Office of Conservation Investment

U.S. Fish and Wildlife Service

OK T-124-R-1 Quantifying freshwater mussel abundance and composition in two prairie rivers of northern Oklahoma with the aid of side-scan sonar to identify novel habitat patches

Performance Report Approval Status:

Awaiting Federal Approval

Recipient:

OKLAHOMA DEPARTMENT OF WILDLIFE

Recipient Grant ID:

Federal Award Number:

F22AF01090

Funding Program(s) Name:

SWG Implementation

Federal Award Start and End Date:

Jan 01, 2023 to Jun 30, 2025

Performance Reporting Period:

Jan 01, 2025 to Jun 30, 2025

Federal Award Recipient Contact(s):

Andrea Crews

Federal Award Specialist(s):

Joshua Cocke

TRACS Group

Oklahoma Department of Wildlife Conservation

Type of Performance Report:

Final Performance Report

Public Description:

Prairie rivers of northern Oklahoma such as the Verdigris and Caney rivers harbor a diverse assemblage of freshwater mussels, but drivers of their abundance and composition are not well known. Previous research focused on proportional abundance using timed searches,

which impedes inferences about temporal trends. Moreover, recent studies in Kansas have documented increases in rare species, such as Cyprogenia aberti, suggesting some species may be more prevalent than previously documented or locally abundant in certain locations. Side-scan sonar has since become a tool increasingly used in freshwater rivers to document mussel beds directly and submerged habitat generally. Specifically, side-scan sonar was more effective than traditional tools for identifying freshwater mussel habitat, but the approach has not been applied in prairies systems. This project will identify freshwater mussel habitat within the Verdigris and Caney rivers of northern Oklahoma and use quantitative sampling in identified mesohabitats to estimate density and community composition. Calculation of detection and occupancy estimates among mesohabitat types will aid development of future monitoring efforts.

Federal Award Accomplishments				
Strategy	**Proposed Objective**	**Activity**	**Unit of Measure - Proposed**	**Unit of Measure - Reported**
Research, Survey, Data Collection and Analysis	Conduct investigations (legacy)	Fish and wildlife species data acquisition and analysis (legacy)	1 Investigations	1 Investigations

Table of Contents - Project Statements

Project Statement: OK T-124-R-1 Quantifying freshwater mussel abundance and composition in two prairie rivers of northern Oklahoma with the aid of side-scan sonar to identify novel habitat patches
Project Statement Approval Status: Final Approved

Objective Name: Objective 1: Estimate density and community structure of freshwater mussels in representative reaches of the Caney and Verdigris rivers according to mesohabitats identified with the aid of side-scan sonar, by June 30, 2025.

Strategy: Research, Survey, Data Collection and Analysis
Proposed Objective: Conduct investigations (legacy)
Pertains to R3: No

Activity Performed: Fish and wildlife species data acquisition and analysis (legacy)
# of Investigations: 1
Principal Investigator:
Geographic Location:

- General Location: Oklahoma
- Includes Marine Federal Waters: No
- Detailed Location:
  - Nowata County
  - Osage County
  - Rogers County
  - Tulsa County
  - Washington County
- Location Description:

  Caney River and Verdigris River, OK (Appendix II).

Activity Report Comments

* Totals to date represents a cumulative total of all periods of performance and may exceed the objective.

Objective Report	
Period of Performance	**# of Investigations**
Jan 1, 2023 to Dec 31, 2023	
Jan 1, 2024 to Dec 31, 2024	
Jan 1, 2025 to Jun 30, 2025	1
Totals to Date*	1

Species Tags

Species Tags		
threeridge; three-ridge *Amblema plicata*	**western fanshell** *Cyprogenia aberti*	**Wabash pigtoe** *Fusconaia flava*
plain pocketbook *Lampsilis cardium*	**yellow sandshell** *Lampsilis teres*	**white heelsplitter** *Lasmigona complanata*
fragile papershell *Leptodea fragilis*	**washboard** *Megalonaias nervosa*	**three-horn wartyback; threehorn wartyback** *Obliquaria reflexa*
round pigtoe *Pleurobema coccineum*	**bleufer** *Potamilus purpuratus*	**rabbitsfoot** *Quadrula cylindrica*
monkeyface *Quadrula metanevra*	**wartyback** *Quadrula nodulata*	**pimpleback** *Quadrula pustulosa*
pistolgrip *Tritogonia verrucosa*	**fawnsfoot** *Truncilla donaciformis*	

Activity Performed Attachments

Note: Some attachments listed here may not appear in the Appendix due to file incompatibility. All attachments can be accessed using the links below.

Descriptive Name	Field Tags	Attachment Type
No Files Attached		

Performance Reporting Questionnaire

1. What progress has been made towards completing the objective(s) of the project?

We conducted surveys for freshwater mussels (dead shells, qualitative [snorkeling], and quantitative [quadrat]) at each of 10 reaches on the Verdigris River and 16 reaches on the Caney River during the summers of 2023 and 2024 to compare estimates of mussel richness and abundance across different survey methods. Shell surveys on the Verdigris and Caney rivers consistently captured fewer species at the reach level compared to snorkel and quadrat surveys but accurately captured the live community at the whole river level. Snorkeling for live mussels is faster, allowing for more surveys across the river, but imprecise with regards to detailed information on mussel location and habitat. Quadrat surveys, on the other hand, are intensive, requiring one to dig and sift through sediment, but produce precise data on mussel location, size distribution, and density. From resampling methods, we found that excavating ~10 quadrats would achieve the same estimates of richness and relative abundance as the reach-level snorkel surveys, which would allow researchers and managers to achieve the speed afforded by snorkeling with the precision of using quadrats. From quantitative sampling data, we also compared mussel density and species richness among different mesohabitat types (upper recirculation zone, lower recirculation zone, pool, riffle, run, outerbend, pointbar, shoal). On the Verdigris River, upper recirculation zones, pools, and riffles contained the greatest densities and richness of freshwater mussels, whereas, on the Caney River, run mesohabitats harbored the highest mussel densities and richness. Differences in habitat associations with freshwater mussels between these two rivers may be the result of differing hydrological regimes.

2. Please describe and justify any changes in the implementation of your objective(s) or approach(es).

Through the development of the project, we determined that the use of side-scan sonar to detect and evaluate mussel beds in this system did not prove to be effective because the substrate composition was not adequate. Mussel communities were still identified and surveyed using other methods therefore this did not affect the overall outcome of the project.

3. If applicable, please share if the project resulted in any unexpected benefits, promising practices, new understandings, cost efficiencies, management recommendations, or lessons learned.

This project provided an updated comprehensive mussel community evaluation of these systems combined which helps our agency make management decisions. It also uncovered an unknown population of the federally listed rabbitsfoot mussel that was not previously known to exist at this particular location.

4. For Survey projects only: If applicable, does this project continue work from a previous

grant? If so, how do the current results compare to prior results? (Recipients may elect to add attachments such as tables, figures, or graphs to provide further detail when answering this question.)
Not Applicable

5. If applicable, identify and attach selected publications, photographs, screenshots of websites, or other documentation (including articles in popular literature, scientific literature, or other public information products) that have resulted from this project that highlight the accomplishments of the project.
Not Applicable

6. Is this a project you wish to highlight for communication purposes?
No

Questionnaire Attachments

Note: Some attachments listed here may not appear in the Appendix due to file incompatibility. All attachments can be accessed using the links below.

Descriptive Name	Field Tags	Attachment Type
T-124 OSU Verdigris & Caney Mussels Fina...	• Objective Completion Progress	Performance Report / Other

<u>Appendix</u>

FINAL PERFORMANCE REPORT

FEDERAL AID GRANT NO. F22AF01090 (T-124-R-1)

Quantifying Freshwater Mussel Abundance and Composition in Two Prairie Rivers of Northern Oklahoma with the Aid of Side Scan Sonar to Identify Novel Habitat Patches

Oklahoma Department of Wildlife Conservation

Report Period: January 1, 2023 – June 30, 2025

Grant Period: January 1, 2023 – June 30, 2025

Final Report

STATE: Oklahoma **GRANT NUMBER:** F22AF01090 (T-124-R-1)

GRANT PROGRAM: State Wildlife Grants

GRANT NAME: Quantifying freshwater mussel abundance and composition in two prairie rivers of northern Oklahoma with the aid of side scan sonar to identify novel habitat patches

GRANT PERIOD: January 1, 2023 – June 30, 2025

REPORT PERIOD: January 1, 2023 – June 30, 2025

PRINCIPAL INVESTIGATORS:

Hunter Torolski, MS, Graduate Research Assistant, Department of Natural Resource Ecology and Management, Oklahoma State University

James M. Long, PhD, Unit Leader-Fisheries and Adjunct Professor, U.S. Geological Survey, OK Cooperative Fish and Wildlife Research Unit, Oklahoma State University

Robert C. Lonsinger, PhD, Assistant Unit Leader-Wildlife and Adjunct Associate Professor, U.S. Geological Survey, OK Cooperative Fish and Wildlife Research Unit, Oklahoma State University

Lindsey A. Bruckerhoff, PhD, Assistant Professor, Aquatic Ecology Laboratory, Department of Evolution, Ecology, and Organismal Biology, Ohio State University

<u>Executive Summary</u>

We conducted surveys for freshwater mussels (dead shells, qualitative [snorkeling], and quantitative [quadrat]) at each of 10 reaches on the Verdigris River and 16 reaches on the Caney River during the summers of 2023 and 2024 to compare estimates of mussel richness and abundance across different survey methods. Shell surveys on the Verdigris and Caney rivers consistently captured fewer species at the reach level compared to snorkel and quadrat surveys but accurately captured the live community at the whole river level. Snorkeling for live mussels is faster, allowing for more surveys across the river, but imprecise with regards to detailed information on mussel location and habitat. Quadrat surveys, on the other hand, are intensive, requiring one to dig and sift through sediment, but produce precise data on mussel location, size distribution, and density. From resampling methods, we found that excavating ~10 quadrats would achieve the same estimates of richness and relative abundance as the reach-level snorkel surveys, which would allow researchers and managers to achieve the speed afforded by snorkeling with the precision of using quadrats. From quantitative sampling data, we also compared mussel density and species richness among different mesohabitat types (upper recirculation zone, lower recirculation zone, pool, riffle, run, outerbend, pointbar, shoal). On the Verdigris River, upper recirculation zones, pools, and riffles contained the greatest densities and

richness of freshwater mussels, whereas, on the Caney River, run mesohabitats harbored the highest mussel densities and richness. Differences in habitat associations with freshwater mussels between these two rivers may be the result of differing hydrological regimes.

I. OBJECTIVES

Objective 1: Estimate density and community structure of freshwater mussels in representative reaches of the Caney and Verdigris rivers according to mesohabitats identified with the aid of side-scan sonar

SUMMARY OF PROGRESS:

A. METHODS

<u>Study Area</u>

This study focuses on the Verdigris and Caney rivers (Figure 1), located in the prairie region of northeastern Oklahoma. Prairie rivers in the southern Great Plains are flashy and dynamic, characterized by strong floods and seasonal drying (Dodds et al. 2004). Rivers in this region of the Great Plains do not draw significant water from snowpack melt and flows depend primarily on seasonal precipitation (Kloesel et al. 2018). Land use in the area is dominated by agriculture, pasture, and rangeland (U.S. Geological Survey 2024). However, the headwaters of the Verdigris and Caney rivers in the Flint Hills of Kansas consists primarily of native grassland (Edds 2012).

The Caney River is a tributary to the Verdigris River, flowing 290 km before emptying into the Verdigris River south of Lake Oologah (USGS 1981a). The Verdigris River is contained within the Arkansas River watershed, flowing 499 km before meeting the Arkansas River around Muskogee, Oklahoma (USGS 1981b). The flood regimes and flow patterns of these rivers have been significantly altered by channelization, urbanization, and the construction of reservoirs, affecting unionid mussel populations (ODWC 2016, Mather 2005).

<u>Field Methods</u>

We conducted three distinct surveys (i.e., dead shell, qualitative [snorkeling], and quantitative [quadrat]), at each of 10 reaches in the Verdigris River and at each of 16 reaches in the Caney River (Figure 1 and 2) from June–August 2023 and May–August 2024 to document mussel species occurrence and community composition. Reach selection was based on the most recent mussel survey of the area conducted by Boeckman et al. (2010) to allow comparison with past results. Priority was given to reaches with high species richness, high abundance, and past presence of rare species (e.g., Western Fanshell *Cyprogenia aberti*). Several additional sites not previously surveyed by Boeckman et al. (2010) were selected based on aerial imagery depicting the presence of gravel bars.

At every reach, we first conducted a shell survey within 1 m of the shore with four, 100-m transects (Figure 2) to determine the potential for species occurrences in the reach. These

transects were placed near the river's edge because preliminary surveys indicated this location as the most likely for freshly dead individuals to occur. Transects were placed randomly on both sides of the river unless logistical conditions warranted otherwise (e.g., bank too steep to walk). Only shells that appeared recently dead (e.g., intact periostracum, lustrous nacre (Williams 2022), presence of soft tissue (Rasmussen et al. 2021), or the connection of both valves) were enumerated. Then, a qualitative, 60-minute timed snorkel survey was performed throughout the reach (Figure 2) to rapidly determine species occurrence and relative abundance. Two snorkelers searched the river bottom for the entire 60 minutes, while another researcher identified mussels to the species level and measured for shell length along the longest axis. Quantitative surveys were subsequently conducted by excavating 25, 1-m^2 quadrats to a depth of 10 cm (Heidi 2000; Figure 2). Quadrat locations were randomly generated using ArcGIS Pro and subsequently uploaded to a Garmin GPS unit. Each quadrat was excavated for 20 minutes, as substrate conditions did not always permit excavation to a depth of 10 cm. All mussels found within the quadrats were measured, identified, photographed, and returned alive to the sample location. Mussels were placed back into the substrate with the anterior end facing down (USFWS 2020). During quantitative sampling, microhabitat variables such as depth, flow, and primary substrate were collected at each quadrat. If a randomized quadrat was located above the water line, we moved to the closest randomized quadrat within the river or recorded a new GPS point. Mussel surveys were conducted during river discharges below 2.8 cubic meters per second (m^3/s).

Survey methods (i.e., shell, snorkel, and quadrat) were compared using Jaccard and Bray-Curtis Similarity indexes, abundance histograms, and species accumulation curves. The Jaccard Similarity Index (Fletcher and Islam 2018) uses species presence data and ranges from 0–1, where a similarity of 0 indicates the two datasets have no common elements (completely dissimilarity) while a similarity of 1 indicates the two sets are identical (complete similarity). The Bray-Curtis Similarity index (Baselga 2013) incorporates abundance of each species and ranges from 0–1, with higher values indicating greater similarity.

Quadrat sampling required greater effort than snorkel surveys (e.g., 16 hours total for snorkeling compared to 133 hours for quadrats on the Caney River). Therefore, we employed data rarefaction while computing Jaccard and Bray-Curtis Similarity values between snorkeling and quadrat surveys. Rarefaction uses resampling of the species-abundance data to provide an estimate of mean similarity that would have occurred at lower sample sizes (Colwell et al. 2012). For every reach, we resampled 100 replicates, randomly selecting 3 quadrats from the 25 total number of quadrats per reach. This approach, where excavating 3 quadrats equaled the effort of snorkel surveys at each site, allowed us to compare the two methods at the same level of effort. We then repeated this process to determine Jaccard and Bray-Curtis similarity indexes across the entire Caney River. We again employed a method involving 100 replicates, however, at the scale of the Caney River, we randomly selected 48 quadrats from the 400 total number of quadrats. This approach, excavating 48 quadrats on the Caney, equaled snorkel survey across all sites and enabled us to compare the two methods for species richness and mussel abundance at the same effort level.

We also resampled the quadrat data to determine the number of quadrats required to match the species richness and abundance observed during snorkel surveys. By doing so, we sought to achieve higher quality data from quadrats (e.g., density, population trends) with the

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benefit of reduced time that comes with snorkeling. To determine the mean number of quadrats required to match the species richness of snorkel surveys across the entire river, we generated species accumulation curves by randomly selecting iteratively from 1 quadrat to 400 quadrats and computing the mean (± 1 SD). Means and standard deviations of the number of species were then plotted and referenced against the species richness obtained via snorkeling. To evaluate the number of quadrats needed to match the abundance of snorkel surveys across the entire river, we again repeatedly sampled from up to 400 quadrats on the Caney and 250 on the Verdigris River using 100 randomized permutations. Quadrats were sampled until the cumulative abundance equaled that of the snorkel data. Abundance histograms were then generated to display the mean and distribution of quadrat counts across all permutations. On the reach scale, we generated species accumulation curves and abundance histograms by randomly selecting repeatedly from 1 quadrat to 25.

To compare the average shell length of mussels found via snorkeling versus quadrat sampling, we conducted two-sample t-tests for each species with $n > 30$ for at least one survey method. Since the sample size of each species varied depending on survey method, we applied the Welch correction, which is designed to provide a valid t-test in the presence of unequal population variances (Shingala and Rajyaguru 2015). The Welch correction adjusts the degrees of freedom to accurately assess the significance of the t-statistic, which is calculated in the standard way (Shingala and Rajvaguru 2015).

We recorded side-scan sonar (Humminbird MEGA SI side-scan sonar unit) imagery on June 8 and August 17 2023 at five reaches of the Verdigris River where mussel surveys were conducted (Figure 3). Side-scan imagery was captured using canoe and kayak during river discharges ranging from 3.2 to 19.5 (m^3/s). Pre-existing sonar imagery captured during a previous project quantifying suitable spawning substrate for Paddlefish (*Polyodon spathula*) (Long et al. 2021) was too coarse for identifying habitats relevant for freshwater mussels (Smit and Kaeser 2016). Side-scan imagery taken in 2023 was imported into PING-Mapper (Bodine et. al 2022) and we then attempted to identify habitat according to Smit and Kaeser (2016: point bar, inner recirculation zone, outer recirculation zone, mid channel, and pool/outer bend).

To supplant side-scan sonar delineations of mesohabitats, which proved unreliable for defining these areas, we relied on aerial imagery (Figure 2). After completing mussel surveys, we used aerial imagery to categorize study reaches into eight distinct mesohabitat types (upper recirculation zone, lower recirculation zone, pool, riffle, run, outerbend, pointbar, and shoal) (Table 1). This classification scheme followed Smit and Kaeser's (2006) methodology, who developed mesohabitat categories through a review of literature associated with large-river classifications. Using open-source Google Earth software, we examined our study reaches during low-flow conditions and classified mesohabitats based upon position within the river channel, hydrological patterns, and the river's flow regime. Once defined, these mesohabitats were delineated in ArcGIS Pro and overlaid onto the locations of excavated quadrats to assign each quadrat to its corresponding mesohabitat. Mesohabitat classifications were cross-referenced with field-collected environmental variables (depth, flow, primary substrate) to ensure accuracy (Table 2–3).

To evaluate differences in mussel richness and density among mesohabitats, we conducted Kruskal-Wallis tests and post-hoc pairwise Dunn tests using the R statistical programming language (v.4.3.1). We conducted the analysis in two phases: first, considering all quadrats, and second, excluding unoccupied quadrats to better describe differences in areas where mussels do occur. Additionally, we examined the data in three distinct categories: all mussels, adult mussels, and juvenile mussels. We adopted the <30-mm (Stagliano 2010) size threshold as a foundational guideline for identifying juveniles, while considering the unique characteristics of each mussel species. For example, Fawnsfoot *Truncilla donaciformis*, which only reaches a maximum size of 52 mm (Fisheries and Oceans Canada 2011), had a threshold of 10 mm to classify juveniles.

B. RESULTS:

Verdigris River Survey Method Comparison

During the summers of 2023 and 2024, we completed mussel surveys at 10 sites along the Verdigris and 16 sites along the Caney River (Table 4). Sampling on the Verdigris detected over 1,500 individuals representing 19 different mussel species with more species and individuals found via quantitative sampling (Table 5). Catch-per-unit effort from qualitative surveys averaged 16 individuals/found per hour. When determining catch-per-unit effort for each site, we accounted for the number of searchers (2 snorkelers x 60 minutes= 120 minutes total search time). Density estimates from quantitative surveys averaged $5.016/m^2$. Shell surveys detected most species found alive (14 species), with rare species (N < 5) being most often not detected alive. Species dominance was similar between methods, except that Fawnsfoot was the most abundant species found with quadrat sampling and Monkeyface was the dominant species found with snorkeling. Significantly, we found Western Fanshell, recently listed as threatened under the Endangered Species Act, at reaches 36 river kilometers further downstream than previously documented, along with Ouachita Kidneyshell *Ptychobranchus occidentalis*, which has not been documented in the Verdigris River in Oklahoma for over 100 years (Torolski et al. 2024).

Shell surveys did not fully capture the community present at the reach level on the Verdigris River compared to snorkel and quadrat surveys (mean Jaccard of 0.44 and 0.43) but performed similarly at the river level (Jaccard of 0.93 and 0.73) (Table 6). Snorkel surveys and quadrat surveys performed similarly for species richness at the reach and river level on the Verdigris River (mean Jaccard of 0.82 and 0.80) but not for community composition (mean Bray-Curtis of 0.30 and 0.47).

Resampling of quadrat data (Table 7), which produced the most species and abundance but with much greater effort (10 hours for snorkeling compared to 83 hours for quadrats on the Verdigris River), generated species accumulation curves and abundance histograms to show it would take ~79 quadrats to achieve the same richness (Figure 4) and ~65 quadrats to achieve the same abundance as snorkel surveys (Figure 5), which require less effort, across the entire Verdigris River.

The mean length of mussels detected during quantitative surveys was 65.2 mm, which was nearly one-half of values obtained from qualitative surveys (mean = 102 mm; Table 8). In part, the smaller mean length was a result of more Fawnsfoot, which is a small-bodied species, found during quadrat sampling compared to snorkeling. However, smaller individuals for every species documented were also generally found via quadrat sampling compared to snorkeling.

Caney River Survey Method Comparison

Sixteen sites were surveyed for mussels in the Caney River during the summers of 2023 and 2024, with sites spanning the length of the river from the upper reaches near the Kansas border to the lower stretches near the confluence with the Verdigris River. Live mussels were found at every site, with over 800 individuals representing 15 different species detected (Table 9). Quantitative sampling with quadrats yielded a greater abundance of individuals but the same number of species as qualitative sampling from snorkeling. Shell surveys detected every species found alive (15 species) and two species not detected alive (Paper Pondshell *Utterbackia imbecillis* and Mapleleaf *Quadrula quadrula*). Catch-per-unit effort from qualitative surveys averaged 10.7 mussels/hour while density estimates from quantitative surveys averaged 1.28 mussels/m^2. Species dominance varied between methods; Pimpleback *Pustulosa pustulosa* and Threehorn Wartyback *Obliquaria reflexa* were the most abundant species in quadrat samples and Pistolgrip *Quadrula verrucosa* and Monkeyface *Quadrula metanevra* were dominant in snorkeling surveys. Notably, we documented four live Rabbitsfoot *Theliderma metanevra*, a species listed as threatened under the Endangered Species Act, at a reach approximately 7-km upstream of the confluence with the Verdigris River (Torolski et al. 2025). Rabbitsfoot has not been previously documented alive in the Caney River and was known only from weathered shells (Vaughn 1998, Boeckman et al. 2010).

Shell surveys on the Caney River poorly captured the extant mussel community revealed by snorkel and quadrat surveys at the reach level (mean Jaccard = 0.41 and 0.50) and performed similarly at the river level (Jaccard of 0.82 and 0.82; Table 10). Snorkel surveys and quadrat surveys indicated similar mussel communities at the river level (Jaccard = 0.75) but less so at the reach level (mean Jaccard = 0.19). Community composition of results from quadrat surveys and snorkel surveys indicated low similarity (Bray-Curtis < 0.3).

Similar to the Verdigris River, the mean length of mussels detected during quantitative surveys on the Caney River (65.2 mm) was significantly smaller than values obtained from qualitative surveys (mean = 101.8 mm; t-test $P < 0.01$, Table 11). Smaller individuals were generally more common in quadrat sampling compared to snorkeling. Two-sample t-tests indicated that out of 8 species with n > 30 for at least one survey method, the average length from quantitative surveys was significantly lower for 5 species (Pimpleback, Threehorn Wartyback, Pistolgrip, Fragile Papershell *Potamilus fragilis*, Wabash Pigtoe *Fusconaia flava*) and not significantly different for 3 species (Wartyback *Pustulosa nodulata*, Fawnsfoot, Monkeyface; Table 11).

Qualitative efforts on the Caney occurred over ~16 hours while quantitative efforts took place over 133 hours. Resampling of quadrat data demonstrated ~125 quadrats would be needed to match species richness and ~270 quadrats to achieve the same abundance as snorkel surveys across the entire Caney River (Table 12; Figure 6 and 7). Across all sites, 400 quadrats were

excavated during quantitative sampling. On the site level, resampling indicated 7.01 quadrats achieved the same richness, while 9.62 quadrats matched abundance levels observed in the site-level snorkel surveys.

Verdigris River Mesohabitat Comparison

Overall Mussel Density and Richness.— From 1,255 mussels excavated from 250 quadrats, we found significant differences in density (χ^2 = 32.30; P < 0.01) and richness (χ^2 = 27.06; P < 0.01) among mesohabitats (Table 13; Figure 8). These results were mirrored when unoccupied quadrats were excluded from analysis (χ^2 = 24.51; P < 0.01 for density; χ^2_6 = 24.51; P < 0.01 for richness; Table 14 and 15). Too few samples came from pointbar habitats (N = 3), which were removed from statistical analyses. For all quadrats and for only occupied quadrats, a greater density and number of species typically occurred in upper recirculation zones, riffles, and pools.

Adult Mussel Density and Richness.—Differences in adult mussel density (χ^2 = 37.997, P < 0.01; Table 13) and richness (χ^2 = 31.26; P < 0.01) among mesohabitats mirrored that of all mussels combined. The highest densities and richness (Figure 8) were observed in riffles, upper recirculation zones, and pools. When excluding unoccupied quadrats, differences in density persisted (χ^2 = 13.45; P = 0.04; Table 14 and 15), but variation in mussel richness did not (χ^2= 9.93; P = 0.13).

Juvenile Mussel Density and Richness.—In contrast with all mussels and adult mussels, juvenile mussel density showed no differences among mesohabitat types whether considering all quadrats (χ^2_6 = 4.730, P = 0.58; Table 13) or when considering only occupied habitats (χ^2 = 6.342, P = 0.39; Table 14 and 15). Similarly, juvenile mussel richness among mesohabitats did not vary significantly when considering all quadrats (χ^2 = 4.63, P = 0.59) or excluding unoccupied quadrats (χ^2 = 7.380, P = 0.29).

Caney River Mesohabitat Comparison

Overall Mussel Density and Richness.—Along the Caney River, 512 mussels were excavated from 400 quadrats. We observed significant differences in density (χ^2 = 59.958; P < 0.01) and richness (χ^2 = 54.72; P < 0.01) among mesohabitats (Table 16), with mussel density and richness (Figure 9) highest in runs and lowest in shoals. Few samples were collected in pointbar habitats (n = 7), so they were removed from statistical analyses. When excluding unoccupied quadrats, differences in density (χ^2 = 12.745; P = 0.03) and richness (χ^2 = 19.73; P < 0.01) persisted (Table 17 and 18), with run habitat again containing greater mussel densities and richness. When excluding unoccupied quadrats, outerbend (n = 1) and shoal (n = 0) were removed from statistical analyses due to low sample size.

Adult Mussel Density and Richness.—Differences in adult mussel density (χ^2 = 48.864; P < 0.01) and richness (χ^2 = 50.563; P < 0.01, Table 16) among mesohabitats paralleled those observed for the overall mussel population. Runs again contained the highest adult densities and richness (Figure 9), while shoals exhibited the lowest. When considering only occupied quadrats, Kruskal-Wallis tests indicated significance differences for both adult density (χ^2 = 11.517; P = 0.04) and richness (χ^2 = 15.048; P = 0.01; Table 17 and 18). However, post-hoc pairwise Dunn tests revealed none of the comparisons met the significance threshold (P < 0.05).

Juvenile Mussel Density and Richness.—In contrast with the Verdigris River, juvenile mussel density ($\chi^2 = 24.434$; $P < 0.01$) and richness ($\chi^2 = 24.823$; $P < 0.01$) varied significantly among mesohabitats (Table 16), with runs containing the greatest juvenile mussel density and richness (Figure 9) while shoals contained the lowest. However, when excluding unoccupied quadrats (Table 17 and 18), there was no significant difference in juvenile density ($\chi^2 = 5.4571$; $P = 0.36$) or richness ($\chi^2 = 8.1$; $P < 0.15$).

C. DISCUSSION:

Our results indicated a stabilized mussel community since the last survey conducted 15 years ago by Boeckman et al. (2010). In the Verdigris River, for example, our snorkel-based estimate of 6.8 species per reach mirrored that of Boeckman et al. (2010) who reported 5.2 mussel species per reach. Similar results were documented for the Caney River, where our estimated 2.9 species per reach resembled the 2.1 species per reach estimate of Boeckman et al. (2010). Notably, our surveys documented all previously recorded species from the last two mussel surveys in the same study area (Vaughn 1998, Boeckman et al. 2010) with the exception of the Mapleleaf in both rivers (Table 19). Further, Rabbitsfoot was documented by Boeckman et al. (2010) only in the Verdigris River below Lake Oologah where we did not sample.

Lower observed mussel densities in the Caney River compared to the Verdigris may be attributed to habitat conditions and river size. Quadrats were randomly distributed using ArcGIS, leading to many being placed on bedrock substrate, which is unsuitable for mussel burrowing and was more prevalent in the Caney River. The prevalence of bedrock substrate in the Caney River may be linked to water releases from upstream Hulah (completed in 1951, USACE 2024) and Copan (completed in 1983, USACE 2024) reservoirs. Long-distance scouring of the riverbed (Yang et al. 2022) and channel erosion (Kondolf et al. 2014) downstream of dams has been documented in other systems and could be reducing the availability of suitable substrates for freshwater mussels in the Caney River. Additionally, many of our surveyed reaches were located in proximity to the city of Bartlesville (population ~40,000) and this urbanization and associated pollution from industrial and municipal sources may be negatively affecting mussel populations, as documented in other rivers (Gillis et al. 2017, Gillies et al. 2003, Gangloff et al 2009). In contrast, our sites on the Verdigris River were situated upstream of Lake Oologah, in rural areas away from major urban centers.

Shell surveys on the Verdigris and Caney rivers consistently captured fewer species at the site level compared to snorkel and quadrat surveys but performed similarly at the river level. This suggests shell surveys alone may be insufficient for site-specific analyses, but they may still provide valuable insights at broader spatial scales. Shell surveys may complement live sampling but relying on shell surveys as the sole method for assessing site-level mussel communities would likely fail to adequately characterize mussel communities. Anecdotally, shell surveys still provided a useful indication of species that may be detected during snorkel and quadrat surveys. Given the limitations with catch-per-unit-effort (CPUE), our density estimates derived from quadrat sampling offer a reliable and consistent approach over time (Miller and Lynott 2006). The higher level of detail provided by quadrat sampling is crucial for long-term monitoring by facilitating more accurate assessments of population changes (Obermeyer 1998). While we lack

historic density estimates for the Oklahoma portions of the Verdigris and Caney rivers, comparisons with quadrat data can be made from upstream reaches in Kansas. Mussel densities in the Oklahoma portion of the Verdigris were lower than densities reported by previous quadrat-based efforts conducted in the Kansas section of the river (i.e., 5.9/m^2 in 1991, 8.5/m^2 in 1997, and 16.1/m^2 in 2003; Miller and Lynott 2006). The lower observed densities we observed may suggest that mussel populations in Oklahoma are still recovering from past habitat disturbances, such as the 2007 oil spill in Coffeyville, Kansas, which released over 2,000 barrels of crude oil into the Verdigris River (Miley 2011).

Although snorkeling is faster than quadrat surveys, the approaches yielded different results with respect to community composition. Notably, quadrat sampling and snorkel sampling identified different dominant species in the Verdigris, which may have been due to differences in the ability to detect smaller mussels. For example, the relatively small size of adult Fawnsfoot (maximum length = 52 mm; Fisheries and Oceans Canada 2011) made them more difficult to detect when snorkeling. Differences in community composition were also evident on the Caney River, where Pimpleback dominated quadrat sampling whereas Pistolgrip dominated snorkel surveys. Across both rivers, quadrat sampling generally found smaller individuals among various species compared to snorkel sampling, improving the potential to document recruitment where it occurred.

Our resampling effort was intended to determine the level at which the speed of snorkel sampling could be combined with the data quality of quadrat sampling, seeking a balance between these complimentary methods. For both the Verdigris and Caney rivers, excavating ~10 quadrats would achieve the same estimates of richness and relative abundance as the site-level snorkel surveys allowing one to obtain the benefit of sampling more sites across the entire river while simultaneously generating robust density estimates and more representative size distributions of individuals. Future surveys could be further refined by selectively excavating limited numbers of quadrats in mesohabitats predicted to harbor high densities and richness of freshwater mussels. However, to prevent underestimation of species richness and detection of rare species, snorkel sampling can be conducted as a complementary approach (Vaughn et al. 1997).

Our quantitative sampling on both the Verdigris and Caney rivers demonstrated that freshwater mussel density and richness varied significantly across mesohabitat types. Previous literature has shown the importance of considering both complex hydraulic variables (such as shear stress) and substrate stability when investigating freshwater mussel habitat associations (Strayer 1999, Allen and Vaughn 2010, Randklev et al. 2019). Given that mesohabitats are defined and characterized by hydraulic factors such as flow, depth, and substrate composition, they serve as effective proxies for hydraulic conditions and can be used to determine areas that mussels cannot tolerate (Farò et al. 2022). For example, one characteristic of outerbend mesohabitats is bank erosion and instability during high flow events (Murningsih 2018). Since substrate stability during high flows is associated with greater mussel density and richness (Randklev et al. 2019), one would predict lower mussel density and richness in outerbend mesohabitats. This prediction was supported by our data from the Verdigris River, where outerbends harbored the lowest mussel density and richness of any mesohabitat type.

While mussel density and richness varied among mesohabitats in both the Verdigris and Caney rivers, the observed patterns were not consistent between the two systems. For the Verdigris River, upper recirculation zones, pools, and riffles contained the greatest densities and richness of freshwater mussels. Previous studies have suggested both low and high flow conditions are likely limiting factors for suitable mussel habitat (Strayer 2008, Steuer et al. 2008). Recirculation zones may be providing freshwater mussels with important hydraulic refugia during high flow events (Smit and Kaeser 2016), while pools may provide thermal refuge and protection from desiccation during low flows (Cushway and Schwalb 2023). The greater flow rate found in riffles compared to other mesohabitats may be advantageous to freshwater mussels by facilitating the transport of nutrients, oxygen, and waste products (Steuer et al. 2008).

In the Caney River, shoal mesohabitats harbored the lowest mussel density and richness with no live mussels detected, while run mesohabitats contained the highest. The absence of mussels in shoals was not unexpected, as shoal mesohabitats were characterized by swift water moving across bedrock. Bedrock prevents mussels from burrowing into the substrate, leaving them vulnerable to being dislodged and swept downstream. The higher density and richness of freshwater mussels in runs was unexpected, as these mesohabitats are associated with unstable substrates during high flow events (Smit and Kaeser 2016). However, long-term persistence of mussel beds in reaches with significant bed mobility have been documented in other systems, indicating flow refugia and substrate stability cannot completely explain the occurrence of freshwater mussels (Sansom et al. 2018). Alternatively, freshwater mussels may be actively engineering their habitat or changing behavior to persist in unstable environments (Sansom et al. 2018). For example, freshwater mussels may orient themselves parallel to flow to reduce the chances of being dislodged (Di Mao and Corkum 1997), while dense assemblages of freshwater mussels can compact and stabilize sediments (Strayer et al. 2004).

We were unable to successfully identify mesohabitats from our side-scan imagery, primarily attributed to the distinct hydrological conditions of the Verdigris River and relatively uniform distribution of large, hard substrates (e.g., cobble), which is in stark contrast to the predominate sand substrates of the Apalachicola River studied by Smit and Kaeser (2016), who inspired our proposed use of side-scan sonar in the Verdigris River. For example, in the Apalachicola River, circulation zones were identifiable by the presence of wavy lines in the sediment (A. Kaeser, USFWS, oral communication, 2023), whereas the substrate of the Verdigris River is largely composed of bedrock, boulder, and large cobble (Long et al. 2021), lacking distinct boundaries in many cases. As a result, we relied on aerial imagery instead to delineate these mesohabitats.

II. RECOMMENDATIONS

None. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

III. SIGNIFICANT DEVIATIONS

None.

IV. EQUIPMENT

No equipment was purchased during the grant that exceeded $5,000 in cost.

V. PREPARED BY:

        Graduate Research Assistant: Hunter Torolski, Department of Natural Resource Ecology and Management, Oklahoma State University

        Principal Investigators: James M. Long and Robert C. Lonsinger
        U.S. Geological Survey, Oklahoma Cooperative Fish and Wildlife Research Unit
        Lindsey A. Bruckerhoff
        Ohio State University

Date: August 10, 2025

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Table 1. Mesohabitat classification scheme for mesohabitats on the Verdigris and Caney rivers in Oklahoma, USA.

Mesohabitat	Characteristics
Pointbar	Close proximity (within 3 m) of gravel bar, shallow, coarse substrate, low velocity
Upper Recirculation Zone (Upper R)	Upstream of gravel bar, deposition of fine particles, recirculation of flow, low velocity
Lower Recirculation Zone (Lower R)	Downstream of gravel bar, deposition of fine particles, recirculation of flow, low velocity
Pool	Above average depth, no velocity, deposition of fine particles
Riffle	Shallow, turbulent flow, high velocity, coarse substrate
Run	Moderate depth and velocity, laminar flow, middle of channel
Outerbend	Outside curve of meander, moderate depth and velocity, high erosion
Shoal	Shallow, turbulent flow, high velocity, bedrock substrate

Table 2. Mean depth, water velocity (standard deviation), and predominant substrate (percent) among mesohabitats from quantitative surveys on the Verdigris River (Summer 2023), located in northeastern Oklahoma.

Mesohabitat	Mean Depth (cm)	Mean Water Velocity (m/s)	Predominant substrate (percent)	# of quadrats
Pointbar	17.67 (9.45)	0.00 (0.00)	Gravel (67%)	3
Upper R	49.16 (26.13)	0.04 (0.09)	Cobble (38%)	29
Lower R	47.48 (21.67)	0.07 (0.03)	Cobble (38%)	26
Pool	62.04 (23.09)	0.02 (0.04)	Gravel (69%)	13
Riffle	23.53 (12.84)	0.41 (0.27)	Cobble (65%)	46
Run	50.54 (23.48)	0.10 (0.10)	Cobble (53%)	110
Outerbend	54.09 (22.37)	0.12 (0.31)	Cobble (39%)	23
River	45.62 (24.46)	0.13 (0.21)	Cobble (48%)	250

Table 3. Mean depth, water velocity (standard deviation), and predominant substrate (percent) among mesohabitats from quantitative surveys on the Caney River (Summer 2023 and 2024), located in northeastern Oklahoma.

Mesohabitat	Mean Depth (cm)	Mean Water Velocity (m/s)	Predominant substrate type (percent)	# of quadrats
Pointbar	60.43 (18.04)	0.00 (0.00)	Sand (43%) Gravel (43%)	7
Upper R	58.67 (22.17)	0.06 (0.03)	Gravel (37%)	41
Lower R	58.64 (21.61)	0.02 (0.04)	Gravel (43%)	44
Pool	76.65 (8.54)	0.01 (0.03)	Gravel (29%)	34
Riffle	21.80 (7.64)	0.36 (0.19)	Cobble (54%)	76
Run	54.04 (16.05)	0.10 (0.13)	Gravel (46%)	144
Outerbend	67.4 (15.72)	0.03 (0.07)	Gravel (40%)	10
Shoal	24.34 (10.74)	0.32 (0.23)	Bedrock (100%)	44
River	48.0 (23.32)	0.14 (0.20)	Gravel (38%)	400

Table 4. Abundances of mussel species documented during shell, snorkel, and quadrat surveys on the Verdigris and Caney rivers of Oklahoma (Summer 2023/2024).

Species	Verdigris River			Caney River		
	Shell Presence	Snorkel Abundance	Quadrat Abundance	Shell Presence	Snorkel Abundance	Quadrat Abundance
Fawnsfoot (*Truncilla donaciformis*)	Yes	3	345	Yes	2	38
Monkeyface (*Theliderma metanevra*)	Yes	144	313	Yes	49	24
Pistolgrip (*Quadrula verrucosa*)	Yes	89	204	Yes	131	80
Threehorn Wartyback (*Obliquaria reflexa*)	Yes	24	96	Yes	29	81
Pimpleback (*Pustulosa pustulosa*)	Yes	15	89	Yes	11	82
Plain Pocketbook (*Lampsilis cardium*)	Yes	9	37	Yes	17	17
Bleufer (*Potamilus purpuratus*)	Yes	7	34	Yes	16	11
Yellow Sandshell (*Lampsilis teres*)	Yes	4	16	Yes	17	11
Threeridge (*Amblema plicata*)	Yes	3	12	Yes	20	7
Wartyback (*Pustulosa nodulata*)	Yes	4	11	Yes	8	48
White Heelsplitter (*Lasmigona complanata*)	Yes	1	4	Yes	3	3
Round Pigtoe (*Pluerobema sintoxia*)	Yes	1	4	No	0	0
Fragile Papershell (*Potamilus fragilis*)	Yes	12	80	Yes	20	57
Pink Papershell (*Potamilus ohiensis*)	No	0	4	Yes	0	11
Western Fanshell (*Cyprogenia aberti*)	Yes	4	2	No	0	0
Washboard (*Megalonaias nervosa*)	No	0	1	No	0	0

Species						
Wabash Pigtoe (*Fusconaia flava*)	No	2	1	Yes	15	42
Ouachita Kidneyshell (*Ptychobranchus occidentalis*)	No	0	1	No	0	0
Fatmucket (*Lampsilis siliquoidea*)	No	0	1	No	0	0
Rabbitsfoot (*Theliderma cylindrica*)	No	0	0	Yes	4	0
Paper Pondshell (*Utterbackia imbecillis*)	No	0	0	Yes	0	0
Mapleleaf (*Quadrula quadrula*)	No	0	0	Yes	0	0
Total Abundance	NA	322	1255	NA	342	512
N Species	14	15	19	17	14	14

Table 5. Mussel species richness and abundance (standard error) by survey method on the reach and river level on the Verdigris River (Summer 2023), located in northeastern Oklahoma. Reaches listed from upstream to downstream (refer to Figure 1). Mean mussel densities and richness (standard error) from quadrat surveys are also shown.

	Shell	Snorkel (Time = 120 min)		Quadrats (Total Area = 25 m^2)			
Reach	Species Richness	Species Richness	Abundance	Species Richness	Abundance	Mean Density (m^2)	Mean Richness (m^2)
2	7	8	17	14	104	4.16 (1.04)	2.68 (0.47)
4	7	7	36	11	84	3.36 (1.48)	1.60 (0.39)
6	5	5	14	11	167	6.68 (1.60)	2.00 (0.30)
8	11	7	45	11	104	4.16 (0.86)	2.28 (0.39)
10	8	6	18	11	116	4.64 (0.45)	2.84 (0.24)
11	9	6	43	13	237	9.48 (2.23)	3.52 (0.47)
13	10	12	97	13	256	10.24 (2.01)	3.44 (0.47)
Upstream BR	9	2	11	8	73	2.92 (1.08)	1.12 (0.28)
18	9	10	31	11	86	3.44 (0.93)	1.88 (0.43)
19	9	5	10	6	28	1.12 (0.44)	0.80 (0.22)
Reach Mean	8.40 (0.54)	6.80 (0.88)	32.20 (8.30)	11.60 (0.75)	125.50 (23.03)	5.02 (0.92)	2.22 (0.29)
River	14	15	322	19	1255	5.02 (0.45)	2.22 (0.13)

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Table 6. Jaccard and Bray-Curtis similarity values on the reach and river level on the Verdigris River (Summer 2023), located in northeastern Oklahoma. Reaches listed from upstream to downstream. Values range from 0 (complete dissimilarity) to 1 (complete similarity).

| Reach | Jaccard | | | Bray-Curtis |
	Shell-Snorkel	Shell-Quadrat	Snorkel-Quadrat	Snorkel-Quadrat
2	0.5	0.5	0.82	0.50
4	0.25	0.36	0.89	0.25
6	0.57	0.67	0.84	0.29
8	0.5	0.31	0.83	0.22
10	0.25	0.42	0.78	0.39
11	0.33	0.53	0.81	0.44
13	0.31	0.23	0.81	0.30
Upstream BR	0.78	0.45	0.86	0.18
18	0.42	0.33	0.83	0.27
19	0.44	0.5	0.72	0.11
Reach Mean	0.44	0.43	0.82	0.30
River	0.93	0.73	0.80	0.47

Table 7. Mean number of quadrats (standard error) required to achieve the same richness and abundance as snorkel surveys on the reach and river level along the Verdigris River (Summer 2023), located in northeastern Oklahoma. Reaches listed from upstream to downstream.

Reach	Mean # Quadrats to Achieve Snorkel Richness	Mean # Quadrats to Achieve Snorkel Abundance
2	4.95 (0.25)	4.85 (0.20)
4	7.82 (0.46)	10.83 (0.60)
6	3.73 (0.21)	3.07 (0.14)
8	5.33 (0.20)	11.49 (0.22)
10	3.72 (0.14)	4.49 (0.10)
11	2.94 (0.18)	5.53 (0.22)
13	16.74 (0.55)	9.83 (0.24)
Upstream BR	2.30 (0.15)	5.01 (0.28)
18	13.43 (0.45)	9.61 (0.32)
19	8.59 (0.46)	9.37 (0.48)
Reach Mean	6.96 (1.51)	7.41 (0.98)
River	71.35 (3.02)	65.45 (0.92)

Table 8. Mean mussel length (mm; standard deviation) and abundance (n) by species and survey method (snorkel versus quadrat) on the Verdigris River (Summer 2023), located in northeastern Oklahoma. "X" indicates the species was not detected using that survey method. For species with > 30 observations in one survey method, a two-sample t-test was conducted to compare the mean length of mussels between snorkel and quadrat survey methods.

Species	Snorkel	Quadrat	t-value	df	P-value
Fawnsfoot (*Truncilla donaciformis*)	26.00 (3.60), n=3	19.70 (5.00), n=345	3.01	2.07	0.09
Monkeyface (*Theliderma metanevra*)	97.20 (57.70), n=144	79.90 (39.60), n=313	3.26	207.23	0.001
Pistolgrip (*Quadrula verrucosa*)	127.50 (18.60), n=89	109.80 (33.50), n=204	5.78	274.77	<0.001
Threehorn Wartyback (*Obliquaria reflexa*)	67.90 (8.30), n=24	51.90 (21.50), n=96	5.77	98.07	<0.001
Pimpleback (*Pustulosa pustulosa*)	73.90 (17.70), n=15	52.70 (41.90), n=89	3.33	46.35	0.002
Plain Pocketbook (*Lampsilis cardium*)	116.80 (28.10), n=9	89.10 (40.50), n=37	2.41	17.15	0.03
Bleufer (*Potamilus purpuratus*)	138.10 (22.30), n=7	122.30 (28.20), n=34	1.63	10.40	0.13
Yellow Sandshell (*Lampsilis teres*)	54.80 (15.50), n=4	73.10 (35.80), n=16	Na	Na	Na
Threeridge (*Amblema plicata*)	118.30 (12.70), n=3	100.10 (34.60), n=12	Na	Na	Na
Wartyback (*Pustulosa nodulata*)	56.00 (12.20), n=4	58.40 (10.10), n=11	Na	Na	Na
White Heelsplitter (*Lasmigona complanata*)	163.00 (NA), n=1	91.00 (81.70), n=4	Na	Na	Na
Round Pigtoe (*Pluerobema sintoxia*)	86.00 (NA), n=1	76.30 (19.40), n=4	Na	Na	Na
Fragile Papershell (*Potamilus fragilis*)	88.60 (35.80), n=12	73.20 (37.80), n=80	1.38	14.93	0.18
Pink Papershell (*Potamilus ohiensis*)	X	82.30 (28.00), n=4	Na	Na	Na
Western Fanshell (*Cyprogenia aberti*)	87.50 (11.30), n=4	83.50 (14.80), n=2	Na	Na	Na

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Washboard (*Megalonaias nervosa*)	X	159.00 (NA), n=1	Na	Na	Na
Wabash Pigtoe (*Fusconaia flava*)	101.50 (3.50), n=2	95.00 (NA), n=1	Na	Na	Na
Ouachita Kidneyshell (*Ptychobranchus occidentalis*)	X	105.00 (NA), n=1	Na	Na	Na
Fatmucket (*Lampsilis siliquoidea*)	X	85.00 (NA), n=1	Na	Na	Na
Mean Length (All species)	102.00 (46.44), n=322	65.20 (45.30), n=1255	12.75	489.80	<0.001

Table 9. Mussel species richness and abundance (standard error) by survey method on the reach and river level on the Caney River (Summer 2023 and 2024), located in northeastern Oklahoma. Reaches listed from upstream to downstream. Mean mussel densities and richness (standard error) from quadrat surveys are also shown.

Reach	Shell	Snorkel (Time = 120 min)		Quadrats (Total Area = 25 m²)			
	Species Richness	Species Richness	Abundance	Species Richness	Abundance	Mean Density (m²)	Mean Richness (m²)
A	6	2	3	6	22	0.88 (0.19)	0.76 (0.16)
AB	4	1	1	0	0	0.00	0.00
B	5	3	10	7	21	0.84 (0.33)	0.60 (0.21)
10	9	5	8	12	111	4.44 (1.24)	2.36 (0.52)
13	4	3	3	6	6	0.24 (0.10)	0.24 (0.10)
17	3	5	17	8	19	0.76 (0.35)	0.60 (0.25)
19	6	5	47	4	10	0.40 (0.18)	0.32 (0.14)
20	7	6	29	7	76	3.04 (0.67)	1.64 (0.24)
23	8	6	39	7	51	2.04 (0.64)	1.20 (0.33)
24	6	1	1	10	42	1.68 (0.37)	1.20 (0.27)
26	10	4	4	3	5	0.20 (0.13)	0.20 (0.13)
27	7	6	29	3	3	0.12 (0.01)	0.12 (0.01)
E	8	3	11	7	10	0.40 (0.17)	0.36 (0.15)
West C	10	13	122	12	37	1.48 (0.27)	1.32 (0.23)
East C	5	5	16	12	53	2.12 (0.46)	1.60 (0.31)
M	5	2	2	12	46	1.84 (0.45)	1.52 (0.37)
River	17	14	342	14	512	1.28 (0.13)	0.88 (0.07)
Reach Mean	6.40 (0.53)	2.90 (0.72)	21.40 (7.60)	7.30 (0.92)	32.00 (7.62)	1.28 (0.30)	0.88 (0.17)

Table 10. Jaccard and Bray-Curtis similarity values on the reach and river level on the Caney River (Summer 2023-2024), located in northeastern Oklahoma. Reaches listed from upstream to downstream (see Figure 1). Values range from 0 (complete dissimilarity) to 1 (complete similarity).

	Jaccard			Bray-Curtis
Reach	Shell-Snorkel	Shell-Quadrat	Snorkel-Quadrat	Snorkel-Quadrat
A	0.33	0.71	0.36	0.32
AB	0.25	0	0	0
B	0.33	0.71	0.23	0.18
10	0.4	0.62	0.46	0.43
13	0.17	0.25	0.02	0.05
17	0.33	0.38	0.13	0.12
19	0.83	0.43	0.12	0.04
20	0.63	0.75	0.47	0.35
23	0.75	0.67	0.27	0.16
24	0.17	0.60	0.20	0.25
26	0.4	0.30	0.11	0.15
27	0.63	0.43	0.03	0.02
E	0.22	0.67	0.04	0.03
West C	0.64	0.70	0.25	0.06
East C	0.11	0.42	0.29	0.26
M	0.40	0.31	0.13	0.17
Reach Mean	0.41	0.50	0.19	0.16
River	0.82	0.82	0.75	0.29

Table 11. Mean mussel length (mm; standard deviation) and abundance (n) by species and survey method (snorkel versus quadrat) on the Caney River (Summer 2023/2024), located in northeastern Oklahoma. "X" indicates the species was not detected using that survey method. For species with > 30 observations in one survey method, a two-sample t-test was conducted to compare the mean length of mussels between snorkel and quadrat survey methods.

Species	Snorkel	Quadrat	t-value	df	P-value
Pimpleback (*Pustulosa pustulosa*)	62.20 (7.90), n=11	44.70 (18.80), n=82	5.54	28.91	<0.001
Threehorn Wartyback (*Obliquaria reflexa*)	61.60 (8.70), n=29	46.80 (13.90), n=81	6.62	79.36	<0.001
Pistolgrip (*Quadrula verrucosa*)	127.60 (18.70), n=131	111.30 (35.60), n=80	3.79	106.04	<0.001
Wartyback (*Pustulosa nodulata*)	52.90 (7.50), n=8	50.10 (13.00), n=48	0.63	18.98	0.54
Wabash Pigtoe (*Fusconaia flava*)	79.00 (22.60), n=15	47.90 (22.80), n=42	4.56	24.90	<0.001
Fawnsfoot (*Truncilla donaciformis*)	27.50 (2.10), n=2	24.40 (8.10), n=38	1.56	3.14	0.21
Monkeyface (*Theliderma metanevra*)	76.40 (23.10), n=49	73.40 (27.00), n=24	0.47	39.99	0.64
Plain Pocketbook (*Lampsilis cardium*)	123.20 (27.80), n=17	91.60 (33.10), n=17	Na	Na	Na
Bleufer (*Potamilus purpuratus*)	133.30 (32.90), n=16	107.30 (21.80), n=11	Na	Na	Na
Yellow Sandshell (*Lampsilis teres*)	82.90 (18.60), n=17	67.60 (33.70), n=11	Na	Na	Na
Fragile Papershell (*Potamilus fragilis*)	100.10 (23.00), n=20	74.40 (36.80), n=57	3.63	53.75	<0.001
Pink Papershell (*Potamilus ohiensis*)	X	95.20 (21.10), n=11	Na	Na	Na
Threeridge (*Amblema plicata*)	97.60 (29.20), n=20	119.00 (5.70), n=7	Na	Na	Na
White Heelsplitter (*Lasmigona complanata*)	98.00 (44.00), n=3	106.00 (45.10), n=3	Na	Na	Na
Rabbitsfoot (*Theliderma cylindrica*)	82.50 (27.80), n=4	X	Na	Na	Na
Mean Length (All species)	101.80 (34.30), n=342	65.20 (37.10), N=512	14.78	768.87	<0.001

Table 12. Mean number of quadrats (standard error) required to achieve the same richness and abundance as snorkel surveys on the reach and river level along the Caney River, located in northeastern Oklahoma, during the summer of 2023 and 2024. Reaches listed from upstream to downstream. ">25" indicates sites where quantitative surveys detected lower mussel richness or abundance as snorkel surveys. We used 25 quadrats for calculations, but this value is likely underestimated. NA indicates sites where quantitative surveys did not detect mussels.

Site	Mean # Quadrats to Achieve Snorkel Richness	Mean # Quadrats to Achieve Snorkel Abundance
A	3.09 (0.16)	3.78 (0.18)
AB	NA	NA
B	5.83 (0.34)	11.34 (0.46)
10	2.87 (0.18)	2.92 (0.18)
13	12.71 (0.51)	12.71 (0.51)
17	10.54 (0.54)	19.77 (0.36)
19	>25.00	>25.00
20	12.02 (0.41)	10.13 (0.25)
23	12.17 (0.65)	18.88 (0.32)
24	1.68 (0.10)	1.68 (0.10)
26	>25.00	14.18 (0.56)
27	>25.00	>25.00
E	9.75 (0.52)	>25.00
West C	>25.00	>25.00
East C	4.07 (0.17)	8.25 (0.22)
M	2.36 (0.15)	2.14 (0.14)
Reach Mean	7.01 (1.34)	9.62 (1.96)
River	126.91 (6.24)	267.0 (1.97)

Table 13. Mean density and species richness (standard deviation) for all mussels, adult mussels, and juvenile mussels among mesohabitats from quantitative surveys on the Verdigris River (Summer 2023), located in northeastern Oklahoma.

Mesohabitat	All Mussels		Adult Mussels		Juvenile Mussels		# quadrats
	Density (n/m^2)	Richness (n/m^2)	Density (n/m^2)	Richness (n/m^2)	Density (n/m^2)	Richness (n/m^2)	
Pointbar	4.66 (7.23)	2.33 (3.21)	3.67 (5.51)	2.00 (2.65)	1.00 (1.73)	1.00 (1.73)	3
Upper R	6.97 (7.74)	3.10 (2.85)	6.14 (7.50)	2.72 (2.79)	0.83 (1.28)	0.55 (0.74)	29
Lower R	1.73 (2.66)	1.23 (1.56)	0.88 (1.61)	0.65 (1.16)	0.85 (1.64)	0.65 (1.23)	26
Pool	6.85 (9.43)	3.34 (2.06)	5.69 (8.96)	2.46 (1.94)	1.15 (1.91)	1.08 (1.66)	13
Riffle	8.07 (10.60)	2.59 (1.93)	7.15 (10.24)	2.15 (1.81)	0.91 (1.53)	0.61 (0.77)	46
Run	4.55 (5.54)	2.17 (1.83)	3.83 (5.11)	1.79 (1.76)	0.73 (1.16)	0.58 (0.82)	110
Outerbend	1.43 (2.27)	1.04 (1.40)	1.17 (2.12)	0.83 (1.30)	0.26 (0.45)	0.26 (0.45)	23
River	5.02 (7.15)	2.22 (2.04)	4.25 (6.76)	1.80 (1.93)	0.77 (1.31)	0.60 (0.90)	250

Table 14. Mean density and species richness (standard deviation) for all mussels, adult mussels, and juvenile mussels among occupied mesohabitats from quantitative surveys on the Verdigris River, located in northeastern Oklahoma, during summer 2023 (unoccupied quadrats were excluded). "NA" indicates no mussels were detected in that mesohabitat.

Mesohabitat	All Mussels			Adult Mussels			Juvenile Mussels		
	Density (n/m^2)	Richness (n/m^2)	# quadrats	Density (n/m^2)	Richness (n/m^2)	# quadrats	Density (n/m^2)	Richness (n/m^2)	# quadrats
Pointbar	7.00 (8.49)	3.50 (3.54)	2	5.50 (6.36)	3.00 (2.83)	2	NA	NA	1
Upper R	9.62 (7.56)	4.29 (2.45)	21	8.48 (7.61)	3.76 (2.61)	21	2.00 (1.28)	1.33 (0.49)	12
Lower R	2.65 (2.91)	1.88 (1.58)	17	2.30 (1.89)	1.70 (1.34)	10	2.00 (2.05)	1.55 (1.51)	11
Pool	6.85 (9.43)	3.31 (2.06)	13	5.69 (8.96)	2.46 (1.94)	13	2.14 (2.19)	2.00 (1.83)	7
Riffle	8.83 (10.78)	2.83 (1.84)	42	8.02 (10.53)	2.41 (1.75)	41	2.00 (1.70)	1.33 (0.58)	21
Run	5.69 (5.65)	2.72 (1.65)	88	5.33 (5.33)	2.49 (1.59)	79	1.74 (1.22)	1.39 (0.68)	46
Outerbend	2.75 (2.53)	2.00 (1.35)	12	3.00 (2.5)	2.11 (1.27)	9	1.00 (0)	1.00 (0)	6
River	6.44 (7.51)	2.84 (1.89)	195	6.07 (7.37)	2.57 (1.82)	175	1.85 (1.47)	1.42 (0.88)	104

Table 15. Occupied quadrats compared to total quadrats for all mussels, adult mussels, and juvenile mussels among mesohabitats from quantitative surveys on the Verdigris River, located in northeastern Oklahoma, during the summer of 2023.

Mesohabitat	All Mussels		Adult Mussels		Juvenile Mussels	
	Occupied Quadrats	Total Quadrats	Occupied Quadrats	Total Quadrats	Occupied Quadrats	Total Quadrats
Pointbar	2	3	2	3	1	3
Upper R	21	29	21	29	12	29
Lower R	17	26	10	26	11	26
Pool	13	13	13	13	7	13
Riffle	42	46	41	46	21	46
Run	88	110	79	110	46	110
Outerbend	12	23	9	23	6	23
River	195	250	175	250	104	250

Table 16. Mean density and species richness (standard deviation) for all mussels, adult mussels, and juvenile mussels among mesohabitats from quantitative surveys on the Caney River, located in northeastern Oklahoma, during the summer of 2023 and 2024.

Mesohabitat	All Mussels		Adult Mussels		Juvenile Mussels		# quadrats
	Density (n/m^2)	Richness (n/m^2)	Density (n/m^2)	Richness (n/m^2)	Density (n/m^2)	Richness (n/m^2)	
Pointbar	2.14 (2.73)	1.43 (1.90)	2.14 (2.73)	1.43 (1.90)	0.00 (0.00)	0.00 (0.00)	7
Upper R	0.95 (1.61)	0.88 (1.44)	0.76 (1.50)	0.71 (1.33)	0.20 (0.40)	0.20 (0.40)	41
Lower R	0.98 (2.19)	0.64 (1.16)	0.84 (1.95)	0.55 (1.07)	0.14 (0.41)	0.11 (0.32)	44
Pool	0.91 (1.44)	0.59 (0.86)	0.65 (1.28)	0.44 (0.75)	0.26 (0.67)	0.21 (0.48)	34
Riffle	0.96 (1.81)	0.66 (1.08)	0.70 (1.34)	0.51 (0.93)	0.26 (0.68)	0.20 (0.46)	76
Run	2.15 (3.43)	1.42 (1.68)	1.60 (2.57)	1.15 (1.47)	0.54 (1.28)	0.40 (0.72)	144
Outerbend	0.20 (0.63)	0.20 (0.63)	0.00 (0.00)	0.00 (0.00)	0.20 (0.63)	0.20 (0.63)	10
Shoal	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	44
River	1.28 (2.54)	0.88 (1.39)	0.97 (1.98)	0.71 (1.23)	0.31 (0.89)	0.24 (0.55)	400

Table 17. Mean density and species richness (standard deviation; SD) for all mussels, adult mussels, and juvenile mussels among occupied mesohabitats from quantitative surveys on the Caney River, located in northeastern Oklahoma, during summer 2023 and 2024 (unoccupied quadrats were excluded). NA indicates sites where mussels were not detected or when calculations of SD were based on a sample size of N = 1.

Mesohabitat	All Mussels			Adult Mussels			Juvenile Mussels		
	Density (n/m²)	Richness (n/m²)	# quadrats	Density (n/m²)	Richness (n/m²)	# quadrats	Density (n/m²)	Richness (n/m²)	# quadrats
Pointbar	5.00 (1.00)	3.33 (1.15)	3	5.00 (1.00)	3.33 (1.15)	3	NA	NA	0
Upper R	2.17 (1.82)	2.00 (1.57)	18	2.07 (1.87)	1.93 (1.58)	15	1.00 (0.00)	1.00 (0.00)	8
Lower R	3.07 (3.00)	2.00 (1.24)	14	2.85 (2.73)	1.85 (1.21)	13	1.20 (0.45)	1.00 (0.00)	5
Pool	2.21 (1.48)	1.43 (0.76)	14	2.00 (1.55)	1.36 (0.67)	11	1.50 (0.84)	1.17 (0.41)	6
Riffle	2.35 (2.20)	1.61 (1.15)	31	2.12 (1.56)	1.56 (1.00)	25	1.54 (0.88)	1.15 (0.38)	13
Run	3.81 (3.81)	2.53 (1.48)	81	3.12 (2.85)	2.24 (1.32)	74	1.86 (1.79)	1.36 (0.69)	42
Outerbend	2.00 (NA)	2.00 (NA)	1	NA	NA	0	2.00 (NA)	2.00 (NA)	1
Shoal	NA	NA	0	NA	NA	0	NA	NA	0
River	3.16 (3.16)	2.17 (1.41)	162	2.76 (2.49)	2.00 (1.28)	141	1.64 (1.43)	1.25 (0.57)	75

Table 18. Occupied quadrats compared to total quadrats for all mussels, adult mussels, and juvenile mussels among mesohabitats from quantitative surveys on the Caney River, located in northeastern Oklahoma, during summer 2023 and 2024.

Mesohabitat	All Mussels		Adult Mussels		Juvenile Mussels	
	Occupied Quadrats	Total Quadrats	Occupied Quadrats	Total Quadrats	Occupied Quadrats	Total Quadrats
Pointbar	3	7	3	7	0	7
Upper R	18	41	15	41	8	41
Lower R	14	44	13	44	5	44
Pool	14	34	11	34	6	34
Riffle	31	76	25	76	13	76
Run	81	144	74.	144	42	144
Outerbend	1	10	0	10	1	10
Shoal	0	44	0	44	0	44
River	162	400	141	400	75.00	400

Table 19. Mussel species detected during current and previous surveys on the Verdigris and Caney rivers in northeastern Oklahoma.

| Scientific Name	Common name	Verdigris River			Caney River		
		Vaughn (1998)	Boeckman et al. (2010)	This study	Vaughn (1998)	Boeckman et al. 2010	This study
Amblema plicata	Threeridge	X	X	X	X	X	X
Cyprogenia aberti	Western Fanshell		X	X			
Fusconia flava	Wabash Pigtoe	X	X	X		X	X
Lampsilis cardium	Plain Pocketbook	X	X	X		X	X
Lampsilis siliquoidea	Fatmucket			X			
Lampsilis teres	Yellow Sandshell	X	X	X	X		X
Lasmigona complanata	White Heelsplitter	X	X	X	X		X
Megalonaias nervosa	Washboard	X	X	X			
Obliquaria reflexa	Threehorn Wartyback	X	X	X	X	X	X
Pleurobema sintoxia	Round Pigtoe	X	X	X			
Potamilus fragilis	Fragile Papershell	X	X	X	X	X	X
Potamilus ohiensis	Pink Papershell	X		X		X	X
Potamilus purpuratus	Bleufer	X	X	X	X	X	X
Ptychobranchus occidentalis	Ouachita Kidneyshell			X			
Theliderma cylindrica	Rabbitsfoot		X				X
Theliderma metanevra	Monkeyface	X	X	X	X		X
Pustulosa nodulata	Wartyback		X	X	X	X	X
Pustulosa pustulosa	Pimpleback	X	X	X	X	X	X
Quadrula quadrula	Mapleleaf	X			X		
Quadrula verrucosa	Pistolgrip	X	X	X	X	X	X
Truncila donaciformis	Fawnsfoot	X	X	X	X	X	X
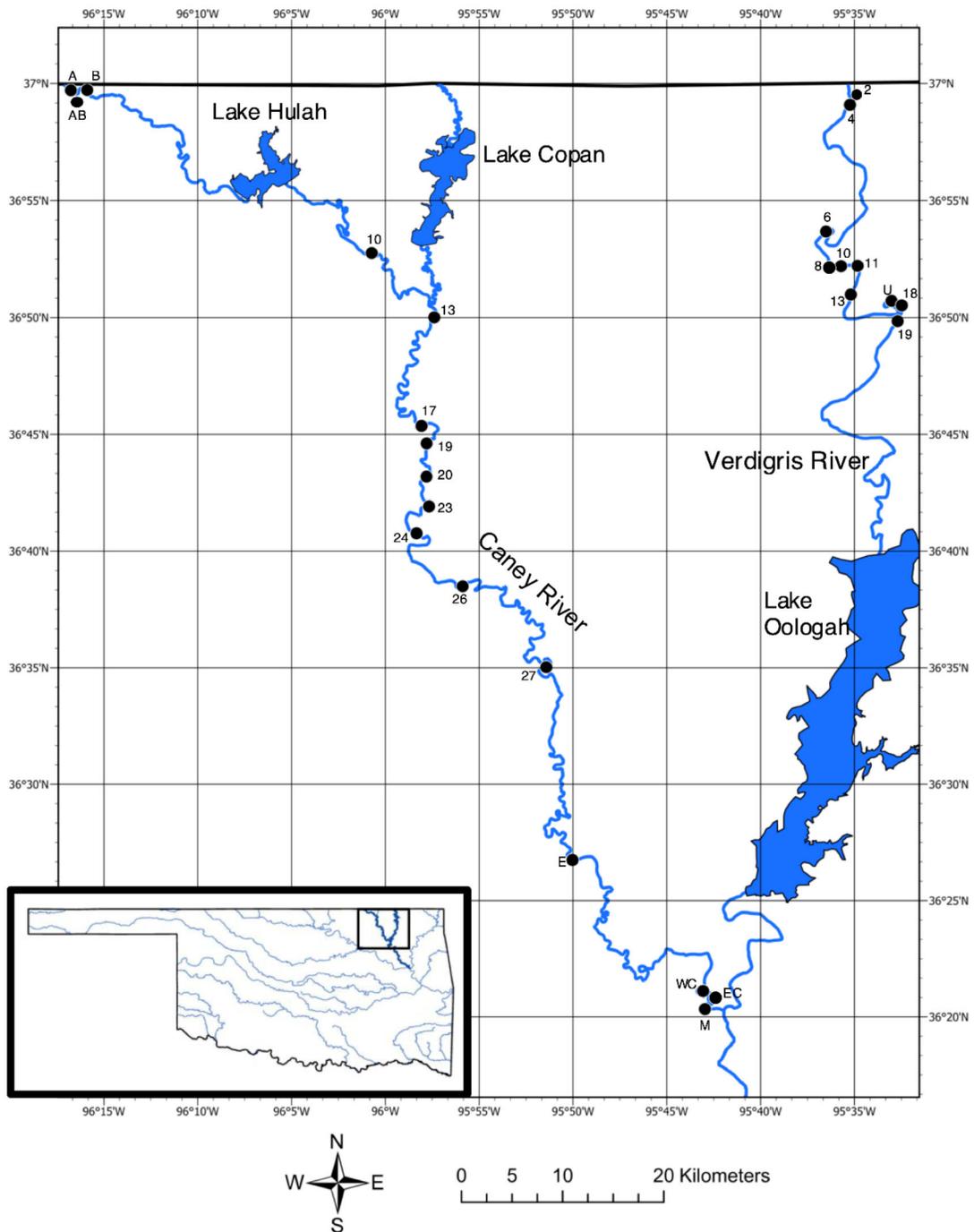
Figures:

Figure 1. Survey locations (black circles) on the Verdigris and Caney rivers sampled during the summer of 2023/2024. Numbered sites are those samples previously by Vaughn (1998) and Boeckman et al. (2010). Other sites are indicted with acronyms: "WC" =West C, "EC" =East C, and "U" =Upstream BR.

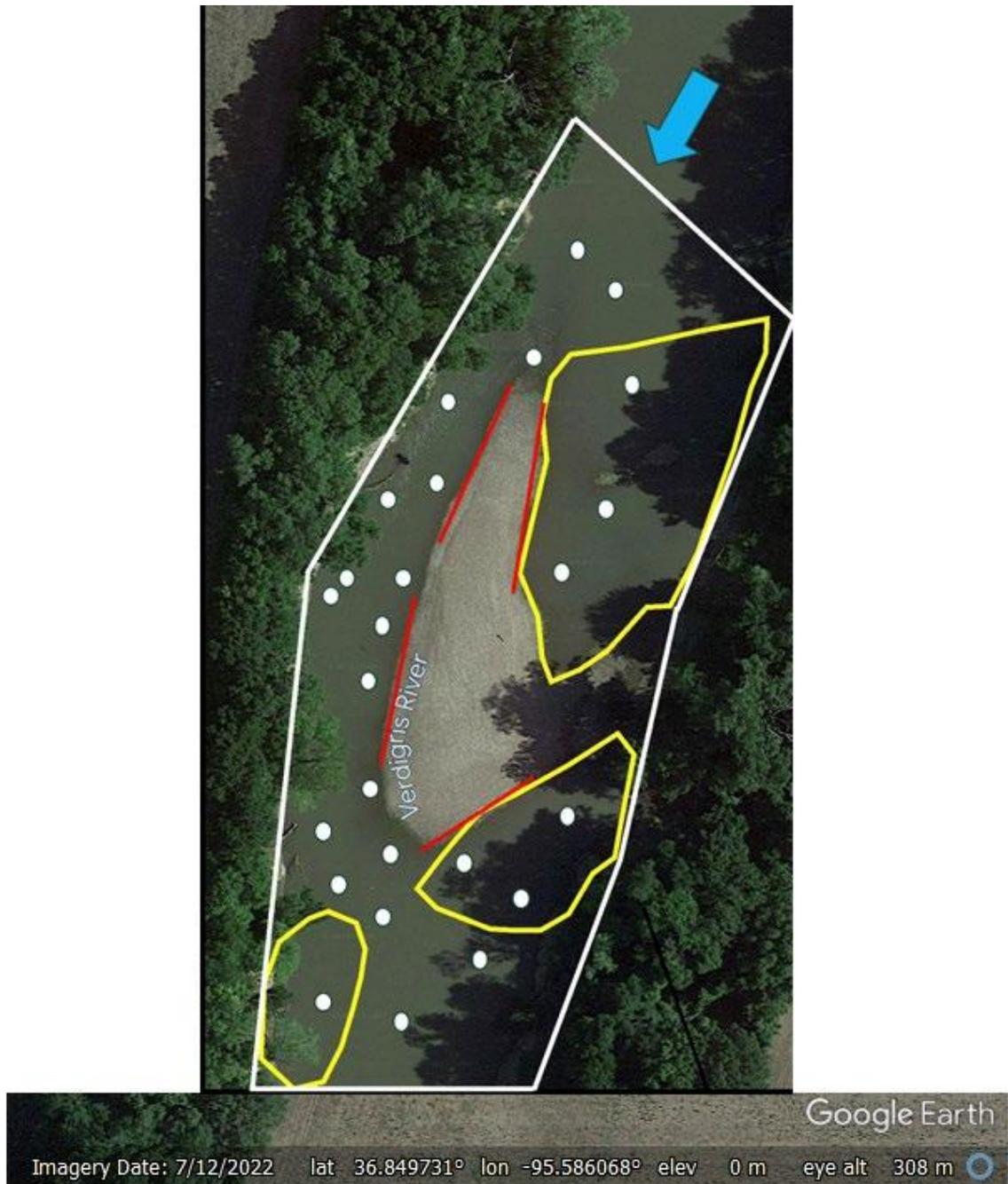Figure 2. Representative reach (Verdigris River 13 in northeastern Oklahoma) indicating boundary of sampling area (white line), transects of shell surveys (red lines), randomly distributed quadrats (white circles), recirculation zones (yellow polygons), and the direction of flow (blue arrow).
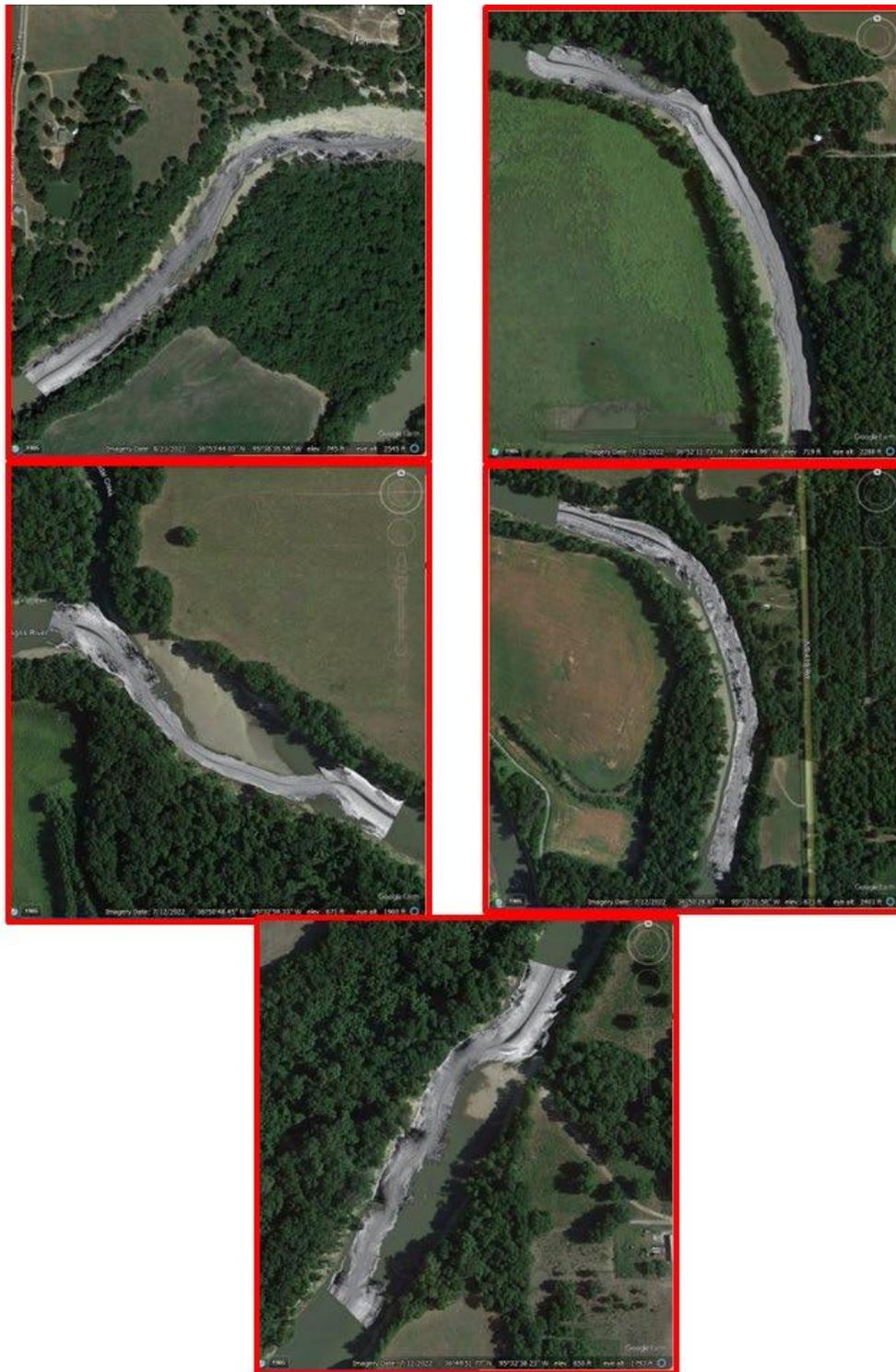
Figure 3. Side-scan sonar imagery at 5 reaches of the Verdigris River in northeastern Oklahoma recorded during the summer of 2023.

Figure 4. Mean number of quadrats (71.35) required to equal the species richness (15) observed during snorkel surveys across the entire Verdigris River, located in northeastern Oklahoma. A total of 250 quadrats were excavated across 10 sites on the Verdigris River. The black line displays the mean across all permutations, while dashed lines indicate the standard deviation.
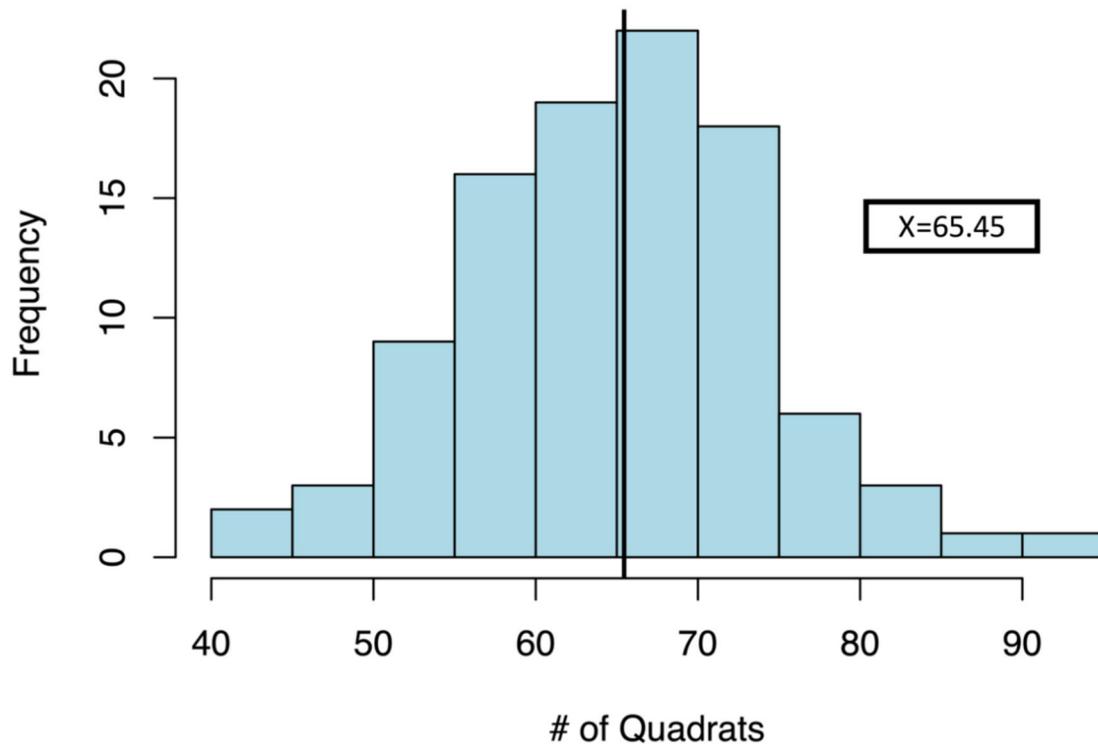
Figure 5. Mean number of quadrats (65.45) required to equal the abundance (322) observed during snorkel surveys across the entire Verdigris River, located in northeastern Oklahoma. A total of 250 quadrats were excavated across 10 sites on the Verdigris River.
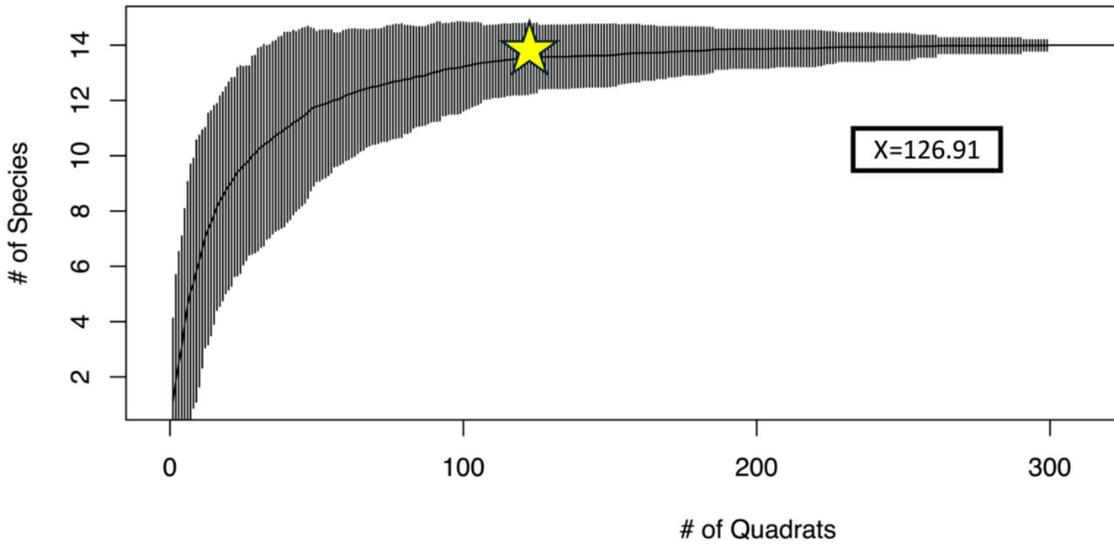
Figure 6. Mean number of quadrats (126.91) required to equal the species richness (14) observed during snorkel surveys across the entir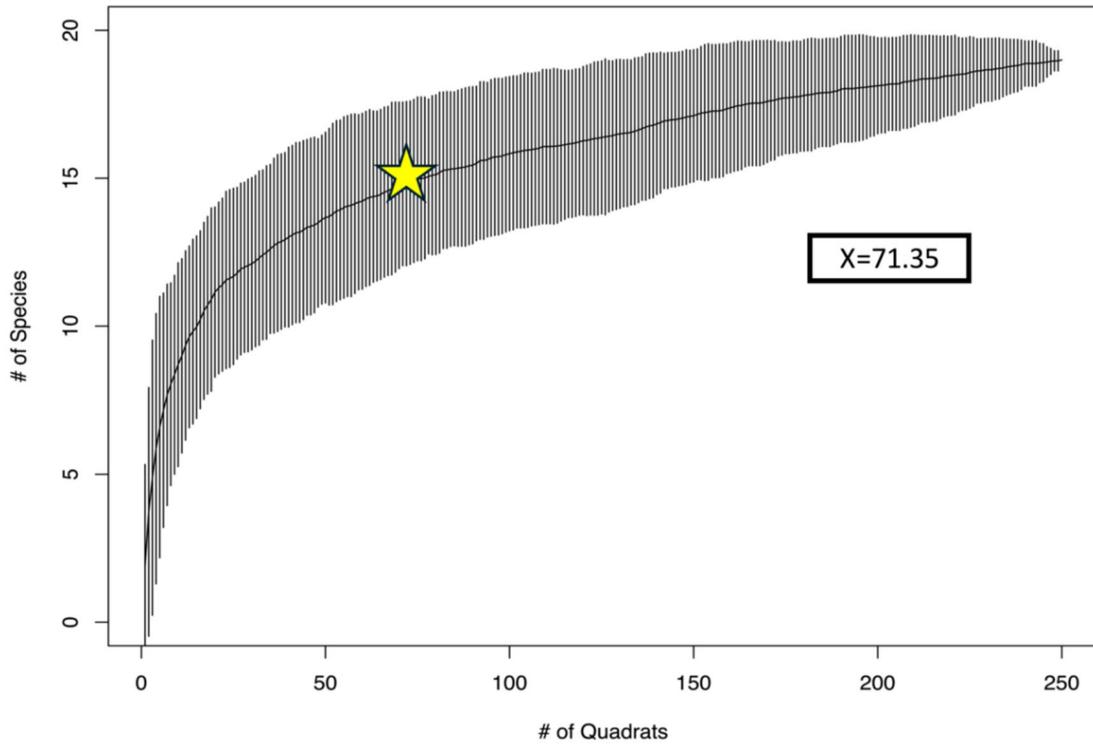e Caney River, located in northeastern Oklahoma. A total of 400 quadrats were excavated across 16 sites on the Caney River. The black line displays the mean across all permutations, while dashed lines indicate the standard deviation.
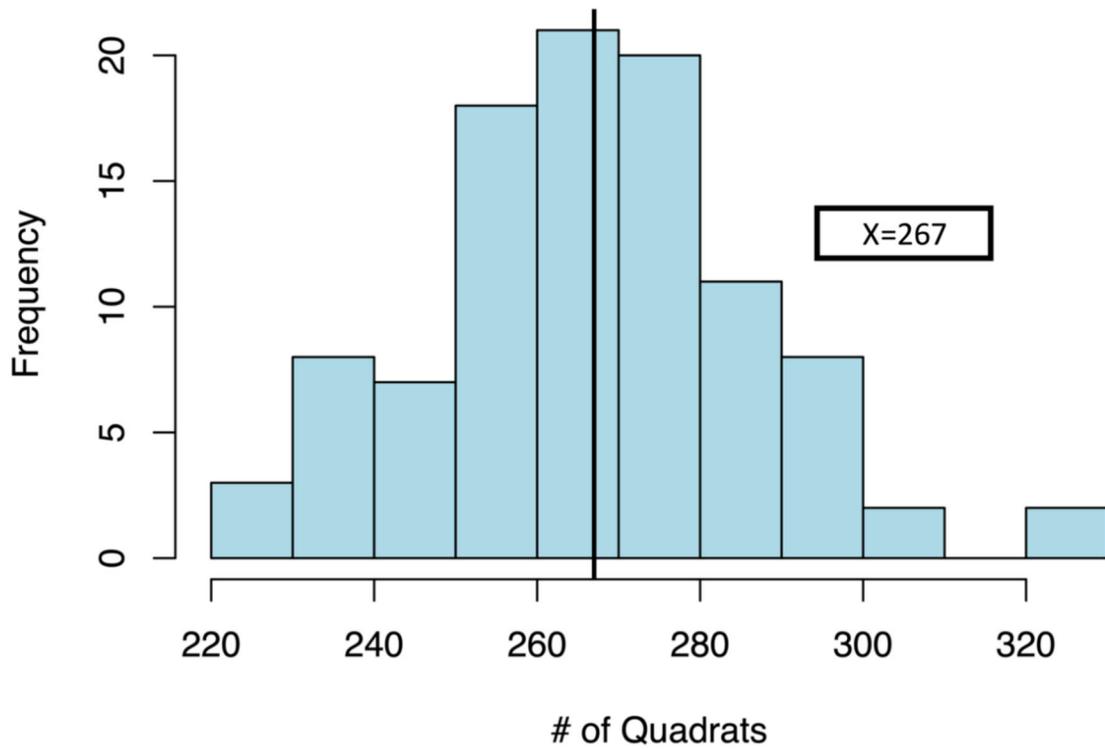
Figure 7. Mean number of quadrats (267) required to equal the abundance (342) observed during snorkel surveys across the entire Caney River, located in northeastern Oklahoma. A total of 400 quadrats were excavated across 16 sites on the Caney River.
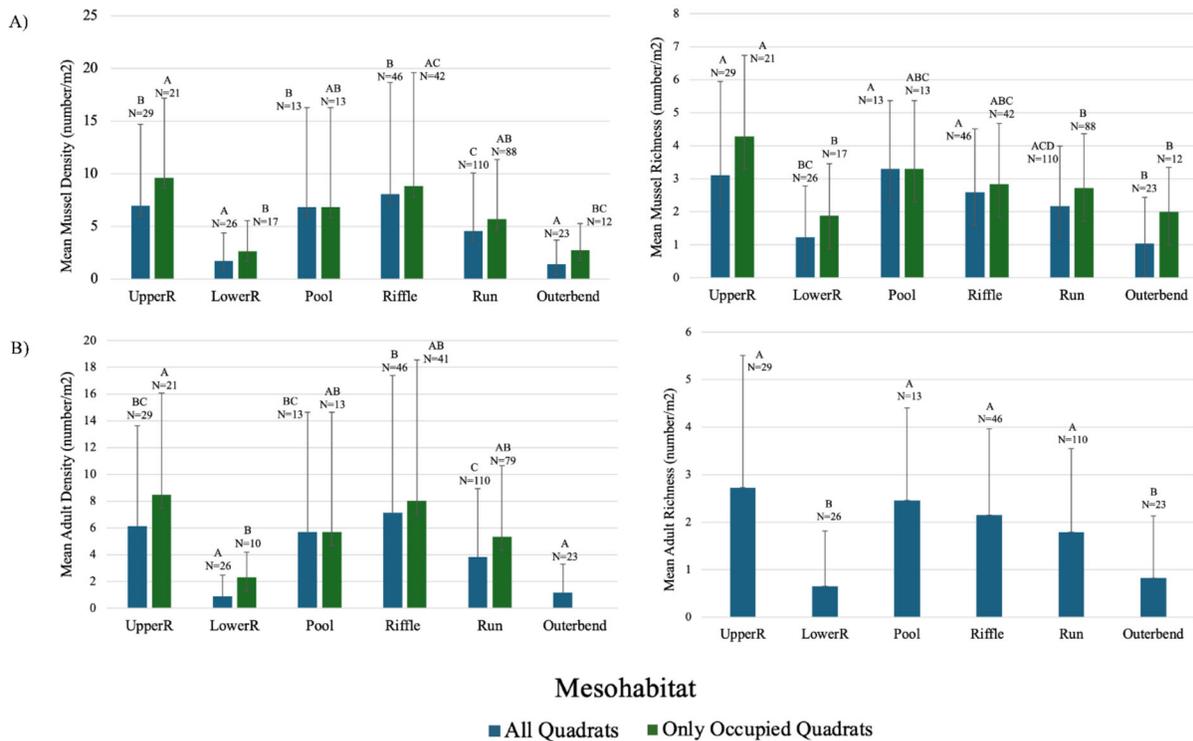
Figure 8. Mean density and richness (number per m²) and standard deviation for all mussels (A) and adult mussels (B) among mesohabitats from all quantitative surveys (including those without mussels) and from only occupied quadrats on the Verdigris River, located in northeastern Oklahoma. during the summer of 2023. UpperR = upper recirculation zone and LowerR= lower recirculation zone. Mesohabitats with n<10 were excluded.
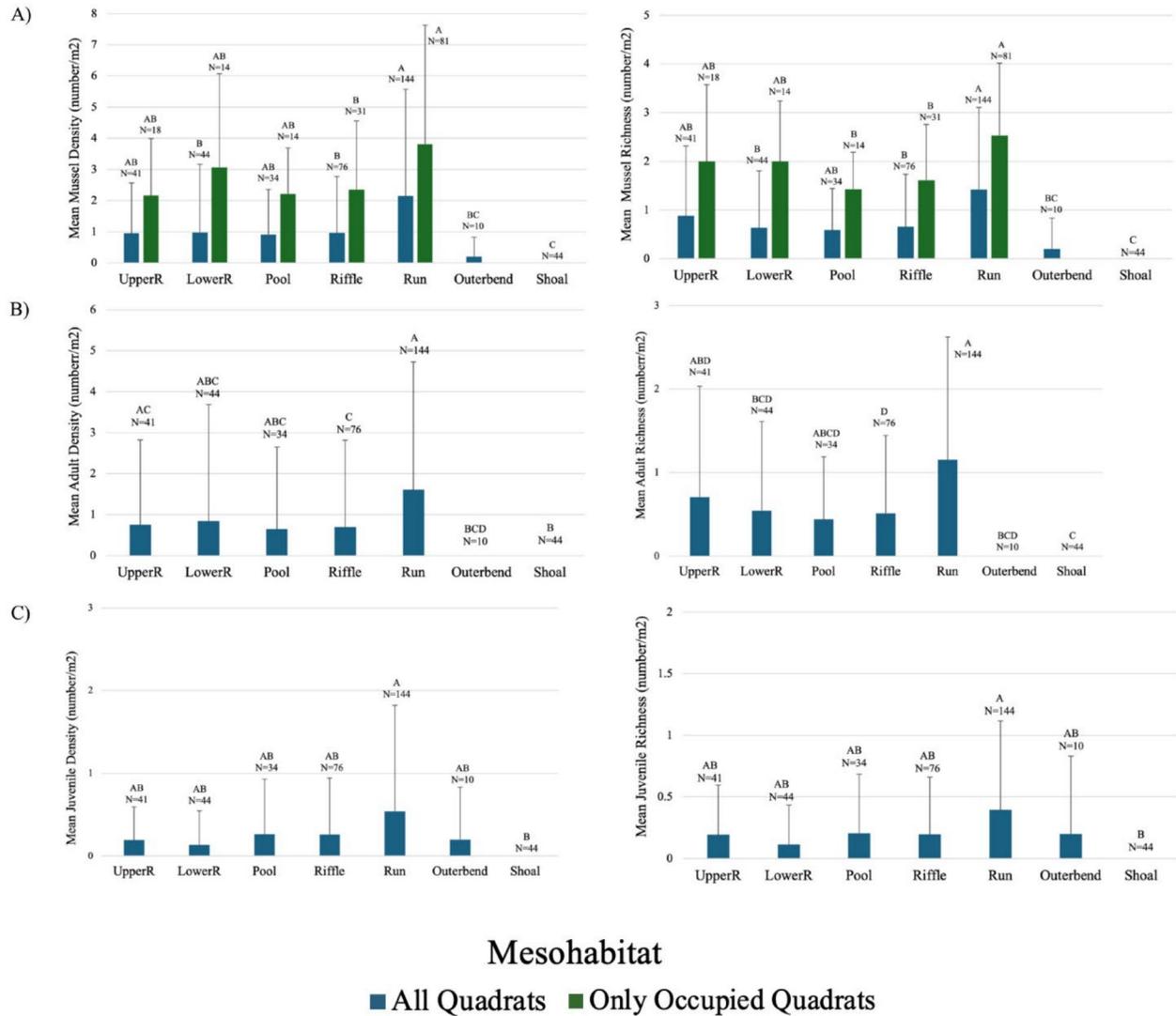
Figure 9. Mean density and richness (number per m^2) including standard deviation for all mussels (A), adult mussels (B), and juvenile mussel (C) among mesohabitats from all quantitative surveys (including those without mussels) and from only occupied quadrats on the Caney River, located in northeastern Oklahoma during the summers of 2023 and 2024. UpperR = upper recirculation zone and LowerR= lower recirculation zone. Mesohabitats with n<10 were excluded. No mussels were detected within shoals.

Appendix A. Qualitative and quantitative abundance of freshwater mussels at individual sample reaches in the Verdigris River and Caney River, Oklahoma in 2023 and 2024. NA indicates that abundance of dead shells was not calculated.

Verdigris River

Site: Boeckman 2

Coordinates: 36.987624, -95.584345

Species	Quantitative Abundance	Qualitative Abundance	Shell Presence
Fawnsfoot (*Truncilla donaciformis*)	16	1	No
Monkeyface (*Theliderma metanevra*)	15	7	Yes
Pistolgrip (*Quadrula verrucosa*)	24	3	No
Threehorn Wartyback (*Obliquaria reflexa*)	12	2	Yes
Pimpleback (*Pustulosa pustulosa*)	7	1	Yes
Fragile Papershell (*Potamilus fragilis*)	10	1	Yes
Plain Pocketbook (*Lampsilis cardium*)	2	0	No
Bleufer (*Potamilus purpuratus*)	10	1	Yes
Yellow Sandshell (*Lampsilis teres*)	3	0	Yes
Threeridge (*Amblema plicata*)	1	0	Yes
White Heelsplitter (*Lasmigona complanata*)	1	0	No
Round Pigtoe (*Pluerobema sintoxia*)	1	0	No
Pink Papershell (*Potamilus ohiensis*)	1	0	No
Western Fanshell (*Cyprogenia aberti*)	1	1	No
Total Abundance	**104**	**17**	**NA**
N Species	**14**	**8**	**7**

Verdigris River

Site: Boeckman 4

Coordinates: 36.984723, -95.587964

Species	Quantitative Abundance	Qualitative Abundance	Shell Presence
Fawnsfoot (*Truncilla donaciformis*)	12	0	No
Monkeyface (*Theliderma metanevra*)	28	22	Yes
Pistolgrip (*Quadrula verrucosa*)	9	3	Yes
Threehorn Wartyback (*Obliquaria reflexa*)	14	2	Yes
Pimpleback (*Pustulosa pustulosa*)	7	2	Yes
Fragile Papershell (*Potamilus fragilis*)	4	3	Yes
Bleufer (*Potamilus purpuratus*)	2	0	No
Yellow Sandshell (*Lampsilis teres*)	1	2	No
Threeridge (*Amblema plicata*)	1	0	No
Wartyback (*Pustulosa nodulata*)	5	2	Yes
Round Pigtoe (*Pluerobema sintoxia*)	1	0	Yes
Total Abundance	**84**	**36**	**NA**
N Species	**11**	**7**	**7**

Verdigris River

Site: Boeckman 6

Coordinates: 36.895809, -95.607158

Species	Quantitative Abundance	Qualitative Abundance	Shell Presence
Fawnsfoot (*Truncilla donaciformis*)	68	0	No
Monkeyface (*Theliderma metanevra*)	57	4	Yes
Pistolgrip (*Quadrula verrucosa*)	20	7	Yes
Threehorn Wartyback (*Obliquaria reflexa*)	11	0	Yes
Pimpleback (*Pustulosa pustulosa*)	4	0	No
Fragile Papershell (*Potamilus fragilis*)	1	1	Yes
Plain Pocketbook (*Lampsilis cardium*)	0	1	No
Bleufer (*Potamilus purpuratus*)	1	0	No
Yellow Sandshell (*Lampsilis teres*)	1	1	No
Threeridge (*Amblema plicata*)	0	0	Yes
White Heelsplitter (*Lasmigona complanata*)	2	0	No
Round Pigtoe (*Pluerobema sintoxia*)	1	0	No
Pink Papershell (*Potamilus ohiensis*)	1	0	No
Total Abundance	**167**	**14**	**NA**
N Species	**11**	**5**	**5**

Verdigris River

Site: Boeckman 8

Coordinates: 36.869167, -95.600833

Species	Quantitative Abundance	Qualitative Abundance	Shell Presence
Fawnsfoot (*Truncilla donaciformis*)	27	0	Yes
Monkeyface (*Theliderma metanevra*)	16	14	Yes
Pistolgrip (*Quadrula verrucosa*)	32	21	Yes
Threehorn Wartyback (*Obliquaria reflexa*)	3	4	Yes
Pimpleback (*Pustulosa pustulosa*)	9	0	Yes
Fragile Papershell (*Potamilus fragilis*)	9	0	Yes
Plain Pocketbook (*Lampsilis cardium*)	4	2	Yes
Bleufer (*Potamilus purpuratus*)	1	2	Yes
Yellow Sandshell (*Lampsilis teres*)	1	0	No
Wartyback (*Pustulosa nodulata*)	1	1	No
White Heelsplitter (*Lasmigona complanata*)	1	1	Yes
Round Pigtoe (*Pluerobema sintoxia*)	0	0	Yes
Western Fanshell (*Cyprogenia aberti*)	0	0	Yes
Total Abundance	**104**	**45**	**NA**
N Species	**11**	**7**	**11**

Verdigris River

Site: Boeckman 10

Coordinates: 36.870147, -95.594358

Species	Quantitative Abundance	Qualitative Abundance	Shell Presence
Fawnsfoot (*Truncilla donaciformis*)	39	0	No
Monkeyface (*Theliderma metanevra*)	21	9	Yes
Pistolgrip (*Quadrula verrucosa*)	19	5	Yes
Threehorn Wartyback (*Obliquaria reflexa*)	7	0	No
Pimpleback (*Pustulosa pustulosa*)	7	1	Yes
Fragile Papershell (*Potamilus fragilis*)	14	1	Yes
Plain Pocketbook (*Lampsilis cardium*)	4	0	Yes
Bleufer (*Potamilus purpuratus*)	1	1	Yes
Yellow Sandshell (*Lampsilis teres*)	2	0	No
Threeridge (*Amblema plicata*)	1	1	Yes
White Heelsplitter (*Lasmigona complanata*)	0	0	Yes
Ouachita Kidneyshell (*Ptychobranchus occidentalis*)	1	0	No
Total Abundance	**116**	**18**	**NA**
N Species	**11**	**6**	**8**

Verdigris River

Site: Boeckman 11

Coordinates: 36.870151, -95.580796

Species	Quantitative Abundance	Qualitative Abundance	Shell Presence
Fawnsfoot (*Truncilla donaciformis*)	33	0	No
Monkeyface (*Theliderma metanevra*)	79	19	Yes
Pistolgrip (*Quadrula verrucosa*)	53	18	Yes
Threehorn Wartyback (*Obliquaria reflexa*)	18	3	Yes
Pimpleback (*Pustulosa pustulosa*)	18	1	Yes
Fragile Papershell (*Potamilus fragilis*)	16	1	Yes
Plain Pocketbook (*Lampsilis cardium*)	5	1	Yes
Bleufer (*Potamilus purpuratus*)	6	0	Yes
Yellow Sandshell (*Lampsilis teres*)	2	0	No
Threeridge (*Amblema plicata*)	4	0	No
Wartyback (*Pustulosa nodulata*)	1	0	No
White Heelsplitter (*Lasmigona complanata*)	0	0	Yes
Round Pigtoe (*Pluerobema sintoxia*)	0	0	Yes
Pink Papershell (*Potamilus ohiensis*)	1	0	No
Wabash Pigtoe (*Fusconaia flava*)	1	0	No
Total Abundance	**237**	**43**	**NA**
N Species	**13**	**6**	**9**

Verdigris River

Site: Boeckman 13

Coordinates: 36.850268, -95.586127

Species	Quantitative Abundance	Qualitative Abundance	Shell Presence
Fawnsfoot (*Truncilla donaciformis*)	88	2	Yes
Monkeyface (*Theliderma metanevra*)	77	51	Yes
Pistolgrip (*Quadrula verrucosa*)	16	15	Yes
Threehorn Wartyback (*Obliquaria reflexa*)	27	10	Yes
Pimpleback (*Pustulosa pustulosa*)	18	7	Yes
Fragile Papershell (*Potamilus fragilis*)	10	3	Yes
Plain Pocketbook (*Lampsilis cardium*)	6	0	Yes
Bleufer (*Potamilus purpuratus*)	3	3	Yes
Yellow Sandshell (*Lampsilis teres*)	0	1	No
Threeridge (*Amblema plicata*)	4	1	Yes
Wartyback (*Pustulosa nodulata*)	4	0	No
Round Pigtoe (*Pluerobema sintoxia*)	1	1	No
Western Fanshell (*Cyprogenia aberti*)	1	2	Yes
Washboard (*Megalonaias nervosa*)	1	0	No
Wabash Pigtoe (*Fusconaia flava*)	0	1	No
Total Abundance	**256**	**97**	**NA**
N Species	**13**	**12**	**10**

Verdigris River

Site: Upstream BR

Coordinates: 36.845347, -95.550259

Species	Quantitative Abundance	Qualitative Abundance	Shell Presence
Fawnsfoot (*Truncilla donaciformis*)	40	0	Yes
Monkeyface (*Theliderma metanevra*)	13	9	Yes
Pistolgrip (*Quadrula verrucosa*)	1	0	Yes
Threehorn Wartyback (*Obliquaria reflexa*)	1	0	No
Pimpleback (*Pustulosa pustulosa*)	11	0	Yes
Fragile Papershell (*Potamilus fragilis*)	2	0	Yes
Plain Pocketbook (*Lampsilis cardium*)	4	2	Yes
Bleufer (*Potamilus purpuratus*)	0	0	Yes
Yellow Sandshell (*Lampsilis teres*)	0	0	Yes
Threeridge (*Amblema plicata*)	0	0	Yes
Pink Papershell (*Potamilus ohiensis*)	1	0	No
Total Abundance	**73**	**11**	**NA**
N Species	**8**	**2**	**9**

Verdigris River

Site: Boeckman 18

Coordinates: 36.841636, -95.541420

Species	Quantitative Abundance	Qualitative Abundance	Shell Presence
Fawnsfoot (*Truncilla donaciformis*)	8	0	Yes
Monkeyface (*Theliderma metanevra*)	7	5	Yes
Pistolgrip (*Quadrula verrucosa*)	30	15	Yes
Threehorn Wartyback (*Obliquaria reflexa*)	3	3	Yes
Pimpleback (*Pustulosa pustulosa*)	5	1	Yes
Fragile Papershell (*Potamilus fragilis*)	10	1	Yes
Plain Pocketbook (*Lampsilis cardium*)	9	2	Yes
Bleufer (*Potamilus purpuratus*)	8	0	Yes
Yellow Sandshell (*Lampsilis teres*)	4	0	No
Threeridge (*Amblema plicata*)	1	1	No
Wartyback (*Pustulosa nodulata*)	0	1	Yes
Western Fanshell (*Cyprogenia aberti*)	0	1	No
Wabash Pigtoe (*Fusconaia flava*)	0	1	No
Fatmucket (*Lampsilis siliquoidea*)	1	0	No
Total Abundance	**86**	**31**	**NA**
N Species	**11**	**10**	**9**

Verdigris River

Site: Boeckman 19

Coordinates: 36.830795, -95.544810

Species	Quantitative Abundance	Qualitative Abundance	Shell Presence
Fawnsfoot (*Truncilla donaciformis*)	14	0	Yes
Monkeyface (*Theliderma metanevra*)	0	4	Yes
Pistolgrip (*Quadrula verrucosa*)	0	2	Yes
Threehorn Wartyback (*Obliquaria reflexa*)	0	0	Yes
Pimpleback (*Pustulosa pustulosa*)	4	2	Yes
Fragile Papershell (*Potamilus fragilis*)	4	1	Yes
Plain Pocketbook (*Lampsilis cardium*)	2	1	Yes
Bleufer (*Potamilus purpuratus*)	2	0	Yes
Yellow Sandshell (*Lampsilis teres*)	2	0	No
Wabash Pigtoe (*Fusconaia flava*)	0	0	Yes
Total Abundance	**28**	**10**	**NA**
N Species	**6**	**5**	**9**

Caney River

Site: A

Coordinates: 36.995055, -96.279500

Species	Quantitative Abundance	Qualitative Abundance	Shell Presence
Pistolgrip (*Quadrula verrucosa*)	0	0	Yes
Threehorn Wartyback (*Obliquaria reflexa*)	1	0	Yes
Pimpleback (*Pustulosa pustulosa*)	7	0	No
Fragile Papershell (*Potamilus fragilis*)	8	1	Yes
Plain Pocketbook (*Lampsilis cardium*)	3	2	Yes
Bleufer (*Potamilus purpuratus*)	1	0	Yes
Yellow Sandshell (*Lampsilis teres*)	2	0	Yes
Total Abundance	**22**	**3**	**NA**
N Species	**6**	**2**	**6**

Caney River

Site: AB

Coordinates: 36.992063, -96.276148

Species	Quantitative Abundance	Qualitative Abundance	Shell Presence
Threehorn Wartyback (*Obliquaria reflexa*)	0	0	Yes
Pimpleback (*Pustulosa pustulosa*)	0	0	Yes
Bleufer (*Potamilus purpuratus*)	0	0	Yes
Plain Pocketbook (*Lampsilis cardium*)	0	1	Yes
Total Abundance	**0**	**1**	**NA**
N Species	**0**	**1**	**4**

Caney River

Site: B

Coordinates: 36.995349, -96.265196

Species	Quantitative Abundance	Qualitative Abundance	Shell Presence
Pistolgrip (*Quadrula verrucosa*)	2	0	Yes
Threehorn Wartyback (*Obliquaria reflexa*)	2	0	No
Pimpleback (*Pustulosa pustulosa*)	5	0	Yes
Fragile Papershell *(Potamilus fragilis*)	4	2	No
Plain Pocketbook (*Lampsilis cardium*)	6	7	Yes
Bleufer (*Potamilus purpuratus*)	1	1	Yes
Yellow Sandshell (*Lampsilis teres*)	1	0	Yes
Total Abundance	**21**	**10**	**NA**
N Species	**7**	**3**	**5**

Caney River

Site: Boeckman 10

Coordinates: 36.878980, -96.012828

Species	Quantitative Abundance	Qualitative Abundance	Shell Presence
Pistolgrip (*Quadrula verrucosa*)	8	1	No
Threehorn Wartyback (*Obliquaria reflexa*)	12	1	Yes
Pimpleback (*Pustulosa pustulosa*)	17	1	Yes
Fragile Papershell (*Potamilus fragilis*)	3	0	Yes
Yellow Sandshell (*Lampsilis teres*)	3	0	Yes
Pink Papershell (*Potamilus ohiensis)*	3	0	No
Threeridge *(Amblema plicata)*	1	0	No
Wartyback (*Pustulosa nodulata*)	14	2	Yes
White Heelsplitter (*Lasmigona complanata*)	1	0	Yes
Bleufer (*Potamilus purpuratus*)	1	0	Yes
Fawnsfoot (*Truncilla donaciformis*)	16	0	No
Paper Pondshell (*Utterbackia imbecillis)*	0	0	Yes
Wabash Pigtoe (*Fusconaia flava*)	32	3	Yes
Total Abundance	**111**	**8**	**NA**
N Species	**12**	**5**	**9**

Caney River

Site: Boeckman 13

Coordinates: 36.833537, -95.956670

Species	Quantitative Abundance	Qualitative Abundance	Shell Presence
Pistolgrip (*Quadrula verrucosa*)	1	0	No
Threehorn Wartyback (*Obliquaria reflexa*)	1	0	No
Pimpleback (*Pustulosa pustulosa*)	0	1	No
Fragile Papershell (*Potamilus fragilis*)	1	0	Yes
Yellow Sandshell (*Lampsilis teres*)	0	0	Yes
Wartyback (*Pustulosa nodulata*)	1	1	Yes
White Heelsplitter (*Lasmigona complanata*)	0	1	No
Bleufer (*Potamilus purpuratus*)	0	0	Yes
Fawnsfoot (*Truncilla donaciformis*)	1	0	No
Plain Pocketbook (*Lampsilis cardium*)	1	0	No
Total Abundance	**6**	**3**	**NA**
N Species	**6**	**3**	**4**

Caney River

Site: Boeckman 17

Coordinates: 36.756821, -95.967364

Species	Quantitative Abundance	Qualitative Abundance	Shell Presence
Pistolgrip (*Quadrula verrucosa*)	6	10	No
Threehorn Wartyback (*Obliquaria reflexa*)	2	0	No
Pimpleback (*Pustulosa pustulosa*)	2	1	No
Fragile Papershell (*Potamilus fragilis*)	2	3	Yes
Yellow Sandshell (*Lampsilis teres*)	1	2	Yes
Wartyback (*Pustulosa nodulata*)	0	1	No
Bleufer (*Potamilus purpuratus*)	2	0	No
Fawnsfoot (*Truncilla donaciformis*)	3	0	Yes
Plain Pocketbook (*Lampsilis cardium*)	1	0	No
Total Abundance	**19**	**17**	**NA**
N Species	**8**	**5**	**3**

Caney River

Site: Boeckman 19

Coordinates: 36.744068, -95.963119

Species	Quantitative Abundance	Qualitative Abundance	Shell Presence
Pistolgrip (*Quadrula verrucosa*)	4	42	Yes
Threehorn Wartyback (*Obliquaria reflexa*)	2	0	Yes
Pimpleback (*Pustulosa pustulosa*)	3	2	Yes
Fragile Papershell (*Potamilus fragilis*)	0	1	Yes
Yellow Sandshell (*Lampsilis teres*)	0	1	Yes
Wartyback (*Pustulosa nodulata*)	1	0	No
Wabash Pigtoe (*Fusconaia flava*)	0	1	Yes
Total Abundance	**10**	**47**	**NA**
N Species	**4**	**5**	**6**

Note: Shells of Fawnsfoot (*Truncilla donaciformis)* were also found during quantitative sampling.

Caney River

Site: Boeckman 20

Coordinates: 36.719979, -95.963442

Species	Quantitative Abundance	Qualitative Abundance	Shell Presence
Pistolgrip (*Quadrula verrucosa*)	20	16	Yes
Threehorn Wartyback (*Obliquaria reflexa*)	27	7	Yes
Pimpleback (*Pustulosa pustulosa*)	22	2	Yes
Fragile Papershell (*Potamilus fragilis*)	3	0	Yes
Bleufer (*Potamilus purpuratus*)	0	0	Yes
Yellow Sandshell (*Lampsilis teres*)	1	1	Yes
Wartyback (*Pustulosa nodulata*)	2	2	Yes
White Heelsplitter (*Lasmigona complanata*)	1	0	No
Wabash Pigtoe (*Fusconaia flava*)	0	1	No
Total Abundance	**76**	**29**	**NA**
N Species	**7**	**6**	**7**

Note: Shells of Fawnsfoot (*Truncilla donaciformis)* were also found during quantitative sampling.

Caney River

Site: Boeckman 23

Coordinates: 36.698146, -95.961524

Species	Quantitative Abundance	Qualitative Abundance	Shell Presence
Pistolgrip (*Quadrula verrucosa*)	17	31	Yes
Threehorn Wartyback (*Obliquaria reflexa*)	11	4	Yes
Pimpleback (*Pustulosa pustulosa*)	11	1	Yes
Fragile Papershell (*Potamilus fragilis*)	7	0	Yes
Yellow Sandshell (*Lampsilis teres*)	0	1	Yes
Wartyback (*Pustulosa nodulata*)	1	0	No
Bleufer (*Potamilus purpuratus*)	0	1	Yes
Fawnsfoot (*Truncilla donaciformis*)	3	0	Yes
Wabash Pigtoe (*Fusconaia flava*)	1	1	Yes
Total Abundance	**51**	**39**	**NA**
N Species	**7**	**6**	**8**

Caney River

Site: Boeckman 24

Coordinates: 36.679535, -95.972331

Species	Quantitative Abundance	Qualitative Abundance	Shell Presence
Pistolgrip (*Quadrula verrucosa*)	6	0	Yes
Threehorn Wartyback (*Obliquaria reflexa*)	6	0	Yes
Pimpleback (*Pustulosa pustulosa*)	4	0	Yes
Fragile Papershell (*Potamilus fragilis*)	6	0	Yes
Yellow Sandshell (*Lampsilis teres*)	1	0	No
Wartyback (*Pustulosa nodulata*)	11	1	Yes
Bleufer (*Potamilus purpuratus*)	1	0	No
Fawnsfoot (*Truncilla donaciformis*)	2	0	No
Wabash Pigtoe (*Fusconaia flava*)	4	0	Yes
Pink Papershell (*Potamilus ohiensis)*	1	0	No
Total Abundance	**42**	**1**	**NA**
N Species	**10**	**1**	**6**

Note: One weathered Rabbitsfoot (*Theliderma cylindrica*) shell was also found during quantitative sampling.

Caney River

Site: Boeckman 26

Coordinates: 36.641377, -95.931586

Species	Quantitative Abundance	Qualitative Abundance	Shell Presence
Pistolgrip (*Quadrula verrucosa*)	2	1	Yes
Threehorn Wartyback (*Obliquaria reflexa*)	0	0	Yes
Pimpleback (*Pustulosa pustulosa*)	1	0	Yes
Fragile Papershell (*Potamilus fragilis*)	2	1	Yes
Bleufer (*Potamilus purpuratus*)	0	1	Yes
Yellow Sandshell (*Lampsilis teres*)	0	1	Yes
Threeridge (*Amblema plicata*)	0	0	Yes
Wartyback (*Pustulosa nodulata*)	0	0	Yes
Paper Pondshell (*Utterbackia imbecillis)*	0	0	Yes
Mapleleaf *(Quadrula quadrula*)	0	0	Yes
Total Abundance	**5**	**4**	**NA**
N Species	**3**	**4**	**10**

Note: Shells of Fawnsfoot (*Truncilla donaciformis)* were also found during quantitative sampling

Caney River

Site: Boeckman 27

Coordinates: 36.583961, -95.856355

Species	Quantitative Abundance	Qualitative Abundance	Shell Presence
Pistolgrip (*Quadrula verrucosa*)	1	12	Yes
Threehorn Wartyback (*Obliquaria reflexa*)	0	2	Yes
Pimpleback (*Pustulosa pustulosa*)	1	0	Yes
Fragile Papershell (*Potamilus fragilis*)	1	8	Yes
Bleufer (*Potamilus purpuratus*)	0	1	Yes
Yellow Sandshell (*Lampsilis teres*)	0	5	Yes
White Heelsplitter (*Lasmigona complanata*)	0	1	No
Pink Papershell (*Potamilus ohiensis*)	0	0	Yes
Total Abundance	**3**	**29**	**NA**
N Species	**3**	**6**	**7**

Note: One Pink Papershell (*Potamilus ohiensis)* was also observed outside of quantitative and qualitative sampling.

Caney River

Site: E

Coordinates: 36.445863, -95.833483

Species	Quantitative Abundance	Qualitative Abundance	Shell Presence
Pistolgrip (*Quadrula verrucosa*)	1	6	Yes
Threehorn Wartyback (*Obliquaria reflexa*)	1	0	No
Pimpleback (*Pustulosa pustulosa*)	0	0	Yes
Fragile Papershell (*Potamilus fragilis*)	3	0	Yes
Yellow Sandshell (*Lampsilis teres*)	1	4	Yes
Wartyback (*Pustulosa nodulata*)	2	0	Yes
Bleufer (*Potamilus purpuratus*)	1	0	Yes
Pink Papershell (*Potamilus ohiensis*)	1	0	Yes
Fawnsfoot (*Truncilla donaciformis*)	0	0	Yes
White Heelsplitter (*Lasmigona complanata*)	0	1	No
Total Abundance	**10**	**11**	**NA**
N Species	**7**	**3**	**8**

Caney River

Site: West C

Coordinates: 36.352498, -95.717275

Species	Quantitative Abundance	Qualitative Abundance	Shell Presence
Fawnsfoot (*Truncilla donaciformis*)	2	2	Yes
Monkeyface (*Theliderma metanevra*)	3	38	Yes
Pistolgrip (*Quadrula verrucosa*)	4	11	Yes
Threehorn Wartyback (*Obliquaria reflexa*)	7	13	Yes
Pimpleback (*Pustulosa pustulosa*)	2	2	Yes
Fragile Papershell (*Potamilus fragilis*)	1	4	Yes
Plain Pocketbook (*Lampsilis cardium*)	1	5	No
Bleufer (*Potamilus purpuratus*)	0	12	Yes
Threeridge (*Amblema plicata*)	4	20	No
Wartyback (*Pustulosa nodulata*)	9	1	No
Rabbitsfoot (*Theliderma cylindrica*)	0	4	No
Yellow Sandshell (Lampsilis teres)	1	1	Yes
Pink Papershell (*Potamilus ohiensis)*	2	0	Yes
Wabash Pigtoe (*Fusconaia flava*)	1	9	Yes
Total Abundance	**37**	**122**	**NA**
N Species	**12**	**13**	**10**

Note: Fresh Rabbitsfoot (*Theliderma cylindrica*) shells were observed outside of shell surveys.

Caney River

Site: East C

Coordinates: 36.351153, -95.713284

Species	Quantitative Abundance	Qualitative Abundance	Shell Presence
Fawnsfoot (*Truncilla donaciformis*)	6	0	No
Monkeyface (*Theliderma metanevra*)	12	10	No
Pistolgrip (*Quadrula verrucosa*)	3	1	Yes
Threehorn Wartyback (*Obliquaria reflexa*)	6	2	No
Pimpleback (*Pustulosa pustulosa*)	4	1	No
Fragile Papershell (*Potamilus fragilis*)	6	0	Yes
Plain Pocketbook (*Lampsilis cardium*)	3	2	No
Bleufer (*Potamilus purpuratus*)	2	0	Yes
Threeridge (*Amblema plicata*)	2	0	Yes
Wartyback (*Pustulosa nodulata*)	5	0	Yes
Pink Papershell (*Potamilus ohiensis)*	1	0	No
Wabash Pigtoe (*Fusconaia flava*)	3	0	No
Total Abundance	**53**	**16**	**NA**
N Species	**12**	**5**	**5**

Note: One Yellow Sandshell (*Lampsilis teres*) was also observed outside of quantitative and qualitative sampling.

Caney River

Site: M

Coordinates: 36.338794, -95.716427

Species	Quantitative Abundance	Qualitative Abundance	Shell Presence
Fawnsfoot (*Truncilla donaciformis*)	5	0	No
Monkeyface (*Theliderma metanevra*)	9	1	Yes
Pistolgrip (*Quadrula verrucosa*)	5	0	Yes
Threehorn Wartyback (*Obliquaria reflexa*)	3	0	No
Pimpleback (*Pustulosa pustulosa*)	3	0	No
Fragile Papershell (*Potamilus fragilis*)	10	0	Yes
Plain Pocketbook (*Lampsilis cardium*)	2	0	No
Bleufer (*Potamilus purpuratus*)	2	0	Yes
Yellow Sandshell (*Lampsilis teres*)	0	1	Yes
Wartyback (*Pustulosa nodulata*)	2	0	No
White Heelsplitter (*Lasmigona complanata*)	1	0	No
Pink Papershell (*Potamilus ohiensis)*	3	0	No
Wabash Pigtoe (*Fusconaia flava*)	1	0	No
Total Abundance	**46**	**2**	**NA**
N Species	**12**	**2**	**5**

Note: This site was surveyed earlier the same year, during backwater flooding from the Verdigris River, resulting in water too deep to adequately sample. Limited quantitative sampling found 1 Threeridge (*Amblema plicata*), 2 Fragile Papershell (*Potamilus fragilis*), and 1 Bleufer (*Potamilus purpuratus*). No mussels were documented during qualitative sampling.