thin section was not included in analysis.

Data analysis

To be consistent with typical fisheries analysis, 01 January was considered the "date of birth" for mussels collected during this study. Because specimen collection occurred relatively late in the year (October), near the end of the growing season, a proportion of a year (i.e., 0.75 years) was added to the integer age of the mussel to increase accuracy during growth analysis.

The Beverton-Holt, or "typical", parameterization of von Bertalanffy growth function (Equation 1) (von Bertalanffy 1938; Beverton and Holt 1957) was used to compare individual growth between and among *Q. pustulosa* populations in the Neosho River.

$$E[L|t] = L_{\infty}\left(1 - e^{-K(t-t_0)}\right) \qquad \text{Equation 1.}$$

For the von Bertalanffy growth function, $E[L|t]$ is the mean length-at-age at time t, and L_{∞}, K, and t_0 are parameters that must be estimated for each population. The parameter L_{∞} is the mean maximum length of the population. The parameter K describes the rate at which the function approaches L_{∞}. The units for K are inverse time (e.g., year^{-1}), and, therefore, K is not a true growth rate. For growth rate, the unit is the change of some measured increment over a unit of time [e.g., $\text{mm}(\text{year}^{-1})$] (Ricker 1975; Ogle 2016). The parameter t_0 is the x-intercept for the function and represents the theoretical time at which $L = 0$. The parameter is necessary for model fitting, but has little to no biological significance.

Starting values for von Bertalanffy growth functions were obtained by using a second-degree polynomial fit to mean length-at-age data in the R package FSA (Ogle 2017). Model parameters were estimated by using a nonlinear least squares regression in the R package nlstools (Baty and Delignette-Muller 2015). Assumptions of homoscedasticity and residual normality were assessed by using residual plots and histograms.

Parameters of von Bertalanffy growth functions were compared by using likelihood ratio tests in the R package fishmethods (Nelson 2017), following the methods described by Kimura (1980). Parameters of von Bertalanffy growth functions were compared between upstream and downstream samples at each sampled dam (e.g., Iola upstream [IU], Iola downstream [ID], etc.). To compare differences between samples along a stream discharge gradient, a third von Bertalanffy growth function was produced for each dam by combining the upstream and downstream sample at each dam (e.g., Iola(I) = IU&ID), and compared pairwise among the 3 dams (i.e., I,P,O) by using likelihood ratio tests.

RESULTS

Agreement of age estimates

During October 2015, 215 Pimpleback were collected from the Neosho River. Six individuals were removed from the sample after sectioning due to poor quality or extensive erosion near the umbo. After estimating the age of 209 individuals, 37 individuals were removed from the sample due to disagreement in age estimates, and 172 individuals were retained for growth analysis (Table 2). Age estimates agreed for 69 individuals, or 33.0% of the sample (n=209) between the first 2 readings. Agreement with a difference of one year occurred for 39.2% of the sample, and agreement with a difference 2 years for 14.4% of the sample (Table 3). After a third reading of 140 individuals for which initial age estimates differed, age estimates agreed with either the first or second estimate for 103 individuals, or 73.6%. Agreement within one year occurred for 18.6% of the sample, and agreement within 2 years for 3.3% of the sample (Table 3).

Likelihood ratio comparisons of parameters for upstream and downstream samples

The von Bertalanffy growth function parameters fit to each sample are included in Tables 4 and 5. Comparison of Iola upstream (IU) and downstream (ID) samples suggested parameters differed significantly (X^2=22.9, df=3, p<0.001) between the samples (Table 6, Figure 5). Subsequent tests suggested L_∞ (X^2=4.58, df=1, p=0.032) was the only parameter to significantly differ between IU and IP (Table 6). Comparison of Parsons upstream (PU) and Parsons downstream (PD) samples suggested no parameters differed significantly between the samples (X^2=2.27, df=3, p=0.518)

(Table 7, Figure 6). Comparison of Oswego upstream (OU) and downstream (OD) samples suggested parameters differed significantly (X^2=26.7, df=3, p<0.001) between the samples (Table 8, Figure 10); however, subsequent tests did not detect a significant difference in any parameter (Table 8).

Likelihood ratio comparisons of parameters for sites along a stream discharge gradient

Comparison of Iola (I) and Parsons (P) samples suggested no parameters differed significantly between the samples (X^2=33.88, df=3, p<0.001) (Table 9, Figure 11). Comparison of Iola and Oswego (O) samples suggested parameters differed between samples (X^2=26.7, df=3, p<0.001) (Table 10, Figure 11). Subsequent tests suggested L_∞ was the only parameter to significantly differ between the samples (X^2=10.9, df=1, p=0.003) (Table 10). Similarly, comparison of Parsons and Oswego samples suggested parameters differed between samples (X^2=22.12, df=3, p<0.001) (Table 11). Subsequent tests suggested L_∞ was the only parameter to significantly differ between the samples (X^2=9.05, df=1, p=0.003) (Table 11).

DISCUSSION

Agreement of age estimates

Agreement of age estimates for Pimpleback, 33% between the first and second readings, was similar to the 35% agreement between the independent readers in Wolf (2006) for the same species; however, agreement for these studies was rather low compared to that achieved by trained and experienced readers, with agreement between independent readers exceeding 90% (Haag and Commens-Carson 2008). A large percentage of age estimates differed by 1 to 2 years, which might suggest differences in placement of the first, last, or first and last annuli.

For unknown reasons, and despite the use of similar equipment and methods, the Pimpleback thin sections produced during this study were cloudy and annuli were less distinct than those produced by Wolf (2005). The quality of thin section also seemed to vary among sites. Haag and Commens-Carson (2008) reported the production of double-annuli in Pimpleback, and proposed these marks could develop during “cold-snaps” near the start or end of a growing season. This is a potential source of error in the age estimates made in this study. If the sections produced during this study were aged by experienced individuals, it is plausible that more individuals would be retained for analysis and clearer results might be observed.

Likelihood ratio comparisons of parameters for upstream and downstream samples

Likelihood ratio tests did not detect a significant difference in the growth coefficient K between upstream and downstream samples at any of the 3 dams used for this study. Therefore, my hypothesis that K differs between Pimpleback populations upstream and downstream of lowhead dams was not supported.

Tests should be conducted to determine if differences in physiochemical variables exist upstream and downstream of the lowhead dams at Iola, Parsons, and Oswego. Tiemann et al. (2004) reported no difference in the physiochemical variables upstream and downstream of a lowhead dam in the Neosho River upstream from John Redmond Reservoir, and this potentially was true for the dams sampled downstream from the reservoir during this study.

Likelihood ratio tests suggested a difference in L_∞ between Iola upstream and downstream samples (Table 6, Figure 8). Length-frequencies between Iola upstream and downstream were similar, though no individuals greater than 90 mm were collected downstream, and 2 individuals greater than 90 mm were collected upstream (Figures 5, 8). Sampling effort between sites was not standardized and was restricted to relatively shallow areas. It is likely the difference detected is an effect of sampling bias and the rarity of large, or old, individuals in the population. Standardized sampling of the Iola upstream and downstream populations could be used to examine the difference in L_∞ detected during this study.

Likelihood ratio tests suggested a significant difference in parameters between Oswego upstream and downstream samples, but subsequent tests did not specify which parameter differed (Table 8). The difference could be caused by the absence of individuals less than 30 mm long in the Oswego downstream sample relative to the upstream sample (Figures 7, 10).

Likelihood ratio comparisons of parameters for sites along a stream discharge gradient

Likelihood ratio tests did not detect a significant difference in the growth coefficient K among Iola, Parsons, and Oswego. Therefore, my hypothesis that K differs among Pimpleback populations along a discharge gradient was not supported.

Likelihood ratio tests detected a significant difference among L_∞, for which Oswego differed significantly from Iola and Parsons. At Oswego, no individuals greater than 70 mm in length were collected, and the sample had smaller individuals ($\bar{x}$=51.6, n=72) relative to the samples at Iola ($\bar{x}$=66.3, n=54) (Figures 5, 11) and Parsons ($\bar{x}$=63.7, n=46) (Figures 6, 11). This could indicate a disturbance within the last decade or a change in habitat or water quality downstream of Parsons. Again, the simplest explanation for the observed difference is rarity of large individuals and potential sampling bias. Standardized sampling of mussels and assessment of habitat and water quality could be used to investigate the difference in L_∞ detected among sites during this study.

Other considerations

Despite the benefits of increased habitat connectivity and the restoration of flow regimes similar to historical conditions, the removal of lowhead dams is often controversial (Stanley and Doyle 1993; Schuman 1995; Bednarek 2001; Grant 2001). Negative effects associated with dam removal include increased sediment transport from impounded areas, which often contain contaminants (Pejchar and Warner 2001; Hart et al. 2002; Ashley et al. 2006), and dispersal of invasive species (Rahel and Olden 2008). Accordingly, considerations of lowhead dam removal in the Neosho River should be addressed on a case-by-case basis, and all aquatic taxa should be considered as they might be influenced differently by dam removal.

Gangloff et al. (2011) reported elevated historical mussel extirpation in streams with bypassed lowhead dams relative to streams with only intact lowhead dams. The anecdotal observation of reduced Pimpleback densities upstream from the Parsons dam might warrant further investigation. Because this area is downstream from the bypassed dam (Figure 1), a comparison of historical data, if available, to the current mussel community could provide insight about the effects of dam removal on freshwater mussels in the Neosho River.

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Table 1. Locality information for *Quadrula pustulosa* sample sites in the Neosho River, Kansas.

Site	Latitude	Longitude	Distance from lowhead dam (km)	Sample Date
IU	37.96983	-95.4847	11.50	10/18/2015
ID	37.91143	-95.4274	2.66	10/02/2015
PU	37.50036	-95.1578	33.31	10/17/2015
PD	37.30776	-95.1094	0.28	10/03/2015
OU	37.23538	-95.0929	11.00	10/03/2015
OD	37.17714	-95.0995	0.33	10/03/2015

Table 2. Summary of *Quadrula pustulosa* samples collected from the Neosho River, Kansas.

Site	Individuals			Length (mm)				Age (years)			
	Collected	Aged	Retained	min	max	mean	stdev	min	max	mean	stdev
IU	30	30	30	27.9	93.5	68.2	18.6	2	24	12.1	7.0
ID	36	35	24	21.5	85.3	64.8	15.8	2	29	13.7	7.6
PU	30	28	22	28.4	90.4	66.8	15.2	2	34	14.3	8.5
PD	37	36	24	22.1	91.6	61.0	18.0	1	34	12.5	9.6
OU	43	42	36	14.1	71.0	49.5	14.9	1	23	8.0	5.1
OD	39	38	36	34.0	74.6	53.7	10.8	3	29	7.3	4.9
I	66	65	54	21.5	93.5	66.3	17.0	2	29	13.0	7.3
P	67	64	46	22.1	91.6	63.7	16.8	1	34	13.3	9.1
O	82	80	72	14.1	74.6	51.6	13.1	1	29	7.6	5.0
Overall	215	209	172	14.1	93.5	59.5	16.7	1	34	10.8	7.5

Table 3. Percent agreement for age estimates of *Quadrula pustulosa* collected from the Neosho River, Kansas.

Age Difference (absolute)	Agreement (%) Between Aging Attempts 1&2 (n=209)	Agreement (%) Aging Attempt 3 relative to Attempts 1&2 (n=140)
0	33.0	73.6
1	39.2	18.6
2	14.4	3.6
3	5.7	1.4
4	3.3	0.7
5	2.4	0.0

Table 4. Fitted von Bertalanffy growth function parameters for *Quadrula pustulosa* collected upstream and downstream from lowhead dams in the Neosho River near Iola, Parsons, and Oswego, Kansas.

Site	$L\infty$	K	$t0$
IU	86.26*	0.171	0.30
ID	78.91*	0.175	0.78
PU	77.95	0.196	0.16
PD	83.11	0.117	-1.92
OU	70.22	0.176	0.03
OD	74.46	0.153	-1.53

Table 5. Fitted von Bertalanffy growth function parameters of combined upstream and downstream *Quadrula pustulosa* samples from the Neosho River near Iola, Parsons, and Oswego Kansas.

Site	$L\infty$	K	$t0$
I	81.89	0.172	0.45
P	80.11	0.151	-0.87
O	68.95	0.211	0.07

Table 6. Results of likelihood ratio tests comparing von Bertalanffy growth curve parameters between Iola upstream (IU) and Iola downstream (ID) sites for *Quadrula pustulosa* collected from the Neosho River, Kansas.

Hypothesis	X^2	df	p-value
$L\infty_{[IU]} = L\infty_{[ID]}$, $K_{[IU]} = K_{[ID]}$, $t0_{[IU]} = t0_{[ID]}$	22.90	3	0.000
$L\infty_{[IU]} = L\infty_{[ID]}$	4.58	1	0.032
$K_{[IU]} = K_{[ID]}$	0.01	1	0.920
$t0_{[IU]} = t0_{[ID]}$	0.35	1	0.554

Table 7. Results of likelihood ratio tests comparing von Bertalanffy growth curve parameters between Parsons upstream (PU) and Parsons downstream (PD) sites for *Quadrula pustulosa* collected from the Neosho River, Kansas.

Hypothesis	X^2	df	p-value
$L\infty_{[PU]} = L\infty_{[PD]}$, $K_{[PU]} = K_{[PD]}$, $t0_{[PU]} = t0_{[PD]}$	2.27	3	0.518
$L\infty_{[PU]} = L\infty_{[PD]}$	1.30	1	0.254
$K_{[PU]} = K_{[PD]}$	2.20	1	0.138
$t0_{[PU]} = t0_{[PD]}$	1.94	1	0.164

Table 8. Results of likelihood ratio tests comparing von Bertalanffy growth curve parameters between Oswego upstream (OU) and Oswego downstream (OD) sites for *Quadrula pustulosa* collected from the Neosho River, Kansas.

Hypothesis	X^2	df	p-value
$L\infty_{[OU]} = L\infty_{[OD]}$, $K_{[OU]} = K_{[OD]}$, $t0_{[OU]} = t0_{[OD]}$	26.70	3	0.000
$L\infty_{[OU]} = L\infty_{[OD]}$	0.66	1	0.417
$K_{[OU]} = K_{[OD]}$	0.19	1	0.663
$t0_{[OU]} = t0_{[OD]}$	1.65	1	0.199

Table 9. Results of likelihood ratio tests comparing von Bertalanffy growth curve parameters between Iola (I) and Parsons (P) sites for *Quadrula pustulosa* collected from the Neosho River, Kansas.

Hypothesis	X^2	df	p-value
$L\infty_{[I]} = L\infty_{[P]}$, $K_{[I]} = K_{[P]}$, $t0_{[I]} = t0_{[P]}$	6.73	3	0.081
$L\infty_{[I]} = L\infty_{[P]}$	0.33	1	0.566
$K_{[I]} = K_{[P]}$	0.36	1	0.549
$t0_{[I]} = t0_{[P]}$	2.44	1	0.118

Table 10. Results of likelihood ratio tests comparing von Bertalanffy growth curve parameters between Iola (I) and Oswego (O) sites for *Quadrula pustulosa* collected from the Neosho River, Kansas.

Hypothesis	X^2	df	p-value
$L\infty_{[I]} = L\infty_{[O]}$, $K_{[I]} = K_{[O]}$, $t0_{[I]} = t0_{[O]}$	33.39	3	0.000
$L\infty_{[I]} = L\infty_{[O]}$	10.88	1	0.001
$K_{[I]} = K_{[O]}$	0.91	1	0.340
$t0_{[I]} = t0_{[O]}$	0.33	1	0.566

Table 11. Results of likelihood ratio tests comparing von Bertalanffy growth curve parameters between Parsons (P) and Oswego (O) sites for *Quadrula pustulosa* collected from the Neosho River, Kansas.

Hypothesis	X^2	df	p-value
$L\infty_{[P]} = L\infty_{[O]}$, $K_{[P]} = K_{[O]}$, $t0_{[P]} = t0_{[O]}$	22.12	3	0.000
$L\infty_{[P]} = L\infty_{[O]}$	9.05	1	0.003
$K_{[P]} = K_{[O]}$	2.12	1	0.145
$t0_{[P]} = t0_{[O]}$	1.44	1	0.230

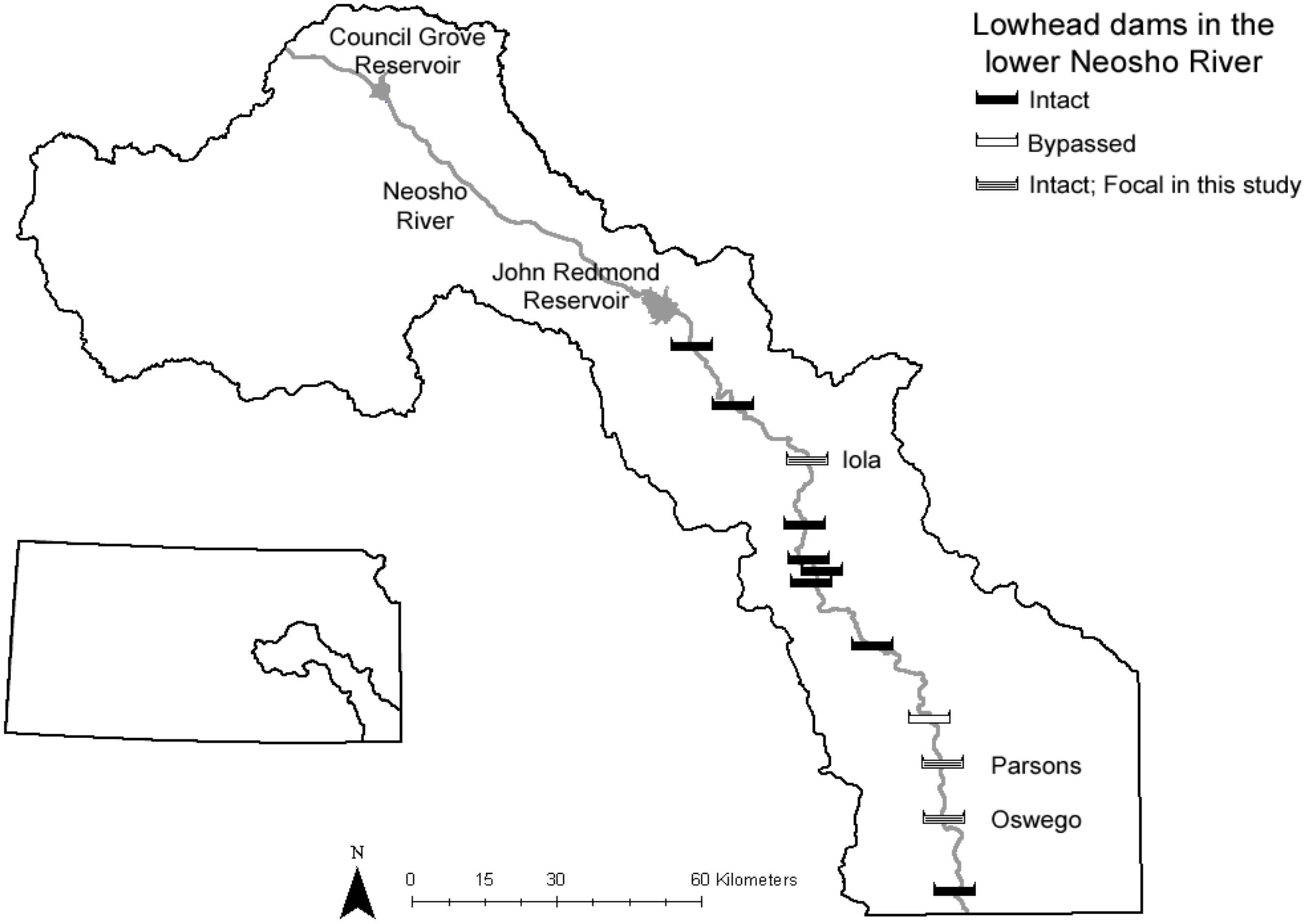

Figure 1. Map of the Neosho River Basin and lowhead dams in the lower Neosho River in Kansas. *Quadrula pustulosa* used in this study were collected upstream and downstream of the lowhead dams at Iola, Parsons, and Oswego.

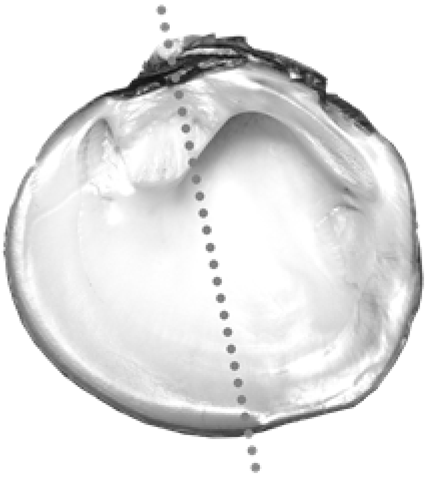

Figure 2. Depiction of plane through which initial thin cuts were made.

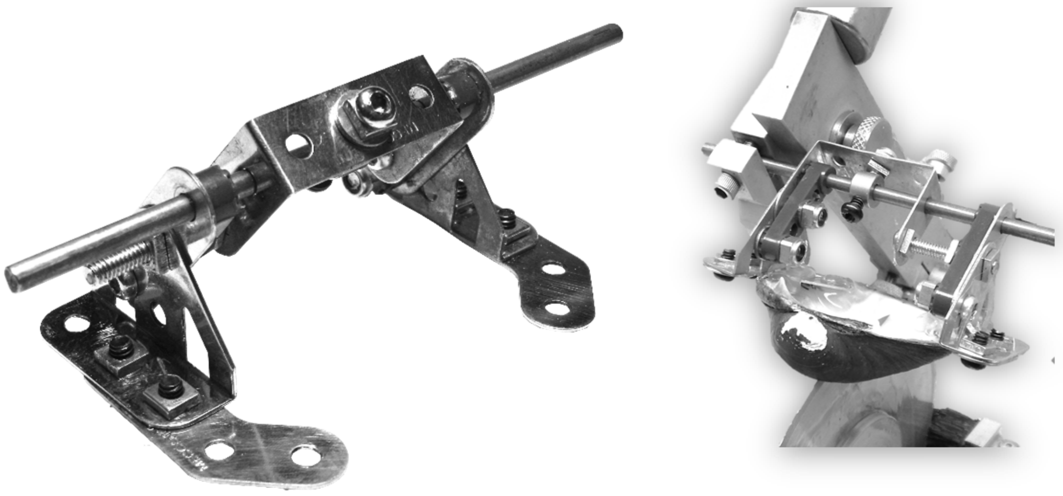

Figure 3. Image of jig used during initial cuts for mussel valves.

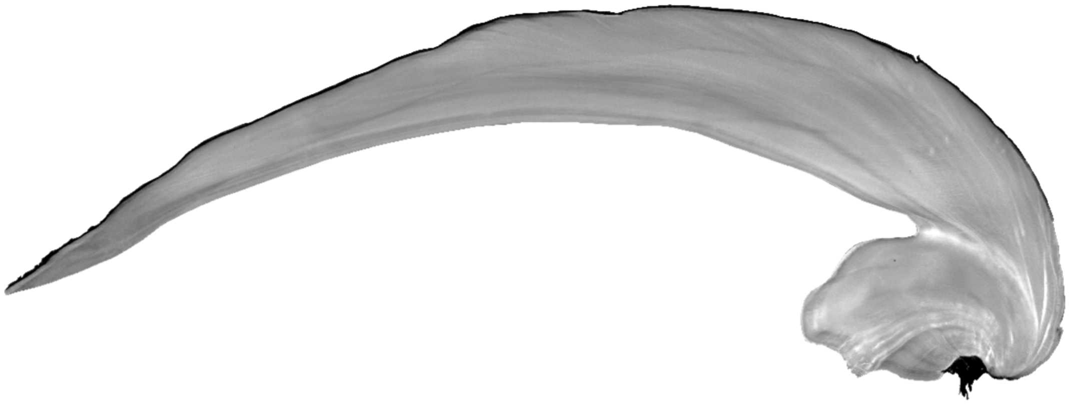

Figure 4. Image of *Quadrula pustulosa* thin section.

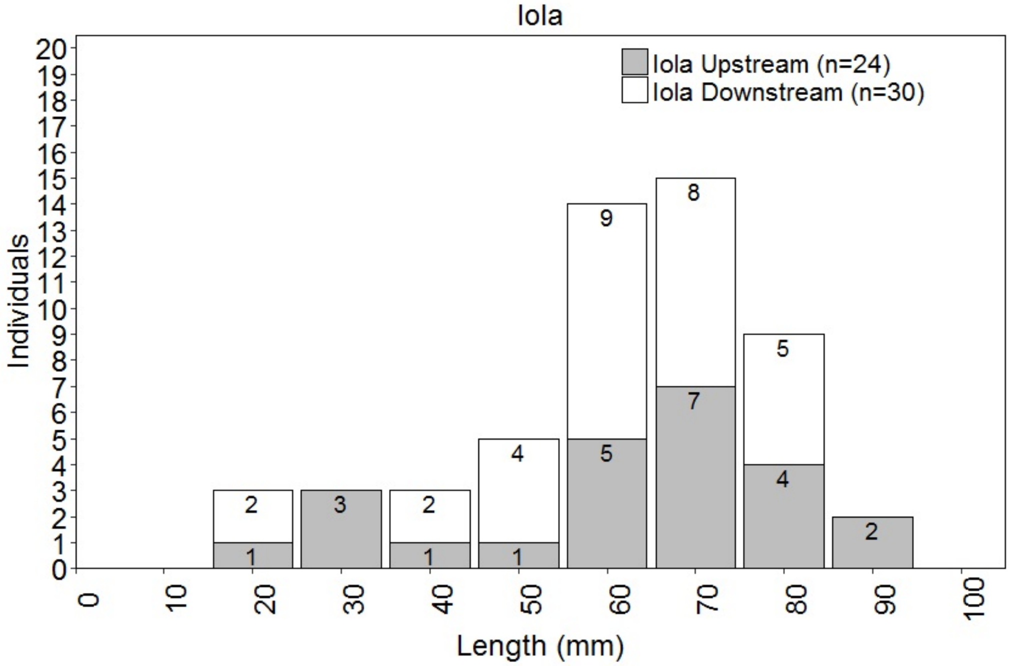

Figure 5. Length-frequency distribution of *Quadrula pustulosa* collected from the Neosho River upstream and downstream from the lowhead dam near Iola, Kansas.

Figure 6. Length-frequency distribution of *Quadrula pustulosa* collected from the Neosho River upstream and downstream from the lowhead dam near Parsons, Kansas.

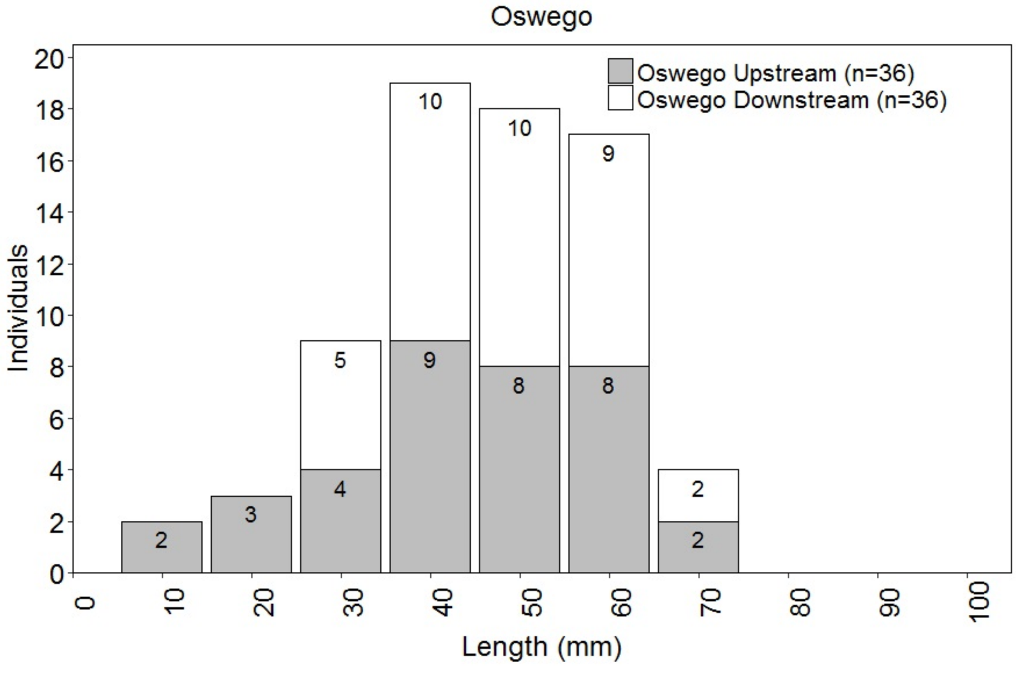

Figure 7. Length-frequency distribution of *Quadrula pustulosa* collected from the Neosho River upstream and downstream from the lowhead dam near Oswego, Kansas.

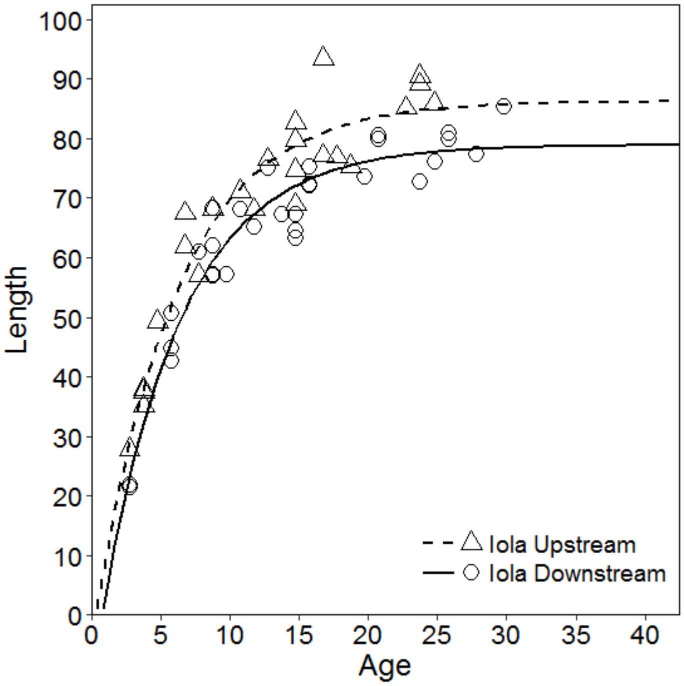

Figure 8. Length-at-age plot and fitted von Bertalanffy growth curves for *Quadrula pustulosa* collected in the Neosho River upstream and downstream from the lowhead dam near Iola, Kansas.

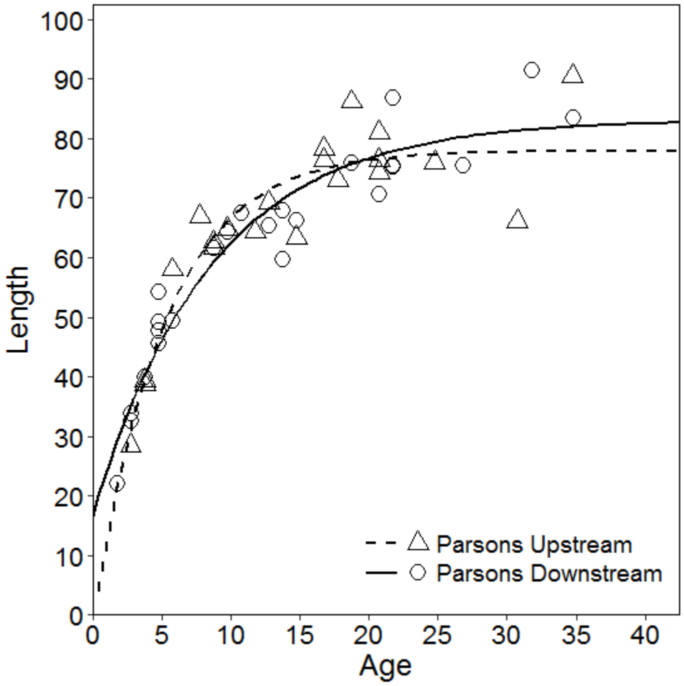

Figure 9. Length-at-age plot and fitted von Bertalanffy growth curves for *Quadrula pustulosa* collected in the Neosho River upstream and downstream from the lowhead dam near Parsons, Kansas.

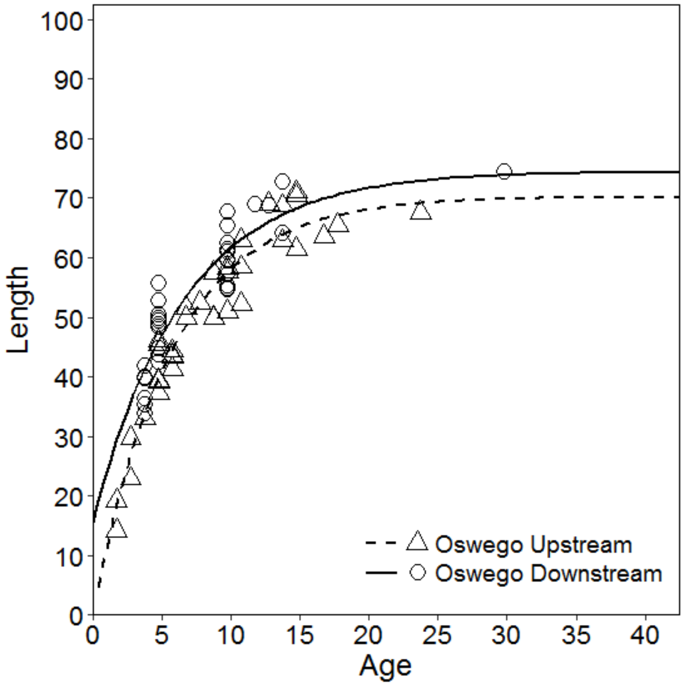

Figure 10. Length-at-age plot and fitted von Bertalanffy growth curves for *Quadrula pustulosa* collected in the Neosho River upstream and downstream from the lowhead dam near Oswego, Kansas.

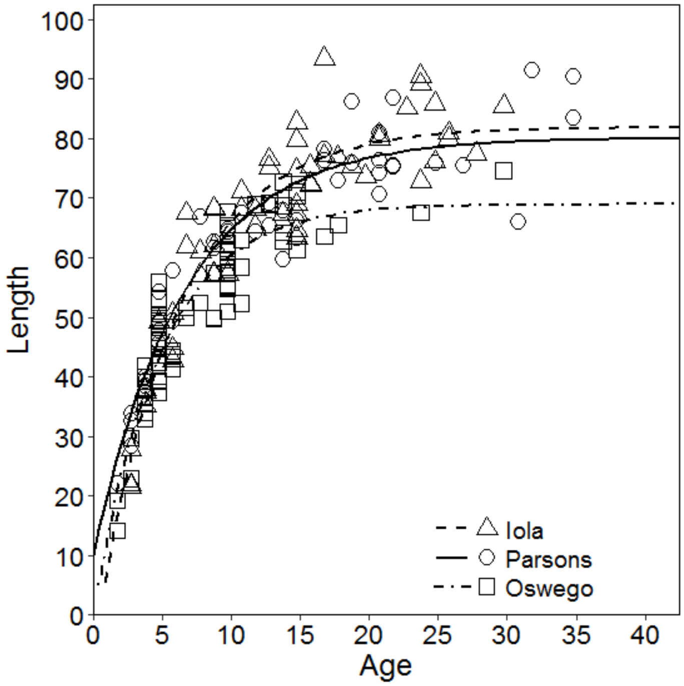

Figure 11. Length-at-age plot and fitted von Bertalanffy growth curves for *Quadrula pustulosa* collected in the Neosho River near Iola, Parsons, and Oswego Kansas.