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Status and Distribution of Freshwater Mussels in the Louisiana Section of Bayou Bartholomew

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Abstract: As a major tributary to the species-rich Ouachita River and one of the few remaining non-channelized rivers in the Alluvial Plains physiographic division, Bayou Bartholomew is a key ecosystem for the freshwater mussel diversity of southeast Arkansas and northeast Louisiana. Bayou Bartholomew is known to contain 16 mussel Species of Greatest Conservation Need (SGCN) but the mussel assemblage of the Louisiana section of Bayou Bartholomew has not been assessed since the early 2000s. In 2021, we sampled over 100 river km on the main channel of Bayou Bartholomew and four tributaries from just downstream of the Louisiana/Arkansas border to the confluence with the Ouachita River. We used a novel two-phase timed-search protocol to characterize the mussel assemblage and measured shell length (long axis) to determine the size distribution of each species encountered. A suite of relevant habitat variables and site attributes were also quantified or qualitatively noted. One site was selected for sampling using a grid survey to determine quantitative estimates of mussel density. Our survey confirmed the presence of 35 species including 12 SGCN in the Louisiana section of the Bayou Bartholomew drainage. In total, 3,292 live mussels representing 33 species were collected in the main channel, 234 live mussels representing 18 species were found in a quantitative grid, and four species were found in tributaries. Two additional species were only found in tributaries as dead shells. Length frequencies of all common and abundant species indicated ongoing annual recruitment. Patterns of ubiquity in the main channel of Bayou Bartholomew varied by species, and mussels were rare in the tributaries. Generalized linear modelling and non-metric multidimensional scaling analyses identified relationships between mussel assemblage composition and the distance from the confluence with the Ouachita River and habitat variables including substrates, depth, and mesohabitat types. A comparison with previous studies did not provide any evidence of major changes in overall mussel species distributions or occurrence in Bayou Bartholomew in Louisiana. We attribute the apparent stability in the mussel assemblage to the fact that major anthropogenic alterations such as channelization, impoundments, and watershed urbanization have been minimal since the earlier studies, and we conclude that Bayou Bartholomew will likely continue to be a hotspot of regional mussel diversity and a haven for several of Louisiana's SGCN if large-scale anthropogenic alterations to the system do not occur and management actions are taken to protect and allow for the persistence of heterogenous habitats.

Key words: Unionidae, endangered species, extirpated species, aquatic mollusks

Bayou Bartholomew is a key ecosystem for the aquatic biodiversity of southeast Arkansas and northeast Louisiana due to its speciose fish and freshwater mussel assemblages (Pezold *et al.* 2002). This slow-moving river is a major tributary of the Ouachita River and is the only remaining non-channelized river in the Alluvial Plains physiographic division region (Brooks *et al.* 2008). The Ouachita River is the principal drainage for south Arkansas and northeast Louisiana, has a total watershed area of approximately 67,340 km^2, and is part of the Mississippi Embayment – a region that contains 59 species of freshwater mussels (Haag 2012). The Louisiana portion of the Ouachita basin is approximately 26,900 km^2 of rich alluvial plains cultivated in soybeans, cotton, and corn (Holcomb *et al.* 2015).

A limited number of past studies have confirmed high mussel diversity in both the Louisiana and Arkansas sections of Bayou Bartholomew (Appendix 1). George and Vidrine (1993) observed 29 species in a 6 km section of Bayou Bartholomew centered around the confluence with Bayou Chemin-a-Haut. In a more extensive survey, Vidrine (1995) reported 37 species in Bayou Bartholomew at 28 sites on the main channel in Louisiana and in two off-channel tributaries (Bartholomew Lake and Bayou DiSiard). Neither study reported the number of individuals captured or the amount of time spent searching for mussels at each site (Catch Per Unit Effort, or CPUE). Pezold *et al.* (2002) reported 32 species at 50 sites in the main channel of Bayou Bartholomew in Louisiana and reported the cumulative number of live individuals,

dead specimens, and CPUE; in all, 5,873 live individuals and 1,235 dead specimens were collected. Pezold *et al.* (2002) commented that the number of dead mussels appeared to be high and attributed this observation to the coincidence of severe drought conditions in the summer and fall of 2000 when the survey was conducted and increased demand for water from the bayou for crop irrigation. Except for the two off-channel locations sampled by Vidrine (1995), prior to our survey the only mussels reported in a tributary to Bayou Bartholomew in Louisiana were *Lampsilis teres* (Rafinesque, 1820) collected in 1988 and *Sagittunio subrostratus* (Say, 1831) collected in 1992 from Chemin-a-Haut Bayou and deposited in the mollusk collection at the Illinois Natural History Survey (https://invertebase.org/portal/). In the Arkansas section of Bayou Bartholomew, Brooks *et al.* (2008) reported the number of live individuals and dead shells of 35 species across 50 sites, including eight Arkansas species of special concern. At two archaeological sites in Drew County, Arkansas (Taylor Site and Tillar Farms), Peacock *et al.* (2013) found 44 species. In these two studies, 48 mussel species have been reported from Bayou Bartholomew in Arkansas.

Freshwater mussels are one of the most imperiled faunal groups in North America (Haag 2012). Across Louisiana, approximately 63 species have been reported (Vidrine 2019) based on currently recognized taxonomy. In the Louisiana section of Bayou Bartholomew alone, approximately 38 species have been reported but the validity of several species is questionable and undoubtedly this number will change with advances in species level genetic evidence. There are 16 species of greatest conservation need (SGCN) historically occurring in the lower reaches of Bayou Bartholomew (Holcomb *et al.* 2015, Appendix 2). The distribution of mussels in the Louisiana portion of Bayou Bartholomew has not been assessed since Pezold *et al.* (2002). The primary purpose of our study was to evaluate the current mussel assemblage structure of this system, with a focus on SGCN.

MATERIALS AND METHODS

Study area and sampling sites

Bayou Bartholomew originates in the loess hills near Pine Bluff, Arkansas and flows in a primarily southward direction for 457 km to the confluence with the Ouachita River in Louisiana. The lower 113 km of Bayou Bartholomew are within Morehouse Parish, Louisiana, and receive flow from Bayou Chemin-a-Haut, Bayou de Glaize, Cypress Bayou, Caney Bayou, Horse Bayou, and Bayou Disiard. Our study area included the main channel of Bayou Bartholomew and four tributaries: Bayou Chemin-a-Haut, Bayou de Glaize, Cypress Bayou, and Horse Bayou. Between 23 September and 3 October 2021, we sampled 25 sites on the main channel of Bayou Bartholomew from just downstream of the Louisiana/Arkansas border to the confluence with the Ouachita River, two sites on Bayou Chemin-a-Haut, and one site each on Bayou de Glaize, Cypress Bayou, and Horse Bayou (Fig. 1). To the degree possible, the 25 sites on the main channel were distributed evenly across the study area.

Timed searches and habitat evaluation

A two-phase timed search protocol was designed and used to sample the mussel assemblage at each site. In Phase 1, a crew of three to five investigators searched for mussels for a summed effort of one person-hour. In shallow water (depths generally < 1 m) where the substrate was dominated by roots and submerged woody debris, investigators searched for mussels using their hands. A rake was used in areas where depths were between 1 and 1.5 m and the substrate was uncluttered by woody debris. A surface supplied air system was used in habitats that were too deep to probe by hand or rake. During Phase 1, the sampling crew worked independently and was spatially distributed across a wide area; each investigator collected mussels using the technique they had selected for that site. Following the Phase 1 search, the sampling crew examined the relative abundance and species richness found in their individual efforts and identified the area harboring the greatest mussel species richness and abundance. Based on the results of Phase 1, a one person-hour group search (Phase 2) was conducted in this area of greatest species richness and abundance. Each searcher repeated the method they had used in Phase 1.

In Phase 1, each sampler's catch was individually quantified and in Phase 2 the catch of the group search was pooled. From the pool of live mussels found in both phases, 25 individuals of each species were measured to the nearest mm (long axis). Shells were considered fresh dead if both valves were present, the periostracum was intact, and the nacre lustrous. Fresh dead shells were recorded as a positive occurrence when the species was not present as a live individual.

A suite of relevant habitat variables and site attributes were quantified or qualitatively noted at each site immediately following timed searches. The total length of the bayou searched by the investigators and the median width of the channel was measured using a laser rangefinder. The predominant depth searched, the percent bottom covered by Wentworth substrate classes, and the percent area of the sampling reach in three macrohabitat classes (pool, run, or edgewater) were all estimated by consensus. Dominant bank height and bank erosion were each classified using visual evaluations; bank height was classified as low (0–2 m), intermediate (2–5 m), or high (5–10 m) and the severity of bank erosion was classified as low, moderate, or severe. Additionally, we noted the approximate speed of the surface water and presence of significant habitat or anthropogenic features.

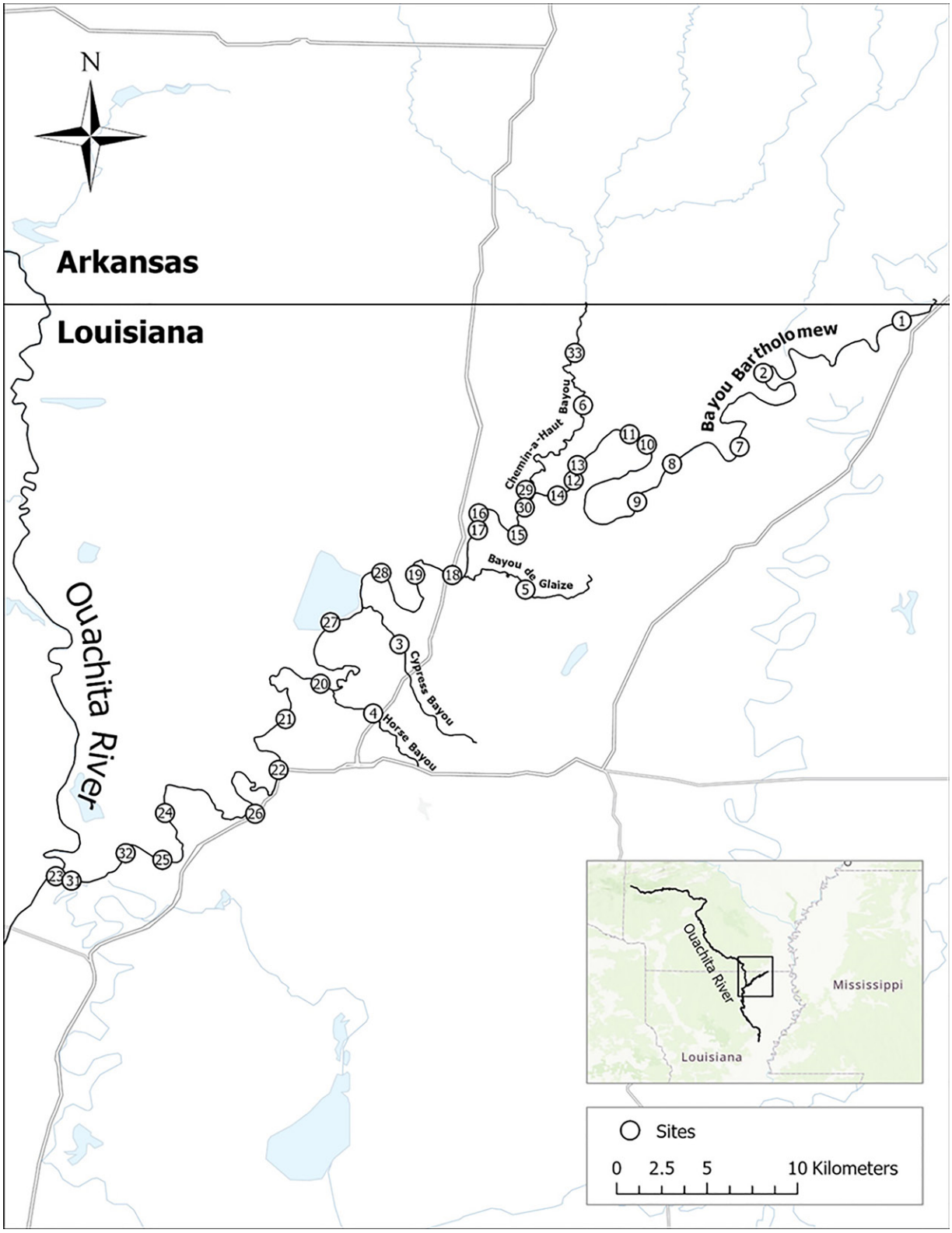

Figure 1. Map of Bayou Bartholomew sampling sites in Louisiana.

Quantitative grid sampling

An intensive quantitative grid site was selected based on several factors, including mussel diversity and abundance observed during a timed search, relative ease of access, and shallow, uniform depth. These combined factors led us to select the shoal along the right descending bank adjacent to Site 20, and sampling was conducted on 29 September 2021. We quantified mussel density in a 5 m × 5 m square grid separated into 5, 1 m wide parallel lanes. Each lane was split along the long axis and divided into 10 units 0.5 m long. We then randomly selected 6 0.25 m^2 quadrats in each lane, and each quadrat was excavated to a depth of approximately 15 cm. Substrate within the quadrat was placed in a large bucket and taken to shore where the contents were examined on a large, white table. All live mussels in each quadrat were identified to species and measured to the nearest mm (long axis). At the conclusion of the quantitative sampling, all live mussels were returned to the grid area.

Taxonomy

Several mussel species historically occurring in Bayou Bartholomew are difficult to identify using shell characters. Peacock *et al.* (2013) noted the similarity of conchological characters in *Toxolasma parvum* (Barnes, 1823) and *Toxolasma texasiense* (Lea, 1857) and discussed conchological differences between *Lampsilis hydiana* (Lea, 1838) and *Lampsilis siliquoidea* (Barnes, 1823) from two Arkansas archaeological sites associated with Bayou Bartholomew. They combined *Lampsilis cardium* Rafinesque, 1820 and *Lampsilis satura* (Lea, 1852) due to morphological similarity between the two species and reported them as *L. cardium/satura*. In our study, we separated *L. cardium* and *L. satura*. We followed the nomenclature of Williams *et al.* (2017), Watters (2018), and the Freshwater Mollusk Conservation Society (FMCS) checklist of names (2021).

Data summary and analysis

We characterized the Bayou Bartholomew mussel assemblage and explored relationships with habitat and location using multiple metrics and analyses. All analyses were conducted on the combined number of live mussels collected in Phases 1 and 2; richness was calculated as the number of mussel species, and diversity was calculated using Shannon's diversity index (Kwak and Peterson 2007). We adopted a generalized linear modelling approach to describe how richness and diversity were influenced by habitat and location in the main channel of Bayou Bartholomew. Poisson regression models were fitted to the richness data while a Gaussian distribution was assumed for the Shannon's diversity index. Habitat variables, as well as the distance from the Ouachita River in river km and river km^2 (to allow for non-linear relationships), were considered as potential independent variables. All subset models of independent variables were built for richness and diversity response variables, and Akaike's Information Criterion (AIC) was used to select the best model from each suite of candidate models (Burnham and Anderson 2002). Once each best-fit model was selected, we estimated measures of their predictive ability. We used R^2 for the linear model of diversity and a pseudo-R^2 value (calculated as [1 – selected model deviance/null model deviance]) for the Poisson regression (Cameron and Windmeijer 1996). We used non-metric multidimensional scaling (NMDS) to visualize overall similarities and differences in the mussel assemblage structure among sites sampled on the main channel of Bayou Bartholomew. These ordinations were conducted on Bray-Curtis similarity measures calculated on the matrix of species relative abundances at all sites on the main channel. The appropriate number of dimensions for the NMDS was selected based on visual evaluation of scree plots of stress values (McCune *et al.* 2002). Ordinations were conducted using the *MetaMDS* function in the *Vegan* package of R (Oksanen *et al.* 2016), with a maximum of 100 random starts; centering, principal components rotation; and half-change scaling. Finally, we calculated the correlations between the NMDS axes and all the habitat variables that were identified as influential for species richness and diversity in the generalized linear modelling exercise and used these values to generate an assemblage-environmental variable overlay bi-plot.

To test for differences in the size distribution of live mussels found in the quantitative sampling and timed search at Site 20, we used two-tailed Kolmogorov–Smirnov tests in the Statistical Package for the Social Sciences (SPSS), version 28. The analysis of the size distribution was applied only to those species in which five or more individuals were found in both sampling efforts.

RESULTS

Habitat characteristics

Channel width and depth were relatively consistent across all main channel sites; mean width was 36.4 m and mean predominant depth was 1.3 m across all sampling areas. Bank height was intermediate (2–5 m) at 15 sites, low (0–2 m) at seven sites, and high (5–10 m) at three sites. Varying degrees of streambank erosion were noted at most sites; erosion was low at 14 sites, moderate at seven sites, and high at four sites. The substrate at all sites in the main channel was primarily composed of clay, silt, sand, and gravel; larger substrate classes were either absent (*e.g.*, boulder) or in such low abundance (*e.g.*, cobble) that they were not quantified. In most reaches, the substrate was dominated by silt or sand, which had mean estimated coverages of 30.4% and 38.0%, respectively; the overall mean coverage of gravel was 18.4% and this substrate

Table 1. Summary of live and fresh dead mussels found in Bayou Bartholomew, Louisiana in 2021 during timed searches; river km in brackets, number of fresh dead specimens in parentheses. All dead specimens represented by both valves except for *Lampsilis abrupta*.

	Site													
Species	**1** [112.5]	**2** [100.8]	**7** [90.5]	**8** [86.0]	**9** [83.1]	**10** [74.0]	**11** [73.0]	**12** [68.7]	**13** [69.6]	**14** [67.4]	**15** [63.8]	**16** [61.0]	**17** [60.0]	**18** [56.4]
Amblema plicata		1		3	3	1	1	44	2	5(3)	3	21	14	24
Arcidens confragosus		1			1			1						1
Cyclonaias nodulata								67	8(1)	1				
Cyclonaias pustulosa		5	1	3	2	1	6	99	5	11	1	3	16	18
Ellipsaria lineolata														
Eurynia dilatata								9	1	(1)		1		
Fusconaia flava				2			1	86	3	3		7	6	10
Lampsilis abrupta														
Lampsilis cardium														
Lampsilis hydiana				3	6(1)	1	1	1	(1)	(3)	1			1
Lampsilis satura							2(1)	14	7(1)	3(1)	3		2	2
Lampsilis straminea													1	
Lampsilis teres	5(8)	8	11	10	16(5)			4		5(5)	3	1	3	1
Ligumia recta														
Leaunio lienosus									(1)		1			
Megalonaias nervosa				2	7			2				22	2	6
Obliquaria reflexa		3	1	2				8	3	1			9	4
Obovaria arkansasensis														
Plectomerus dombeyanus		3	2	7	4		1	8	2	1	1	1	16	4
Pleurobema rubrum								7				7	1	2
Potamilus fragilis	(2)				(2)			3				2		1
Potamilus purpuratus	(2)		3	12	5(1)		(1)	6	1		5		6	7
Quadrula quadrula				1			1	38	2	2		1	3	1
Reginaia ebenus												1		
Theliderma cylindrica								1						
Theliderma metanevra								12				4		
Toxolasma parvum	(3)													
Toxolasma texasiense	3(4)	5	2	1	2(1)	3		1	1	8(1)			1	
Tritogonia verrucosa		1		2				21		2	1	3	2	
Truncilla donaciformis							(1)					1		
Truncilla truncata								4		1				1
Uniomerus tetralasmus						1								
Utterbackia imbecillis						1		1						
Total Live Mussels	8	27	20	48	46	7	13	438	35	43	18	75	82	83
Total Fresh Dead Shells	19	0	0	0	10	0	3	0	4	14	0	0	0	0
Total Species (live and dead)	5	8	6	12	10	6	9	22	13	14	9	14	14	15

(*continued*)

Table 1. Continued.

	Site												
Species	**19 [53.6]**	**20 [35.5]**	**21 [29.3]**	**22 [24.9]**	**23 [0.1]**	**24 [10.5]**	**25 [6.6]**	**26 [17.5]**	**27 [43.9]**	**28 [48.4]**	**30 [65.5]**	**Total Live**	**No. Sites**
Amblema plicata	1	6	26	8	33	33	71	21	3	2	47	372	23
Arcidens confragosus					2							6	5
Cyclonaias nodulata			1					5			1	83	6
Cyclonaias pustulosa	3(1)	75	130	42	7	123	48	82	7	15	72	773	24
Ellipsaria lineolata	(1)							3				3	2
Eurynia dilatata	(1)	1				5	(1)				4	21	6
Fusconaia flava	1(1)	19	75	27	1	60	11	166	1	1	70	546	19
Lampsilis abrupta							(1)					0	1
Lampsilis cardium		1		1				2			2	6	4
Lampsilis hydiana		2	(1)	4	7		1		2	6	1	36	17
Lampsilis satura		9	22	11	2	12	4	7	2	10		112	16
Lampsilis straminea				1			2			2		6	4
Lampsilis teres		1	1	4	19	1	1		7	6	1	102	21
Leaunio lienosus						(1)			1	1	0	3	3
Ligumia recta						1						1	1
Megalonaias nervosa		4	9			3	1	18			8	83	12
Obliquaria reflexa		3	9	9	2	3	6	5			2	69	16
Obovaria arkansasensis		1	(1)				(2)					1	3
Plectomerus dombeyanus	(1)	2	36	10	44	14	31	15	7	12	1	219	23
Pleurobema rubrum	1(1)	2	4	1		8		20			3	56	11
Potamilus fragilis	3	5	1	2		3	2	3			3	28	12
Potamilus purpuratus	1	4	9	5	12	1	9	2	5	5	2	95	19
Quadrula quadrula		12	22	3	5	12	19	48	1	2	21	194	18
Reginaia ebenus	(2)	3	25		4	19	2	29			4	87	9
Theliderma cylindrica		2				(1)						3	4
Theliderma metanevra		25	21	8		46		21			25	162	8
Toxolasma parvum												0	1
Toxolasma texasiense												30	12
Tritogonia verrucosa	1	18	36	2		18	2	13			16	137	15
Truncilla donaciformis		4	3			2	2	3				15	7
Truncilla truncata		2	(1)	1(1)		1		3			4	17	8
Uniomerus tetralasmus												1	1
Utterbackia imbecillis				1								5	2
Total Live Mussels	11	202	430	140	138	365	212	466	36	62	287	3292	
Total Fresh Dead Shells	8	0	3	1	0	2	4	0	0	0	0	68	
Total Species (live and dead)	11	22	20	18	12	21	19	19	10	11	19	33	

class was especially well represented at Sites 16, 20, 22, 24, and 26 where the mean coverage was 50%. Clay had the lowest mean coverage at 17.6%. Observed mesohabitats on the main channel included pool, glide and edgewater. Most sites were dominated by pool habitat, which had a mean area of 56.0%. Glide habitat was present at 11 sites and had a mean area of 29.6%. Edgewater was the rarest mesohabitat, with a mean area of 10.4% at seven sites.

Cypress Bayou, Horse Bayou, and Bayou de Glaize have been channelized and straightened in the reaches we surveyed, resulting in uniform habitats with little variation in depth, channel width, bank height; silt dominated the substrate throughout. Bayou Chemin-A-Haut has not been channelized, but clay and silt dominated the substrate in both reaches we examined. The downstream reach on Bayou Chemin-A-Haut (Site 29) was the deepest tributary site and the thalweg was covered by a thick (>1 m), anoxic layer of organic material.

Timed searches

Main Channel. A total of 3,292 live individuals representing 33 species were sampled in the main channel of Bayou Bartholomew during Phase 1 and Phase 2 timed searches (Table 1). Live mussels were found at all 25 sites and the number of live mussels exceeded the number of dead individuals at all but Site 1. The total number of live mussels ranged from 8–466 individuals/site (mean = 130.8) and species richness ranged from 5–23 species (mean = 13.6). Species with the greatest relative abundances were *Cyclonaias pustulosa* (Lea, 1831) (n = 773, mean = 30.9/site), *Fusconaia flava* (Rafinesque, 1820) (n = 541, mean = 22.2/site), *Amblema plicata* (Say, 1817) (n = 372, mean = 14.9/site), *Plectomerus dombeyanus* (Valenciennes, 1827) (n = 219, mean = 8.8/site), *Quadrula quadrula* (n = 194, mean = 7.8/site), *Theliderma metanevra* (Rafinesque, 1820) (n = 162,mean = 6.5/site), and *Tritogonia verrucosa* (Rafinesque, 1820) (n = 137, mean = 5.5/site).

Patterns of ubiquity varied by species. Only four species were highly ubiquitous, occurring in the vast majority of the 25 main channel sites: *Cyclonaias pustulosa* (n = 24 sites), *Amblema plicata* (n = 23 sites), *Plectomerus dombeyanus* (n = 22 sites), and *Lampsilis teres* (n = 21 sites) (Table 2). Three rare species were only represented by a single live individual at a single site each: *Ligumia recta* (Lamarck, 1819) (Site 24), *Obovaria arkansasensis* (Lea, 1862) (Site 20), and *Uniomerus tetralasmus* (Say, 1831) (Site 10). Two species were represented by fresh dead shells: *Lampsilis abrupta* (Say, 1831) (one valve at Site 25) and *Toxolasma parvum* (three paired specimens at Site 1). The length frequency for all common and abundant species exhibited a bell-shaped curve, indicating annual recruitment (Appendix 3). Small size classes were not evident in four small-shelled species: *Toxolasma texasiense*, *Truncilla donaciformis* (Lea, 1828), *Truncilla truncata* Rafinesque, 1820, and *Leaunio lienosus* (Conrad, 1834).

Tributaries. Mussels were rare or non-existent in the tributaries to Bayou Bartholomew (Table 3). No mussels were found in Horse Bayou, and only one live *Toxolasma texasiense* was found at the site on Cypress Bayou and at the lower site on Bayou Chemin-A-Haut. *Sagittunio subrostratus*, *Pyganodon grandis* (Say, 1829), and *Toxolasma texasiense* were found as fresh dead shells at the upper site on Bayou Chemin-A-Haut, but no live individuals were encountered.

Longitudinal and habitat relationships

Multiple metrics of mussel assemblage composition had significant relationships with the distance from the confluence with the Ouachita River and with habitat variables including substrates, depth, and mesohabitat types. Both models with the lowest AIC values among all candidate model sets described non-linear longitudinal patterns in the mussel assemblage composition of Bayou Bartholomew (Table 4). The top model of both species richness and diversity included a quadratic river kilometer term, reflecting low mussel richness and diversity at each end of Bayou Bartholomew in Louisiana and high richness and diversity at intermediate distances from the Ouachita River confluence (Figs. 2, 3). The top model of species richness also identified glide and edgewater as influential in determining species richness. The top diversity model identified two mesohabitat categories, all substrate categories and depth as influential habitat variables. A two-dimensional NMDS adequately described the between-site similarity in overall assemblage structure and the overlay bi-plot displayed how this variation in assemblage composition was correlated with habitat variables identified as significant by the generalized linear models (Fig. 4).

Quantitative grid survey

A total of 234 individuals representing 18 species were found in the quantitative grid at Site 20 (Table 5). *Cyclonaias pustulosa* was the most abundant species (n = 78, density = 10.4/m^2), followed by *Truncilla donaciformis* (n = 34, density = 4.5/m^2), *Quadrula quadrula* (n = 28, density = 3.7/m^2), *Tritogonia verrucosa* (n = 21, density = 2.7/m^2), *Theliderma metanevra* (n = 15, density 2.0/m^2), *Truncilla truncata* (n = 12, density = 1.6/m^2), and *Fusconaia flava* (n = 10, density = 1.3/m^2). All other species were present at densities < 1.0/m^2. The average density of all mussel species was 1.7/m^2. *Lampsilis cardium*, *Megalonaias nervosa*, *Obovaria arkansasensis*, *Reginaia ebenus*, and *Theliderma cylindrica* were found in the timed search at this site but not in the quantitative sampling. *Cyclonaias nodulata* was found in the quantitative sampling but not in the timed search.

The size distributions of mussels sampled in the quantitative grid were distinct from those sampled in the timed

Table 2. Total count, proportion, catch per unit effort (CPUE, or number of live individuals/hour), and abundance category for species sampled in the timed search survey of Bayou Bartholomew, Louisiana in 2021. Categories include Abundant (>5 individuals/person-hour), Common (5-2 individuals/person-hour), Uncommon (2-0.3 individuals/person-hour), and Rare (<0.3 individuals/person-hour).

Species	No. of Sites	Total Live	Proportion (%)	CPUE	Category
Cyclonaias pustulosa	24	773	23.5	15.46	Abundant
Fusconaia flava	19	546	16.6	10.82	Abundant
Amblema plicata	23	372	11.3	7.44	Abundant
Plectomerus dombeyanus	22	219	6.6	4.38	Common
Quadrula quadrula	18	194	5.9	3.88	Common
Theliderma metanevra	8	162	4.9	3.24	Common
Tritogonia verrucosa	15	137	4.2	2.74	Common
Lampsilis satura	16	112	3.4	2.24	Common
Lampsilis teres	21	102	3.1	2.04	Common
Potamilus purpuratus	19	95	2.9	1.9	Uncommon
Reginaia ebenus	8	87	2.5	1.74	Uncommon
Cyclonaias nodulata	6	83	2.5	1.66	Uncommon
Megalonaias nervosa	12	83	2.5	1.66	Uncommon
Obliquaria reflexa	16	69	2.1	1.38	Uncommon
Pleurobema rubrum	11	56	1.7	1.12	Uncommon
Lampsilis hydiana	15	36	1.1	0.72	Uncommon
Potamilus fragilis	12	28	0.8	0.56	Uncommon
Toxolasma texasiense	10	27	0.8	0.56	Uncommon
Eurynia dilatata	6	21	0.6	0.42	Uncommon
Truncilla truncata	8	17	0.5	0.34	Uncommon
Truncilla donaciformis	6	15	0.5	0.3	Uncommon
Arcidens confragosus	5	6	0.2	0.12	Rare
Lampsilis cardium	4	6	0.2	0.12	Rare
Lampsilis straminea	4	6	0.2	0.12	Rare
Utterbackia imbecillis	3	5	0.2	0.1	Rare
Theliderma cylindrica	2	3	0.1	0.08	Rare
Ellipsaria lineolata	1	3	0.1	0.06	Rare
Leaunio lienosus	3	3	0.1	0.06	Rare
Ligumia recta	1	1	<0.1	0.02	Rare
Obovaria arkansasensis	1	1	<0.1	0.02	Rare
Uniomerus tetralasmus	1	1	<0.1	0.02	Rare
Total Live Mussels		3292			

Table 3. Summary of live mussels and fresh dead specimens (in parentheses) found in tributaries to Bayou Bartholomew. Louisiana during timed searches in 2021; CB = Cypress Bayou, HB = Horse Bayou, BG = Bayou de Glaize, CH = Bayou Chemin-A-Haut.

	Site					
	3	4	5	6	29	Total
Species	CB	HB	BG	CH	CH	No. Sites
Sagittunio subrostratus				(1)		1
Pyganodon grandis				(4)		1
Toxolasma texasiense	1			(1)	1	3
Utterbackia imbecillis			1			1
Total Live Mussels	1	0	1	0	1	
Total Fresh Dead Shells	0	0	0	6	0	
Total Species (live and dead)	1	0	1	3	1	

search, and mussels sampled in the quantitative grid were generally smaller than those sampled in the timed search. The two-tailed Kolmogorov-Smirnov test revealed significant differences in the length frequencies distributions of six of the seven species tested (Table 6) and the observed mean, median, and maximum lengths of all these species were greater in the quantitative grid than the timed search (Fig. 5).

DISCUSSION

This survey represents the only comprehensive study of the diversity and distribution of mussels in Bayou Bartholomew, Louisiana since the work of Pezold *et al.* (2002). Our work builds on previous research to reveal novel information on mussels in this important ecosystem including

up-to-date and detailed information on Louisiana's SGCN. Additionally, our study is the first to use multiple techniques to sample mussels and quantitatively evaluate habitat and mussel assemblage-habitat relationships across the whole length of Bayou Bartholomew in Louisiana.

Table 4. Model parameters and coefficients of regression models of Shannon's index of diversity and species richness of mussels in the main channel of Bayou Bartholomew, Louisiana. The diversity regression is a linear model and the richness regression is a Poisson generalized linear model. The linearized (log-mean) estimates are displayed for the Poisson model for ease of interpretation. *= $p < 0.05$, **= $p < 0.01$, ***= $p < 0.001$.

Predictors	Shannon's Diversity (H')		Richness	
	Estimates	*Std. Error*	*Linearized Estimates*	*Std. Error*
(Intercept)	0.0783	0.3897	3.0130***	0.1788
River Kilometer	0.0106*	0.0046	0.0053	0.0081
River Kilometer^2	-0.0002**	0.0001	-0.0001	0.0001
Depth	0.0762	0.0595		
Clay	0.0114**	0.0032		
Silt	0.0096**	0.0026		
Sand	0.0115**	0.0031		
Gravel	0.0091**	0.0026		
Pool	0.0073**	0.0018	-0.0034**	0.0014
Glide	0.0099***	0.0022		
Edgewater			-0.0151***	0.0044
R^2 or Pseudo R^2	0.891		0.903	

Longitudinal patterns in assemblage composition and relationships to habitat

Our study revealed significant longitudinal patterns in the mussel assemblage composition and relationships with physical habitat in the Louisiana section of Bayou Bartholomew. We expected to find the greatest mussel species abundance, richness, and diversity at sites nearest the confluence with the Ouachita River because large rivers are often a source of mussel abundance and diversity to tributary streams (Haag 2012). This pattern held for several species such as *Fusconaia flava*, *Quadrula quadrula*, *Theliderma metanevra*, and *Reginaia ebenus* (Lea, 1831), which were absent from the upper survey sites but commonly occurred in the middle and lower reaches. Except for *F. flava*, a habitat generalist, these species are typically found in large rivers (Williams *et al.* 2008, Haag 2012, Jones *et al.* 2021). These results indicate that connection with the Ouachita River influences the mussel assemblage in the lower reaches of Bayou Bartholomew. Surprisingly, diversity and richness peaked at intermediate distances from the confluence. We attribute this overall pattern to tradeoffs between relative proximity to the mainstem Ouachita River versus habitat conditions that favored high diversity. Several reaches of Bayou Bartholomew near the confluence with the Ouachita River were characterized by bank failure, a channel choked

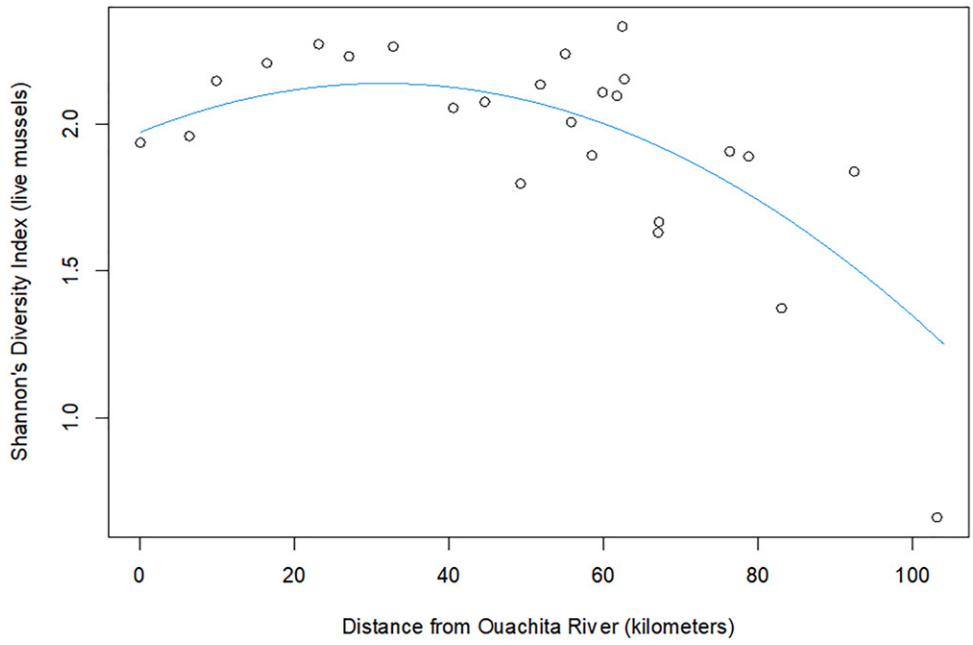

Figure 2. Modeled Shannon's diversity index of mussels (blue line) and observed values (open circles) of Shannon's diversity index of mussels over the entire length of Bayou Bartholomew in Louisiana. The model line represents the mean predicted diversity index at mean observed values of depth; clay, silt, sand, and gravel substrate percentages; and percent of mesohabitats as glide.

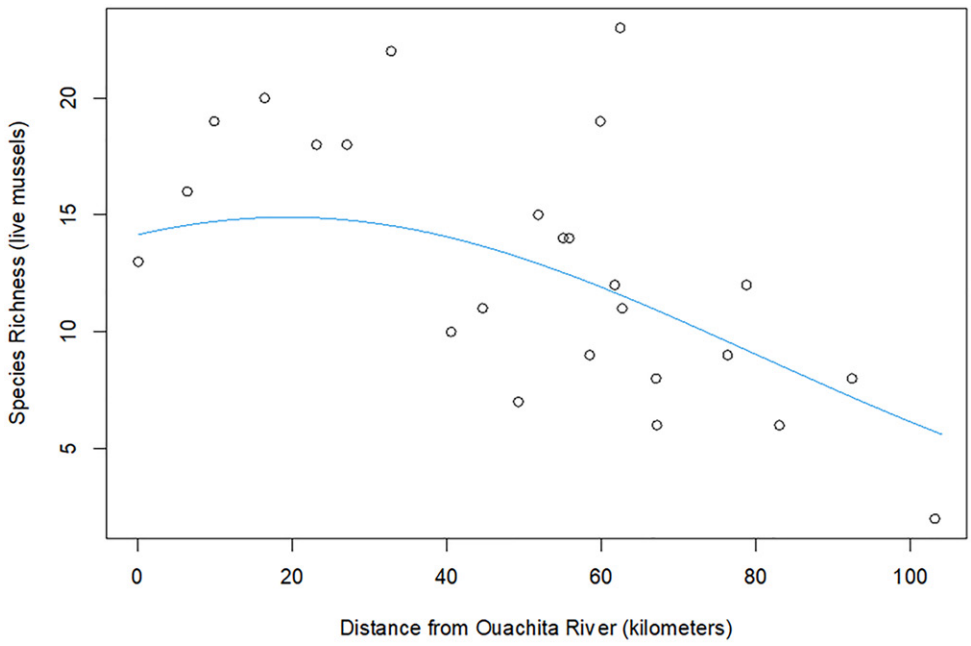

Figure 3. Modeled mussel species richness (blue line) and observed species richness (open circles) over the entire length of Bayou Bartholomew in Louisiana. The model line represents the mean predicted species richness at mean observed values of percent pool and edgewater mesohabitats.

with fallen trees, and uniformly fine substrates. In these lower reaches, there also was a predominance of deep pool and edgewater habitats, which were variables associated with low diversity. Sites at intermediate distances (ca. 30 to 65 km) from the confluence were close enough to support large river species and had habitat variables including glide mesohabitats and the presence of sand and gravel substrates that were associated with high mussel abundance and diversity.

Size Structure

Numerous size classes were observed in the length frequencies of live individuals of all species sampled in the timed searches with the exceptions of *Leaunio lienosa*, *Toxolasma texasensis*, *Truncilla donaciformis*, and *T. truncata*. All four are considered to be small species, none of which achieve a shell size exceeding 75 mm (Williams *et al.* 2008, Jones *et al.* 2021). Mussels found in the quantitative sampling at Site 20 exhibited smaller size distributions compared to those found in the timed search at the same location. A sampling bias toward larger individuals in timed searches was shown by Hornbach and Deneka (1996). In our study, we attribute this bias to the difficulty of detecting small individuals in highly turbid and sometimes deep conditions using a tactile search method. Our quantitative collection method was likely more effective for sampling small individuals because it involved excavating substrate in moderately shallow water followed by a visual examination of the collected substrate at the surface.

Comparison with previous surveys

Comparison of our survey results with George and Vidrine (1993), Vidrine (1995), and Pezold *et al.* (2002) does not provide any evidence of major changes in overall mussel species distributions or occurrence in Bayou Bartholomew in Louisiana over the last 20 to 30 years. The relative ubiquity of most mussel species in our study was similar to the earlier surveys. For example, species such as *Amblema plicata*, *Cyclonaias pustulosa*, and *Plectomerus dombeyanus*, were found to be highly ubiquitous by all studies, while some historically rare species continue to be present in low abundance. We found *Theliderma cylindrica* (Say, 1817) and *Ellipsaria lineolata* (Rafinesque, 1820) at only a few sites and we report *Obovaria arkansasensis* (Lea, 1862), a species not found in previous surveys. We found *Pleurobema rubrum* (Rafinesque, 1820) at 11 of 25 sites, which Vidrine (1995) found at eight of 30 sites, and Pezold *et al.* (2002) found at a single site. Seven species reported by Vidrine (1995) were not encountered in our survey. Overall, Vidrine (1995) reported 40 species, Pezold *et al.* (2002) reported 33 species, and we report 34 species. However, differences in sampling methods, effort, and reporting limits our ability to compare the abundance of individual species across the three studies.

Three SCGN reported by Vidrine (1995) were not found in our survey: *Cyprogenia aberti* (Conrad, 1850), *Obovaria olivaria* (Rafinesque, 1820), and *Ptychobranchus occidentalis* (Conrad, 1836). Pezold *et al.* (2002) reported *P. occidentalis*

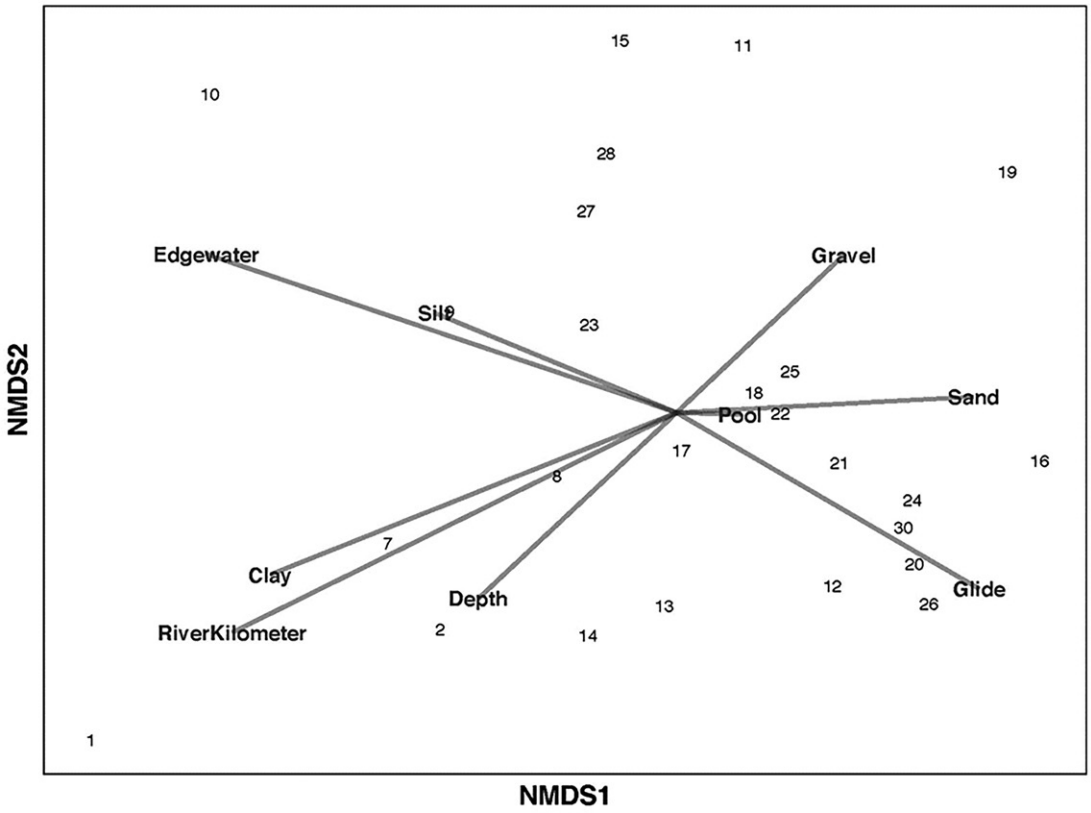

Figure 4. Non-metric multidimensional scaling (NMDS) bi-plot of mussel assemblage structure and environmental variable correlation vectors. Numbers correspond to study sites and the correlation vector length is proportional to the strength of correlation.

but not *C. aberti* or *O. olivaria*. Vidrine (1995) reported *Utterbackiana suborbiculata* (Say, 1831) in two off-channel sites (Bayou DiSiard and Bartholomew Lake) but did not find this species in the main channel of Bayou Bartholomew. Similarly, we did not find it in the main channel of Bayou Bartholomew or in the tributaries, but we found one individual along the margin of the Ouachita River directly across from the mouth of Bayou Bartholomew. *Utterbackiana suborbiculata* prefers waters with little to no current, such as floodplain lakes, sloughs, oxbows, and reservoirs associated with large creeks (Williams *et al.* 2008). In Tennessee, it has expanded its range upstream in the Tennessee and Cumberland Rivers because of mainstem impoundments (G. Dinkins, unpubl. data). If *U. suborbiculata* occurs in the main channel of Bayou Bartholomew, it is likely rare, localized, and confined to the lower reaches near the confluence with the Ouachita River, or in the floodplain where there are pockets of standing water disconnected from the main channel during normal flow levels.

Vidrine (1995) reported *Quadrula pustulosa mortoni* (Conrad, 1835) at four sites on the main channel of Bayou Bartholomew, all in the middle section, and expressed perplexity over the conchological differences between this taxon and *Q. pustulosa pustulosa*. Serb *et al.* (2003) supported elevating both to species status based on molecular data, and this was recognized by Williams *et al.* (2017). Based on genetic and morphological analyses, Johnson *et al.* (2018) synonymized *Cyclonaias mortoni* (along with *C. aurea*, *C. houstonensis*, and *C. refulgens*) with *Cyclonaias pustulosa* (Conrad, 1835).

Vidrine (1995) reported five specimens of *Quadrula apiculata* (Say, 1829) at one location in Bayou Bartholomew and noted that these individuals "…may simply be a highly pustulose form of *Q. quadrula*, which is highly variable in this stream." We also noted the variable nature of *Q. quadrula* in Bayou Bartholomew, but we treated them as a single species as proposed by Lopes-Lima *et al.* (2019).

Vidrine (1995) reported a single individual of *Uniomerus declivis* (Say, 1831) and *Uniomerus tetralasmus* at one site each in Bayou Bartholomew; the two sites were adjacent and separated by only a short distance. Brooks *et al.* (2008) reported both species in the Arkansas portion of Bayou Bartholomew, with *U. declivis* widespread (present at 13 of 50 sites) whereas *U. tetralasmus* was present at only two widely separated sites. We found a single individual of *U. tetralasmus* in our study (Site 10). The systematic relationship of various forms within *Uniomerus* is poorly understood,

Table 5. Species, percent occurrence, density, and size characteristics of live individuals recorded in quantitative grid and timed search at Site 20, Bayou Bartholomew, Louisiana, river km 35.5.

	Quantitative Grid							Timed Search				
Species	N	% occur.	Density (No./m^2)	Size Range (mm)	Mean size (mm)	S.D.	S.E.	N	% occur.	Size Range (mm)	Mean size (mm)	S.D.	S.E.
Amblema plicata	4	1.7	0.5	18-59	37.3	17.11	8.56	6	3.0	58-92	67.2	12.46	5.09
Cyclonaias nodulata	1	0.4	0.1	28	28.0	-	-	0	0.0	-	-	-	-
Cyclonaias pustulosa	78	33.7	10.4	9-58	25.1	10.76	1.21	75	37.1	21-58	40.5	9.71	1.94
Eurynia dilatata	2	0.4	0.1	17-22	19.5	-	-	1	0.5	51	51.0	-	-
Fusconaia flava	10	4.3	1.3	11-32	17.5	6.04	1.91	19	9.4	17-59	37.8	10.27	2.42
Lampsilis hydiana	1	0.4	0.1	15	15.0	-	-	2	1.0	14-77	45.5	-	-
Lampsilis satura	7	3.0	0.9	6-90	54.9	36.43	13.77	9	4.5	72-96	85.1	7.41	2.47
Lampsilis teres	2	0.9	0.3	14-79	46.5	-	-	1	0.5	89	89.0	-	-
Obliquaria reflexa	6	2.6	0.8	6-23	15.7	6.38	2.60	3	1.5	11-29	23.0	10.39	6.00
Plectomerus dombeyanus	2	0.9	0.3	23-40	31.5	-	-	2	1.0	65-90	77.5	-	-
Pleurobema rubrum	4	1.7	0.5	13-27	20.5	6.24	3.12	3	1.4	29-40	33.3	5.86	3.38
Potamilus fragilis	5	2.2	0.7	18-21	19.6	1.14	0.51	5	2.5	46-60	50.8	5.4	2.42
Potamilus purpuratus	1	0.4	0.1	11	11.0	-	-	3	1.5	74-79	77.0	-	-
Quadrula quadrula	28	12.1	3.7	7-43	22.2	9.58	1.81	13	6.4	34-71	50.2	13.36	3.71
Theliderma metanevra	15	6.5	2.0	5-49	19.1	12.92	3.34	25	12.4	30-75	50.1	10.22	2.04
Tritogonia verrucosa	21	9.0	2.7	6-55	22.2	12.39	12.00	18	8.9	41-91	68.5	15.19	3.48
Truncilla donaciformis	34	14.7	4.5	8-22	14.6	4.24	0.73	4	2.0	14-17	15.3	1.26	0.63
Truncilla truncata	12	5.2	1.6	10-19	16.3	2.38	0.66	2	1.0	22-29	25.5	-	-
Total	234							202					

Table 6. Summary of Kolmogorov-Smirnov (K-S) test for length frequency distributions of selected species found in the quantitative grid and timed search at Site 20, Bayou Bartholomew, Louisiana, river km 35.5. Only species for which >5 live individuals were found in both datasets are included.

Species	K-S test statistic (z)	p-Value
Cyclonaias pustulosa	2.383	<0.001
Fusconaia flava	2.000	<0.001
Lampsilis satura	1.134	0.153
Potamilus fragilis	1.581	0.013
Quadrula quadrula	2.554	<0.001
Theliderma metanevra	2.735	<0.001
Tritogonia verrucosa	2.858	<0.001

and conchological characters appear to be insufficient to delineate species (Williams *et al.* 2008). Currently, *Uniomerus* spp. occurring in the Gulf Slope, lower Mississippi Basin, and southeast Atlantic drainages are the focus of a detailed phylogenetic analysis (N. Johnson, U.S. Geological Survey, pers. comm.), the results of which should provide clarity regarding these species in Bayou Bartholomew.

Louisiana's mussel species of greatest conservation need in Bayou Bartholomew

A length frequency distribution for each SGCN found in the timed searches is provided in Fig. 6, and individual species profiles are provided below.

Cyprogenia aberti: The taxonomy of this species is under review with recent molecular analysis by Chong *et al.* (2016) indicating the Ouachita River population of Arkansas and Louisiana is an independent evolutionary lineage. The U.S. Fish and Wildlife Service is using the name "Ouachita Fanshell" for *C. aberti* in the Ouachita basin. Live "Ouachita Fanshell" were recently found in the Ouachita River in the Upper Ouachita National Wildlife Refuge, Arkansas (J. Harris, pers. comm.). This species has not been observed in Louisiana since Vidrine (1995) reported finding a long-dead shell in Bayou Bartholomew on a gravel shoal at river km 17.5. *Cyprogenia aberti* was not observed in the Arkansas portion of Bayou Bartholomew by Brooks *et al.* (2008). We could not confirm the presence of *C. aberti* in Bayou Bartholomew, as no live individuals or dead shells were found. The U.S. Fish and Wildlife Service has proposed to list *C. aberti*, along with the undescribed "Ouachita Fanshell", as threatened species and to designate critical habitat for both under the Endangered Species Act of 1973 (U.S. Fish and Wildlife Service 2022). Critical habitat for the "Ouachita Fanshell" was proposed but did not include Bayou Bartholomew (U.S. Fish and Wildlife Service 2022).

Ellipsaria lineolata: Vidrine (1995) found this species at three locations in Bayou Bartholomew and considered it to be extremely rare in Louisiana, with Bayou Bartholomew the only remaining refugium in the state. Pezold *et al.* (2002) found a single live individual in 2001 at river km 68.7. We found three live *E. lineolata* (two males and one female) at Site 26 and one weathered shell at Site 19, indicating the species is extant but extremely rare in in Bayou Bartholomew.

Eurynia dilatata (Rafinesque, 1820): Vidrine (1995) found this species at 12 locations in Bayou Bartholomew, mostly in the middle section of the river but he did not report the number of individuals. Pezold *et al.* (2002) found one live and three dead *E. dilatata* in 2001 but did not provide the location where they were found. We found 21 live *E. dilatata* across six sites during timed searches and dead shells at three additional sites. Like Vidrine (1995), we found this species at intermediate distances from the mouth of the Ouachita River and the Arkansas border. Multiple size classes were observed, indicating that this species is uncommon but persisting in the middle section of Bayou Bartholomew in Louisiana. We also found two young individuals in the quantitative grid samples, indicating ongoing recruitment of this species.

Lampsilis abrupta: George and Vidrine (1993) reported finding this species in Bayou Bartholomew at a single location downstream from the mouth of Bayou Chemin-A-Haute. Vidrine (1995) did not find *L. abrupta* in a subsequent survey of Bayou Bartholomew despite having handled "more than 25,000 native mussels". We found a single, fresh dead valve of *L. abrupta* at Site 25 indicating the species is extant but exceedingly rare in Bayou Bartholomew.

Lampsilis cardium: George and Vidrine (1993) reported this species as a new state record from the Louisiana section of Bayou Bartholomew, but did not provide exact locations or number of individuals found. Vidrine (1995) reported *L. cardium* from two sites (river km 55.0 and 51.8). We found a total of six *L. cardium* at four sites (river km 17.5, 24.9, 35.5, and 65.5) in low abundance at each of these locations, being represented by either one or two individuals. The difficulty of separating this species from the conchologically similar *Lampsilis satura* in the lower Mississippi River Basin and *Lampsilis ovata* (Say, 1817) in the middle and upper Mississippi Basin was discussed by Vidrine (1995) and Williams *et al.* (2008), respectively. Williams *et al.* (2008) chose to not recognize *L. cardium* as occurring anywhere in Alabama, stating that any differences in shell morphology between it and *L. ovata* was an expression of ecophenotypic variation. Our specimens of *L. cardium* resemble the typical form associated with the species. Therefore, we confirm *L. cardium* occurs in Bayou Bartholomew but recognize that it is does not appear to be widely distributed

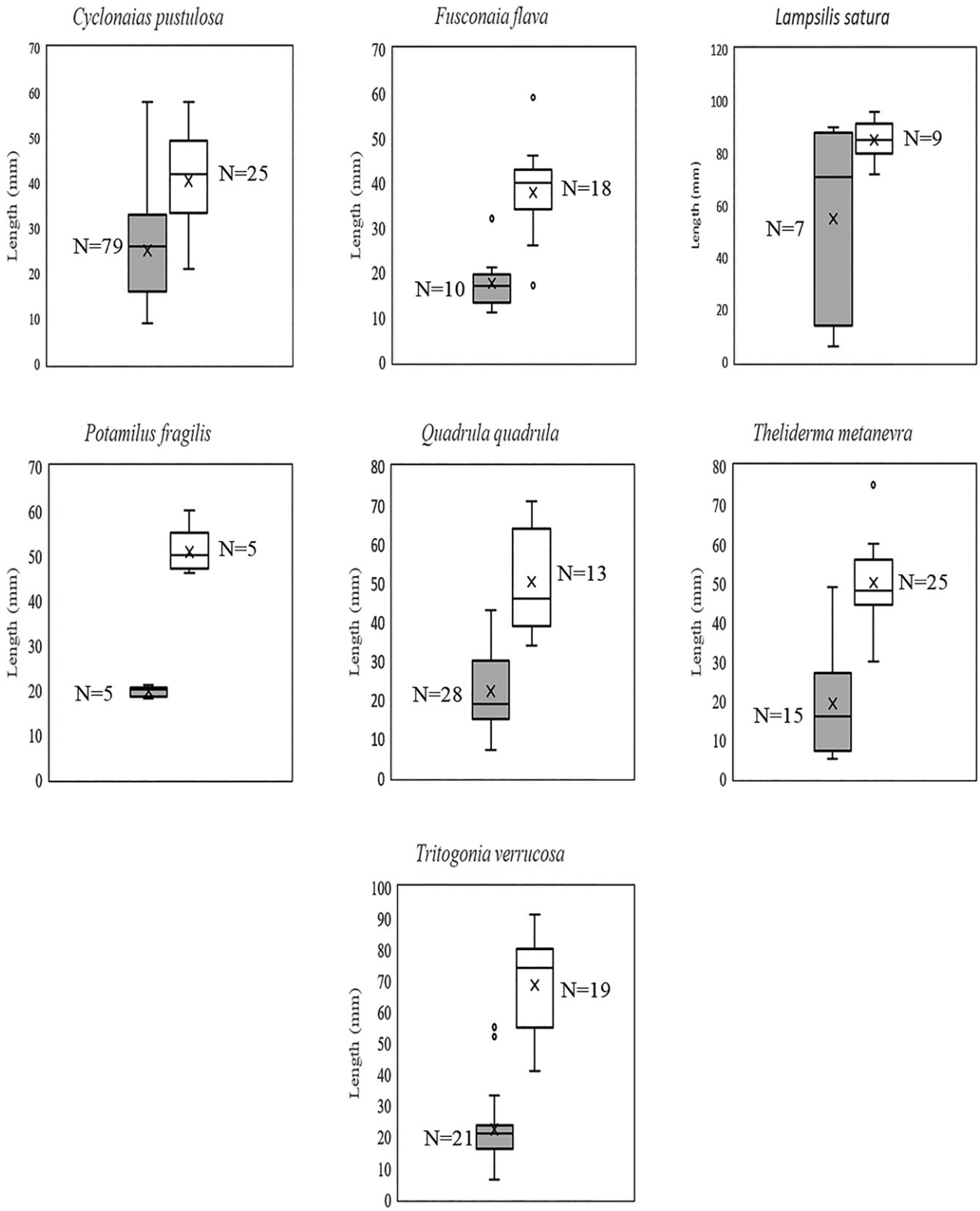

Figure 5. Size distribution of mussels found in quantitative grid (gray bar) and timed search (white bar) at Site 20 (river km 35.5).

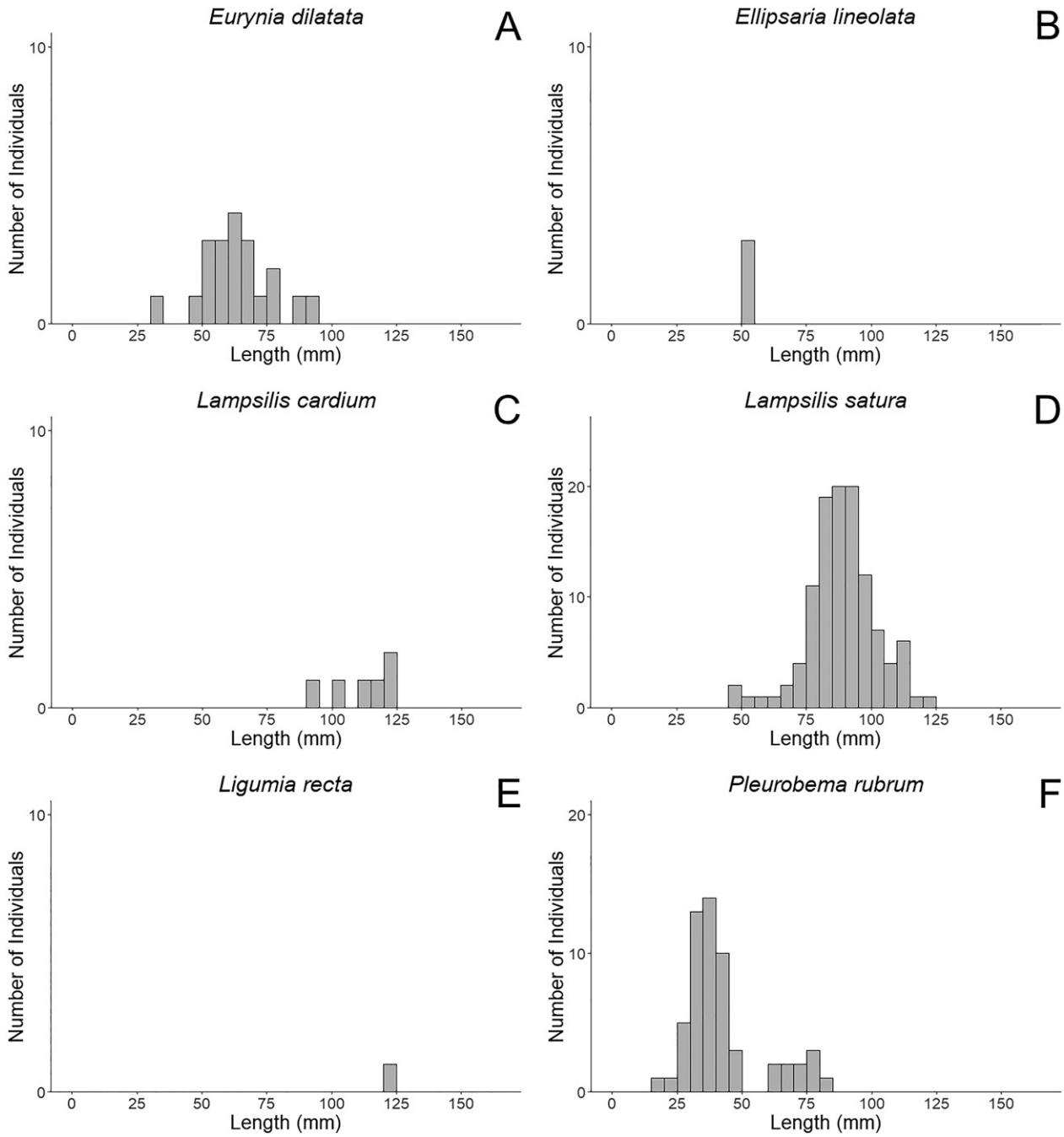

Figure 6. Length frequency of Species of Greatest Conservation Need found in Bayou Bartholomew, Louisiana. A: *Eurynia dilatata* (n = 20). B: *Ellipsaria lineolata* (n = 3). C: *Lampsilis cardium* (n = 6). D: *Lampsilis satura* (n = 112). E: *Ligumia recta* (n = 1). F: *Pleurobema rubrum* (n = 57) (*continued*).

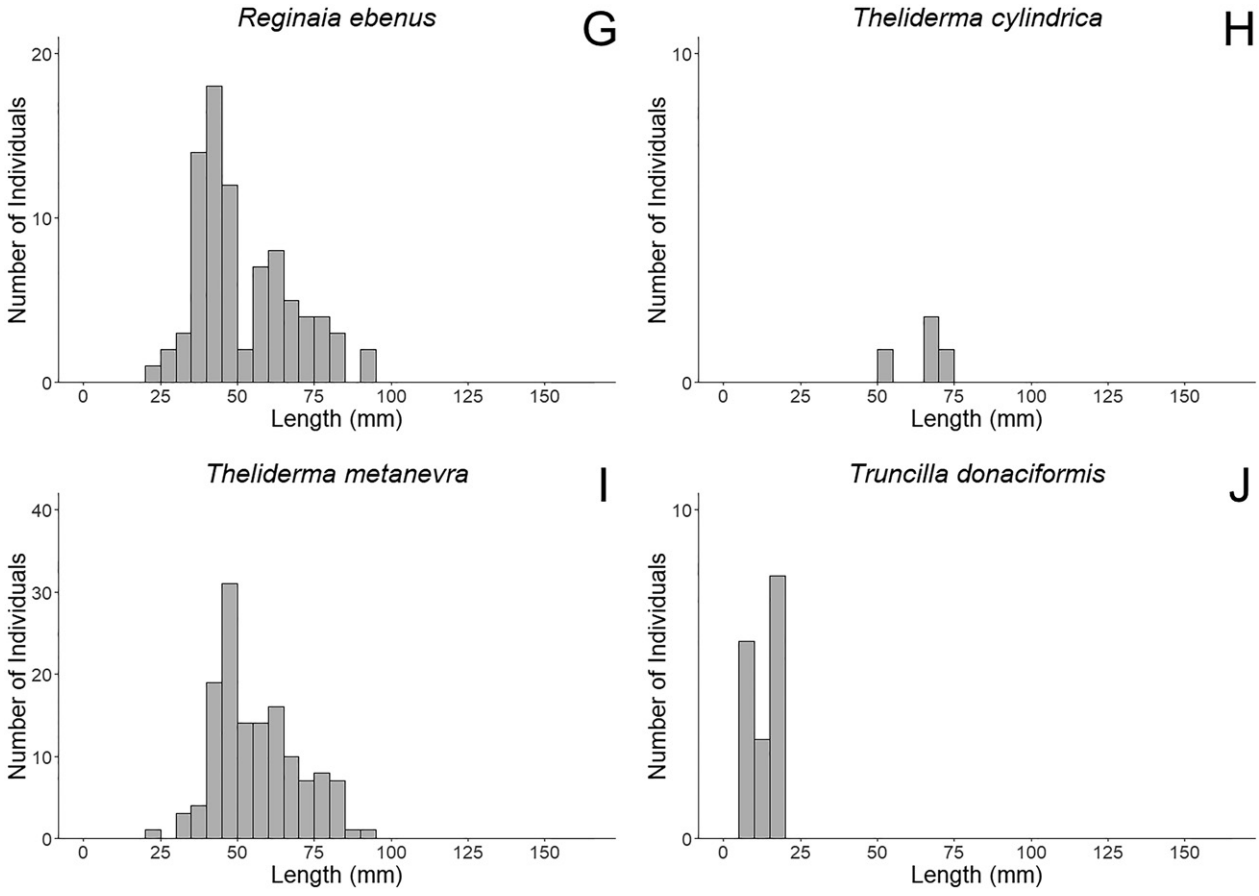

Figure 6 (Continued). G: *Reginaia ebenus* (n = 85). H: *Theliderma cylindrica* (n = 4). I: *Theliderma metanevra* (n = 136). J: *Truncilla donaciformis* (n = 17).

or abundant in the system. *Lampsilis cardium* is still considered a valid species in the most recent nomenclatural treatment of mussels of the U.S. and Canada (Williams *et al.* 2017, FMCS 2021).

Lampsilis satura: Vidrine (1995) found this species from a single site in Bayou Bartholomew (river km 51.8) but did not report the number of individuals. In contrast, we found this species to be relatively common and abundant, and observed 112 individuals representing numerous size classes across 16 sites from river km 35.5 to 73.0. We also found 7 individuals in the quantitative grid samples, ranging in size from 6–90 mm. *Lampsilis satura* was not found in the Arkansas portion of Bayou Bartholomew by Brooks *et al.* (2008). *Lampsilis satura* is restricted to the Louisiana portion of Bayou Bartholomew where it is stable and reproducing.

Lampsilis siliquoidea: Vidrine (1995) discussed the difficulty of distinguishing *L. siliquoidea* from *L. hydiana* and reported finding *L. siliquoidea* in Bayou Bartholomew at river km 49.2 and 51.8. We agree these species are conchologically similar and difficult to separate when both are present, but we did not find any specimens identifiable as *L. siliquoidea*. Pezold *et al.* (2002) did not find *L. siliquoidea* in the Louisiana portion of Bayou Bartholomew, and Brooks *et al.* (2008) did not report the species from the Arkansas portion. If *L. siliquoidea* is still present in the Louisiana portion of Bayou Bartholomew, it is very rare.

Ligumia recta: Vidrine (1995) found two eroded, long dead specimens of this species at two sites in the middle section of Bayou Bartholomew (river km 29.3 and 56.4). Similarly, we found two heavily eroded, dead specimens at these same sites and a live individual at river km 10.5. Pezold *et al.* (2002) found single dead specimens at two sites in Bayou Bartholomew a few hundred meters upstream of the Arkansas/Louisiana border. Based on these results, *L. recta* is persisting in Bayou Bartholomew in Louisiana, but it is very rare.

Obovaria arkansasensis: Vidrine (1995) and Pezold *et al.* (2002) did not report this species from the Louisiana portion of Bayou Bartholomew. Brooks *et al.* (2008) found one live individual at two sites in the Arkansas portion of

Bayou Bartholomew and either one or two dead shells at four sites. We found a single live individual at river km 35.5, one fresh dead specimen at river km 29.3, and two fresh specimens at river km 6.6. Based on these results, *O. arkansasensis* is extant in the Louisiana portion of Bayou Bartholomew, but it is very rare.

Obovaria olivaria: Vidrine (1995) reported this species from a single site in Bayou Bartholomew at an intermediate distance from the mouth of the Ouachita River. Pezold *et al.* (2002) did not find *O. olivaria* in Bayou Bartholomew in Louisiana and Brooks *et al.* (2008) did not find the species in the Arkansas portion. We did not find *O. olivaria* in our survey, indicating the species may be extremely rare or extirpated from Bayou Bartholomew.

Pleurobema rubrum: Vidrine (1995) found an unknown number of live *P. rubrum* at eight sites distributed across most of the length of the Louisiana section of Bayou Bartholomew. Pezold *et al.* (2002) found four live individuals at one site several kilometers upstream from the confluence with the Ouachita River. In the Arkansas portion, Brooks *et al.* (2008) found live individuals and dead shells at 13 sites; at one site just upstream of the Louisiana border they found 29 live individuals and 59 dead shells. We found *P. rubrum* to be widespread but observed low abundances at most sites where it was found. We found a total of 56 live individuals across 11 sites; two distinct size classes were evident. We also found 4 small individuals ranging in size from 13–27 mm in the quantitative grid sample. These data indicate the species is stable and reproducing in Bayou Bartholomew. *Pleurobema rubrum* is currently the subject of a range-wide molecular analysis to determine its relationship with several other closely related species of *Pleurobema* (Nathan Johnson, U.S. Geological Survey, pers. comm.).

Ptychobranchus occidentalis: George and Vidrine (1993) found a live male and female of *P. occidentalis* at river km 51.8 and Vidrine (1995) found a live individual at river km 62.4. Pezold *et al.* (2002) found a total of four live individuals at two sites in 2001, and Brooks *et al.* (2008) did not find the species in the Arkansas portion. We did not find live individuals or dead shells of *P. occidentalis*, indicating the species is extremely rare or extirpated from Bayou Bartholomew.

Reginaia ebenus: Vidrine (1995) reported this species to be abundant at most of the 11 sites where it occurred but noted only a few individuals were present at the lowermost sites (river km 32.8 and 16.4). Pezold *et al.* (2002) found *R. ebenus* at 13 sites spread across most of the Louisiana portion of Bayou Bartholomew, but only reported 20 live individuals and over twice the number of dead shells (n = 45). In Arkansas, Brooks *et al.* (2008) reported live individuals or dead shells at nine sites; live individuals were found at only five, most of which were near the border with Louisiana. We found a total of 87 live *R. ebenus* across eight sites, mostly in the lower reaches of the bayou. A normal distribution of several size classes indicated the species is successfully recruiting. Based on these findings, *R. ebenus* is relatively common and reproducing in Bayou Bartholomew.

Theliderma cylindrica: Vidrine (1995) found an unreported number of *T. cylindrica* at two sites that were at intermediate distances from the Ouachita River confluence (river km 55.8 and 51.8). Pezold *et al.* (2002) found a single live individual in the Louisiana portion, and Brooks *et al.* found none in the Arkansas portion. We found a total of three live individuals at two sites (river km 35.5 and 68.7) and a fresh dead shell at river km 10.5. At least two size classes were possibly evident from the limited observation of four individuals. Based on these results, *T. cylindrica* is extant in Bayou Bartholomew but is extremely rare.

Theliderma metanevra: This species was observed in Bayou Bartholomew by George and Vidrine (1993), and Vidrine (1995) recorded it at five sites, mostly in the middle section, but he did not report the number of individuals. Pezold *et al.* (2002) found a total of 97 live individuals and 48 dead shells at 17 sites ranging from just upstream of the confluence with the Ouachita River upstream to the Arkansas/Louisiana border. In our survey, *T. metanevra* was moderately widespread and abundant. A total of 162 live individuals were found across 8 sites, which were primarily close to or at an intermediate distance from the confluence with the Ouachita River. The length frequency histogram of 136 live individuals from our survey exhibited a normal distribution with several size classes represented. In the quantitative grid samples, we found 15 live *T. metanevra* ranging in size from 5–49 mm indicating the species is recruiting. Our results indicated *T. metanevra* is relatively widespread, abundant, and stable in Bayou Bartholomew.

Truncilla donaciformis: Vidrine (1995) reported finding a single valve of this species in his 1994 survey, but this record is from the survey conducted by George and Vidrine (1995) and the location of this earlier record was not given. Pezold *et al.* (2002) found five live individuals but did not report the location(s) where the species was found. Brooks *et al.* (2008) found *T. donaciformis* to be present in the Arkansas portion of Bayou Bartholomew only at the two survey sites located just upstream of the Arkansas/Louisiana border, reporting a total of four live individuals. We found six live *T. donaciformis* in the timed searches at 15 sites; the length frequency distribution indicates a single size class was present. In the quantitative grid samples, *T. donaciformis* was the second most common species (n = 34 individuals), and individuals ranged in size from 8–22 mm. Our results indicate *T. donaciformis* is widespread and stable in Bayou Bartholomew.

Conclusions and management implications

Bayou Bartholomew is a haven of regional mussel diversity that deserves continued protection from additional anthropogenic alterations. We confirmed the presence and persistence of 35 species of mussels in the Bayou Bartholomew drainage in Louisiana, including 13 SGCN, two of which are federally endangered. Mussel species richness, diversity, and abundance were all greatest at sites of intermediate distances from the mouth of the bayou at the Ouachita River and the Arkansas state line. Mussel assemblage composition was found to be related to several physical habitat variables; the most specious and abundant sites were characterized by diverse and stable substrates of sand and gravel, glide mesohabitats, and relatively shallow depths. Conversely, sites dominated by silt and clay substrates and homogeneous pool habitats were often characterized by low richness, diversity, and abundances. Our comparison to previous surveys did not provide any evidence of major changes in overall mussel species distributions or occurrence in Bayou Bartholomew in Louisiana since the year 2000 and before. This apparent stability in the mussel assemblage in the main channel is likely attributable to the fact that major anthropogenic alterations have been minimal (*e.g.*, channelization, damming, and watershed urbanization). Bayou Bartholomew will likely continue to be a hotspot of regional mussel diversity and a haven for several of Louisiana's SGCN if additional large-scale anthropogenic alterations do not occur and management actions that allow for the persistence of heterogenous habitats are in place.

Where appropriate, measures should be taken to stabilize eroding banks and channelized tributaries. In the main channel, we observed numerous reaches where bank failure was severe and poses a threat to the integrity of the channel. Stretches of substrate dominated by coarse gravel occur sporadically in the middle sections of Bayou Bartholomew. Locally known as "rock bars", these features should be delineated and targeted in future monitoring efforts. Finally, given the number of freshwater mussel species that within Louisiana are primarily limited to this river, periodic monitoring of this system should be conducted to conserve its unique biodiversity.

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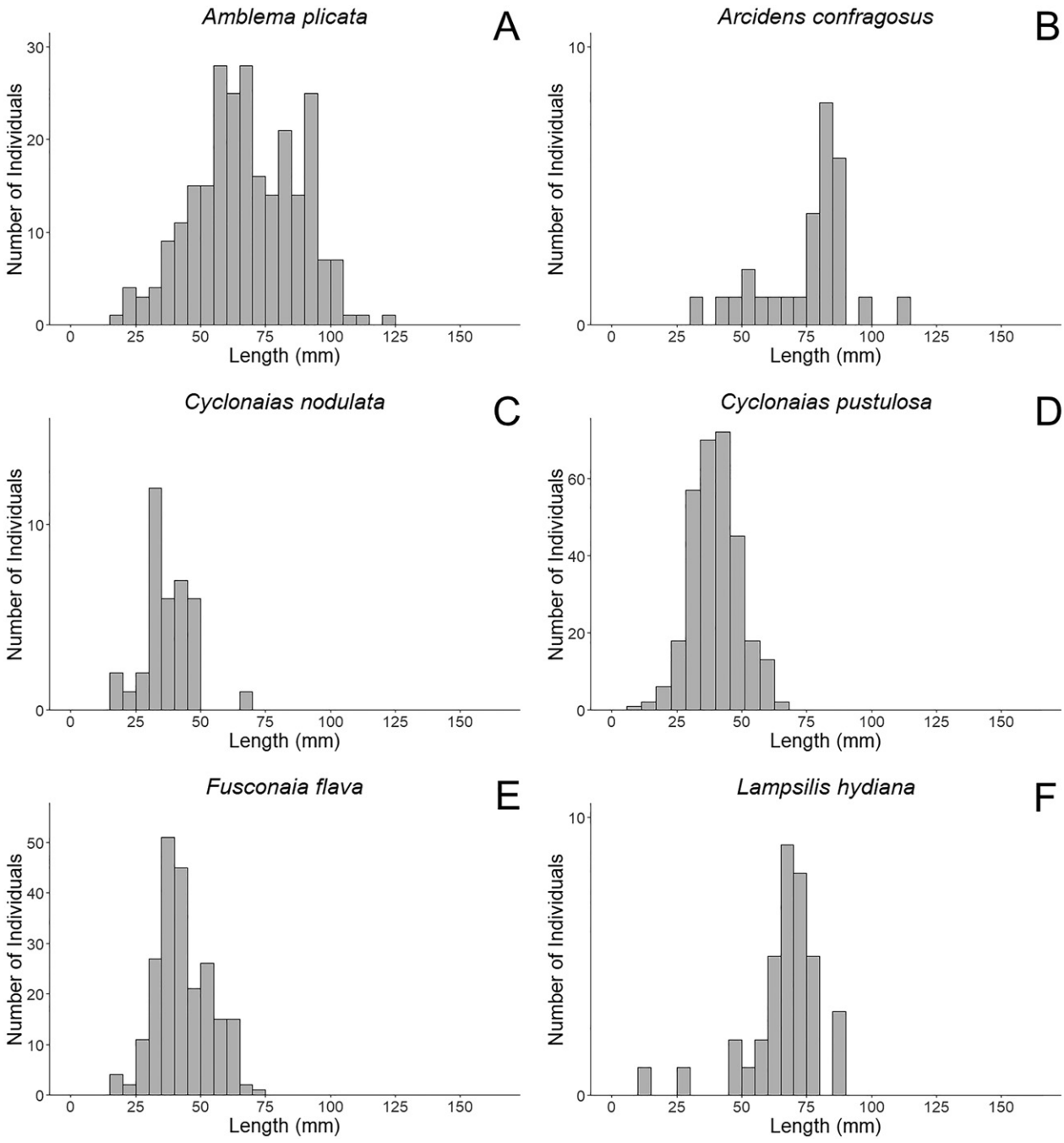
Appendix 1. Mussels previously reported from Bayou Bartholomew. Species names adjusted to reflect current nomenclature.

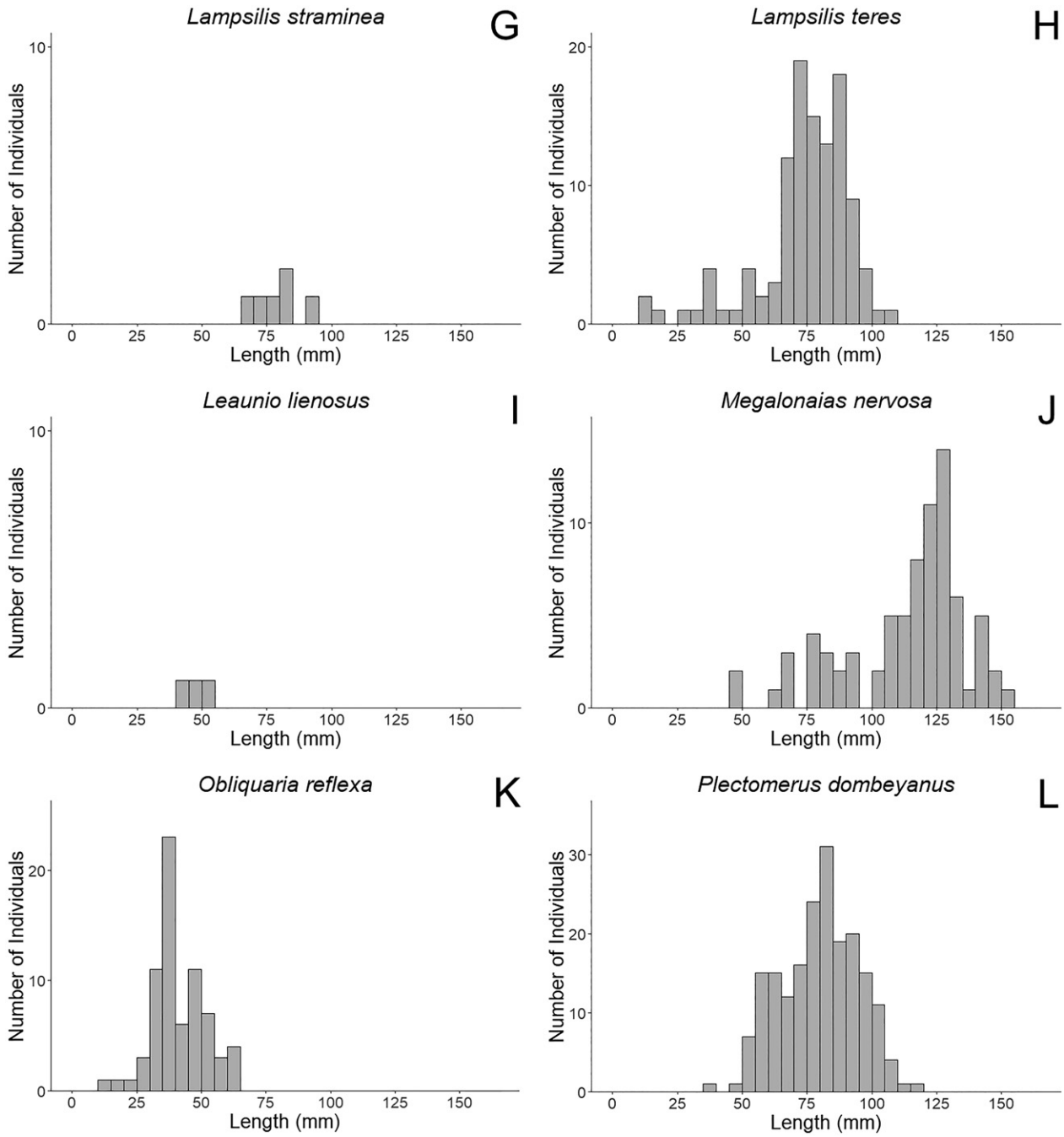
	Louisiana Section			Arkansas Section	
Species	**George and Vidrine (1993)**	**Vidrine (1995)**	**Pezold. (2002)**	**Brooks *et al.* (2008)**	**Peacock *et al.* (2013)**
Actinonaias ligamentina					X
Amblema plicata	X	X	X	X	X
Anodontoides sp.					X
Arcidens confragosus	X	X	X	X	X
Cyclonaias nodulata		X	X	X	X
Cyclonaias pustulosa	X	X	X	X	X
Cyclonaias tuberculata					X
Cyprogenia aberti		X			X
Ellipsaria lineolata	X	X	X		
Eurynia dilatata	X	X	X	X	X
Fusconaia flava	X	X	X	X	X
Glebula rotundata					X
Lampsilis abrupta	X	X		X	X
Lampsilis cardium	X	X	X	X	X
Lampsilis hydiana	X	X	X	X	
Lampsilis ovata					X
Lampsilis satura	X	X		X	X
Lampsilis siliquoidea	X	X			X
Lampsilis teres	X	X	X	X	X
Lasmigona complanata					X
Lasmigona costata					X
Leaunio lienosus	X	X		X	X
Ligumia recta		X	X	X	X
Megalonaias nervosa	X	X	X	X	X
Obliquaria reflexa	X	X	X	X	X
Obovaria arkansasensis				X	X
Obovaria olivaria	X	X			X
Plectomerus dombeyanus	X	X	X	X	X
Pleurobema rubrum	X	X	X	X	X
Potamilus fragilis	X	X	X	X	X
Potamilus purpuratus	X	X	X	X	X
Ptychobranchus occidentalis	X	X	X		X
Pyganodon grandis	X	X	X	X	
Quadrula quadrula	X	X	X	X	X
Reginaia ebenus	X	X	X	X	X
Sagittunio subrostratus			X	X	X
Strophitus undulatus				X	X
Theliderma cylindrica	X	X	X		X
Theliderma metanevra	X	X	X	X	X
Toxolasma parvus		X	X	X	X
Toxolasma texasiense		X	X	X	X
Tritogonia verrucosa	X	X	X	X	X
Truncilla donaciformis	X	X	X	X	X
Truncilla truncata	X	X	X	X	X
Uniomerus declivis		X		X	X
Uniomerus tetralasmus		X	X	X	X
Utterbackia imbecillis		X	X	X	X
Utterbackiana suborbiculata			X	X	
No. Species	29	37	32	35	44

Appendix 2. Species of Greatest Conservation Need (SGCN) historically reported to occur in Bayou Bartholomew, Louisiana. SH = Possibly extirpated or possibly eliminated, S1 = Critically imperiled, S2 = Imperiled, S3 = Vulnerable, LE = Listed endangered, LT = Listed threatened, PT = Proposed threatened.

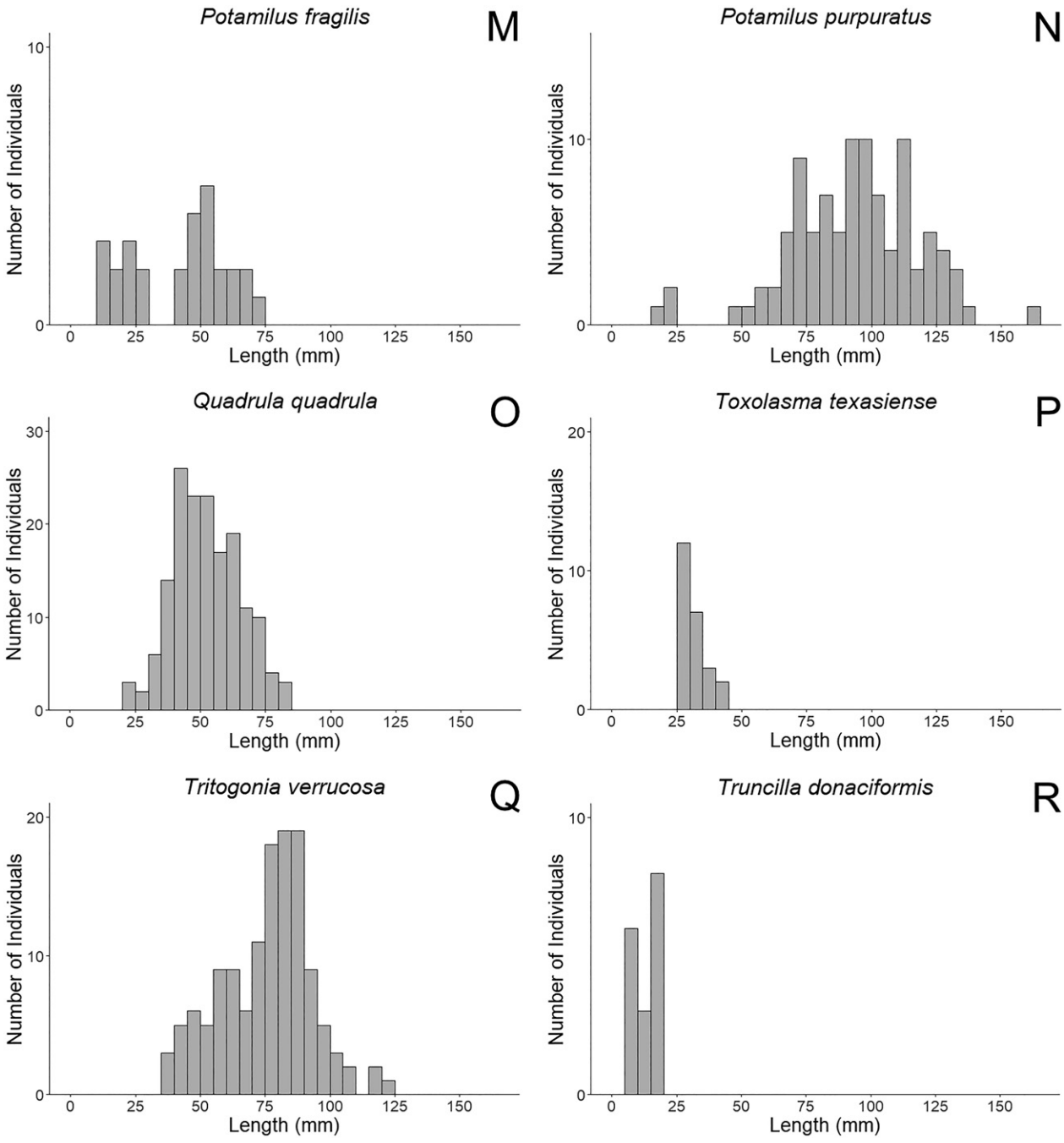
Scientific Name	Common Name	State Rank	Federal Status
Cyprogenia aberti	Western Fanshell	SH	PT
Ellipsaria lineolata	Butterfly	S1	
Eurynia dilatata	Spike	S2S3	
Lampsilis abrupta	Pink Mucket	S1	LE
Lampsilis cardium	Plain Pocketbook	S1	
Lampsilis satura	Sandbank Pocketbook	S2	
Lampsilis siliquoidea	Fatmucket	S2	
Ligumia recta	Black Sandshell	S1	
Obovaria arkansasensis	Southern Hickorynut	S1S2	
Obovaria olivaria	Hickorynut	S1	
Pleurobema rubrum	Pyramid Pigtoe	S2	
Ptychobranchus occidentalis	Ouachita Kidneyshell	S1	
Reginaia ebenus	Ebonyshell	S3	
Theliderma cylindrica	Rabbitsfoot	S1	LT
Theliderma metanevra	Monkeyface	S1	
Truncilla donaciformis	Fawnsfoot	S3	



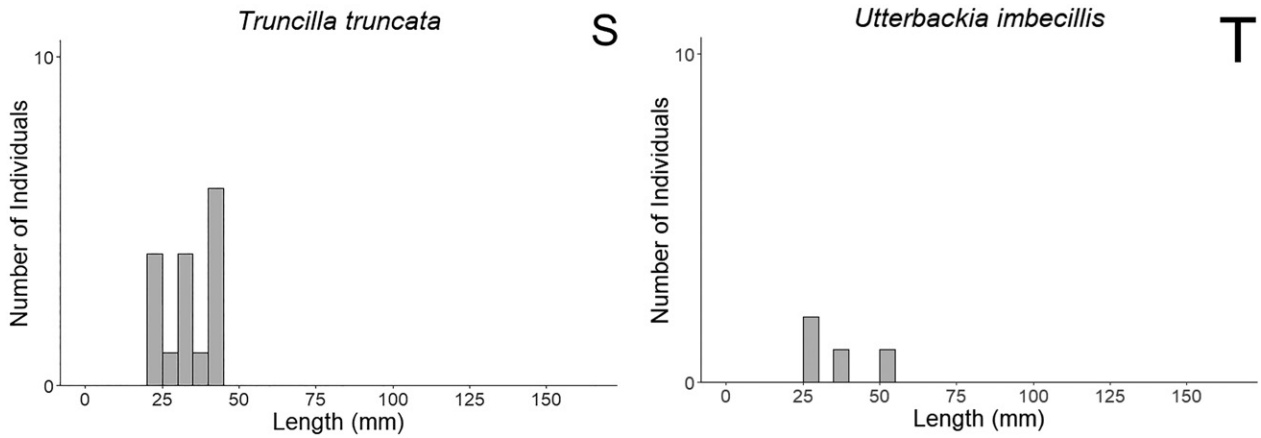
Appendix 3. Length frequency of common mussel species found in Bayou Bartholomew, Louisiana. A: *Amblema plicata* (n = 250). B: *Arcidens confragosus* (n = 29). C: *Cyclonaias nodulata* (n = 37). D: *Cyclonaias pustulosa* (n = 304). E: *Fusconaia flava* (n = 220). F: *Lampsilis hydiana* (n = 37) (*continued*).



Appendix 3 (Continued). G: *Lampsilis straminea* (n = 6). H: *Lampsilis teres* (n = 112). I: *Leaunio lienosus* (n = 3). J: *Megalonaias nervosa* (n = 78). K: *Obliquaria reflexa* (n = 71). L: *Plectomerus dombeyanus* (n = 193) (*continued*).



Appendix 3 (Continued). M: *Potamilus fragilis* (n = 28). N: *Potamilus purpuratus* (n = 98). O: *Quadrula quadrula* (n = 161). P: *Toxolasma texasensis* (n = 24). Q: *Tritogonia verrucosa* (n = 132). R: *Truncilla donaciformis* (n = 17) (*continued*).



Appendix 3 (Continued). S: *Truncilla truncata* (n = 16). T: *Utterbackia imbecillis* (n = 4).