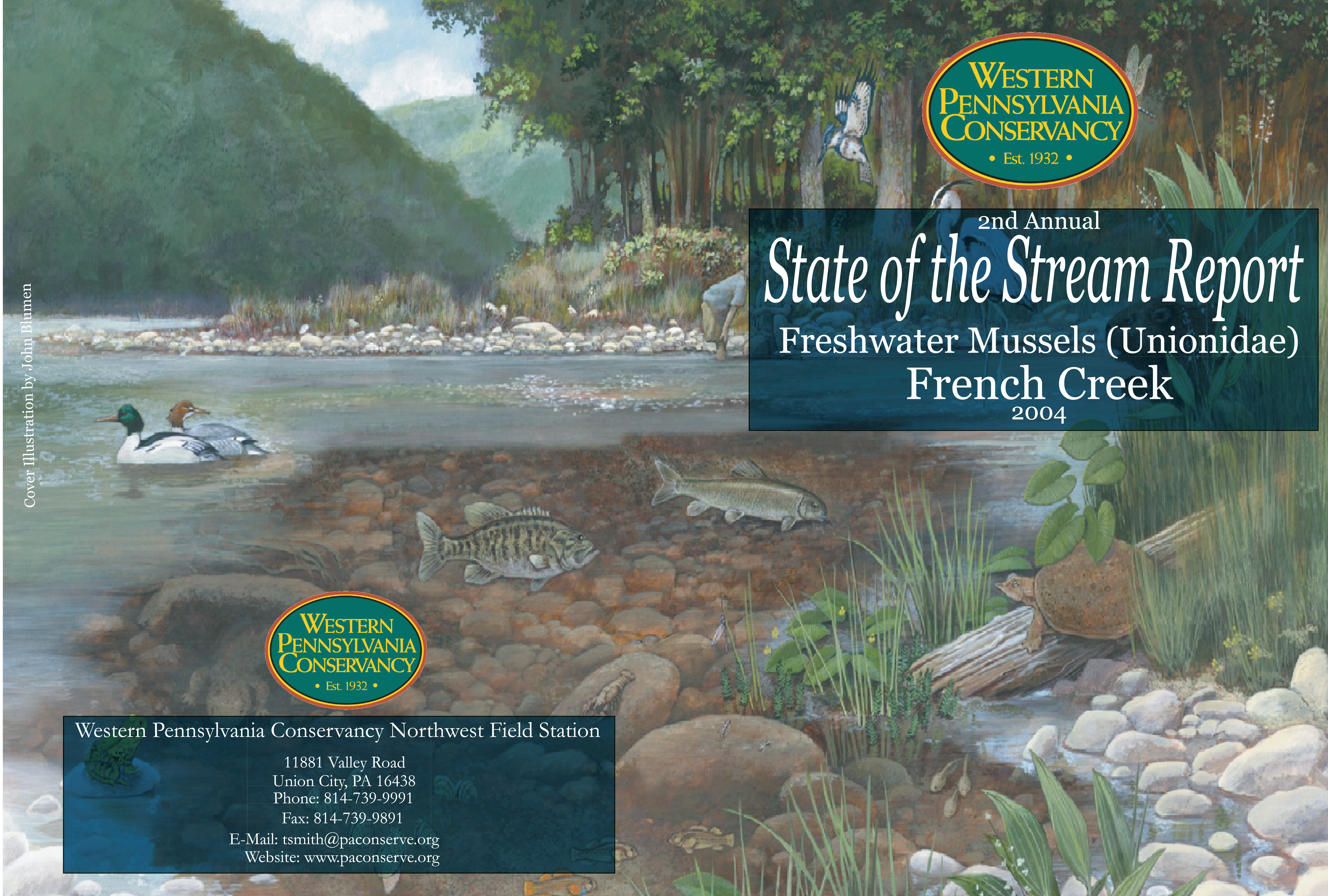

Cover Illustration by John Blumen

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2nd Annual

State of the Stream Report

Freshwater Mussels (Unionidae)

French Creek

2004

2nd Annual

State of the Stream Report: Freshwater Mussels (Unionidae) French Creek, Pennsylvania

2004

Prepared By
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Western Pennsylvania Conservancy

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MISSION

Western Pennsylvania Conservancy's mission is to save the places we care about by connecting people to the natural world.

ACHIEVING OUR MISSION IN FRENCH CREEK

Since the 1950s, Western Pennsylvania Conservancy (WPC) has recognized the uniqueness and need to protect the glacial region of northwest Pennsylvania for future generations to enjoy. Home to significant geological, archaeological, and ecological resources, this region holds treasures found nowhere else in the Commonwealth.

Even at that time, WPC scientists recognized the significance of the wetlands within the French Creek watershed. The first land protection efforts began in the 1960s with acquisition of rare wetland communities that would become a National Natural Landmark, the Wattsburg Fen Natural Area. The importance of the river system itself became recognized in the early 1980s, because French Creek held the highest degree of biodiversity found anywhere in the northeastern United States and therefore became a priority project area for WPC. WPC continued its scientific research in the French Creek watershed and in 1995, to further accomplish its mission, joined with the Pennsylvania Environmental Council and Allegheny College to form the French Creek Project, a nationally recognized community education and outreach endeavor to further raise awareness of French Creek and connect its watershed residents to this natural treasure. Scientists from WPC worked with other conservation organizations like The Nature Conservancy to raise awareness of French Creek, an effort that lead to its inclusion in the TNC publication, *Rivers of Life* in 1998.

In 2000, as a way to better engage with French Creek watershed communities and more thoroughly study the creek, WPC established its Northwest Field Station in the watershed. As a partner in the French Creek Project, WPC completed the comprehensive French Creek Watershed Conservation Plan in early 2002. This provided, for the first time, a blueprint for environmental education, conservation, and restoration of French Creek. Today, Western Pennsylvania Conservancy continues its efforts to better understand the natural processes governing the French Creek watershed and human impacts on water quality, aquatic biodiversity, as well as important factors for human quality of life. We are working with our partners in the French Creek Project, County Conservation Districts, local governments, environmental agencies, and conservation organizations to engage landowners in voluntary, incentive-based conservation practices, and we are striving to ensure important community decisions have sound, scientific data to inform them.

Western Pennsylvania Conservancy and many of our partners, including French Creek Project, The Nature Conservancy, County Conservation Districts, USDA Natural Resource Conservation Service, Conneaut Lake/French Creek Valley Conservancy and others are committed to protecting the rural, agricultural heritage of French Creek communities. This is evident in the hundreds of thousands of dollars raised by these organizations to assist farmers to implement Best Management Practices. Furthermore, WPC and our partners have worked diligently to expand programs like the Conservation Reserve and Enhancement Program (CREP), Growing Greener, and landowner incentive programs that could mean millions of dollars in support for French Creek farmers. Projects like this French Creek watershed assessment are crucial to understanding human impacts to our aquatic resources. This report will be a useful tool in leveraging much of the funding needed to work cooperatively with French Creek's communities to protect French Creek's amazing natural resources and its watershed residents' rural quality of life.

The ***2004 State of the Stream Report on French Creek*** is the second of an annual report series we plan to make to the communities of French Creek Watershed. We hope information such as this can help us to achieve our mission of connecting people to this special place. As an annual report, WPC pledges to continue engaging our partners in conservation and updating the public on the health of this watershed. In French Creek, we are striving to protect this place we care about by providing scientific insight and connecting people to its natural wonders.

ACKNOWLEDGEMENTS

The French Creek Watershed Assessment and resulting State of the Stream Report were funded in part by a Pennsylvania State Wildlife Grant administered by the PA Game Commission and the PA Fish and Boat Commission. The Nature Conservancy, and the Western Pennsylvania Conservancy provided additional funding. Dr. Eric Straffin, Edinboro University of Pennsylvania, Department of Geosciences, provided expertise and in-kind match for the physical habitat assessment and the development of a master's thesis research project.

Western Pennsylvania Conservancy would like to thank staff from our partners at French Creek Project, The Nature Conservancy, Venango and Crawford County Conservation Districts, and the Pennsylvania Department of Environmental Protection who provided input on sampling design, assisted with rain or water sample collection, or assisted in any of the various fieldwork components. Also important to the success of this project were many competent student interns and volunteers from local universities and the Student Conservation Association. Megan Bradburn, Erica Maynard, Amy Bush, Lucas Mattera, Elizabeth Peck, Nathan Irwin, Philip Kukulski, and Curtis Stumpf provided crucial assistance in the office, field, and laboratory.

Tamara Smith
Northwest Conservation Programs
Western Pennsylvania Conservancy
February 2005

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I. OBJECTIVES

The objectives of this study were to detail the specific locations of freshwater mussel species within this watershed and to compare that data with previous mussel data for French Creek, with an emphasis on species considered to be imperiled. We plan to interpret unionid distributional trends within French Creek with respect to present habitat, water quality, and fish data. Specifically, we are interested in information on density, relative abundance and age structure of unionid populations. These data will then be included in the development of a monitoring and protection plan for French Creek and could be used for restoration recommendations for nearby watersheds.

II. INTRODUCTION

French Creek, originating in western New York and flowing 117 miles (188 km) to its confluence with the Allegheny River at Franklin, Pennsylvania, is perhaps the most ecologically significant waterway in the state, containing more species of fish and freshwater mussels (Unionidae) than any other similar sized stream in the northeast United States. Over 80 species of fish and 27 native species of freshwater mussels are found in the watershed along with various other wildlife and plant species.

Two of the mussels found in French Creek are presently listed as Endangered under the U.S. Endangered Species Act, the northern riffleshell (*Epioblasma torulosa rangiana*) and the clubshell (*Pleurobema clava*). The rayed bean mussel (*Villosa fabalis*) has been named as a candidate for federal listing, and the snuffbox (*Epioblasma triquetra*) and the rabbitsfoot (*Quadrula cylindrica*) are both proposed candidates for federal listing. Nine other mussel species are considered rare, threatened, or endangered in Pennsylvania by the Pennsylvania Biological Survey. Special concern fish species include several madtom and lamprey species, as well as eight of the 15 species of darters found in the French Creek watershed.

There are a number of activities in the French Creek watershed such as agriculture, logging, mineral extraction, point source discharges, and development that may jeopardize water and habitat quality. Not only are these potential threats to aquatic organisms, but also impacts from these activities may ultimately jeopardize the quality of life for watershed residents.

STUDY LOCATION

French Creek is part of the Allegheny River watershed and therefore contributes to the Ohio River, the Mississippi River, and ultimately the Gulf of Mexico. The entire French Creek watershed covers an area of approximately 1235 mi^2 (790,400 acres or 3199 km^2). Approximately 93% of the watershed is within Pennsylvania, and the remaining 7% is made up of headwater streams in New York. The headwaters of the West Branch of French Creek and the French Creek main-stem form in Chautauqua County, New York and flow southwest to their confluence in Erie County, Pennsylvania. The South Branch of French Creek originates near Corry in Erie County and flows west to its confluence with French Creek west of Union City in Erie County. French Creek flows south through Crawford County, the northeast corner of Mercer County, and finally into Venango County where it flows southeast to its confluence with the Allegheny River at Franklin, Pennsylvania (Figure 1).

The French Creek watershed is mostly rural with only a few urban areas. The watershed is home to approximately 116,000 people, with the largest city being Meadville, PA (2000 Census). Although the landscape has various land uses, most can be categorized as either agricultural or forested (Smith et *al.* 2003).

III. METHODS

SITE SELECTION

Starting at the New York/Pennsylvania border, the main stem of French Creek was divided into 25 stretches of approximately 3.5 mi (5.6km) in length. Sites within each of these stretches were chosen according to habitat mapping from the 2002 field season. Because our main goal was to map mussel communities, site selection favored optimal habitat types for rare species and high species diversity (riffle-run), however pool habitat types were sampled if no riffle-runs are found within a 3.5-mile (5.6km) stretch. We sampled 24 of the initial 25 chosen sites. We were unable to survey one chosen site near Cochranton (Crawford County), because of high water levels and high turbidity on the dates we visited the site (Sites 21 and 26). However, we were able to add sites to take advantage of lower flows further up in the watershed. We randomly chose two sites in Erie County, and another in Crawford County. EnviroSci sampled sites 27 and 28 in 2001, so we did not sample for mussels at these sites, however we did survey them for fish and macroinvertebrates in 2004.

HABITAT MEASUREMENTS

Water quality and physical habitat were measured in conjunction with the biological surveys for each site to determine macrohabitat and microhabitat associations for mussels. Water quality was assessed using a YSI field meter and measurements included: temperature, pH, conductivity, and dissolved oxygen. Physical habitat measurements included current velocity, stream width, water depths, and substrate composition.

The riparian area was assessed using visual estimation of the following: riparian buffer width, riparian vegetation type, riparian vegetation thickness, bank vegetation type, bank vegetation thickness, bank stability, water pathways, channel modification, canopy cover, and land-use (Schneir 2003, Appendix A). Also included in this visual assessment were in-stream cover, embeddedness, and aquatic vegetation. Water clarity was visually assessed as either clear or turbid.

To create a cross section of the stream bottom at each site, we utilized a Laser Transit 229 Series. North, east, and Z coordinates were mapped at 1-meter intervals from bank to bank from at least 2 representative cross sections of each site. We used an electronic flow meter (FLOW MATE model 2000) to measure current velocity at 1-meter intervals in conjunction with the stream bottom mapping. These data were used to calculate sheer stress, discharge water depth, wetted area at low flow, wetted area at bank full, wetted perimeter and hydraulic radius (Maynard 2005, Appendix B).

A water sample was taken at each mussel site using a US DH-48 suspended sediment sampler and analyzed to determine the amount of sediment in the water column during the time of each mussel survey (Barbour et *al.* 1999). A one-pint (0.4732 L) bottle was slowly lowered and raised to the surface to completely fill the bottle. Filter paper was weighed to the nearest .001/g after a drying for 20-30 minutes in a 60ºC oven. Each water sample was filtered through the filter paper and dried over night at 60°C. The amount of sediment in each water sample was simply the difference in weight of the filter paper with the sediment and from its initial weight.

A random sample of 100 rocks was measured at each site according to methods modified from Harrelson et al. (1994). The observer walked perpendicular to the flow of the stream from one bank towards the other bank, randomly stopping to measure the first item touched by the tip of the index finger at the toe. Rocks were measured to the nearest mm along the intermediate axis. The ten largest rocks at each site were also measured along the intermediate axis. These data were used to calculate sorting (Maynard 2005, Appendix B). Sorting may reveal variation in velocity and the ability of a particular process to transport and deposit certain grain sizes (Prothero and Schwab 2004).

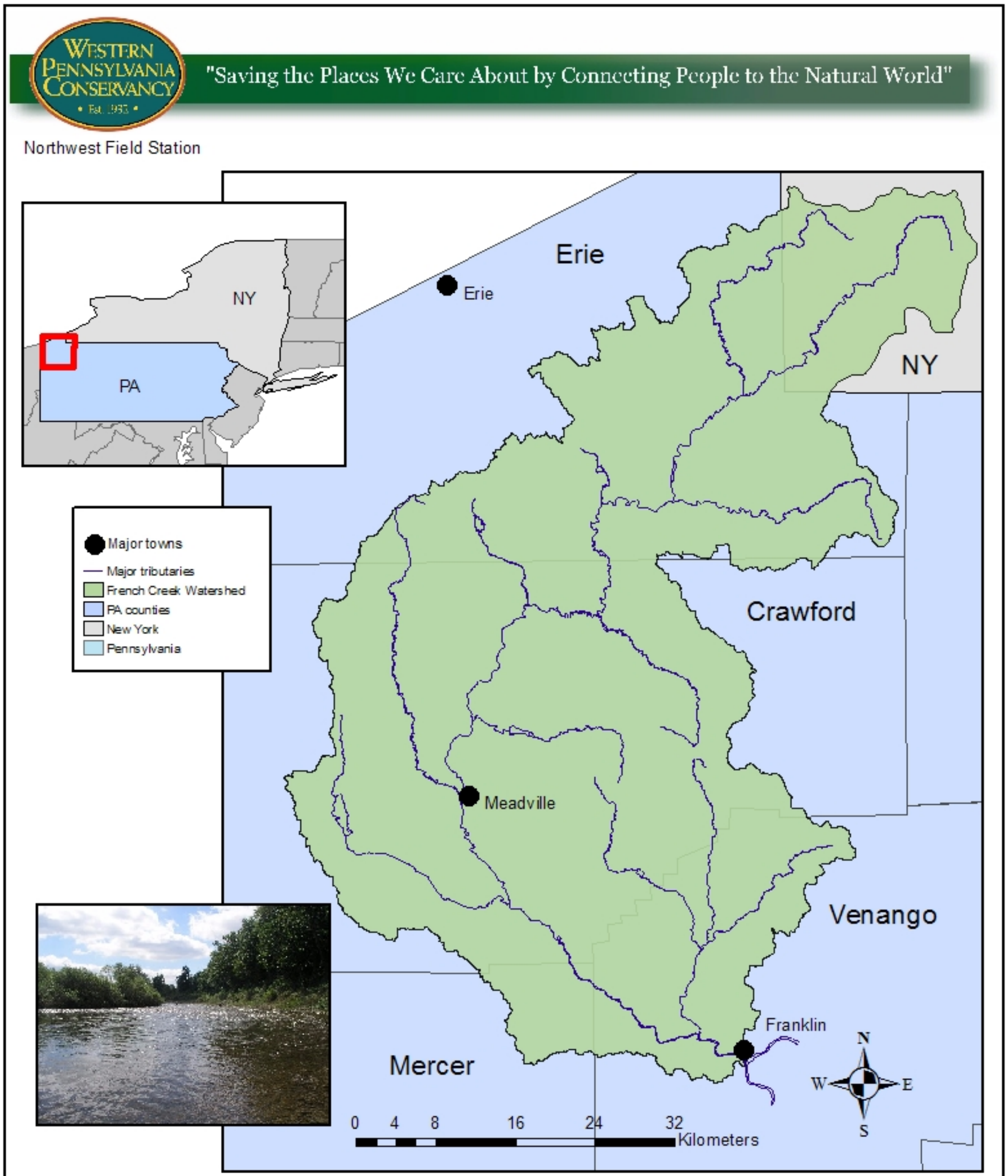

Figure 1: Location of the French Creek Watershed

MUSSEL SAMPLING TECHNIQUES

SNORKEL/SCUBA SURVEYS

We used modified mussel sampling techniques developed by Smith et *al*. (2001). The goal of qualitative sampling was to characterize species richness in a given area. Observers used a combination of tactile and visual methods, and although most of the mussels collected were visible at the surface, observers periodically brushed away sediment, flipped over non-embedded rocks, and did some light raking and digging during each search. Snorkelers collected as many unionid individuals as possible in equal areas for a specified amount of time. Search area was standardized to 2500 m^2 per site with a total search time of 300min/site, which was divided equally among observers (e.g. 5 observers searching for 60 minutes each, each searching their own 500 m^2 cell). Sampling started at the downstream end of the study section and observers moved in an upstream zigzag direction in equally sized transects (cells), covering the entire stream width. SCUBA divers were used in water depths greater than 1.5m and divers zigzagged downstream to minimize physical exertion and air use. We assumed equal efficiencies between both sampling methods with a target search rate of $0.5m^2$/minute. Effective sampling fraction was used (search rate multiplied by search time over cell area) as a means of comparison between timed searches (Smith et *al.* 2001). Data for each cell was tracked separately, to look at variability between cells. Twenty-seven sites were surveyed in 2003.

Live mussels were kept in submersed mesh bags until each survey was completed. Mussels were identified, counted, and returned to the cell in which they were found. A minimum of 45 random mussels of each species was measured to the nearest millimeter. Catch per unit effort (CPUE) was calculated for these searches as number of unionid individuals collected divided by person-hours spent sampling.

Because this report contains sensitive information, it should be noted that site numbers are scrambled; in other words, site numbers do not necessarily correspond to upstream to downstream order on the main-stem of French Creek.

Freshwater mussel surveys also included collection of shells from muskrat middens. The goal of surveying middens is to determine if middens can be used as a less invasive surrogate for in-stream surveying of freshwater mussels. For this to be possible, it is necessary to determine if every species is represented, if species composition (relative abundances) is comparable, and to determine if the age structures (lengths) are comparable.

MUSKRAT MIDDEN COLLECTIONS

Both banks in the study area were searched for muskrat middens, and spent shells were collected for species identification. Locations of middens were mapped and valve pairs were counted and measured to determine relative abundance and species composition of middens. Mussel shells that were collected during the 2004-field season were identified, counted, and measured to the nearest 0.1mm.

During the 2002 habitat mapping, mussel shell middens were collected along the length of French Creek. Mussel shells that were collected during the 2002 field season were identified and counted; however, only *E. torulosa rangiana* shells were measured to the nearest 0.1mm.

IV. ANALYSIS AND RESULTS

PHYSICAL HABITAT ASSESSMENT

Summary statistics of riparian habitat, water quality, and physical habitat data for each site are given in tables 1, 2, and 3. The mean value for each parameter with its 95% confidence interval was calculated. Because of deep water, we were unsuccessful in mapping the stream bottom at sites 11, 12, and 20.

Significant differences between sites were further assessed by comparing each site to all sites on the main-stem of French Creek. We did this to determine if any of the sites stood out as potential problem areas compared to what was typical of French Creek. To test if sites were different from the overall mean, we compared 95% confidence intervals. First, we calculated the overall mean and 95% confidence interval for each parameter using all the data. If the site value did not fall within the overall 95% confidence interval, there is significant difference at the $\alpha = 0.05$ level. These analyses give us a good picture of which sites are outliers compared to what was typically observed. Sites 20, 22, 23 and 24 stood out with many significantly low riparian scores. Sites 20, 15, 9, and 24 had significantly high shear stress. Sites 22, 23, 24, 13, 9, 8, 7 and 5 had poor sorting.

MUSSEL ASSESSMENT: LIVE MUSSELS

The total number, percent total catch, and number of sites in which freshwater mussels species were found in French Creek is given in Table 4. A total of 7680 individual live mussels representing 24 species were found at the 27 sites sampled in 2003 (Table 4). The mucket (*Actinonaias ligamentina*) was the most abundant and widely distributed species, found at 24 sites and accounting for about 45% of the total number of mussels found. The second most abundant species was the kidneyshell (*Ptychobranchus fasciolaris*), which was also found at 24 sites and made up 13.7% of the total catch. The two next most abundant species were spike (*Elliptio dilatata*) (6.9%, 22 sites) and the rayed bean mussel (*Villosa fabalis*) (5.7%, 18 sites). Two federally endangered species were found: the northern riffleshell (*Epioblasma torulosa rangiana*) was found at 9 sites and made up 3.6% of the total catch, and the clubshell (*Pleurobema clava*) was found at 5 sites, and comprised approximately 0.2% of the total catch.

The total numbers of live mussels found at each site surveyed in 2003 are given in Table 5. Total live mussels ranged from zero live mussels to 946 live mussels. The mean number of mussels found was 284 (188,381). CPUE ranged from zero to 189 mussels found per hour. The mean CPUE was 56.88 (37.56,72.20).

Species diversity ranged from zero to 19 live species per site, with a mean of 12 (10,14) across all sites. Interestingly, at only one site were both federally endangered mussels found. Nine sites had above average species diversity for this watershed. On the other hand, seven sites all had lower than average species diversity. No live mussels were found at two sites, and only one live mussel was found at another site. In general, species richness was low in the upper watershed, reached 17-19 species between Muddy Creek and Le Boeuf Creek, dropped off around Cambridge Springs, and then generally stayed between 10 and 15 species lower in the watershed. Figure 2 is a map illustrating species richness and figure 3 shows this upstream to downstream trend using a super-smoother line (S-Plus 2000).

We found evidence of recruitment at several study sites. By studying the length frequency histograms for each species, we looked for obvious breaks that likely indicate year-classes. For most species, we used a cut-off length of specimens less than 30mm to indicate recent recruitment. We used a cut-off of 15-20mm for naturally smaller species such as the rayed bean mussel (*V. fabalis*) and the snuffbox

(*Epioblasma triquetra*), and a higher limit of 50mm for larger species such as the rabbitsfoot (*Quadrula cylindrica*). We did not find evidence of recruitment for five species found in this study; the threeridge (*Amblema plicata*), the cylindrical papershell (*Anodontoides ferussacianus*), the black sandshell (*Ligumia recta*), the rainbow mussel (*Villosa iris*), and paper pondshell (*Utterbackia imbecillis*).

Table 1: Water quality parameters measured for each mussel survey site. Mean and 95% confidence bounds on the mean (LCL, UCL) are also reported.

ID	Temperature (°C)	DO (mg/L)	pH	Conductivity (µs/cm)	Sediment type	Habitat type	Water clarity
1	24.71	10.03	8.32	0.278	cobble	riffle	clear
2	21.27	10.63	6.81	0.252	cobble	riffle	clear
3	19.44	8.68	7.92	0.246	gravel	riffle	clear
4	23.82	11.85	8.14	0.239	cobble	riffle/run	clear
5	22.94	11.73	8.50	0.244	coarse gravel	run	clear
6	21.97	8.97	8.01	0.238	coarse gravel	riffle/run	clear
7	23.63	10.27	8.05	0.243	fine gravel	run	clear
8	21.60	8.36	7.93	0.250	cobble	riffle/run	clear
9	23.33	10.81	8.29	0.246	coarse gravel	riffle/run	clear
10	21.92	8.12	7.90	0.249	coarse gravel	riffle/run	clear
11	22.27	NA	7.88	0.210	sand	pool	turbid
12	22.10	NA	7.86	0.220	sand	pool	turbid
13	24.93	10.06	7.97	0.239	coarse gravel	run	clear
14	23.94	12.73	8.19	0.234	coarse gravel	riffle	clear
15	23.31	8.81	7.82	0.235	coarse gravel	riffle/run	clear
16	22.03	10.52	8.23	0.219	cobble	riffle	clear
17	NA	NA	NA	NA	coarse gravel	run	clear
18	23.05	7.81	7.99	0.230	fine gravel	riffle/run	clear
19	23.87	8.99	8.16	0.231	coarse gravel	run	clear
20	24.05	NA	7.99	0.235	sand	pool	turbid
22	22.50	NA	7.76	0.229	coarse gravel	riffle/run	turbid
23	23.45	9.83	8.02	0.234	fine gravel	riffle/run	clear
24	25.65	13.33	8.81	0.230	cobble	riffle/run	clear
25	22.21	NA	8.45	0.200	boulders	riffle/run	clear
29	22.32	16.02	8.16	0.186	coarse gravel	run	turbid
30	19.89	9.96	8.31	0.222	gravel	riffle	clear
31	21.00	7.23	8.47	0.229	cobble	riffle/run	clear
Mean	**22.74**	**10.23**	**8.07**	**0.233**			
LCL Mean	**22.15**	**9.28**	**7.93**	**0.226**			
UCL Mean	**23.33**	**11.17**	**8.22**	**0.240**			

Table 2: Physical habitat calculated for each mussel survey site. Mean and 95% confidence bounds on the mean (LCL, UCL) are also reported.

ID	Sheer stress(kg/m²)	Discharge (m³/s)	Bankful wetted perimeter (m)	Bankful velocity (m/s)	Bankful discharge (m³/s)	Sorting (mm)	Sediment load(g/cm³)
1	8315.60	4.83	39.30	5.20	137.50	0.65	1.003
2	1981.00	3.06	44.85	3.14	158.02	0.40	1.008
3	5114.70	29.84	40.25	5.92	257.00	0.40	1.009
4	2403.03	11.68	39.23	3.19	139.61	0.65	1.017
5	8068.41	17.79	51.77	4.79	308.75	1.79	1.000
6	1249.35	11.25	41.59	2.30	90.40	0.55	1.004
7	3172.15	18.95	27.68	4.14	75.97	1.94	1.002
8	4531.10	5.68	35.98	4.86	48.92	1.79	1.005
9	14325.76	9.88	46.48	9.09	430.21	1.54	1.001
10	3472.63	3.55	37.08	3.83	106.20	0.80	1.006
11	NA	NA	NA	NA	NA	NA	1.139
12	NA	NA	NA	NA	NA	NA	1.001
13	2546.87	6.31	53.41	2.80	115.32	3.81	1.002
14	866.05	7.10	39.86	2.00	58.90	0.05	1.009
15	16595.97	3.12	41.27	8.54	153.28	0.40	1.006
16	6859.04	6.97	72.92	5.19	376.09	0.10	1.000
17	3456.00	14.34	54.16	4.32	223.06	0.65	1.018
18	1874.98	6.67	50.51	3.20	114.97	0.55	1.001
19	23239.33	7.49	90.46	14.09	1505.62	1.26	1.005
20	22145.13	34.68	83.96	15.95	2225.97	1.10	1.014
22	2453.84	16.77	69.71	3.39	354.33	1.79	1.005
23	739.49	7.86	87.72	1.90	280.81	1.61	1.001
24	8586.58	3.94	48.92	5.04	156.11	1.78	1.002
25	397.58	18.30	80.00	1.34	129.88	0.65	1.002
29	6473.39	8.02	47.03	5.18	235.38	0.65	1.006
30	5792.08	6.63	34.61	4.71	101.37	0.65	1.015
31	4980.16	0.52	32.99	4.13	81.62	0.65	1.008
Mean	**6385.61**	**10.61**	**51.67**	**5.13**	**314.61**	**1.05**	**1.011**
LCL Mean	**3779.72**	**7.19**	**44.13**	**3.69**	**112.61**	**0.71**	**1.000**
UCL Mean	**8991.49**	**14.03**	**59.21**	**6.57**	**516.61**	**1.39**	**1.021**

Table 3: Riparian habitat assessment using protocols developed by Schnier (2003, Appendix A). Score scale ranges from 1 to 10, with higher numbers reflecting better riparian and in-stream conditions. Both sides of the creek were assessed separately then averaged for an overall rating. Mean and 95% confidence bounds on the mean (LCL, UCL) are also reported.

ID	Riparian buffer width	Riparian vegetation type	Riparian vegetation thickness	Bank vegetation type	Bank vegetation thickness	Bank stability	Water path	Channel modification	Shading	In-stream cover	Embeddedness	Aquatic vegetation
1	5.5	6	7	7	7.5	7.25	8	10	6	2	7	10
2	6	6	5.5	6.25	7	6.5	8	10	2	3.5	7	8
3	5.5	6	8	7.75	8.5	6.5	6.5	7	5.5	4.5	7	10
4	10	8	9	7	8.5	8.25	8.5	7	1	3	4	10
5	3.5	4.5	6.5	6	7.5	7	9	7	4	3	6	9
6	2.5	2	7.5	7	7.75	6.5	6	10	3	7	6	2
7	4	4.5	10	4.5	5.5	6.25	7.5	10	2	2.5	7	7
8	6.5	6	6.5	5.5	4.5	3.5	6	10	4	2.75	7	7
9	10	10	7	4	4.5	4.5	7.5	10	2.5	2.5	7	6
10	10	10	10	5.25	1.75	3	4	10	5	5	7	10
13	5	6	9	7	7	7.25	8	8	3.5	3	7	8
14	8	9	9	7	4	1	6	10	2	2	7	7
15	6	6	8	7	6	6.25	8	8	4	7	6	6.5
16	7	7	9	4.75	6	5.5	7	6.5	2	4	3.5	9
17	8	7.75	5.5	7	7	5.5	7	10	3	3	7	9
18	5.5	5.5	6.5	5	4	5.5	8	9	4	5	8	5
19	6	5.5	7	5	6.5	5	6	9	3	3.5	8.5	7
20	2	1	1.5	2.5	1.5	1.5	3.5	4	4	2	6	10
22	3.5	5	4.5	5	4.5	4	4	5	4	3	6	3
23	2.5	2.5	2.5	8.5	3	7	4.5	10	2	2	7	3
24	1	2	7	4.5	5.5	7.5	9	10	2	2	7	2.5
25	5	5	4	2.5	4	6.75	8	3.5	2	3.5	4.5	9
29	1.5	1	7	6.5	6	6	8	4	6	5	7	8
30	4.5	9	7	6	7.5	8	8	5.5	3	2.5	7	10
31	7.5	7.75	6.25	6	5.5	5	5	10	2	6	7.5	10
Mean	**5.5**	**5.7**	**6.8**	**5.8**	**5.6**	**5.6**	**6.8**	**8.1**	**3.3**	**3.6**	**6.6**	**7.4**
LCL Mean	**4.4**	**4.7**	**6.0**	**5.2**	**4.8**	**4.9**	**6.2**	**7.2**	**2.7**	**2.9**	**6.1**	**6.4**
UCL Mean	**6.5**	**6.8**	**7.7**	**6.4**	**6.4**	**6.4**	**7.5**	**9.1**	**3.8**	**4.2**	**7.0**	**8.5**

Table 4: Total number, percent total catch, and number of sites in which freshwater mussels species were found in French Creek. Twenty-seven sites were surveyed in 2003.

Species	Common Name	TOTAL	%Total	#Sites
Actinonaias ligamentina	Mucket	3460	45.1	24
Ptychobranchus fasciolaris	Kidneyshell	1055	13.7	24
Elliptio dilatata	Spike	529	6.9	22
Villosa fabalis	Rayed bean mussel	438	5.7	18
Lasmigona costata	Fluted-shell	407	5.3	22
Alasmidonta marginata	Elktoe	320	4.2	19
Lampsilis siliquoidea	Fatmucket	282	3.7	17
Epioblasma torulosa rangiana	Northern riffleshell	274	3.6	9
Lampsilis ovata	Pocketbook	205	2.7	18
Amblema plicata	Threeridge	176	2.3	11
Strophitus undulatus	Creeper	149	1.9	17
Pleurobema sintoxia	Round pigtoe	74	1.0	16
Lampsilis fasciola	Wavy-rayed lampmussel	69	0.9	14
Epioblasma triquetra	Snuffbox	53	0.7	15
Quadrula cylindrica	Rabbitsfoot	41	0.5	12
Fusconaia subrotunda	Long-solid	39	0.5	7
Lampsilis cardium	Plain pocketbook	32	0.4	13
Ligumia recta	Black sandshell	24	0.3	9
Pyganodon grandis	Giant floater	19	0.3	6
Pleurobema clava	Clubshell	13	0.2	5
Anodontoides ferussacianus	Cylindrical papershell	11	0.1	7
Lasmigona compressa	Creek heelsplitter	6	0.1	6
Villosa iris	Rainbow mussel	3	0.0	3
Utterbackia imbecillis	Paper pondshell	1	0.0	1
Total		**7680**		

Table 5: Total numbers of live mussels found at each site surveyed in 2003.

Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	22	23	24	25	29	30	31
Actinonaias ligamentina		1	18	20	14	93	35	383	170	155	4		222	207	118	23	102	221	270	10	218	418	173	6	479		100
Alasmidonta marginata			1	8	16	24	27	21	8	17			18	16	10	2	20	36	3	1	23	20	3		35		11
Amblema plicata					1	1	1	2	2	17									117	22	3	4	6				
Anodontoides ferussacianus						1		2		2			1	1						1					3		
Elliptio dilatata			12	11	1	1	2	31	15	26			13	45	41	11	18	6	7	1	44	36	80	5	68		55
Epioblasma torulosa rangiana										4			11	14	4			1			9	24	23		184		
Epioblasma triquetra			2			1	1		3	3	1				3	1	3	4	2	2		1			6		20
Fusconaia subrotunda						2	3	14	6	12									1						1		
Lampsilis cardium				2	3		2	1	2	6	1		1				1			1		1			8		3
Lampsilis fasciola				1	5	21	3			3			1			3		17	3		2	5	3	1			1
Lampsilis ovata		2	3		4	15	9	9	13	66			21	3	4		3	7	8		4	11	5		18		
Lampsilis siliquoidea		1	65	101	4	4	5	1	2	2				2			5	1	1			3	3		3		79
Lasmigona compressa			1					1	1											1					1		1
Lasmigona costata			8	7	4	27	6	10	1	14			21	16	16	3	19	54	32	7	14	53	38	1	27		29
Ligumia recta					2	5	2						4				2				3	2	1		3		
Pleurobema clava						3	3	3	1	3																	
Pleurobema sintoxia			1	5		4	1	17	5	12	1		1		6	1		2	2				3		1		12
Ptychobranchus fasciolaris		1	19	66	20	70	33	70	34	58	3		17	56	133	28	60	30	14	3	14	46	41	1	36		202
Pyganodon grandis		10	1					2					1							4							1
Quadrula cylindrica						2	3	1	2	6				7	3	1			3			3	4		6		
Strophitus undulatus	1				2	2		7	4	7			10	6	20	1	13	15	5		10	5	4		37		
Utterbackia imbecillis																				1							
Villosa fabalis						7	3	21	17	8	8		11	8	24	1	9	58	58	15	42	43	76		30		
Villosa iris																							1	1			
Total no. mussels	**1**	**15**	**131**	**221**	**76**	**283**	**140**	**595**	**286**	**421**	**18**	**0**	**353**	**381**	**382**	**75**	**255**	**452**	**526**	**69**	**386**	**675**	**464**	**15**	**946**	**0**	**514**
Total no. species	**1**	**5**	**11**	**9**	**12**	**19**	**18**	**17**	**17**	**19**	**6**	**0**	**15**	**12**	**12**	**11**	**12**	**13**	**15**	**13**	**12**	**16**	**16**	**6**	**18**	**0**	**12**
CPUE (#/hr.)	**0.2**	**3**	**26**	**44**	**15**	**57**	**28**	**119**	**57**	**84**	**4**	**0**	**71**	**76**	**76**	**15**	**51**	**90**	**105**	**14**	**77**	**135**	**93**	**3**	**189**	**0**	**103**

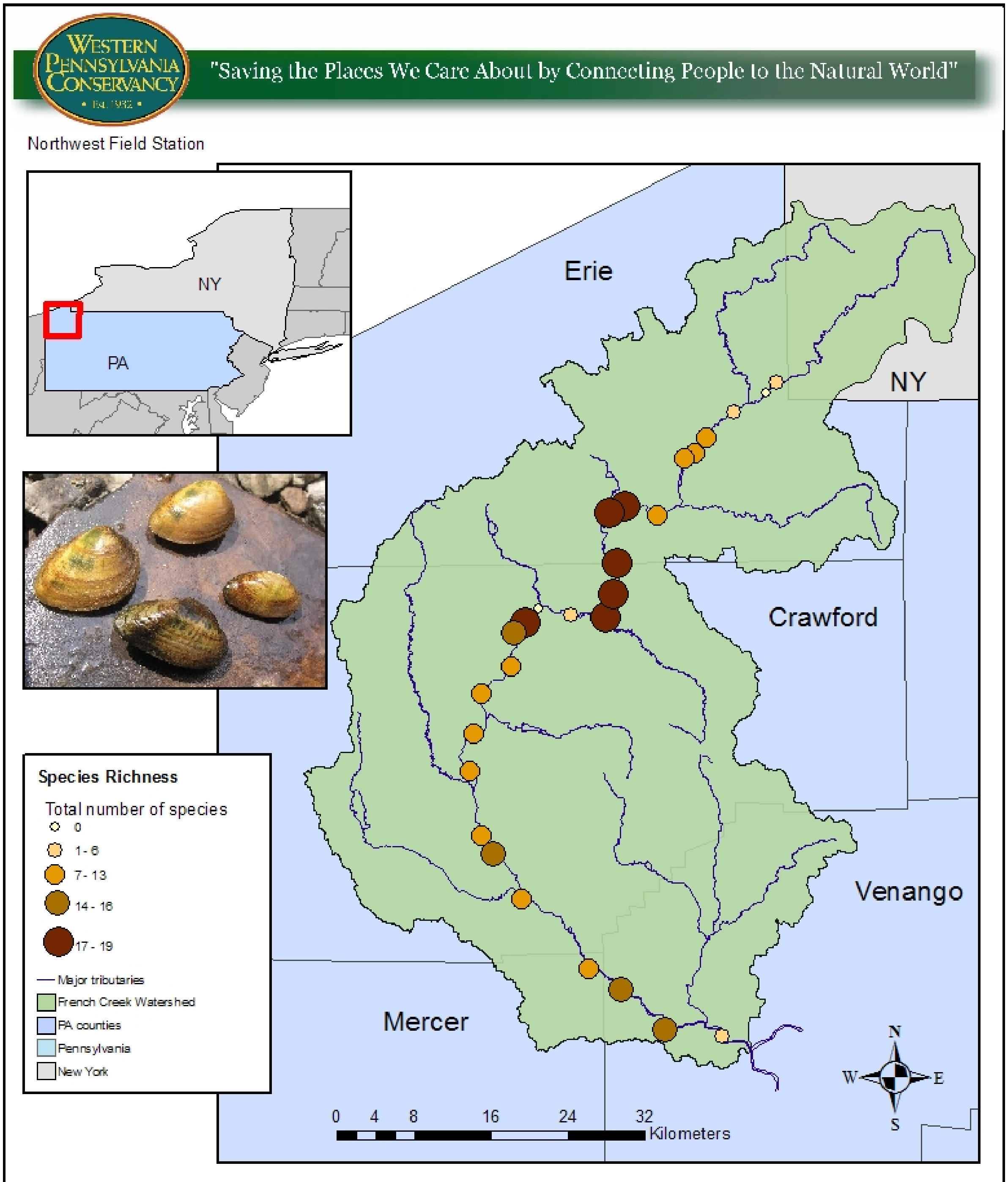

Figure 2: Freshwater Musssel Species Richness (Total number species- live)

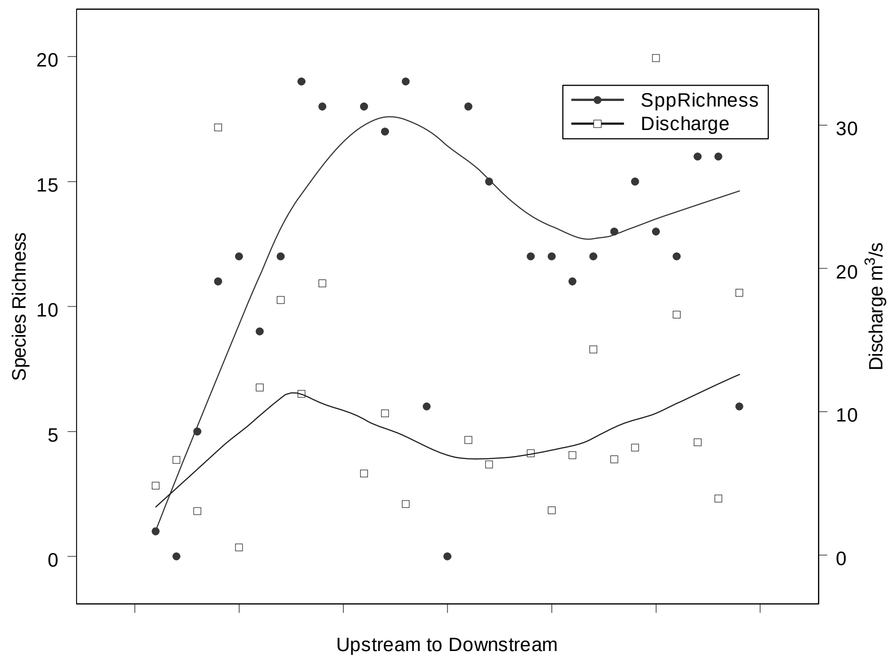

Figure 3: Species richness from upstream to downstream of French Creek. A local regression (loess) smooth line was added to help illustrate the trends (S-plus 2000). Note that discharge was measured in the field on the day of the mussel survey. Summertime mean daily discharge increases from upstream (20-30cfs) to downstream (200-300cfs) based on USGS measurements.

SPECIES SPECIFIC SUMMARIES

We wanted to characterize each species in the watershed by summarizing species-specific data across all sites. Species data is summarized in Table 6, which includes the total numbers alive, fresh dead, and weathered; total numbers male, female, and unknown sex. In addition, we calculated the mean lengths with error estimates for each species and created length frequency histograms for each species.

MUCKET (*Actinonaias ligamentina*)

Muckets were the most abundant and widely distributed species in French Creek. We found a total of 3460 live individuals distributed across 24 sites and in Erie, Mercer, Crawford and Venango counties. *A. ligamentina* made up over 45% of the total catch. At most sites where we found live specimens, we also found fresh dead specimens and/or weathered shells. Because so many live individuals were found, it was not practical to collect every fresh dead or weathered mucket shell observed at each site, therefore numbers of reported shells is considerably low. Shell length of *A. ligamentina* ranged from a minimum of 10.6mm to a maximum of 155mm with a mean of 91.2mm (88.9, 93.5). Fifteen sites had evidence of recent recruitment (specimens with lengths < 30mm, Figure 4). Two sites had a particularly high abundance of individuals less than 30 mm; both in Crawford County.

ELKTOE (*Alasmidonta marginata*)

Elktoes were widely distributed and fairly abundant in French Creek, with 320 live individuals found across 19 sites. *A. marginata* made up approximately 4.2% of the total catch and was found in Erie, Venango, Mercer, and Crawford counties. At most sites where we found live specimens, we also found fresh dead specimens and/or weathered shells. Shell length of *A. marginata* ranged from a minimum of 19.5 to a maximum of 104 mm with a mean of 64.9 mm (63.3,66.5). Three sites had evidence of recent recruitment (specimens with lengths < 30mm, Figure 4).

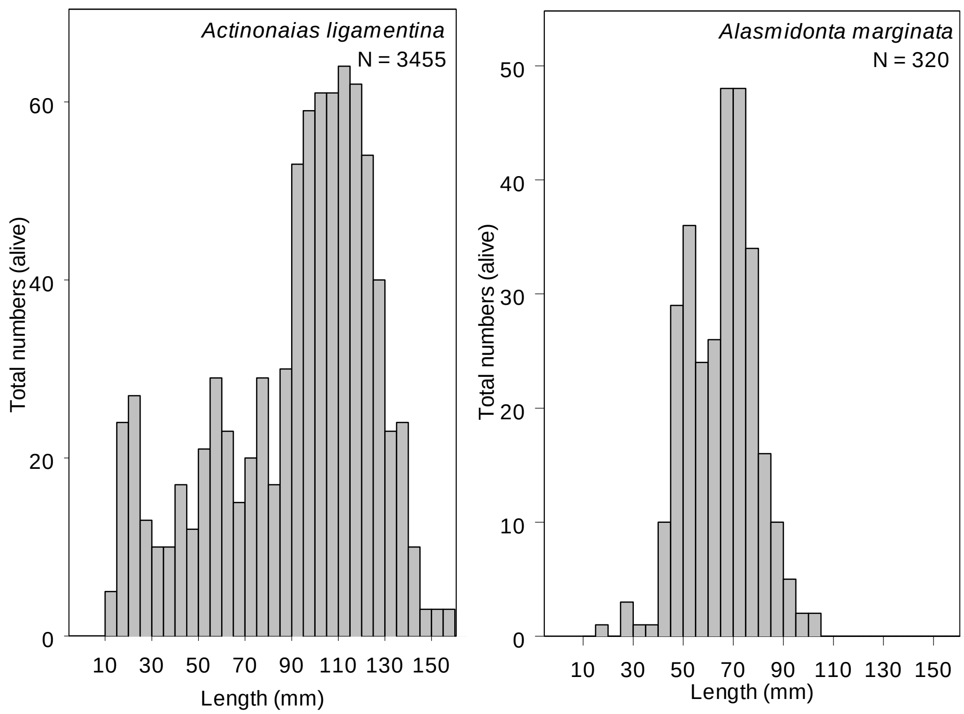

Figure 4: Length frequency histogram of mucket (*Actinonaias ligamentina*) and the elktoe (*Alasmidonta marginata*). Note the different scales of the y-axes.

Table 6: Summary statistics for each species found. Includes total numbers alive, fresh dead, and weathered dead shells. Numbers of female and male, and unknown sex are given for sexually dimorphic species. Mean lengths with the lower (LCL) and upper (UCL) 95% confidence bounds are given. Numbers given for sexes and lengths are based on live individuals only. Reported data is from snorkel/SCUBA sites and does not include midden data.

Species	Alive	Fresh Dead	Weathered Dead	Female	Male	Unknown Sex	Mean Length (mm)	LCL Length	UCL Length
Actinonaias ligamentina	3455	36	46				91.2	88.9	93.5
Elliptio dilatata	529	19	31				76.2	74.4	78.0
Villosa fabalis	439	221	78	217	218	4	26.9	26.4	27.5
Lasmigona costata	407	18	24				97.3	95.4	99.1
Alasmidonta marginata	320	21	13				64.9	63.3	66.5
Lampsilis siliquoidea	282	10	18	144	127	11	74.0	72.0	76.0
Epioblasma torulosa rangiana	274	20	31	142	119	9	45.6	43.9	47.2
Lampsilis ovata	204	6	7	41	21	142	104.2	100.0	108.5
Amblema plicata	176	5	21				93.8	89.5	98.1
Ptychobranchus fasciolaris	148	3	6				81.1	79.4	82.8
Strophitus undulatus	148	3	6				65.3	63.3	67.3
Lampsilis fasciola	70	4	4				56.3	53.0	59.6
Epioblasma triquetra	53	17	14	36	11	4	43.3	40.2	46.3
Pleurobema sintoxia	41	7	11				69.2	61.9	76.4
Quadrula cylindrica	41	7	11				91.3	82.1	100.4
Fusconaia subrotunda	39	1	9				84.8	70.4	99.3
Lampsilis cardium	32	2	1				94.6	81.9	107.2
Ligumia recta	24	8	12				125.0	114.8	135.1
Pyganodon grandis	18	5	2				61.1	45.9	76.3
Pleurobema clava	13	7	2				33.3	23.7	43.0
Anodontoides ferussacianus	11	0	0				58.8	53.1	64.4
Lasmigona compressa	6	1	0				74.4	60.5	88.4
Villosa iris	2	2	0	1		2	34.4	NA	NA
Utterbackia imbecillis	1	1	0				58.3	NA	NA
Unkown juvenile	1	0	0				22.0	NA	NA

THREERIDGE (*Amblema plicata*)

We found 176 live *Amblema plicata* individuals across 11 sites on the main-stem of French Creek and in all four counties (Erie, Crawford, Venango, Mercer). Numbers of live individuals were generally low (between 1 and 22 per site). However, live individuals from one site in Crawford County made up 66.5 % of the total *A. plicata* catch, where 117 individuals were found. In addition to the live individuals, we found a total of 5 fresh dead and 21 weathered *A. plicata* shells. At most sites where we found live specimens, we also found fresh dead specimens and/or weathered shells. Shell length of *A. plicata* ranged from a minimum of 36.5mm to a maximum of 135 mm with a mean of 93.8mm (89.5, 98.1). No sites had evidence of recent recruitment (specimens with lengths < 30mm). The length frequency histogram for *A. plicata* (Figure 5) shows bimodal distribution, indicating a size class ranging from 35-70mm with a median length of ~50mm.

CYLINDRICAL PAPERSHELL (*Anodontoides ferussacianus*)

We found only 11 live *Anodontoides ferussacianus* individuals across 7 sites on the main-stem of French Creek in Erie and Crawford counties. Numbers of live individuals were low (between 1 and 3 per site). We found no fresh dead or weathered *A. ferussacianus* shells. Shell length of ranged from a minimum of 42.8 mm to a maximum of 73.1mm with a mean of 58.8mm (53.1,64.4). There was no evidence of recent recruitment (specimens with lengths < 30mm, Figure 5).

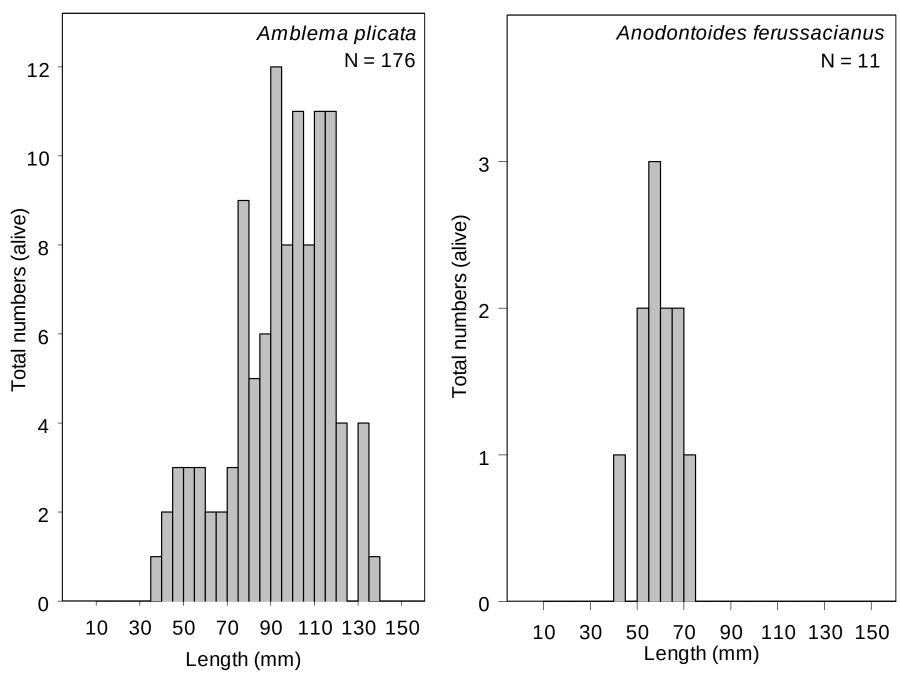

Figure 5: Length frequency histogram of threeridge (*Amblema plicata*) and the cylindrical papershell (*Anodontoides ferussacianus*) for all 27 sites surveyed in 2003. Note the different scales of the y-axes.

SPIKE (*Elliptio dilatata*)

Elliptio dilatata were widely distributed and the third most abundant freshwater mussel species in French Creek, with 529 live individuals found across 22 sites and in all four counties (Erie, Mercer, Crawford, Venango). In addition to the live individuals, we found a total of 19 fresh dead and 31 weathered *E. dilatata* shells. No dead shells were found at any sites where we did not find live individuals. Shell length of *E. dilatata* ranged from a minimum of 14.0mm to a maximum of 124.9mm with a mean of 76.2mm (74.4, 78.0). Eight sites had evidence of recent recruitment (specimens with lengths < 30mm, Figure 6).

NORTHERN RIFFLESHELL (*Epioblasma torulosa rangiana*)

We found northern riffleshell at nine sites on the main-stem of French Creek. At these sites, numbers of live individuals ranged from one to 184 individuals found per site. At only one site, we found both *E. torulosa rangiana* and *P. clava*. One site in Crawford County stood out with a very high abundance of *E. torulosa rangiana*, where 184 individuals were found, and making *E. torulosa rangiana* the 2^{nd} most abundant species at that site. In addition to the 274 live individuals, we found a total of 20 fresh dead and 31 weathered *E. torulosa rangiana* shells. At most sites where we found live specimens, we also found fresh dead specimens and/or weathered shells. We found fresh dead but no live specimens at four sites and only one weathered shell at another site. Shell length of *E. torulosa rangiana* ranged from a minimum of 14.0 mm to a maximum of 78.1 mm with a mean of 45.6mm (44.0,47.2). Six sites had evidence of recent recruitment (specimens with lengths < 30mm, Figure 6). We found a total of 142 live female and 119 live male northern riffleshells, giving an overall female to male ratio of 1.2 to 1. Only one male and zero females were found at site 18. Conversely, site 17 had 17 females to 6 males.

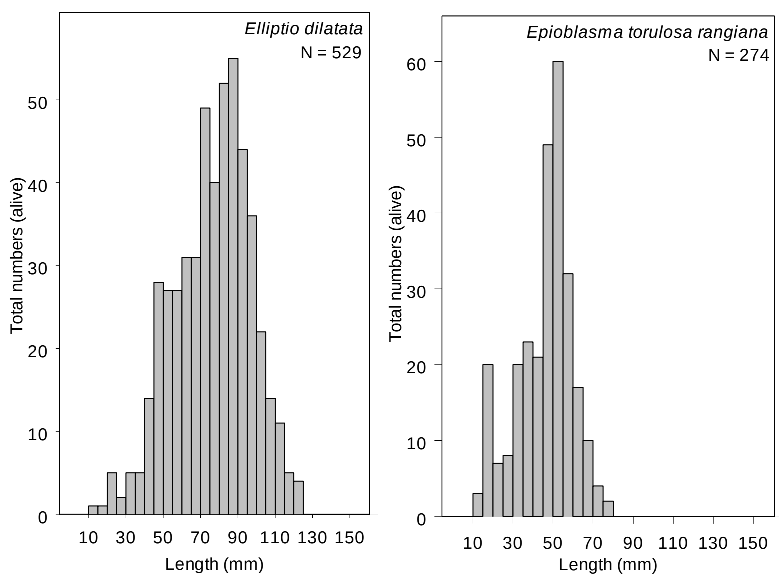

Figure 6: Length frequency histogram for spike (*Elliptio dilatata*) and northern riffleshell (*Epioblasma torulosa rangiana*) for all 27 sites surveyed in 2003. Note the different scales of the y-axes.

SNUFFBOX (*Epioblasma triquetra*)

We found *Epioblasma triquetra* at 15 sites on the main-stem of French Creek, in Erie, Crawford, and Venango counties. Numbers of live individuals were generally low (between 1 and 6). *E. triquetra* from one site in Erie County made up thirty- eight percent of the total *E. triquetra* catch for the entire study, where 20 individuals were found. In addition to the 53 live individuals; we found a total of 17 fresh dead and 14 weathered *E. triquetra* shells. At most sites where we found live specimens, we also found fresh dead specimens and/or weathered shells. We found fresh dead but no live specimens at two sites in Erie County. Two sites in Crawford County had both fresh dead and weathered shells but no live specimens. Shell length of *E. triquetra* ranged from a minimum of 15.5 mm to a maximum of 67.0 mm with a mean of 43.3mm (40.2,46.3). Two sites had evidence of recent recruitment (specimens with lengths ≤ 20mm, Figure 7). We found a total of 36 live female and 11 live male snuffbox, giving an overall female to male ratio of 3.3 to 1. Site 31 had 16 female to 4 male and site 29 had 5 female and one male.

LONG-SOLID (*Fusconaia subrotunda*)

Thirty-nine live *Fusconaia subrotunda* individuals were found across 7 sites, with generally low numbers per site (1-14). All *F. subrotunda* sites were in only Erie and Crawford counties. *F. subrotunda* was most abundant at two sites in Erie County. In addition to the live individuals, we found a total of 1 fresh dead and 9 weathered *F. subrotunda* shells. We did find weathered shells at one site in Venango County, but no live individuals. Shell length of *F. subrotunda* ranged from a minimum of 11mm to a maximum of 136 mm with a mean of 84.8 mm (70.4, 99.3). Two sites had evidence of recent recruitment (specimens with lengths < 30mm, Figure 7).

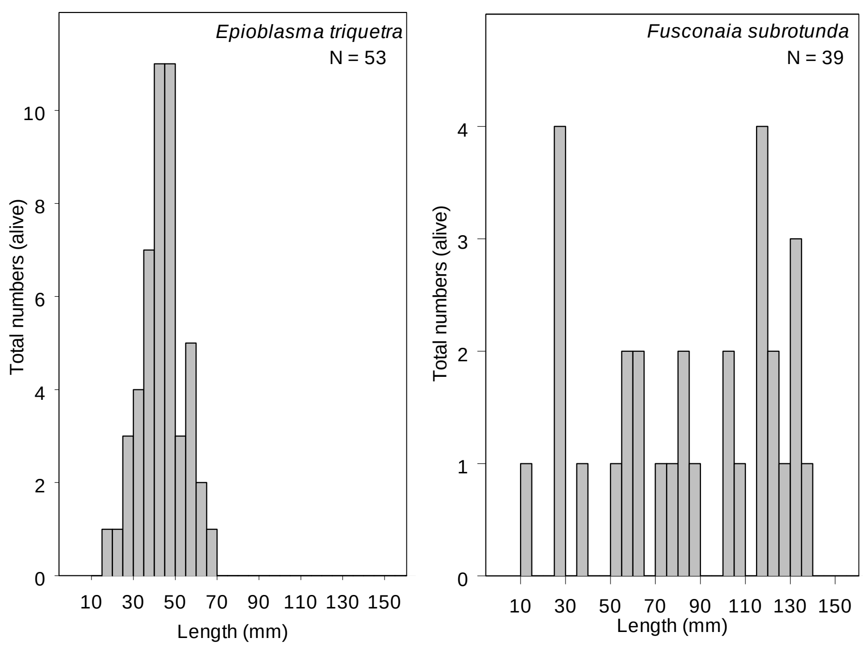

Figure 7: Length frequency histogram for snuffbox (*Epioblasma triquetra*) and long-solid (*Fusconaia subrotunda*) for all 27 sites surveyed in 2003. Note the different scales of the y-axes.

PLAIN POCKETBOOK (*Lampsilis cardium*)

We found 32 live *Lampsilis cardium* individuals found across 13 sites, with generally low numbers per site (1-8). *L. cardium* was found in Erie, Crawford, and Venango counties. In addition to the live individuals, we found a total of 2 fresh dead and 1 weathered *L. cardium* shells. No dead shells were found at any sites where we did not find live individuals. Shell length of *L. cardium* ranged from a minimum of 27mm to a maximum of 135mm with a mean of 94.6 mm (81.9, 107.3). One site had evidence of recent recruitment (specimens with lengths < 30mm). The length frequency histogram appears to separate a few size classes (Figure 8).

WAVY-RAYED LAMPMUSSEL (*Lampsilis fasciola*)

We found 69 live *Lampsilis fasciola* 69 individuals across 14 sites, in all four counties (Erie, Crawford, Mercer, Venango), but with generally low numbers per site (1-5). However, two sites had more individuals; one in Crawford County with 17 live individuals, while one in Erie County had 21 live individuals. In addition to the live individuals, we found a total of 4 fresh dead and 4 weathered *L. fasciola* shells. Sites 14 had no live individuals, but one weathered shell was found. Site 15 had only one fresh dead shell. Shell length of *L. fasciola* ranged from a minimum of 17mm to a maximum of 121.3mm with a mean of 56.3 mm (53.0, 59.6). Only two sites had evidence of recent recruitment (specimens with lengths < 30mm, Figure 8).

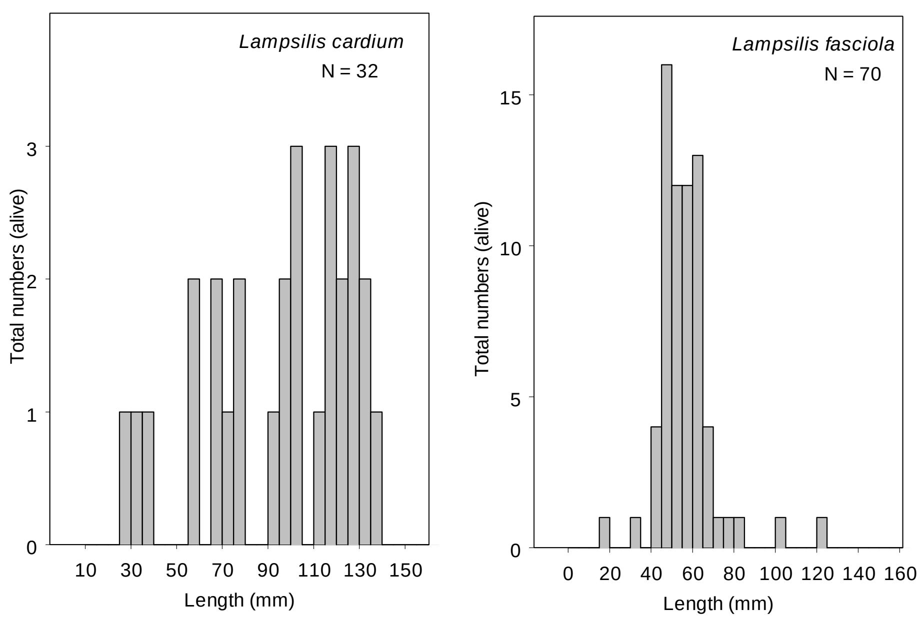

Figure 8: Length frequency histogram of plain pocketbook (*Lampsilis cardium*) and the wavy-rayed lampmussel (*Lampsilis fasciola*) for all 27 sites surveyed in 2003. Note the different scales of the y-axes.

POCKETBOOK (*Lampsilis ovata*)
We found 205 live *Lampsilis ovata* individuals found across 18 sites, with generally low to moderate numbers per site (2-21). We found *L. ovata* in all four counties (Erie, Crawford, Mercer, and Venango). *L. ovata* was most abundant at one site in Erie County, which had 66 live individuals. In addition to the live individuals, we found a total of 6 fresh dead and 7 weathered *L. ovata* shells. One site in Venango County had no live individuals, but one weathered shell was found. Shell length of *L. ovata* ranged from a minimum of 13mm to a maximum of 146.1mm with a mean of 104.2 mm (100.0, 108.5). Nine sites had evidence of recent recruitment (specimens with lengths <50mm, Figure 9).

FATMUCKET (*Lampsilis siliquoidea*)
We found a total of 282 live *Lampsilis siliquoidea* individuals across 17 sites, with generally low to moderate numbers per site (1-5). *L. siliquoidea* was widespread throughout the main-stem, but was most abundant at three sites in Erie County; with 101, 79, and 65 live individuals. *L. siliquoidea* was also found in Crawford and Venango counties. In addition to the live individuals, we found a total of 10 fresh dead and 18 weathered *L. siliquoidea* shells. We found a total of 113 live female and 131 live male fatmuckets, giving an overall female to male ratio of 1 to 1.1. The three sites with high numbers in Erie County all had slightly more females than males. At most sites where more than 1 individual was found, there was at least one male and one female. Shell length of *L. siliquoidea* ranged from a minimum of 33mm to a maximum of 121.2mm with a mean of 74.0mm (72.0,76.1). The 3 sites where *L. siliquoidea* was most abundant also had evidence of recent recruitment (<50mm). We found no individuals less than 30 mm, Figure 9).

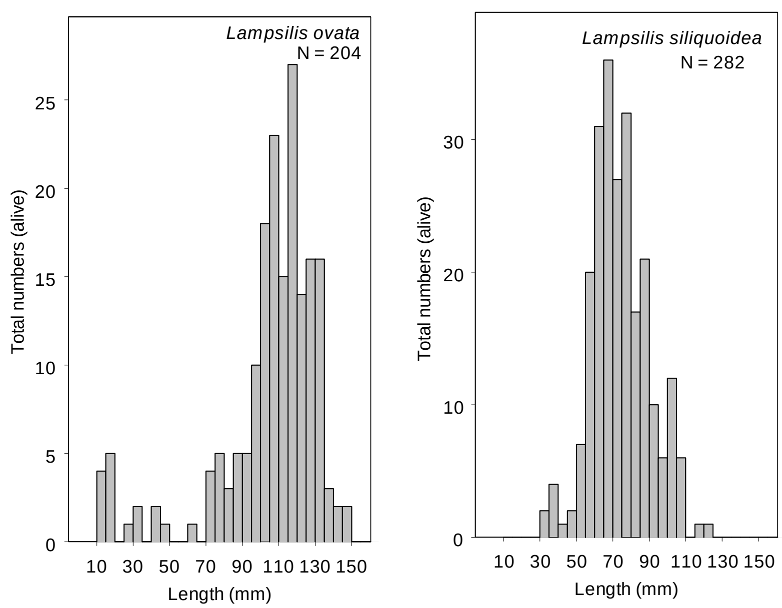

Figure 9: Length frequency histogram for pocketbook (*Lampsilis ovata*) and fatmucket (*Lampsilis siliquoidea*) for all 27 sites surveyed in 2003. Note the different scales of the y-axes.

Creek heelsplitter (*Lasmigona compressa*)
We found only 6 live *Lampsilis compressa* individuals across 6 sites. Live *L. compressa* was found in Erie and Crawford counties. One additional fresh dead shell was found in Crawford County. Shell length of *L. compressa* ranged from a minimum of 60.5mm to a maximum of 89mm with a mean of 74.4mm (60.5,88.4). No sites had evidence of recent recruitment; (specimens < 50mm, Figure 10).

Fluted-shell (*Lasmigona costata*)
Lasmigona costata was our fifth most abundant species found, with a total of 407 live individuals across 22 sites. *L. costata* was found in Erie, Mercer, Crawford, and Venango counties. The only places where *L. costata* was not found were three sites in Erie County and two pool sites in Crawford County. In addition to the live individuals, we found a total of 18 fresh dead and 24 weathered *L. costata* shells. Shell length of *L. costata* ranged from a minimum of 12.8mm to a maximum of 134.9mm with a mean of 97.3 mm (95.4, 99.2). Four sites had evidence of recent recruitment; (specimens < 30mm, Figure 10).

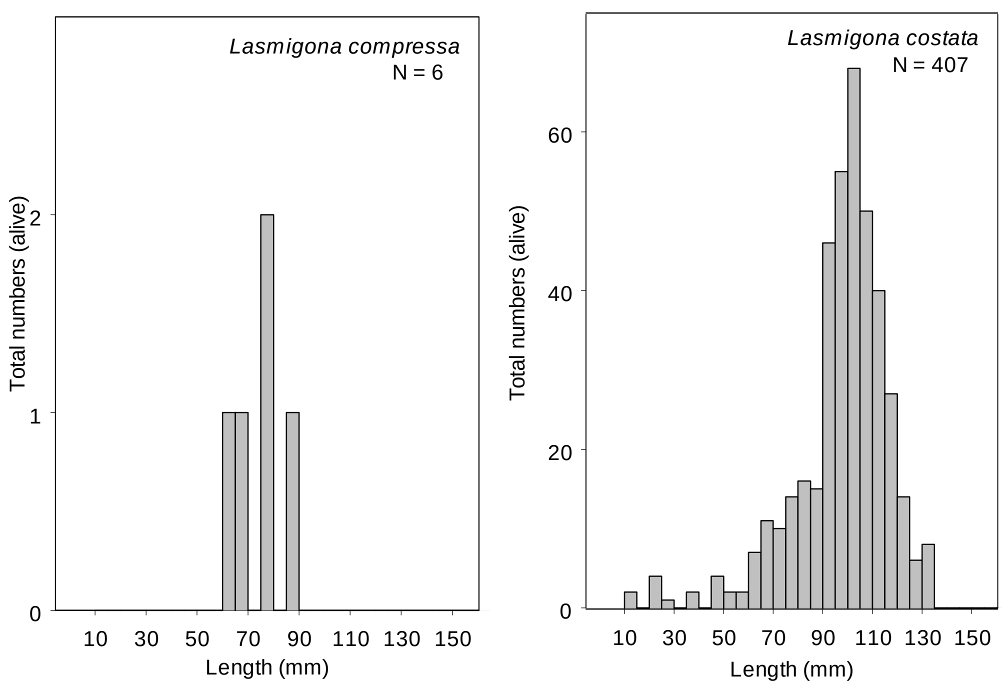

Figure 10: Length frequency histogram for creek heelsplitter (*Lasmigona compressa*) and fluted shell (*Lasmigona costata*) for all 27 sites surveyed in 2003. Note the different scales of the y-axes.

***B**LACK SANDSHELL* (*Ligumia recta*)

Ligumia recta was found at 9 sites and in Erie, Crawford, Mercer, and Venango counties. Numbers of live individuals were very low, with only 1-5 found per site, and a total of only 24 individuals. In addition to the live individuals, we found a total of 8 fresh dead and 12 weathered *L. recta* shells. Several sites had no live individuals, however fresh dead and/ or weathered shells were found: only dead shells were found at four sites in Crawford County, and only weathered shells were found at one site in Erie County and one site in Venango County. Two sites had both freshdead and weathered shells, but no live individuals. Shell length of *L. recta* ranged from a minimum of 81mm to a maximum of 155mm with a mean of 129.4 mm (121.0, 137.9). We found no evidence of recent recruitment, and only two sites had individuals less than 100mm (Figure 11).

***C**LUBSHELL* (*Pleurobema clava*)

We found live *P. clava* in Erie and Crawford counties at five sites on the main-stem of French Creek. Numbers of live individuals were very low, with only 1-3 found per site, and a total of only 13 individuals. In addition to the 13 live individuals, we found a total of 7 fresh dead and 2 weathered *P.clava* shells. At most sites where we found live specimens, we also found fresh dead specimens and/or weathered shells. One exception was site 7, where 3 live individuals but no empty shells were found. Another exception was site 17 (Crawford Co.), where no live individuals were found, but 1 fresh dead shell was found. This site was the lowest point in the watershed where we found evidence of *P. clava.* Clubshell ranged in lengths from a minimum of 17.5 mm to a maximum of 58.5 mm with a mean of 33.3mm (23.7, 43.0). Three of the sites had evidence of recent recruitment (specimens with lengths < 30mm, Figure 11). We were unable to sex *P. clava* in the field.

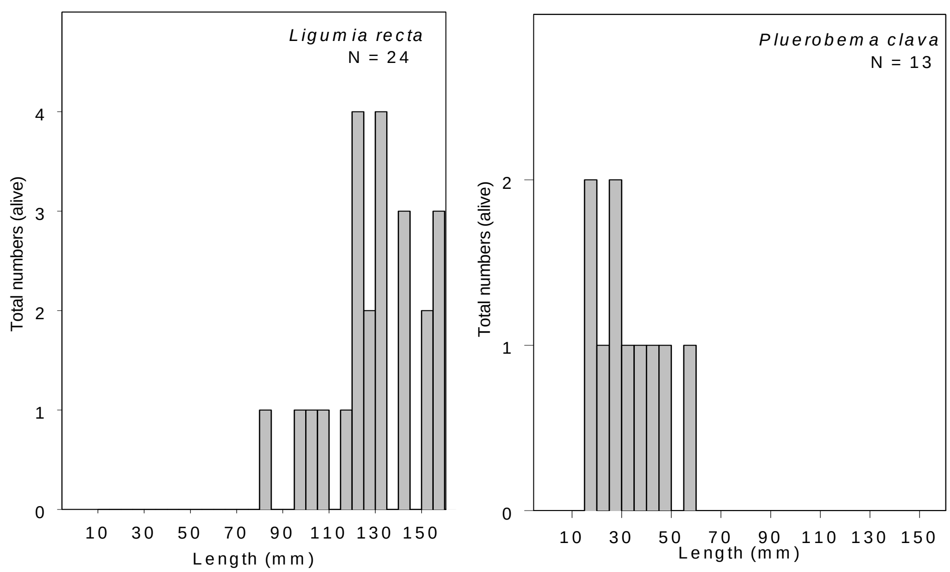

Figure 11: Length frequency histogram for black sandshell (*Ligumia recta*) and clubshell (*Pleurobema clava*) for all 27 sites surveyed in 2003. Note the different scales of the y-axes.

ROUND PIGTOE (*Pleurobema sintoxia*)
We found 74 live *Pleurobema sintoxia* individuals across 16 sites, with generally low numbers per site (1-6). Live *P. sintoxia* was found in Erie, Crawford, and Mercer counties. However, two sites in Crawford County had 12 and 17 live individuals, and one site in Erie County also had 12 live individuals. Shell length of *P. sintoxia* ranged from a minimum of 21.5mm to a maximum of 141mm with a mean of 69.2 mm (61.9, 76.4). Seven sites had evidence of recent recruitment (specimens with lengths < 30mm, Figure 12). The length frequency histogram (Figure 12) appears to be tri-modal, separating out size classes centered on 30, 70 and 130 mm. In addition to the live individuals, we found a total of 17 fresh dead and 23 weathered *P. sintoxia* shells. Three sites had no live individuals, but weathered shells were found, and one of those sites was in Mercer County.

KIDNEYSHELL (*Ptychobranchus fasciolaris*)
Ptychobranchus fasciolaris was our second most abundant species found, with a total of 1055 live individuals across 24 sites. The only sites that did not have any *P. fasciolaris* were the 2 sites highest in the watershed in Erie County, and one pool site in Crawford County. In addition to the live individuals, we found a total of 32 fresh dead and 19 weathered *P. fasciolaris* shells. Because so many live individuals were found, it was not practical to collect every fresh dead or weathered *P. fasciolaris* shell observed at each site, therefore numbers of reported shells is low.
Shell length of *P. fasciolaris* ranged from a minimum of 17mm to a maximum of 129mm with a mean of 81.1 mm (79.5, 82.8). Seven sites had evidence of recent recruitment (specimens <30mm, Figure 12).

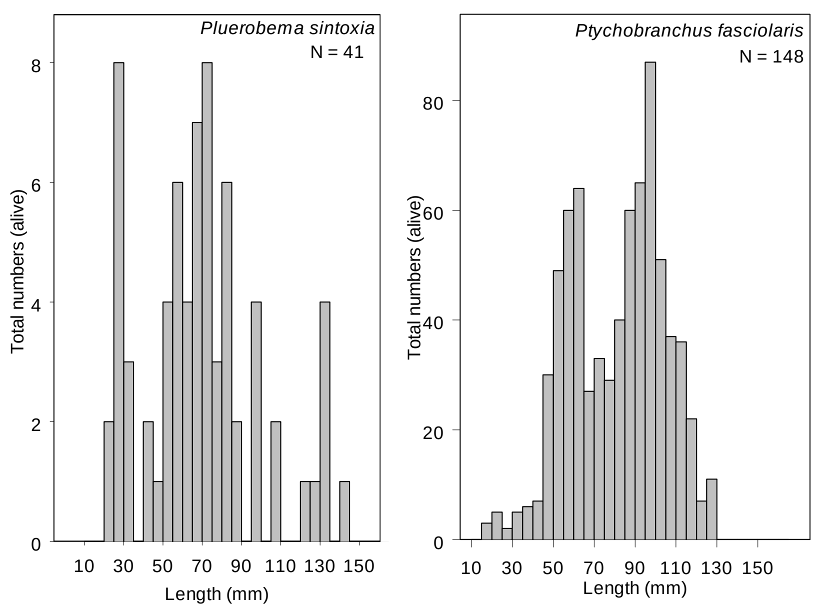

Figure 12: Length frequency histogram for round pigtoe (*Pleurobema sintoxia*) and kidneyshell (*Ptychobranchus fasciolaris*) for all 27 sites surveyed in 2003. Note the different scales of the y-axes.

GIANT FLOATER (*Pyganodon grandis*)
Pyganodon grandis was found at only 6 sites, and only in Erie and Crawford counties. Numbers of live individuals were very low, with only 1-10 found per site, and a total of only 19 individuals. In addition to the live individuals, we found a total of 5 fresh dead and 2 weathered *P. grandis* shells. Two sites had no live individuals, but each had fresh dead shells. One pool site in Crawford County had both fresh dead and weathered shells, but no live individuals. Shell length of *P. grandis* ranged from a minimum of 24.5mm to a maximum of 129mm with a mean of 81.1 mm (79.5, 82.8). Only one site in Erie County had evidence of recent recruitment (specimens < 30mm, Figure 13).

RABBITSFOOT (*Quadrula cylindrica*)
Quadrula cylindrica was found at 12 sites and in three counties; Erie, Crawford, and Venango. Numbers of live individuals were very low, with only 1-7 found per site, and a total of only 41 individuals. The site with the highest abundance of *Q. cylindrica* was in Crawford County, where 7 live individuals were found. *Q. cylindrica* ranged in size from a minimum of 37 mm to a maximum of 140mm with a mean of 91.3 (82.1,100.4). There are a few breaks in the length frequency histogram (Figure 13) that may indicate different size classes. There is evidence of recent recruitment (specimens with lengths < 50mm) at three sites. At several sites where we found live specimens, we also found fresh dead specimens or weathered shells. Only weathered shells were found at two sites; one in Crawford County, the other in Mercer County. We found a total of 7 fresh dead and 11 weathered *Q. cylindrica* shells. Also of note was a site in Crawford County, where we found 13 fresh dead and 5 weathered specimens, but only 1 live individual.

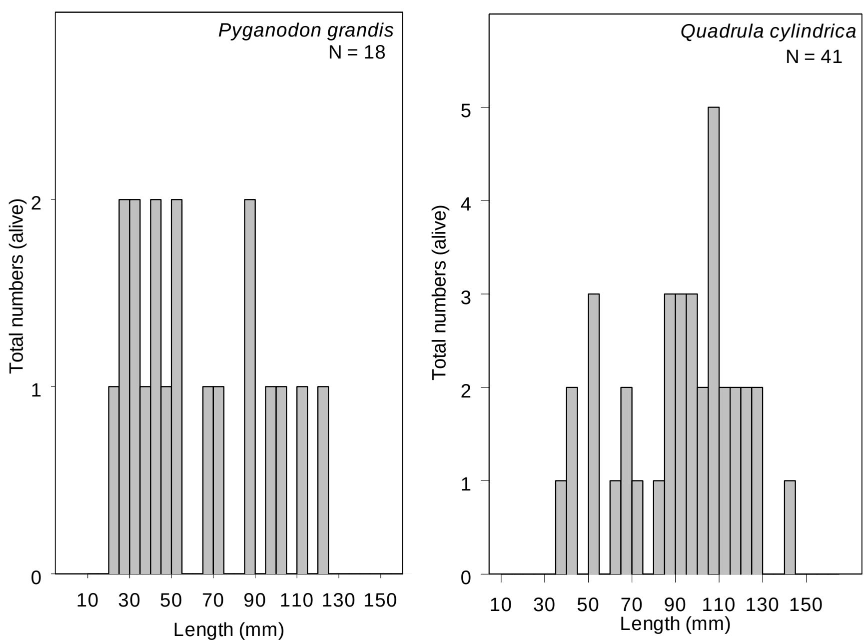

Figure 13: Length frequency histogram for giant floater (*Pyganodon grandis*) and rabbitsfoot (*Quadrula cylindrica*) for all 27 sites surveyed in 2003. Note the different scales of the y-axes.

CREEPER (*Strophitus undulatus*)

We found 149 individual live *Strophitus undulatus* across 17 sites and in all four counties (Erie, Crawford, Venango, and Mercer). *S. undulatus* was most abundant at one site in Crawford County, with 37 live individuals. In addition to the live individuals, we found a total of 3 fresh dead and 6 weathered *S. undulatus* shells. One site in Erie County had only weathered shells and another had only a fresh dead shell, but no live individuals. Shell length of *S. undulatus* ranged from a minimum of 33.5mm to a maximum of 99mm with a mean of 65.3mm (63.3, 67.3). Three sites had one individual less than 40mm; no individual *S. undulatus* under 30 mm were found (Figure 14).

PAPER PONDSHELL (*Utterbackia imbecillis*)

Only one live paper pondshell was found at a pool site in Crawford County with length of 58.3mm. One fresh dead shell was found at the same site.

RAYED BEAN MUSSEL (*Villosa fabalis*)

Villosa fabalis was found in Erie, Venango, Crawford and Mercer counties. Four-hundred and thirty nine live individuals were found across 18 sites, making up nearly 6% of the total catch. One site in Venango County had the highest abundance of *V. fabalis* with 76 live individuals found. At most sites where we found live specimens, we also found fresh dead specimens or weathered shells. We found a total of 221 fresh dead and 78 weathered *V. fabalis* shells. Also of note was a site in Crawford County, where we found 13 fresh dead and 5 weathered specimens, but only 1 live individual. The smallest adult mussels in the French Creek basin, rayed bean mussels ranged in size from a minimum of 10.5 mm to a maximum of 41.8 mm with a mean of 27 (26.4, 27.5). There is no clear break in the length frequency histogram that identifies size classes, however four sites had evidence of recent recruitment (specimens with lengths ≤ 15mm, Figure 14). We found a total of 217 live female and 218 live male-rayed bean, giving an overall female to male ratio of 1:1. Four sites had a lower than average female to male ratio, although the overall numbers at these sites were very low. Four sites had above average female to male ratios.

RAINBOW MUSSEL (*Villosa iris*)

Only 2 live rainbow mussels were found in our 2003 surveys. One live mussel was found each at two separate sites in Venango County. In addition, two fresh dead *V. iris* shells were found at one site in Venango County, but no live individuals were found. Lengths of the two live *V. iris* were 29.0 mm and 39.8mm. Both of these are adult sizes, therefore there is no evidence of recruitment. Since this species has a maximum size of 75 mm (Parmalee and Bogan 1998), we can speculate that recent recruits would be under 20mm.

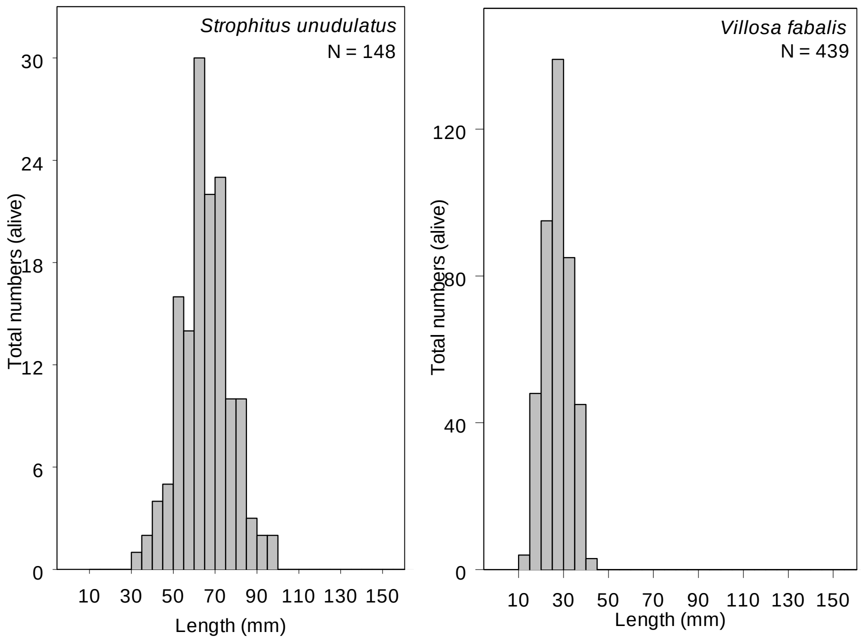

Figure 14: Length frequency histogram for creeper (*Strophitus undulatus*) and rayed bean mussel (*Villosa fabalis*) for all 27 sites surveyed in 2003. Note the different scales of the y-axes.

MUSSEL –HABITAT RELATIONSHIPS

HABITAT VS. SPECIES RICHNESS

We tested for relationships between habitat data and mussel species richness. We used simple regression analysis to see if there were any significant relationships between habitat variables and species richness. Significance for all tests were assessed at the $\alpha = 0.05$ level. Results of the regressions show significant linear relationships between species richness and aquatic vegetation (p-value = 0.175). No other significant relationships were found, however, we did find some trends in the data (Appendix C). An increase in the following parameters scores showed an increasing trend in species richness: sorting, temperature, riparian vegetation thickness score, channel modification score, in-stream cover score, and embeddedness score. An increase in the following parameter scores showed a decreasing trend in species richness: bank stability, water path, bank vegetation thickness, bank vegetation type, and aquatic vegetation. Remember that higher scores for these parameters indicate "better" quality habitat.

For categorical variables, we tested for significant relationships to species richness using Kruskal-Wallis rank sum tests. Significance for all tests were assessed at the $\alpha = 0.05$ level. Results of the Kruskal-Wallis tests show that habitat type (riffle, riffle-run, run, or pool) showed a significant relationship with species richness (p-value=0.01). It is not surprising that riffle, riffle-run, and run habitats had higher species diversity than pool habitats. A significant relationship between species richness and substrate type was also found (p-value =0.047, Figure 15). Sites with boulders as the dominant substrate had a significantly lower species richness than other types of substrates.

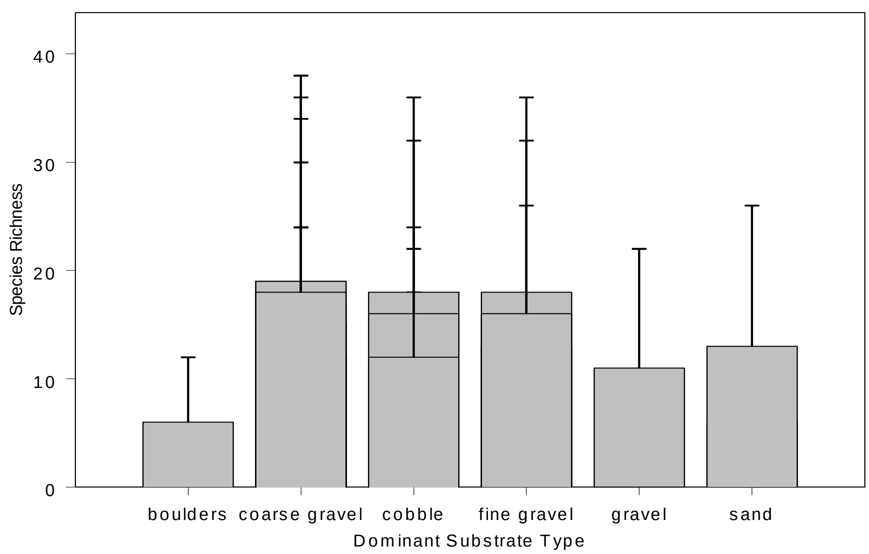

Figure 15: Bar graph with upper 95% confidence interval error bars indicating a significant relationship between species richness and substrate type (p-value =0.047).

Cluster analysis (Morans I) was performed on species diversity to see if the clustered patterns shown in Figure 2 are a result of random chance (ESRI 2003). This tool measures spatial autocorrelation (feature similarity) based on both feature locations and feature values simultaneously. Given a set of features (sites) and an associated attribute (species richness), it evaluates whether patterns are clustered, dispersed, or random. A Moran's Index value near +1.0 indicates clustering; an index value near -1.0 indicates dispersion. A z score is also calculated to assess whether or not the observed clustering or dispersion is statistically significant. Results of the cluster analysis gave a Moran's Index of 0.139, indicating that while there may be some clustering, the pattern may be due to random chance. The z score was 2.62, which is statistically significant at the α =0.05 level.

INDIVIDUAL SPECIES VS. HABITAT AND OTHER SPECIES

We tested the relationships of CPUE of each mussel species with habitat parameters using simple regression techniques. Significance for all tests were assessed at the α = 0.05 level for each of the following variables: dissolved oxygen, temperature, pH, conductivity, habitat type, substrate type, shear stress, wetted perimeter, sorting, sediment load, riparian buffer width, riparian vegetation type, riparian vegetation thickness, bank vegetation type, bank vegetation thickness, bank stability, water pathways, channel modification, canopy cover, in-stream cover, embeddedness, and aquatic vegetation (Schneir 2003, Appendix A). Results are reported for the individual species below. Our investigations showed a strong correlation between bankful velocity and shear stress (r =0.964, p-value =0.00), as well as between bankful discharge and sheer stress (r =0.776, p-value =0.00). Therefore, we left bankful velocity, bankful discharge out of the following analyses, but we included shear stress.

Additionally, we were interested in basic associations between mussel species, so we tested the correlations of CPUEs for each species with each other species using standard Pearson correlation methods (Mathsoft 1999). Significance for all tests were assessed at the α = 0.05 level. Most species were significantly correlated to at least one other species. Interestingly, no species had a negative correlation with another species. Results are reported for the individual species below.

Mucket (*Actinonaias ligamentina*)

We found a significant positive relationship between *A. ligamentina* CPUE and embeddedness (p-value =0.049); *A. ligamentina* CPUE increased with embeddedness scores (Figure 16). We found a significant negative relationship between *A. ligamentina* CPUE and aquatic vegetation scores (p-value =0.049); *A. ligamentina* CPUE decreased with increasing aquatic vegetation scores.

We found significant correlations between CPUE of *A. ligamentina* and *A. marginata* (r=0.642, p-value = 0.000), *A. ferussacianus*(r = 0.531, p-value = 0.003), *E. dilatata* (r = 0.620, p-value = 0.000), *E. torulosa rangiana* (r=0.599, p-value = 0.001), *L. cardium* (r = 0.378, p-value = 0.043), *L. costata* (r = 0.667, p-value = 0.000), *Q. cylindrica* (r=0.548, p-value =0.002), and *S. undulatus* (r=0.679, p-value = 0.000).

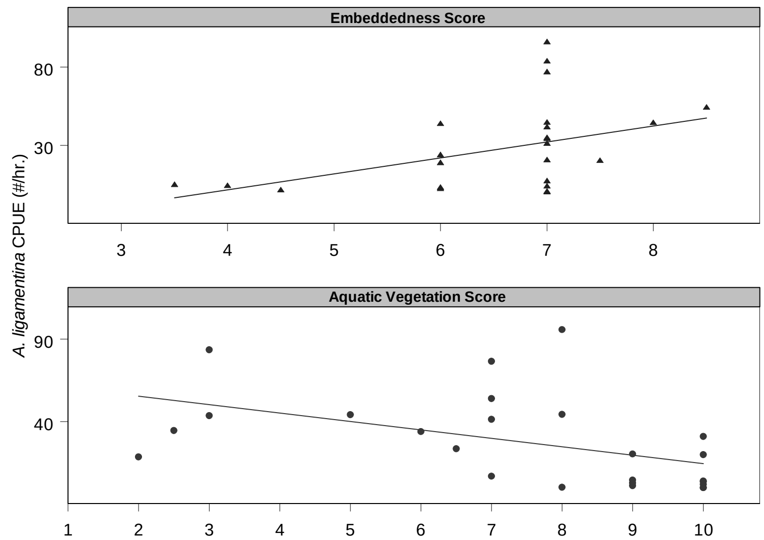

Figure 16: CPUE (total numbers/hour) of *A. ligamentina* versus embeddedness and aquatic vegetation.

Elktoe (*Alasmidonta marginata*)

We found significant relationships between *A. marginata* CPUE and aquatic vegetation (p-value = 0.038). *A. marginata* CPUE decreased with increasing aquatic vegetation scores (Figure 17). We found significant correlations between *A. marginata* and *L. recta* (r = 0.579, p-value =0.001), *L. fasciola* (r = 0.472, p-value = 0.010), and *L. cardium* (r = 0.487, p-value = 0.010), *L. costata* (r = 0.557, p-value = 0.003), *E. torulosa rangiana* (r = 0.435, p-value = 0.003), *A. ligamentina* (r = 0.635, p-value = 0.000), and *A. ferussacianus* (r = 0.469, p-value = 0.000).

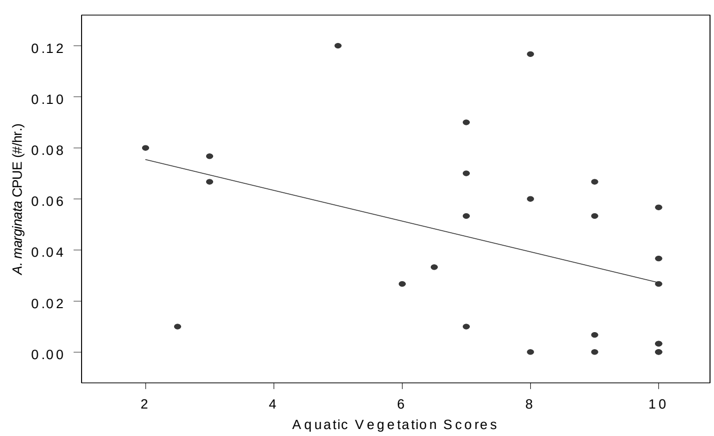

Figure 17: CPUE (total numbers/hour) of *A. marginata* versus aquatic vegetation.

Threeridge (*Amblema plicata*)

We found significant relationships between *A. plicata CPUE* and wetted perimeter (p-value = 0.012) and shear stress (p-value = 0.001). *A. plicata* CPUE increased with increasing wetted perimeter and increasing shear stress (Figure 18). We found significant correlations between *A. plicata* and *A. ferussacianus* (r = 0.700, p-value =0.000), and *L. compressa* (r = 0.664, p-value = 0.002).

Cylindrical papershell (*Anodontoides ferussacianus*)

We found a significant relationship between *A. ferussacianus* CPUE and bank stability (p-value = 0.047) and shading (p-value =0.018). *A. ferussacianus* CPUE increased with shading scores and decreased with increasing bank stability scores. We found significant correlations between *A. ferussacianus* and (r =0.874, p-value = 0.000), *L. compressa* (r =0.405, p-value = 0.036), *A. marginata* (r = 0.469, p-value = 0.014), *E. torulosa rangiana* (r=0.645, p-value = 0.000), *F. subrotunda* (r= 0.553, p-value = 0.003), *P. clava* (r = 0.431, p-value = 0.025), *P. sintoxia* (r = 0. 395, p-value = 0. 042), *Q. cylindrica* (r = 0.544, p-value = 0.003), *S. undulatus* (r=0.564, p-value = 0. 002), and *A. ligamentina* (r = 0.570, p-value = 0.002).

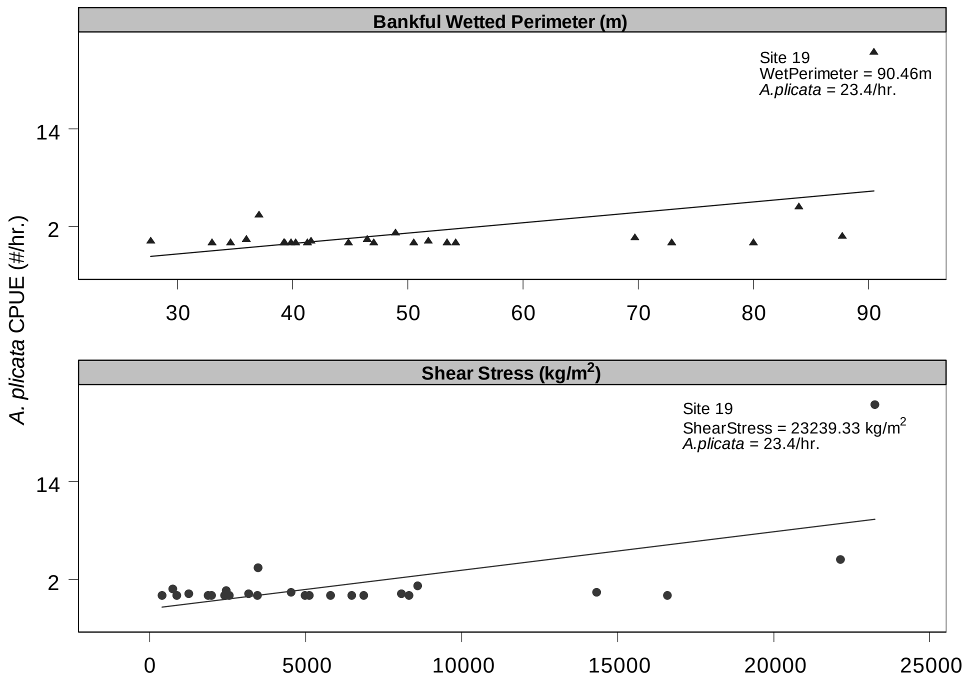

Figure 18: CPUE (total numbers/hour) of *A. plicata* versus wetted perimeter and shear stress.

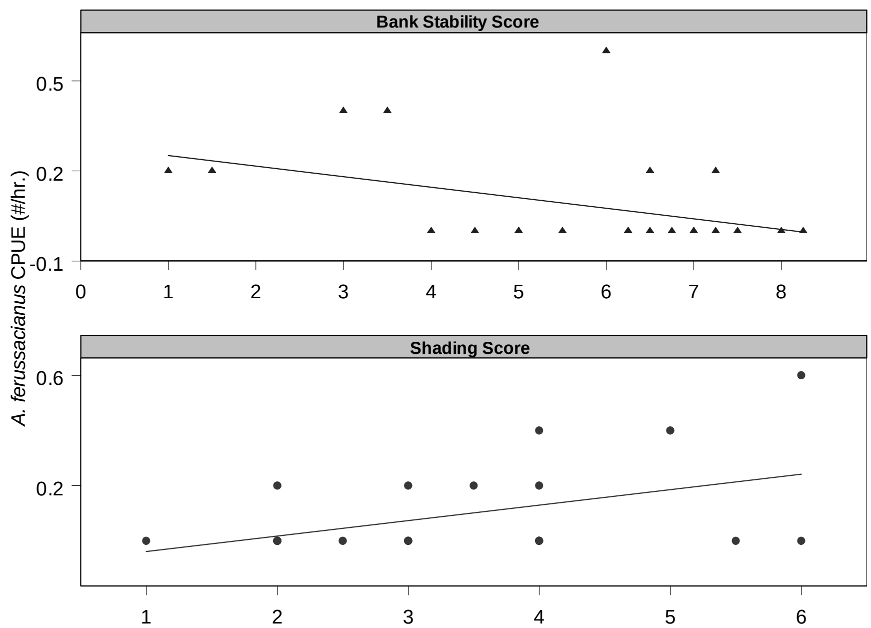

Figure 19: CPUE (total numbers/hour) of *A. ferussacianus* versus bank stability and shading.

Spike (*Elliptio dilatata*)
We found no significant relationships between *E. dilatata* CPUE and habitat parameters. We found significant correlations between *E. dilatata* and *A. ligamentina* (r =0.613, p-value = 0.001), *E. torulosa rangiana* (r= 0.538, p-value = 0.004), *L. costata* (r = 0.486, p-value = 0.010), *P. fasciolaris* (r = 0.514, p-value = 0.006), *Q. cylindrica* (r =0.570, p-value = 0.002), *S. undulatus* (r = 0.531, p-value = 0.004), and *V. fabalis* (r = 0.511, p-value = 0.007).

Northern riffleshell (*Epioblasma torulosa rangiana*)
We found a significant relationship between *E. torulosa rangiana* CPUE and dissolved oxygen (p-value =0.001), conductivity (p-value =0.005), and riparian vegetation type (p-value =0.034). *E. torulosa rangiana* CPUE increased with increasing dissolved oxygen and decreased with increasing conductivity (Figure 20). In fact, it seems that site 29 has driven all of these relationships. We found significant correlations between *E. torulosa rangiana* and *L. cardium* (r =0.674, p-value = 0.000), *Q. cylindrica* (r =0.497, p-value = 0.008), and *S. undulatus* (r =0.779, p-value = 0.000).

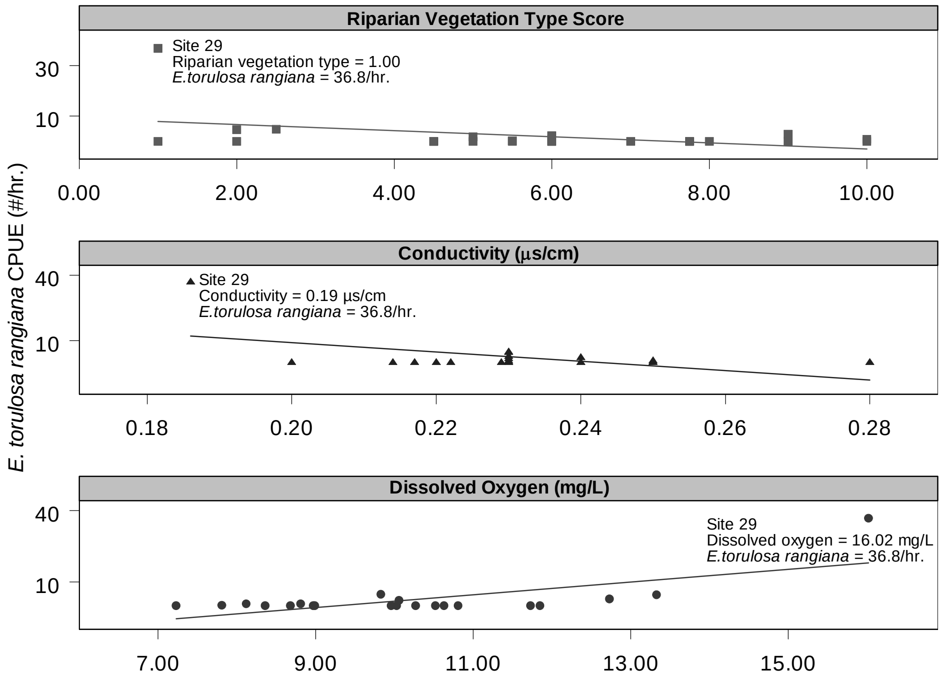

Figure 20: CPUE (total numbers/hour) of *E. torulosa rangiana* versus conductivity, dissolved oxygen and riparian vegetation type.

Snuffbox (*Epioblasma triquetra*)
We found a significant relationship between *E. triquetra* CPUE and in-stream cover (p-value =0.013); *E. triquetra* CPUE increases with in-stream cover (Figure 21). We found significant correlations between *E. triquetra* and *L. cardium* (r= 0.394, p-value =0.042), *L. siliquoidea* (r =0.456, p-value = 0.017), *L. compressa* (r =0.491, p-value = 0.009), *P. sintoxia* (r =0.426, p-value = 0.027), and *P. fasciolaris* (r = 0.747, p-value =0.000).

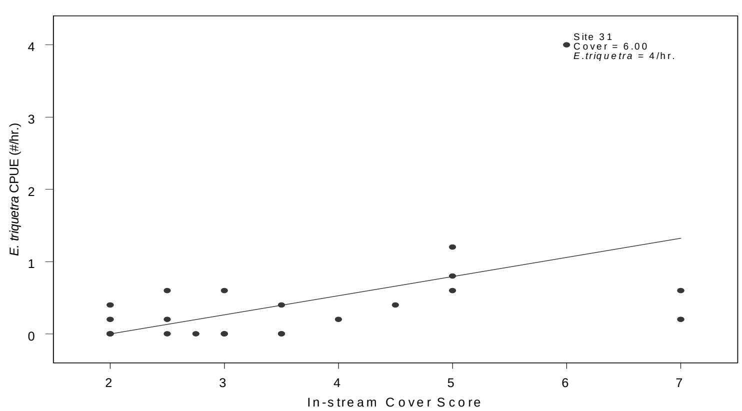

Figure 21: CPUE (total numbers/hour) of *E. triquetra* versus in-stream cover.

Long-solid (*Fusconaia subrotunda*)
We found no significant relationships between *F. subrotunda* CPUE and habitat variables. We found significant correlations between *F. subrotunda* and *A. ferussacianus* (r = 0.553, p-value =0.003), *L. ovata* (r = 0.641, p-value = 0.003), *P. sintoxia* (r = 0.781, p-value =0.000), and *P. clava* (r = 0.791, p-value =0.000).

Plain pocketbook (*Lampsilis cardium*)
We found no significant relationships between *L. cardium* CPUE and habitat variables. We found significant correlations between *L. cardium* and L. ovata (r= 0.600, p-value = 0.001), *E. triquetra* (r = 0.394, p-value = 0.042), *E. torulosa rangiana* (r = 0.397, p-value =0.042), *Q. cylindrica* (r=0.454, p-value = 0.017), and *S. undulatus* (r = 0.505, p-value =0.007).

Wavy-rayed lampmussel (*Lampsilis fasciola*)
We found a significant relationship between *L. fasciola* CPUE and in-stream cover (p-value =0.026) and aquatic vegetation (p-value = 0.004). *L. fasciola* CPUE increased with increasing in –stream cover, and decreased with increasing aquatic vegetation scores (Figure 22). We found significant correlations between *L. fasciola* and *L. recta* (r = 0.436, p-value = 0.003), *L. costata* (r = 0.535, p-value = 0.004), and *A. marginata* (r = 0.472, p-value = 0.010).

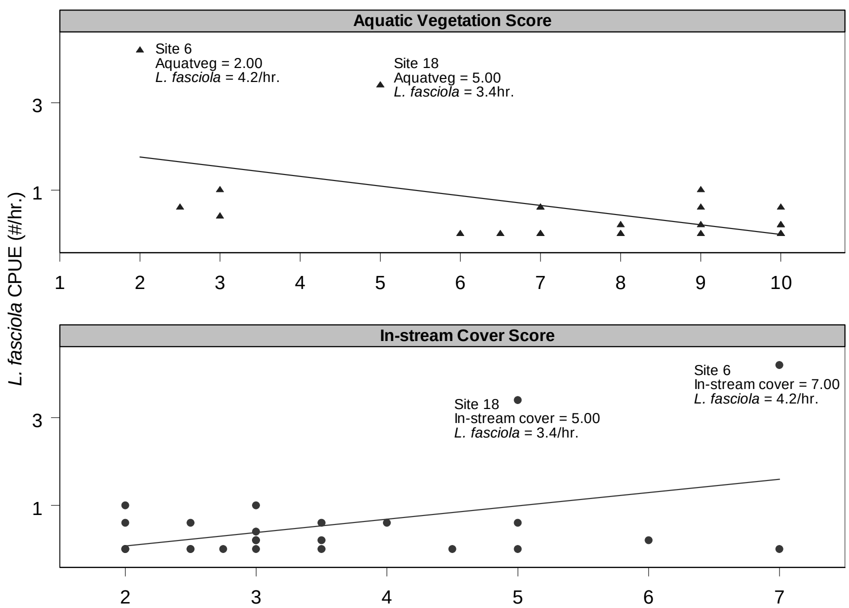

Figure 22: CPUE (total numbers/hour) of *L. fasciola* versus aquatic vegetation and in-stream cover.

Pocketbook (*Lampsilis ovata*)
We found no significant relationship between *L. ovata* CPUE and habitat variables. We found significant correlations between *L. ovata* and *L. cardium* (r = 0.600, p-value =0.001).

Fatmucket (*Lampsilis siliquoidea*)
We found no significant relationship between *L. siliquoidea* CPUE and habitat variables. We found significant correlations between *L. siliquoidea* and *E. triquetra* (r= 0.456, p-value = 0.017).

Creek heelsplitter (*Lasmigona compressa*)
We found no significant relationship between *L. compressa* CPUE and habitat variables. We found significant correlations between *L. compressa* and *A. ferussacianus* (r = 0.405, p-value =0.036) and *E. triquetra* (r = 0.491, p-value = 0.009).

Fluted-shell (*Lasmigona costata*)
We found a significant relationship between *L. costata* CPUE and embeddedness (p-value =0.023) and aquatic vegetation (p-value =0.002). *L. costata* CPUE increased with increased embeddedness scores, and decreased with increasing aquatic vegetation scores (Figure 23). We found significant correlations between *L. costata* and *L. fasciola* (r = 0.535, p-value =0.004), *E. dilatata* (r= 0.486, p-value = 0.010), *A. ligamentina* (r= 0.660, p-value = 0.000), and *A. marginata* (r = 0.557, p-value = 0.003).

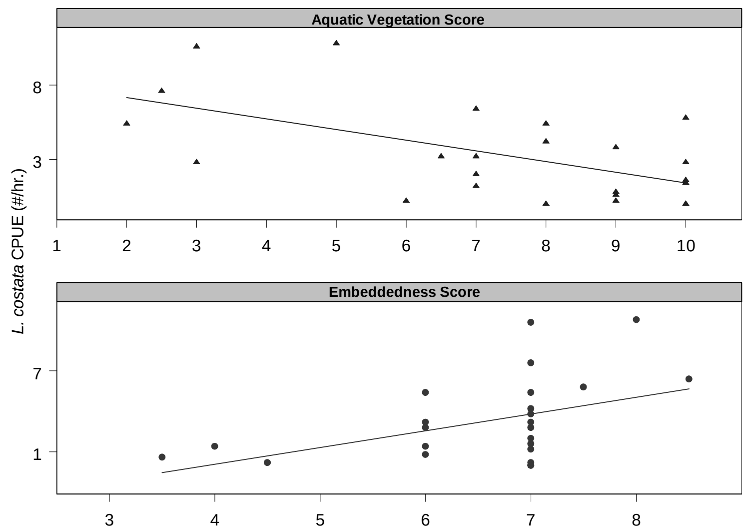

Figure 23: CPUE (total numbers/hour) of *L. costata* versus aquatic vegetation and embeddedness.

Black sandshell (*Ligumia recta*)
We found a significant relationship between *L. recta* CPUE and riparian buffer (p-value =0.010), riparian vegetation type (p-value = 0.014), aquatic vegetation (p-value =0.013), and sorting (p-value =0.016). *L. recta* CPUE increased with riparian buffer, riparian vegetation type, and aquatic vegetation score (Figure 24). As sorting increased, *L. recta* increased. We found significant correlations between *L. recta* and *L. fasciola* (r = 0.436, p-value =0.003).

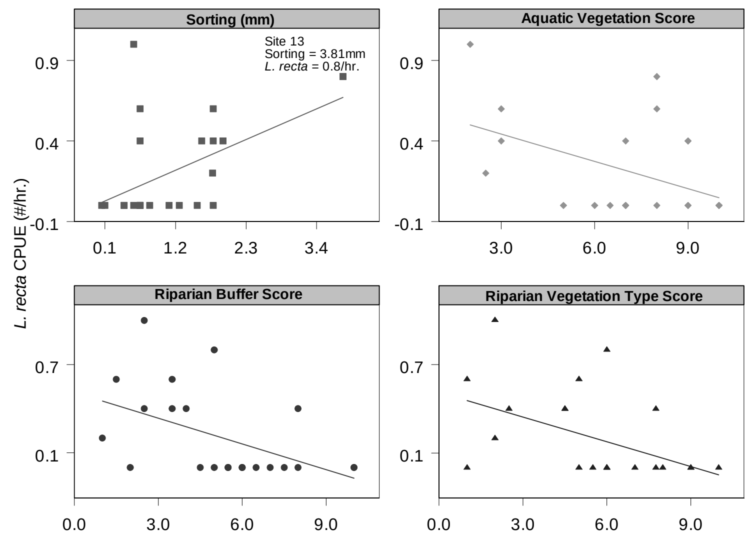

Figure 24: CPUE (total numbers/hour) of *L. recta* versus sorting, aquatic vegetation, riparian buffer, and riparian vegetation type.

Clubshell (*Pleurobema clava*)

We found a significant relationship between *P. clava* CPUE and wetted perimeter (p-value = 0.046) and channel modification (p-value =0.049). As channel modification scores increase, so does *P. clava* CPUE (Figure 25). As wetted perimeter increases, *P. clava* CPUE decreases. We found significant correlations between *P. clava* and *A. marginata* (r = 0.561, p-value =0.002), *F. subrotunda* (r =0.791, p-value = 0.000), and *A. ferussacianus* (r = 0.431, p-value = 0.025).

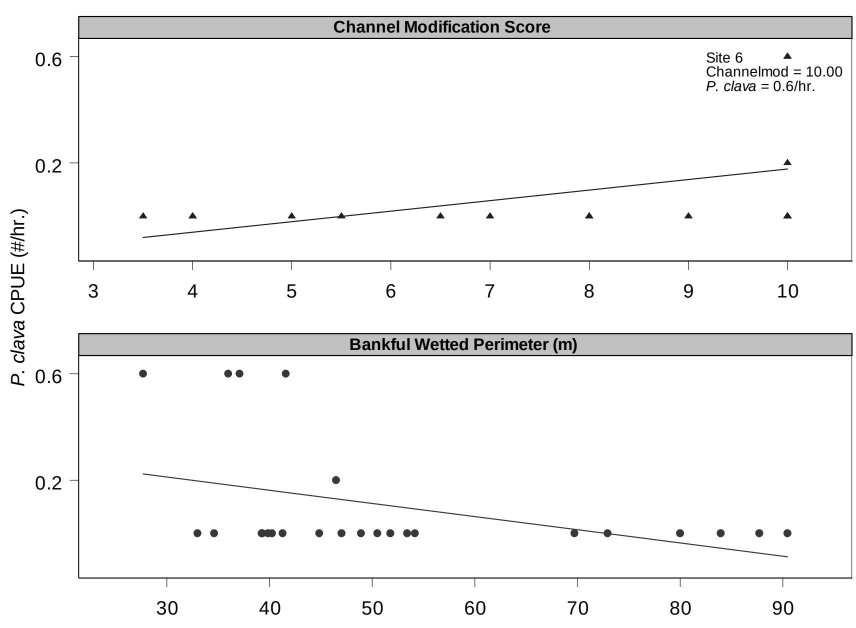

Figure 25: CPUE (total numbers/hour) of *P. clava* versus channel modification and wetted perimeter.

Round pigtoe (*Pleurobema sintoxia*)

We found a significant relationship between *P. sintoxia* CPUE and wetted perimeter (p-value =0.043), dissolved oxygen (p-value 0.038), and riparian buffer (p-value=0.037). As riparian buffer scores increase, so does *P. sintoxia* CPUE (Figure 25). As bankful wetted perimeter and dissolved oxygen increases, *P. sintoxia* CPUE decreases. We found significant correlations between *P. sintoxia* and *E. triquetra* (r = 0.426, p-value = 0.027), *F. subrotunda* (r = 0.781, p-value = 0.000), *A. ferussacianus* (r= 0.395, p-value = 0.042), and *L. compressa* (r = 0.405, p-value = 0.036). It should be noted that dissolved oxygen (as well as temperature) fluctuates temporally, so direct relationships between species and dissolved oxygen should be viewed with caution.

Kidneyshell (*Ptychobranchus fasciolaris*)

We found a significant positive relationship between *P. fasciolaris* CPUE and in-stream cover (p-value = 0.003); as in-stream cover scores increases so does *P. fasciolaris* (Figure 27). We found significant correlations between *P. fasciola* and *E. triquetra* (r = 0.747, p-value = 0.000), *E. dilatata* (r= 0.514, p-value = 0.006), and *L. siliquoidea* (r = 0.474, p-value = 0.013).

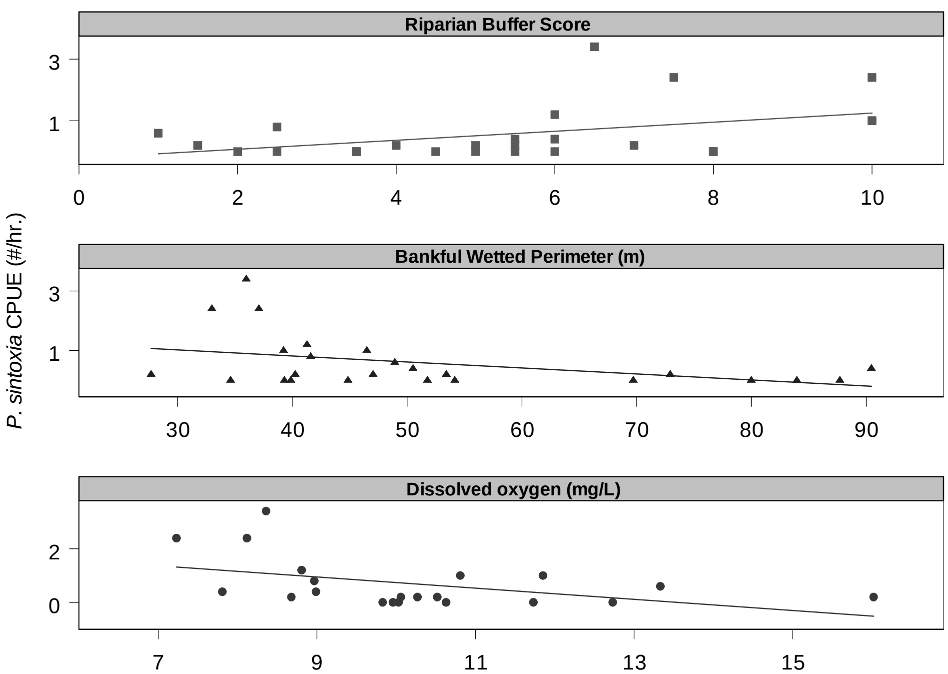

Figure 26: CPUE (total numbers/hour) of *P. sintoxia* versus wetted perimeter and dissolved oxygen.

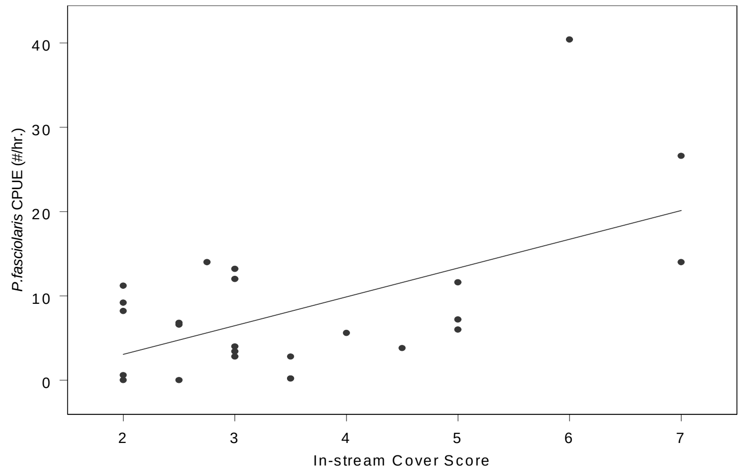

Figure 27: CPUE (total numbers/hour) of *P. fasciolaris* versus in-stream cover.

Giant floater (*Pyganodon grandis*)
We found a significant negative relationship between *P. grandis* CPUE and pH (p-value =0.000); as pH increased, *P. grandis* CPUE decreased (Figured 28). We found no significant correlations between *P. grandis* and other mussel species.

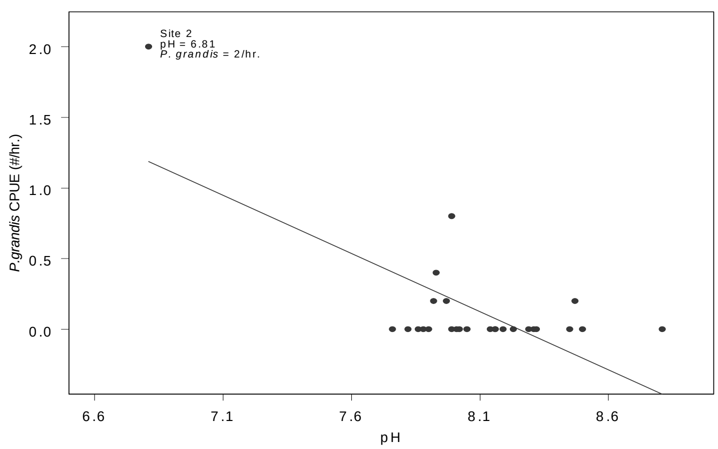

Figure 28: CPUE (total numbers/hour) of *P. grandis* versus pH.

Rabbitsfoot (*Quadrula cylindrica*)
We found no significant relationships between *Q. cylindrica* CPUE and habitat parameters. We found significant correlations between *Q. cylindrica* and *S. undulatus* (r =0.445, p-value = 0.039), *L. cardium* (r = 0.454, p-value =0.017), *A. ferussacianus* (r= 0.544, p-value = 0.003), *E. dilatata* (r= 0.570, p-value = 0.002), *E. torulosa rangiana* (r=0.497, p-value= 0.008), and *A. ligamentina* (r =0.534, p-value = 0.004).

Creeper (*Strophitus undulatus*)
We found a significant relationship between *S. undulatus* CPUE and shading (p-value =0.017) and conductivity (p-value = 0.043). *S. undulatus* CPUE increased with increased shading scores and decreased with increasing conductivity (Figure 29). We found significant correlations between *S. undulatus* and *A. ferussacianus* (r=0.564, p-value = 0.002), *E. dilatata* (r=0.531, p-value =0.004), *E. torulosa rangiana* (r = 0.779, p-value =0.000), *L. cardium*, (r=0.505, p-value = 0.007), and *Q. cylindrica* (r=0.445, p-value =0.039).

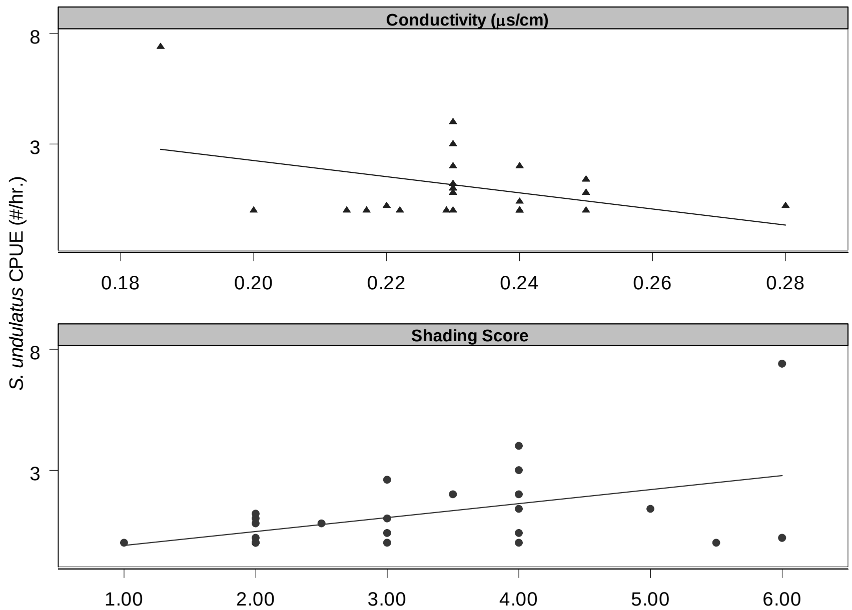

Figure 29: CPUE (total numbers/hour) of *S. undulatus* versus conductivity and shading.

Paper pondshell (*Utterbackia imbecillis*)
We found a significant relationship between *U. imbecillis* CPUE and sheer stress (p-value =0.008), riparian vegetation thickness (p-value =0.007), bank vegetation type (p-value =0.022), bank vegetation thickness (p-value = 0.025), bank stability (p-value =0.021), and waterpath (p-value = 0.002). We found significant correlations between *U. imbecillis* and *A. plicata* (r = 0.809, p-value = 0.000), *A. ferussacianus* (r = 0.8736, p-value = 0.000), and *L. compressa* (r = 0.8554, p-value = 0.000).

Rayed bean mussel (*Villosa fabalis*)
We found a significant positive relationship between *V. fabalis* CPUE and temperature (p-value = 0.022, Figure 30), riparian vegetation type (p-value = 0.044), and embeddedness (p-value = 0.044). We found a significant negative relationship between *V. fabalis* and aquatic vegetation (p-value =0.000). We found significant correlations between *V. fabalis* and *L. costata* (r = 0.748, p-value =0.000), *S. undulatus* (r = 0.399, p-value = 0.039), and *E. dilatata* (r=0.511, p-value = 0.007).

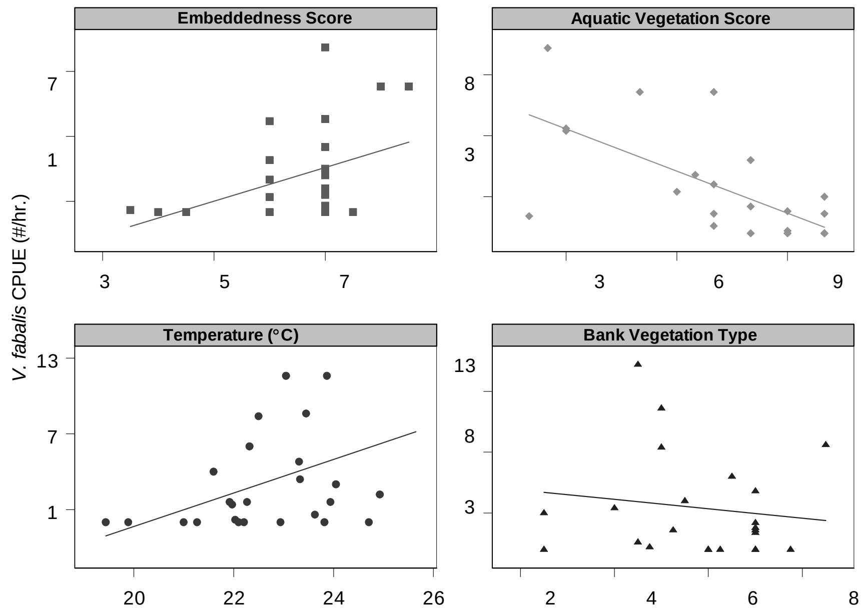

Figure 30: CPUE (total numbers/hour) of *V. fabalis* versus embeddedness, aquatic vegetation, temperature, and bank vegetation type score.

Rainbow mussel (*Villosa iris*)

We found significant relationship between *V. iris* CPUE and bank vegetation type (p-value =0.013). We found significant correlations between *V. iris* and *L. fasciola* (r = 0.477, p-value =0.012) and *E. dilatata* (r =0.7303, p-value =0.000).

MUSKRAT MIDDEN COLLECTIONS

We compared species composition data from the midden collections with data from corresponding mussel survey sites. Specifically, we looked at species composition, relative abundances, and lengths. Ultimately, muskrat midden research may be used an alternative to in-stream sampling techniques.

We looked at presence/absence of mussel species within muskrat middens for two reasons; to see if there were any species found in the middens that were not found during our snorkel surveys and to see if there were species not documented in the middens that we did find in our surveys. In addition, we wanted to compare the relative abundances of species between the middens and the snorkel surveys to see if the muskrats had any bias in which species they consume.

To further assess differences between our snorkel survey and midden data, we compared comparing mean lengths of each species found at five sites. To test if length means were different, we compared 95% confidence intervals between midden and snorkel survey data. These analyses were done to determine if there is a size bias in muskrat diets. In other words, we wanted to see if muskrats favor younger and smaller specimens or do they have a bias for older and larger individuals. Standard two sample t-tests were used to determine if the mean lengths for each species were the same in both the middens and survey data at each site. Significance was tested at the $\alpha = 0.05$ level.

A total of 22 middens was collected in 2002, and 5 additional middens were collected in 2004. Species richness ranged from 6 to 20, with a mean of 11.8 (10.5, 13.0). Midden locations were mapped using GPS technology. Figure 31 illustrates midden species richness.

Nine midden collection sites were within 200m of a 2003 snorkel survey site. Shell lengths of all species were measured at five of these middens, which were compared to 2003 snorkel survey length data. At two sites, a midden was collected in both 2002 and 2004. We compared the data from each of these two sites between both years to see if there were any noticeable changes in species relative abundances in the middens. If the sample had 20 or more individuals of one species, statistical significance of lengths was assessed.

Tables 7-10 show the total numbers and relative abundances of each species found in the 2002 midden collections versus the 2003 in-stream snorkel surveys. Tables 11-13 show the total numbers, relative abundances, mean lengths and 95 % confidence intervals on the mean lengths of each species found in the 2004 midden collection versus the 2003 in –stream mussel survey at sites 17 and 22. Tables 14 and15 show the total numbers, relative abundances, mean lengths, and confidence intervals on the mean lengths of each species found in the 2002 and 2004 midden collections versus the 2003 in-stream mussel survey. Mean lengths of *A. ligamentina* are consistently significantly smaller in the middens than what was observed in the 2003 snorkel surveys. The maximum size of muskrat predation on A. ligamentina was xxmm. *P. fasciolaris* had significantly smaller lengths in the middens from site 15, 17, and 29. Lengths of *E. dilatata* were significantly smaller in middens at sites 17, 22, 24, and 29. At site 17, both *A. marginata* and *S. undulatus* had significantly smaller lengths in middens than in the 2003 snorkel survey. Interestingly, *E. torulosa rangiana* shells were smaller in the middens than in the snorkel survey data for site 24, but larger in site 29.

Twelve species were found in the 2002 midden at site 9 and sixteen were found during the 2004 midden collection (Table 7). Six species found in the 2003 snorkel survey (*A. plicata, A. ligamentina, E. triquetra, L. cardium, Q. cylindrica,* and *V. fabalis*) were not found in the 2002 midden, and two species found in the 2002 midden (*E. torulosa rangiana* and *L. fasciola*) were not found in 2004 midden collection. The fact that zero *A. ligamentina* were collected in the 2002 midden is suspicious, and the collection should be investigated for error. *V. fabalis* comprised 6.2% of the snorkel survey, but was absent from the midden collection. Relative abundances of *E. dilatata, P. sintoxia, P. fasciolaris,* and *S. undulatus* were all much higher in the midden collection than in the snorkel survey.

Table 7: Total numbers and relative abundance of each species found in the 2002 midden collection versus the 2003 in-stream snorkel survey at site 9.

Site 9	**2002 Midden Survey**		**2003 Snorkel Survey**	
	Total Number	**Relative Abundance (%)**	**Total Number**	**Relative Abundance (%)**
A. ligamentina		0.00%	170	62.27%
A. marginata	2	2.47%	8	2.93%
A. plicata			2	0.73%
E. dilatata	22	27.16%	15	5.49%
E. torulosa rangiana	1	1.23%		
E. triquetra			3	1.10%
F. subrotunda	3	3.70%	6	2.20%
L. cardium			2	0.73%
L. fasciola	1	1.23%		
L. siliquoidea	1	1.23%	2	0.73%
L. compressa	3	3.70%	1	0.37%
L. costata	1	1.23%	1	0.37%
P. clava	5	6.17%	1	0.37%
P. sintoxia	11	13.58%	5	1.83%
P. fasciolaris	18	22.22%	34	12.45%
Q. cylindrica			2	0.73%
S. undulatus	13	16.05%	4	1.47%
V. fabalis			17	6.23%
Total	**81**		**273**	

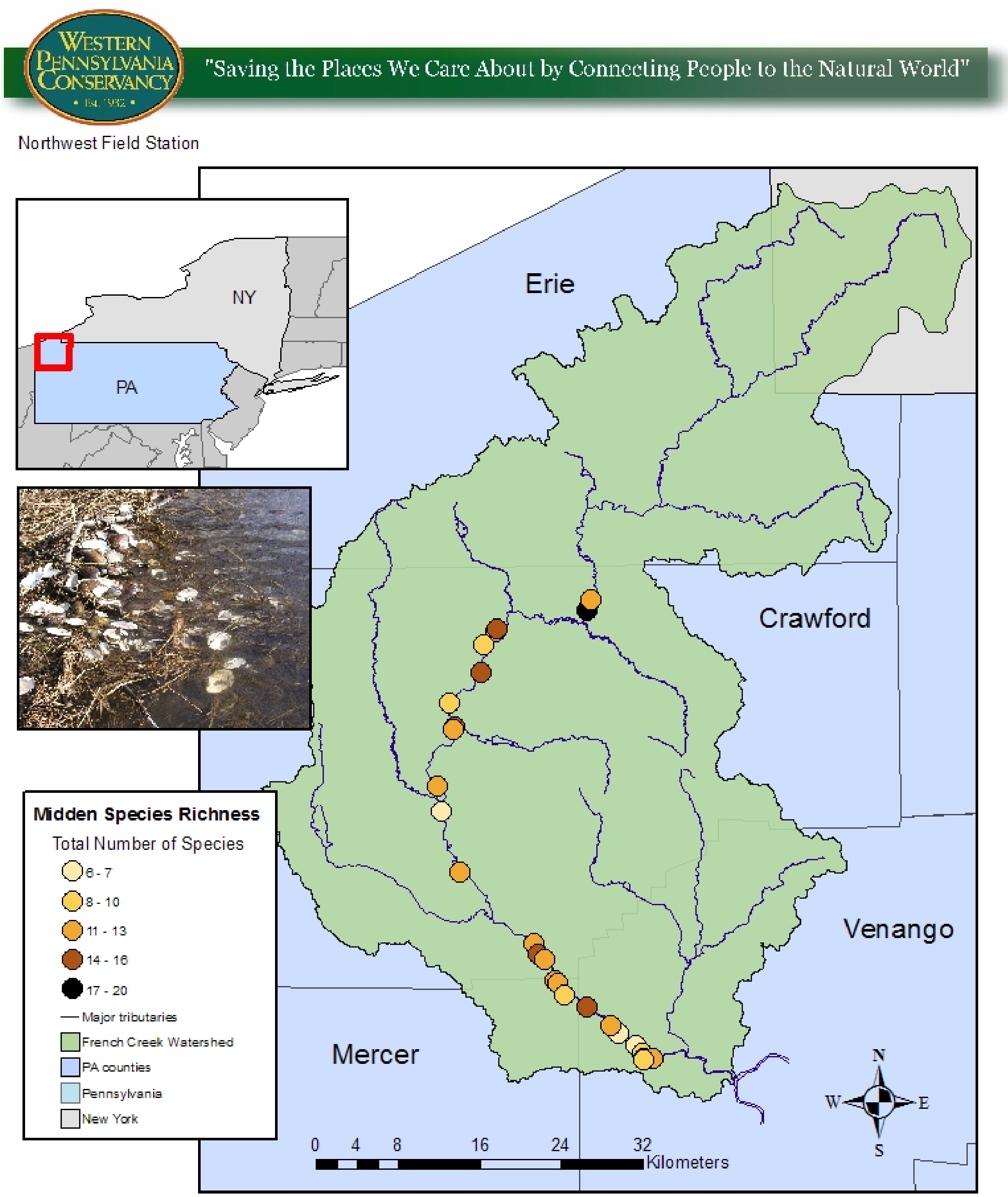

Figure 31: Freshwater Musssel Species Richness
(Total number species) in Muskrat Middens

Sixteen species were found in the 2002 midden at site 13 and fifteen were found during the 2003 snorkel survey (Table 8). Three species found in the 2003 snorkel survey (*L. cardium, L. ovata,* and *L. recta*) were not found in the 2002 midden, and four species found in the 2002 midden (*L. siliquoidea, A. plicata, E. triquetra,* and *Q. cylindrica*) were not found in 2003 snorkel survey. Relative abundances of *A. ligamentina* were much higher in 2003 snorkel surveys (63.9%) than in the midden collection (25.4%). Similarly, *L. ovata* comprised 5.8% of the snorkel survey, but was absent from the midden collection. Relative abundances of *E. dilatata, E. torulosa rangiana,* and *P. fasciolaris* were all much higher in the midden collection than in the snorkel survey.

Table 8: Total numbers and relative abundance of each species found in the 2002 midden collection versus the 2003 in-stream mussel survey at site 13.

Site 13	2002 Midden Survey		2003 Snorkel Survey	
	Total Number	Relative Abundance (%)	Total Number	Relative Abundance (%)
A. ligamentina	90	25.35%	232	63.91%
A. marginata	13	3.66%	18	4.96%
A. ferussacianus	1	0.28%	1	0.28%
A. plicata	1	0.28%		
E. dilatata	56	15.77%	13	3.58%
E. torulosa rangiana	63	17.75%	11	3.03%
E. triquetra	8	2.25%		
L. cardium			1	0.28%
L. fasciola	1	0.28%	1	0.28%
L. ovata			21	5.79%
L. siliquoidea	1	0.28%		
L. costata	3	0.85%	21	5.79%
L. recta			4	1.10%
P. sintoxia	2	0.56%	1	0.28%
P. fasciolaris	86	24.23%	17	4.68%
P. grandis	1	0.28%	1	0.28%
Q. cylindrica	6	1.69%		
S. undulatus	6	1.69%	10	2.75%
V. fabalis	17	4.79%	11	3.03%
Total	**355**		**363**	

Thirteen species were found in the 2002 midden at site 14 and eleven were found during the 2003 snorkel survey (Table 9). Two species found in the 2003 snorkel survey (*L. costata,* and *A. ferussacianus*) were not found in the 2002 midden, and four species found in the 2002 midden (*L. cardium, L. fasciola, E. triquetra, and L. recta*) were not found in 2003 snorkel survey. Relative abundances of *P. fasciolaris* were much higher in 2003 snorkel surveys (15.3%) than in the midden collection (3.2%). Similarly, *E. dilatata* comprised 12.3% of the snorkel survey and only 2.2% of the midden collection. Relative abundances of *A. marginata* was much higher in the midden collections (23.7%) than in the snorkel survey (4.4%).

Table 9: Total numbers and relative abundance of each species found in the 2002 midden collection versus the 2003 in-stream snorkel survey at site 14.

Site 14	**2002 Midden Survey**		**2003 Snorkel Survey**	
	Total	**Relative**	**Total**	**Relative**
	Number	**Abundance (%)**	**Number**	**Abundance (%)**
A. ligamentina	53	56.99%	193	52.90%
A. marginata	22	23.66%	16	4.38%
A. ferussacianus			1	0.27%
E. dilatata	2	2.15%	45	12.33%
E. torulosa rangiana	2	2.15%	14	3.84%
E. triquetra	1	1.08%		
L. cardium	1	1.08%		
L. fasciola	3	3.23%		
L. ovata	1	1.08%	3	0.82%
L. costata			16	4.38%
L. recta	1	1.08%		
P. fasciolaris	3	3.23%	56	15.34%
Q. cylindrica	1	1.08%	7	1.92%
S. undulatus	2	2.15%	6	1.64%
V. fabalis	1	1.08%	8	2.19%
Total	**93**		**365**	

Seven species were found in the 2002 midden at site 19 and fifteen were found during the 2003 snorkel survey (Table 10). Species absent from the midden collection were *Q. cylindrica, A. plicata, F. subrotunda, L. costata, L. fasciola, L. siliquoidea,* P. *sintoxia,* and *S. undulatus.* Relative abundance of *A. ligamentina* was much higher in 2003 snorkel surveys (51.3%) than in the midden collection (44.4%). *A. plicata* comprised 22.2% of the snorkel survey, but was absent from the midden. Relative abundance of *V. fabalis* was higher in the snorkel survey (11.0%) than in the midden collection (5.6%). Relative abundance of *E. torulosa rangiana* was higher in the midden collection (5.6%) than in the snorkel survey (0.4%).

Ten species were found in the midden at site 15 and twelve were found during the snorkel survey (Table 11). Four species found in the 2003 snorkel survey (*Q. cylindrica, L. ovata, L. costata,* and *P. sintoxia*) were not found in the midden, and two species found in the midden (*L. cardium* and *L. fasciola*) were not found in 2003 snorkel survey. Relative abundances of *A. ligamentina* were much higher in 2003 snorkel surveys (30.9%) than in the midden collection (9.2%). Similarly, *E. dilatata* comprised 10.7% of the snorkel survey and only 5.3% the midden collection. Relative abundance of *V. fabalis* was also higher in the snorkel survey (6.3%) than in the midden collection (6.3%). *P. fasciolaris* and *A. marginata* had significantly smaller lengths in the midden collection than those from the snorkel survey.

Table 10: Total numbers and relative abundance of each species found in the 2002 midden collection versus the 2003 in-stream mussel survey at site 19.

Site 19	**2002 Midden Survey**		**2003 Snorkel Survey**	
	Total	**Relative**	**Total**	**Relative**
	Number	**Abundance (%)**	**Number**	**Abundance (%)**
A. ligamentina	8	44.44%	270	51.33%
A. marginata	1	5.56%	3	0.57%
A. plicata			117	22.24%
E. dilatata	5	27.78%	7	1.33%
E. torulosa rangiana	1	5.56%	2	0.38%
F. subrotunda			1	0.19%
L. fasciola			3	0.57%
L. ovata	1	5.56%	8	1.52%
L. siliquoidea			1	0.19%
L. costata			32	6.08%
P. sintoxia			2	0.38%
P. fasciolaris	1	5.56%	14	2.66%
Q. cylindrica			3	0.57%
S. undulatus			5	0.95%
V. fabalis	1	5.56%	58	11.03%
Total	**18**		**526**	

Table 11: Total numbers, relative abundances, mean lengths, and 95% confidence intervals on the mean lengths of each species found in the 2004 midden collection versus the 2003 in-stream mussel survey at site 15. Bolded 2004 midden lengths are significantly ($p < 0.05$) different from bolded 2003 lengths.

Site 15	**2004 Midden Data**				**2003 Snorkel Survey**			
	Total	**Relative**	**Mean**	**95% CI**	**Total**	**Relative**	**Mean**	**95% CI**
	Number	**Abundance (%)**	**Length (mm)**	**Length**	**Number**	**Abundance (%)**	**Length (mm)**	**Length**
A. ligamentina	35	9.23%	**61.6**	**(55.2, 68.0)**	118	30.89%	**95.2**	**(88.0, 102.3)**
A. marginata	12	3.17%	57.6	(51.2, 63.9)	10	2.62%	51.3	(36.4, 66.1)
E. dilatata	20	5.28%	57.6	(50.0,65.1)	41	10.73%	61.5	(54.7, 68.3)
E. torulosa rangiana	5	1.32%			4	1.05%	27.5	(10.3, 44.6)
E. triquetra	1	0.26%	43.5		3	0.79%	34.3	(26.3, 42.3)
L. cardium	2	0.53%	83.5	(0, 216.9)				
L. fasciola	6	1.58%	45.1	(39.7, 50.4)				
L. ovata					4	1.05%	91.0	(40.1,142.0)
L. costata					16	4.19%	86.1	(75.6, 96.5)
P. sintoxia					6	1.57%	46.1	(19.9, 72.2)
P. fasciolaris	79	20.84%	**57.1**	**(54.6, 59.5)**	133	34.82%	**71.6**	**(65.0, 78.3)**
Q. cylindrica					3	0.79%	84.1	(0, 185.4)
S. undulatus	13	3.43%	54.5	(50.2,58.8)	20	5.24%	52.1	(48.2,56.0)
V. fabalis	2	0.53%	34.8	(12.5, 56.9)	24	6.28%	23.4	(21.1,25.8)
Total	**175**				**382**			

Species richness was 12 for both the midden and the snorkel survey at site 17, however species composition differed (Table 12). Three species found in the 2003 snorkel survey (*Q. cylindrica, L. fasciola,* and *E. torulosa rangiana*) were not found in the midden, and three species found in the midden (*L. ovata, L. siliquoidea,* and *L. recta*) were not found in 2003 snorkel survey. Relative abundance of *L. costata* was much higher in 2003 snorkel surveys (7.5%) than in the midden collection (0.5%). Relative abundances of *A. ligamentina, E. dilatata, P. fasciolaris,* and *V. fabalis* were all much higher in the midden collection than in the snorkel survey. *A. ligamentina*, *A. marginata*, and *P. fasciolaris* all had significantly smaller lengths in the midden collection than those from the snorkel survey.

Table 12: Total numbers, relative abundances, mean lengths, and 95% confidence intervals on the mean lengths of each species found in the 2004 midden collection versus the 2003 in-stream mussel survey at site 17. Bolded 2004 midden lengths are significantly ($p < 0.05$) different from bolded 2003 lengths.

Site 17	**2004 Midden Data**				**2003 Snorkel Survey**			
	Total Number	**Relative Abundance (%)**	**Mean Length (mm)**	**95% CI Length**	**Total Number**	**Relative Abundance (%)**	**Mean Length (mm)**	**95% CI Length**
A. ligamentina	275	72.56%	**39.9**	**(38.6, 41.2)**	102	40.00%	**96.2**	**(88.6,103.9)**
A. marginata	26	6.86%	**45.1**	**(41.1, 49.1)**	20	7.84%	**67.4**	**(62.8,72.0)**
E. dilatata	49	12.93%	43.8	(39.4, 48.2)	18	7.06%	66.5	(57.4, 75.6)
E. torulosa rangiana	4	1.06%	35.9	(16.6, 55.2)				
E. triquetra	7	1.85%	34.0	(29.7, 38.3)	3	1.18%	42.0	(27.1,56.9)
L. cardium	2	0.53%	89.0	(0, 311.4)	1	0.39%	129.5	
L. fasciola	7	1.85%	38.6	(27.0, 50.3)				
L. ovata					3	1.18%	99.1	(36.3, 161.9)
L. siliquoidea					5	1.96%	106.9	(99.7,114.1)
L. costata	2	0.53%	38.8	(0, 143.6)	19	7.45%	89.3	(81.4,97.3)
L. recta					2	0.78%	100.5	(0,348.3)
P. fasciolaris	142	37.47%	**41.9**	**(39.3, 44.4)**	60	23.53%	**84.5**	**(77.5, 91.6)**
Q. cylindrica	3	0.79%	29.5	(18.3, 40.7)				
S. undulatus	7	1.85%	41.8	(35.2, 48.4)	13	5.10%	55.9	(51.7, 60.1)
V. fabalis	60	15.83%	25.3	(24.2, 26.4)	9	3.53%	29.5	(22.0, 29.5)
Total	**584**				**255**			

Twelve species were found in the snorkel survey and eight in the midden collection at site 22 (Table 13). Four species found in the 2003 snorkel survey (*Q. cylindrica, L. ovata, L. costata,* and *P. sintoxia*) were not found in the midden, and two species found in the midden (*L. cardium* and *L. fasciola*) were not found in 2003 snorkel survey. Relative abundance of *A. ligamentina* was much higher in 2003 snorkel surveys (56.5%) than in the midden collection (35.5%). Similarly, *V. fabalis* comprised 10.9% of the snorkel survey and only 3.2% of the midden collection. Relative abundances of *E. dilatata* and *P. fasciolaris* were much higher in the midden collection than in the snorkel survey. *A. ligamentina* and *E. dilatata* had significantly smaller lengths in the midden collection than those from the snorkel survey.

Table 13: Total numbers, relative abundances, mean lengths, and 95% confidence intervals on the mean lengths of each species found in the 2004 midden collection versus the 2003 in-stream mussel survey at site 22. Bolded 2004 midden lengths are significantly ($p < 0.05$) different from bolded 2003 survey lengths.

Site 22	2004 Midden Data				2003 Snorkel Survey			
	Total Number	Relative Abundance (%)	Mean Length (mm)	95% CI Length	Total Number	Relative Abundance (%)	Mean Length (mm)	95% CI Length
A. ligamentina	44	35.48%	**60.9**	**(56.0, 65.8)**	218	56.48%	**91.5**	**(82.7, 100.3)**
A. marginata	5	4.03%	54.6	(51.5, 57.7)	23	5.96%	62.7	(57.5, 67.8)
A. plicata		0.00%			3	0.78%	104.9	(53.0, 156.9)
E. dilatata	46	37.10%	**63.6**	**(59.3, 67.9)**	44	11.40%	**74.7**	**(68.8, 80.6)**
E. torulosa rangiana	4	3.23%	41.2	(36.6, 45.9)	9	2.33%	42.5	(33.6, 51.3)
L. fasciola		0.00%			2	0.52%	64.2	(0, 163.3)
L. ovata		0.00%			4	1.04%	81.4	(15.5, 147.2)
L. costata	1	0.81%	90.0		14	3.63%	90.9	(74.2, 107.7)
L. recta		0.00%			3	0.78%	135.3	(91.9, 178.7)
P. fasciolaris	16	12.90%	58.9	(53.5, 64.3)	15	3.89%	73.6	(60.3, 87.0)
S. undulatus	4	3.23%	60.4	(40.6, 80.1)	9	2.33%	59.7	(52.6, 66.7)
V. fabalis	4	3.23%	24.5	(19.2, 29.8)	42	10.88%	31.0	(29.2, 32.9)
Total	**124**				**386**			

Sixteen species were found in the snorkel survey at site 24, nine were found in the midden collected in 2004 and seven in the midden collected in 2002 (Table 14). Species absent from both midden collections were *Q. cylindrica, L. ovata, L. costata, L. recta, L. siliquoidea,* P. *sintoxia,* and *V. iris*. Two additional species were not collected in 2002; *L. fasciola* and *A. plicata*. Relative abundance of *A. ligamentina* was much higher in 2003 snorkel surveys (37.3%) than in the 2004 midden collection (16.6%), however, relative abundance of *A. ligamentina* was highest in the 2002 midden collection (44.4%). *V. fabalis* comprised 16.4% of the snorkel survey, 5.6 % of the 2002 midden collection, and only 2.4% of the 2004 midden collection. Relative abundance of *E. dilatata* was highest in the 2002 midden collection. Lengths of *A. ligamentina* and *E. dilatata* were significantly smaller in the midden collection (2004) than in the snorkel survey. Because of the small sample size, we did not test for significance, however lengths of *E. torulosa rangiana* were generally higher in the midden collection (2004) than in the snorkel survey,

Eighteen species were found in the snorkel survey at site 29, fifteen were found in the midden collected in 2004 and ten in the midden collected in 2002 (Table 15). Species absent from both midden collections were *F. subrotunda*, *L. ovata, P. sintoxia,* and *A. ferussacianus.* Both A. marginata and P. fasciola had higher relative abundances in the 2004 midden collection than either the 2002 midden or the 2003 snorkel survey. Relative abundance of *A. ligamentina* was much higher in 2003 snorkel surveys (50.6%) than in both midden collections. Relative abundances of *E. torulosa rangiana* were much higher in the midden collections (49.0% and 40.6%) than in the snorkel survey (19.5%).

Table 14: Total numbers, relative abundances, mean lengths, and 95% confidence intervals on the mean lengths of each species found in the 2004 midden collection versus the 2003 in-stream mussel survey at site 24. Bolded 2004 midden lengths are significantly ($p < 0.05$) different from bolded 2003 survey lengths.

Site 24	2002 Midden Data		2004 Midden Data				2003 Snorkel Survey			
	Total Number	Relative Abundance (%)	Total Number	Relative Abundance (%)	Mean Length (mm)	95% CI Length	Total Number	Relative Abundance (%)	Mean Length (mm)	95% CI Length
A. ligamentina	8	44.44%	63	16.62%	**64.1**	**(61.0, 67.1)**	173	37.28%	**92.9**	**(84.4, 101.4)**
A. marginata	1	5.56%	2	0.53%	53.0	(40.3, 65.7)	3	0.65%	55.1	(34.0, 76.2)
A. plicata		0.00%	1	0.26%	28.0		6	1.29%	84.2	(72.5, 95.9)
E. dilatata	5	27.78%	75	19.79%	**67.9**	**(65.5, 70.4)**	80	17.24%	**76.0**	**(71.8, 80.2)**
E. torulosa rangiana	1	5.56%	19	5.01%	43.4	(39.9, 46.8)	23	4.96%	38.0	(35.1, 41.0)
L. fasciola		0.00%	3	0.79%	53.0	(38.1, 67.9)	4	0.86%	62.0	(0, 125.7)
L. ovata	1	5.56%		0.00%			4	0.86%	83.0	(12.7, 153.4)
L. siliquoidea		0.00%		0.00%			3	0.65%	95.9	(70.2,121.6)
L. costata		0.00%		0.00%			38	8.19%	99.8	(98.2,101.5)
L. recta		0.00%		0.00%			1	0.22%	98.2	
P. sintoxia		0.00%		0.00%			3	0.65%	53.4	(0, 116.6)
P. fasciolaris	1	5.56%	34	8.97%	66.8	(63.5, 70.1)	41	8.84%	76.8	(69.4, 84.2)
Q. cylindrica		0.00%		0.00%			4	0.86%	87.2	(38.3, 136.1)
S. undulatus		0.00%	2	0.53%	53.5	(21.7, 85.3)	4	0.86%	66.8	(54.8, 78.7)
V. fabalis	1	5.56%	9	2.37%	27.4	(24.2, 30.7)	76	16.38%	26.6	(25.5, 27.8)
V. iris		0.00%		0.00%			1	0.22%	39.8	
Total	**18**		**208**				**464**			

Table 15: Total numbers, relative abundances, mean lengths, and 95% confidence intervals on the mean lengths of each species found in the 2004 midden collection versus the 2003 in-stream mussel survey at site 29. Bolded 2004 midden lengths are significantly ($p < 0.05$) different from bolded 2003 survey lengths.

Site 29	2002 Midden Data		2004 Midden Data				2003 Snorkel Survey			
	Total Number	Relative Abundance (%)	Total Number	Relative Abundance (%)	Mean Length (mm)	95% CI Length	Total Number	Relative Abundance (%)	Mean Length (mm)	95% CI Length
A. ligamentina	15	15.63%	47	12.40%	**24.5**	**(19.2, 29.8)**	479	50.60%	**95.1**	**(84.8, 105.3)**
A. marginata	9	9.38%	65	17.15%	**73.1**	**(70.0, 76.2)**	35	3.70%	**80.3**	**(75.7, 84.9)**
A. ferussacianus		0.00%		0.00%			3	0.30%	59.4	(50.7, 68.1)
E. dilatata	10	10.42%	25	6.60%	**65.0**	**(58.9, 71.0)**	68	7.20%	**82.3**	**(79.6, 88.1)**
E. torulosa rangiana	47	48.96%	154	40.63%	**51.3**	**(50.4, 52.2)**	184	19.50%	**46.7**	**(44.5, 48.8)**
E. triquetra	2	2.08%	2	0.53%	49.8	(0, 129.2)	6	0.60%	49.0	(36.2, 61.9)
F. subrotunda		0.00%		0.00%			1	0.10%	83.0	
L. cardium		0.00%	1	0.26%	105.0		8	0.80%	85.0	(50.1, 119.9)
L. fasciola		0.00%	3	0.79%	51.7	(38.0, 65.4)		0.00%		
L. ovata		0.00%		0.00%			18	1.90%	119.9	(106.9, 132.9)
L. siliquoidea		0.00%	1	0.26%	67.0		3	0.30%	99.2	(75.1, 123.2)
L. compressa		0.00%	4	1.06%	79.0	(74.0, 84.0)	1	0.10%	78.0	
L. costata	1	1.04%	2	0.53%	67.0	(9.8, 124.2)	27	2.90%	115.1	(108.6, 121.6)
L. recta		0.00%	1	0.26%	59.0		3	0.30%	129.9	(66.5, 193.3)
P. sintoxia		0.00%		0.00%			1	0.10%	33.7	
P. fasciolaris	2	2.08%	34	8.97%	**70.1**	**(65.6, 74.5)**	36	3.80%	**91.9**	**(83.9, 99.8)**
P. grandis	1	1.04%								
Q. cylindrica		0.00%	2	0.53%	66.3	(12.3, 120.3)	6	0.60%	108.2	(79.3, 137.1)
S. undulatus	7	7.29%	31	8.18%	68.3	(64.7, 72.0)	37	3.90%	73.9	(69.9, 77.9)
V. fabalis	2	2.08%	7	1.85%	31.1	(27.1, 35.2)	30	3.20%	25.7	(23.3, 28.2)
Total	**96**		**379**				**946**			

COMPARISON STUDY: MUSSEL SURVEYS 1993- 2003

In 1993 and 1994, WPC conducted surveys of freshwater mussels in the French Creek watershed (Bier 1994, Figure 32). In-stream survey methods included using glass bottom buckets or snorkeling methods as well as using rakes to reveal buried mussels. In addition, stream banks were searched for mussel shells. Study sites in 1993 were not randomly chosen, but were instead predetermined by USFWS to fill data gaps for known mussel data in the watershed. Because of this lack of randomization and since there was no standardization for time or area searched; we cannot directly compare CPUE between 2003 and 1993. However, we can look for trends in species distribution, composition, and abundance between these years.

A total of 8,739 specimens were collected from 21 sites on the main-stem of French Creek in 1993, of which 1,625 were live, 6681 fresh dead shells, and 433 weathered dead shells. As in the 2003 survey, twenty-four species were documented in 1993.

SPECIES DISTRIBUTIONS

We examined the distributions of each species to determine if any species had noticeable changes in its distribution (i.e. lost from a county) between 1993/1994 (from here on referred to as 1993) and 2003. For these analyses, we examined only live individuals. One live individual of *P. clava* was found in Venango County in 1993 and none were found in Venango County in 2003. *E. torulosa rangiana* was found in Erie County in 1993, but not in 2003. One live individual *E. triquetra* specimen was found in Venango County in 2003, but no live individuals were found in 1993. *P. sintoxia* was found in Venango County in 2003, but not in 1993. *L. siliquoidea, P. sintoxia,* and *P. grandis* were found in Mercer County in 1993, but not in 2003. *S. undulatus* and *L. ovata* were found in Mercer County in 2003, but not in 1993. *L. cardium* was found in Mercer and Venango Counties in 1993, but not in 2003. *U. imbecillis* was found in all four counties in 1993, but only in Crawford County in 2003. *V. fabalis* was found in all four counties in both 1993 and 2003

SPECIES RICHNESS AND RELATIVE ABUNDANCES

Mean species richness at surveyed sites on the main-stem of French Creek in 1993 was 12.83 with a 95 % confidence interval of (10.99, 14.67). Six sites surveyed in 1993 (sites 8, 14, 15, 17, 23, 24) were surveyed again in 2003 (sites within 200m). Although the survey methods were different, we still wanted to compare species richness and relative abundances between 1993 and 2003, to see if there were any conspicuous changes over the years. We examined only live individuals for these analyses.

Species richness at site 8 was fourteen in 1993 and eighteen in 2003 (Table 16). One individual of both *U. imbecillis* and *E. triquetra* was found in 1993 but not in 2003. Six species present in 1993 were not found in 2003, however most of those species had low numbers, with only 1-7 individuals found in 1993. One exception was *E. dilatata*, of which 31 individuals were found in 2003, but zero were recorded in 1993. Relative abundances looked similar between 1993 and 2003, with the most abundant species being *A. ligamentina*, comprising slightly over 60% of the mussels found in both years.

Table 16: Total number and relative abundances of live mussels from site 8 in 1993 and 2003.

Site 8	1993 Live Mussels		2003 Live Mussels	
	Total	Relative	Total	Relative
	Number	Abundance (%)	Number	Abundance (%)
A. ligamentina	40	61.54%	383	64.37%
A. marginata	1	1.54%	21	3.53%
A. plicata	5	7.69%	2	0.34%
A. ferussacianus			2	0.34%
E. dilatata			31	5.21%
E. triquetra	1	1.54%		
F. subrotunda	3	4.62%	14	2.35%
L. cardium	2	3.08%	1	0.17%
L. ovata	1	1.54%	9	1.51%
L. siliquoidea	2	3.08%	1	0.17%
L. compressa			1	0.17%
L. costata	2	3.08%	10	1.68%
P. clava	1	1.54%	3	0.50%
P. sintoxia	1	1.54%	17	2.86%
P. fasciolaris	3	4.62%	70	11.76%
P. grandis			2	0.34%
Q. cylindrica			1	0.17%
S. undulatus			7	1.18%
U. imbecillis	1	1.54%		
V. fabalis	2	3.08%	20	3.36%
Total Numbers	**65**	**100.00%**	**595**	**100.00%**
Total Species	**14**		**18**	

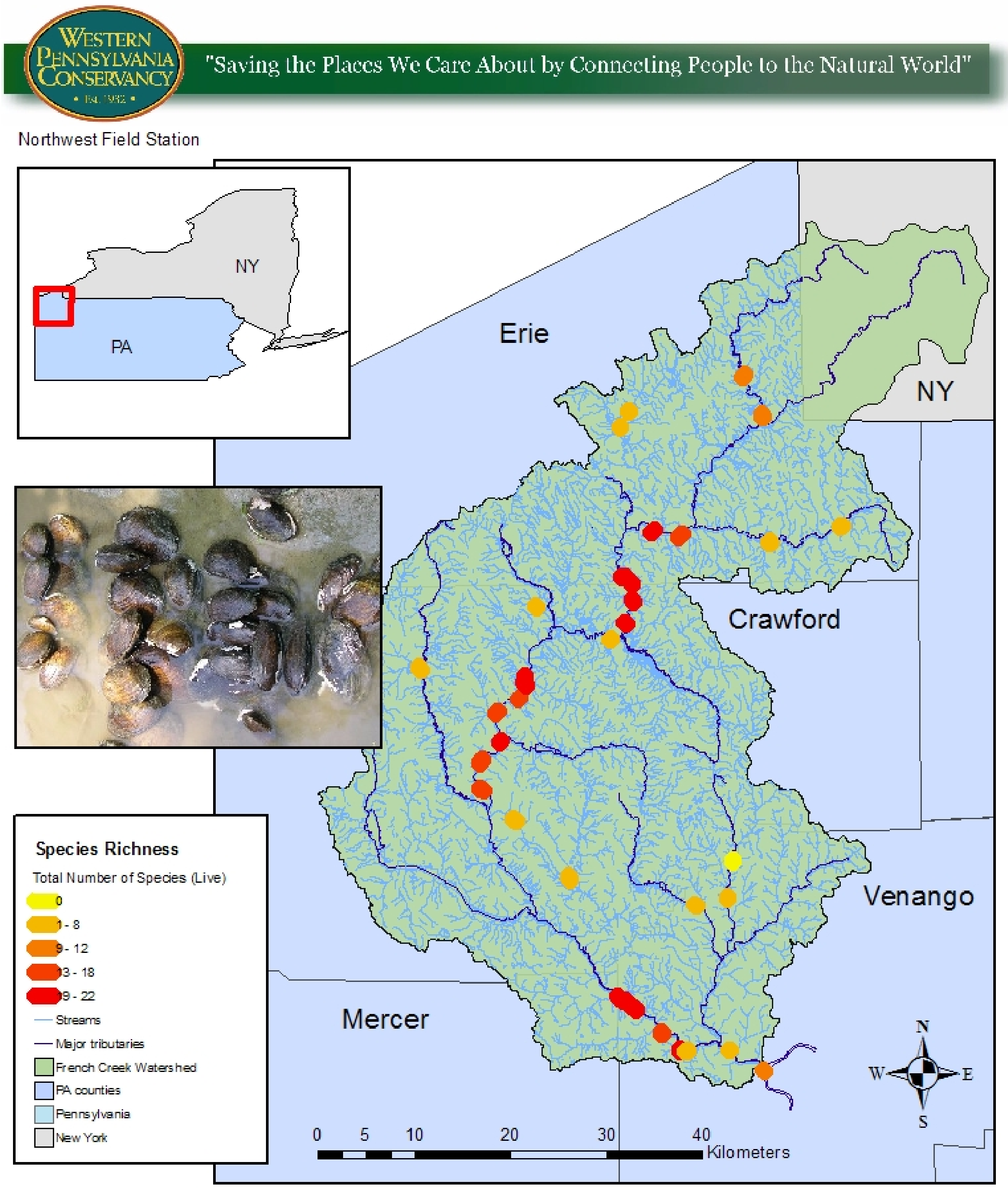

Figure 32: Freshwater Musssel Species Richness from 1993/1994 Survey (Total No. Live Species)

Species richness at site 14 was fifteen in 1993 and seventeen in 2003 (Table 17). Six *E. triquetra* and one *L. fasciola* were found in 1993, but none were found in 2003. One *A. ferussacianus* was found in 2003, and none in 1993. One individual *P. clava* was found both years. There are several notable changes in relative abundances between 1993 and 2003. Three species of concern decreased in relative abundance; *V. fabalis* decreased from 16.3% to 2.1%, *E. torulosa rangiana* decreased from 15.0% to 3.7%, and *E. triquetra* decreased from 4.1% to 0.0%. . The relative abundance of *A. ligamentina* increased from 25.85% to 54.3%.

Table 17: Total number and relative abundances of live mussels from site 14 in 1993 and 2003.

Site 14	1993 Live Mussels		2003 Live Mussels	
	Total Number	Relative Abundance (%)	Total Number	Relative Abundance (%)
A. ligamentina	38	25.85%	207	54.33%
A. marginata	3	2.04%	16	4.20%
A. ferussacianus		0.00%	1	0.26%
E. dilatata	12	8.16%	45	11.81%
E. torulosa rangiana	22	14.97%	14	3.67%
E. triquetra	6	4.08%		
L. fasciola	1	0.68%		
L. ovata	2	1.36%	3	0.79%
L. siliquoidea	2	1.36%	2	0.52%
L. compressa	2	1.36%		
L. costata	4	2.72%	16	4.20%
P. sintoxia	7	4.76%		
P. fasciolaris	16	10.88%	56	14.70%
Q. cylindrica	4	2.72%	7	1.84%
S. undulatus	4	2.72%	6	1.57%
V. fabalis	24	16.33%	8	2.10%
Total Numbers	**147**	**100.00%**	**381**	**100.00%**
Total Species	**15**		**12**	

Species richness at site 15 was thirteen in 1993 and twelve in 2003 (Table 18). Four *L. fasciola* and one *L. compressa* individuals were found in 1993, but none in 2003. Four *L. ovata* individuals were found in 2003, but none in 1993. The most notable change between 1993 and 2003 is the difference of relative abundance of *A. marginata* and *E. dilatata* between the years. It appears that the relative abundance of *A. marginata* decreased from 11.5% to 4.9%, while the relative abundance of *E. dilatata* increased from 7.7% to 19.9%.

Species richness at site 17 was twelve in 1993 and twelve in 2003 (Table 19). Thirteen *S. undulatus* individuals and 1 *L. cardium* were found in 2003, and none in 1993. Five *P. sintoxia* and two *L. fasciola* individuals were found in 1993, and none in 2003. The most notable change between 1993 and 2003 is the difference of relative abundance of *P. fasciolaris* and *A. ligamentina* between the years. It appears that the relative abundance of *P. fasciolaris* increased from 9.5% to 23.5%, while the relative abundance of *A. ligamentina* decreased from 55.4% to 40.0%.

Table 18: Total number and relative abundances of live mussels from site 15 in 1993 and 2003.

Site 15	1993 Live Mussels		2003 Live Mussels	
	Total Number	Relative Abundance (%)	Total Number	Relative Abundance (%)
A. ligamentina	39	50.00%	118	57.28%
A. marginata	9	11.54%	10	4.85%
E. dilatata	6	7.69%	41	19.90%
E. torulosa rangiana	3	3.85%	4	1.94%
E. triquetra	1	1.28%	3	1.46%
L. fasciola	4	5.13%		
L. ovata			4	1.94%
L. compressa	1	1.28%		
L. costata	5	6.41%	16	7.77%
P. sintoxia	2	2.56%	6	2.91%
P. fasciolaris	40	51.28%	133	64.56%
Q. cylindrica	4	5.13%	3	1.46%
S. undulatus	10	12.82%	20	9.71%
V. fabalis	12	15.38%	24	11.65%
Total Numbers	**78**	**100.00%**	**206**	**100.00%**
Total Species	**13**		**12**	

Table 19: Total number and relative abundances of live mussels from site 17 in 1993 and 2003.

Site 17	1993 Live Mussels		2003 Live Mussels	
	Total Number	Relative Abundance (%)	Total Number	Relative Abundance (%)
A. ligamentina	41	55.41%	102	40.00%
A. marginata	1	1.35%	20	7.84%
E. dilatata	2	2.70%	18	7.06%
E. triquetra	2	2.70%	3	1.18%
L. cardium			1	0.39%
L. fasciola	2	2.70%		
L. ovata	1	1.35%	3	1.18%
L. siliquoidea	1	1.35%	5	1.96%
L. costata	6	8.11%	19	7.45%
L. recta	1	1.35%	2	0.78%
P. sintoxia	5	6.76%		
P. fasciolaris	7	9.46%	60	23.53%
S. undulatus			13	5.10%
V. fabalis	5	6.76%	9	3.53%
Total Numbers	**74**	**100.00%**	**255**	**100.00%**
Total Species	**12**		**12**	

Species richness at site 23 was eleven in 1993 and sixteen in 2003 (Table 20). Twenty-four *E. torulosa rangiana* individuals and 1 *E. triquetra* were found in 2003, and none in 1993. The most notable change between 1993 and 2003 is the difference of relative abundance of *A. ligamentina* and *V. fabalis* between the years. It appears that the relative abundance of *V. fabalis* decreased from 15.2% to 6.4%, while the relative abundance of *A. ligamentina* increased from 47.8% to 61.9%.

Table 20: Total number and relative abundances of live mussels from site 23 in 1993 and 2003.

Site 23	1993 Live Mussels		2003 Live Mussels	
	Total Number	Relative Abundance (%)	Total Number	Relative Abundance (%)
A. ligamentina	22	47.83%	418	61.93%
A. marginata	1	2.17%	20	2.96%
A. plicata	3	6.52%	4	0.59%
E. dilatata	3	6.52%	36	5.33%
E. torulosa rangiana		0.00%	24	3.56%
E. triquetra		0.00%	1	0.15%
F. subrotunda	1	2.17%		0.00%
L. fasciola	1	2.17%	5	0.74%
L. cardium		0.00%	1	0.15%
L. ovata	3	6.52%	11	1.63%
L. siliquoidea	1	2.17%	3	0.44%
L. costata	2	4.35%	53	7.85%
L. recta		0.00%	2	0.30%
P. fasciolaris	2	4.35%	46	6.81%
Q. cylindrica		0.00%	3	0.44%
S. undulatus		0.00%	5	0.74%
V. fabalis	7	15.22%	43	6.37%
Total Numbers	**46**	**1**	**675**	**100.00%**
Total Species	**11**		**16**	

Species richness at site 24 was thirteen in 1993 and sixteen in 2003 (Table 21). One individual of *P. clava was* found in 1993, and none in 2003. One individual *V. iris* was found in 2003, and none in 1993. The most notable change between 1993 and 2003 is the difference of relative abundance of *A. marginata* between the years. It appears that the relative abundance of *A. marginata* decreased from 11.5% to 0.7%, while the relative abundance of *E. dilatata* increased from 12.8% to 17.2%.

Table 21: Total number and relative abundances of live mussels from site 24 in 1993 and 2003.

Site 24	**1993 Live Mussels**		**2003 Live Mussels**	
	Total Number	**Relative Abundance (%)**	**Total Number**	**Relative Abundance (%)**
A. ligamentina	51	34.46%	173	37.28%
A. marginata	17	11.49%	3	0.65%
A. plicata	1	0.68%	6	1.29%
E. dilatata	19	12.84%	80	17.24%
E. torulosa rangiana	1	0.68%	23	4.96%
L. fasciola	1	0.68%	3	0.65%
L. ovata	2	1.35%	5	1.08%
L. siliquoidea		0.00%	3	0.65%
L. costata	11	7.43%	38	8.19%
L. recta		0.00%	1	0.22%
P. clava	1	0.68%		0.00%
P. sintoxia		0.00%	3	0.65%
P. fasciolaris	6	4.05%	41	8.84%
Q. cylindrica	3	2.03%	4	0.86%
S. undulatus	4	2.70%	4	0.86%
V. fabalis	31	20.95%	76	16.38%
V. iris		0.00%	1	0.22%
Total Numbers	**148**	**100.00%**	**464**	**100.00%**
Total Species	**13**		**16**	

V. CONTINUED RESEARCH AND RESTORATION

This study documents research completed in the 2003 field season. The Western Pennsylvania Conservancy and its partners have continued research in 2004. There is a need to continue freshwater mussel research in this unique watershed, to fully understand why French Creek has a thriving biological diversity and how to ensure it stays that way (Bier and Sampsell 2003). This knowledge will guide us in developing monitoring plan for French Creek watershed as well as restoration and re-introduction plans for nearby watersheds with depleted mussel populations.

2004 –2005 RESEARCH

QUANTITATIVE MUSSEL SURVEYS

Data from sites surveyed in the 2003 season were used to determine which French Creek sites to quantitatively sample in 2004, to estimate parameters such as mussel density, relative abundance, and recruitment. Ten of these sites were revisited for more intensive, quantitative surveys during the 2004 field season. These quantitative surveys require intense fieldwork including surface counts and/or excavation of at least 400 quadrats per site (Smith et *al*. 2001). Results of this rigorous work will enable quality estimates of mussel densities, abundance, and recruitment, and build a regression model to make predictions from 2003 data. Results from this study are in the final stages of analyses and will be documented in future reports and will help us develop a monitoring program for French creek mussels.

FISH SURVEYS

In addition to mussel surveys, the fish community composition was evaluated to determine the fish species present at each mussel survey site. Fish surveys were completed at 26 of the mussel sites along French Creek. Results from this study are in the final stages of analyses and will be documented in future reports.

WATER CHEMISTRY

Water quality will be assessed using a combination of field and laboratory analyses during a spring high flow event in 2005. Field parameters will be measured with a YSI 600 water quality meter including temperature, conductivity, specific conductance, dissolved oxygen percentage, dissolved oxygen concentration, salinity, and pH. Water samples will be collected at each of the study sites and sent to Microbac Laboratories, Inc. (Erie, PA) for chemical analyses. These water samples will be tested for concentrations of nitrogen, phosphorus, total dissolved solids, suspended solids, ammonia, kjeldahl nitrogen, and biological oxygen demand.

The above field parameters and water quality samples will be taken at each site after a spring rain event. We will focus on springtime high water levels since this water level stage was most documented as most impacted by anthropological inputs in this watershed (Smith et *al.* 2003).

MACROINVERTEBRATE SURVEYS

The macroinvertebrate community was assessed at each of the mussel sites within the French Creek watershed using metrics and procedures modified from, "EPA Rapid Bioassessment Protocols for Use in Wadeable Streams and Rivers" (Barbour et *al*. 1999). Macroinvertebrates are currently being identified to the generic level and communities will be analyzed to get a better picture of water quality at each site. Detailed results will be documented in future reports.

VI. DISCUSSION

French Creek harbors 27 species of freshwater mussels, more than any other watershed in Pennsylvania or anywhere in the northeastern U. S. Of these 27 species, two are federally and state endangered, clubshell (*Pleurobema clava*) and northern riffleshell (*Epioblasma torulosa rangiana*). The Pennsylvania Biological Survey lists fourteen other unionid species, found in French Creek, as proposed threatened or endangered in Pennsylvania. In general, aquatic mollusks, including bivalves and gastropods, are a critically imperiled group throughout much of the world. This fact makes WPC's research extremely important and places special emphasis on the conservation of places like French Creek.

To further underscore the importance of this project, the federally endangered clubshell and northern riffleshell mussels have been lost from over 95% of their historic world ranges. Both maintain healthy populations in the French Creek watershed. Through the project, we have expanded the known ranges for these species. This work will benefit not only the recovery and conservation of these important aquatic species but also the economic viability of local communities through decreased survey costs on permitting issues. This economic benefit is a direct result of taking a proactive approach to understanding and conserving the French Creek watershed's aquatic communities.

The results of this study show that French Creek mussel populations remain relatively healthy. In our 2003 semi-quantitative surveys, we documented 24 species throughout the main-stem, the same that was reported in 1993. Importantly, we have documented evidence of recent recruitment for most species. We have shown some trends in species richness, particularly showing fewer species higher in the watershed and an area of high species richness between Le Boeuf Creek and Muddy Creek. We have also compared muskrat midden data to snorkel sampling data, and generally found smaller individuals of *A. ligamentina, E. dilatata, P. fasciolaris* than in snorkel surveys. We have also found that *V. fabalis* are underrepresented in midden samples. We found no consistent trends in comparing 1993 data to 2003 data for the same sites, changes in species composition and relative abundances varied from site to site, which may be due in part to the differences in sampling strategies.

Several species known historically to the French Creek watershed were not rediscovered during the 1993 or 2003 surveys including; the salamander mussel (*Simpsonaias ambigua*), eastern pondmussel (*Ligumia nasuta*), white heelsplitter (*Lasmigona complanata*), liliput (*Toxolasma parvus*), and the purple wartyback (*Cyclonaias tuberculata*) (Ortman 1919). *L. nasuta*, *L. complanata*, and *T. parvus* are primarily smaller tributary species. Therefore, further investigations in the tributaries should be completed.

Our study identified *P. clava* as having a limited range in the main-stem of French Creek and the number of live individuals was very low wherever it was found. The main-stem may have significant population sources in tributary streams such as Muddy Creek, Conneaut Outlet, and LeBoeuf Creek. Although Muddy Creek has been documented as a relatively healthy stream, LeBoeuf Creek and Conneaut Outlet indicate some water quality issues (Smith et al. 2003). For example, high nutrient levels in Conneaut Lake may contribute significantly to the Conneaut sub-basin nutrient totals. The Pennsylvania DEP has listed Conneaut Lake as impaired by excessive nutrients. The lake is scheduled for the development of Total Maximum Daily Load (TMDL) restrictions. The LeBoeuf Creek sub-basin has significantly higher than average percent agriculture and significantly lower than average percent forested land than what is typical in the French Creek watershed. LeBoeuf Creek watershed also has several golf courses within its boundaries, which may also be significant contributors of nutrients into the system. Nutrient levels in Lake LeBoeuf are high (Wellington, personal communication) and may be a contributing factor as well, especially in the spring after lake turnover. Source mussel populations in these tributaries should be assessed and care should be taken to prevent further disturbances in this portion of the watershed.

It should be noted that several of the water quality parameters were tested at only one point in time. This provides just a snapshot of these variables. Parameters such as temperature and dissolved oxygen are highly variable both spatially and temporally. Both temperature and dissolved oxygen fluctuate seasonally, diurnally, and between microhabitats. Furthermore, freshwater mussels cannot easily escape intolerable temperatures or levels of dissolved oxygen unlike more mobile organisms such as macroinvertebrates and fish. For these reasons, summer temperatures and dissolved oxygen should be studied in more detail and correlations that we found between mussel data and those parameters should be viewed as clues for further investigation, not as direct cause and effect relationships. Permanent water quality stations are needed to get a full view of water quality parameters in French Creek and more controlled experiments are needed to find the effect of changing temperatures, amounts of dissolved oxygen, etc. on mussel health.

This study showed relationships between in-stream and riparian habitat variables and mussel abundances. Habitat parameters that proved to be important were relatively stable variables that were visually assessed, where higher scores for these parameters indicate "better" quality habitat. For example, an increase in the following parameters scores showed an increasing trend in species richness: riparian vegetation thickness score, channel modification score, in-stream cover score, and embeddedness score. An increase in bank stability, water path, bank vegetation thickness, bank vegetation type, and aquatic vegetation scores showed a decreasing trend in species richness. Mussel CPUE increased with better embeddedness scores and generally decreased with increasing aquatic vegetation. Results from previous analyses in French Creek show that as habitat/riparian scores got worse, nutrient and sedimentation increased (Smith et al. 2003). Furthermore, sub-basins of French Creek with high percentages of agriculture generally had high nutrient and sedimentation concentrations, and low riparian habitat scores. Therefore, the health of riparian and in-stream habitats seem to be good indicators of the health of freshwater mussel communities. Riparian zones are crucial to stream health by filtering excess nutrient and sediment runoff, preventing erosion, and providing cooling shade and habitat for organisms.

RECOMMENDED RESEARCH

French Creek's aquatic communities represent some of the last remaining intact high quality natural communities found anywhere in the Ohio River basin. There is a great need to fully understand these aquatic communities throughout the watershed and to apply this research to nearby watersheds with imperiled mussel populations. Furthermore, we need to understand the threats unionids face from invasive species, improper land use, habitat degradation, and pollution. Only through continuing this type of work can we expect to engage the public in education about these important resources and expand conservation efforts to protect them. These types of projects would directly address several of the highest priority recommended implementation projects from the French Creek Watershed Rivers Conservation Plan (Sampsell 2002).

EVALUATE INVASIVE SPECIES

There is a need to assess the extent and source populations of aquatic invasive species within the watershed. Aquatic and semi-aquatic invasive plant species may include purple loosestrife (*Lythrum salicaria*) and Eurasian water-milfoil (*Myriophyllum spicatum*). Aquatic animal invasives, particularly the zebra mussel (*Dreissena polymorpha*) and the asian clam (*Corbicula fluminea*) should be inventoried and habitat should be assessed for its potential to host these invasive species. Inventory of invasive species will aid in developing effecient control programs and help prevent further spread. Exotic invasive species have the potential to drastically alter the ecosystem and bring severe consequences to native species. Our inventories will be a critical first step in controling these organisms.

EXPAND WORK INTO MAJOR SUB-BASINS

There is a need to develop a sub-basin approach to characterization of physical stream and riparian conditions, and aquatic community health as recommended in the French Creek River Conservation Plan (Sampsell 2002). There is a need to assess freshwater mussels, fish, and benthic macroinvertebrate communities within the major subwatersheds of the French Creek watershed; including but not limited to the West Branch of French Creek, LeBoeuf Creek, Conneauttee Creek, Cussewago Creek, and Conneaut Outlet, which were each targeted as priority monitoring and restoration sub-watersheds in the 1st Annual State of the Stream Report on the Health of French Creek (2004). In addition, the following streams have been recommendd for further investigation fof federally listed mussels; Carr Run, East Branch of LeBoeuf Creek, Lake Creek, LeBoeuf Creek, Little Conneautee Creek, Little Sugar Creek, South Branch of French Creek, Sugar Creek, West Branch of French Creek, and Woodcock Creek (Bier 1994). Other sites in additional sub-basins of the French Creek watershed should be assessed in order to make comparisons between relatively degraded and healthy sub-basins. The aquatic communities should be analyzed with water chemistry and physical habitat data and incorporated into GIS to evaluate the impacts from surrounding land use. This study could be modeled after WPC's past two years of research of freshwater mussel, fish, and benthic macroinvertebrate communities in French Creek.

Information from this sub-basin approach will enable conservation organizations, county conservation districts, state and federal agencies, and municipalities to better utilize limited funding for stream conservation by focusing on the most critically imperiled habitat and the most degraded stream sections and the most important sources of threats to aquatic life.

INSTALL PERMANENT WATER QUALTIY MONITORING STATIONS

Because important parameters such as temperature, nutrient/sediment loads, and dissolved oxygen vary spatially and temporally, we recommend permanent water quality/discharge monitoring stations be installed at the mouths of each major sub-basin and along the main-stem river, particularly above and below urban areas. Continuous water quality and turbidity data would allow us to determine sediment loads and their sources. The proposed permanent water quality monitoring should also take place in strategic areas across the watershed, particularly in areas of high mussel species richness and those streams we noted as problem areas in the 1st Annual State of the Stream Report (Smith et *al.* 2003). These data will be used to develop a hydrologic model and a water budget for the system. After the sediment and pollution sources are known, we can better address restoration efforts to control any areas of concern.

STUDY GEOFLUVIAL MORPHOLOGY (IN-STREAM HYDROLOGY)

A comprehensive study of French Creek's hydrology and geomorphology should be undertaken, paying special attention to the affects of the Union City and Woodcock dams. Geomorphology, hydrology, and glacial geology data should be analyzed with freshwater mussel data to evaluate biogeographical relationships between mussel ranges and physical stream parameters.

EXPAND WORK INTO NEARBY WATERSHEDS

There is a great need to evaluate other portions of the Allegheny River watershed and the Shenango River watershed by comparing mussel and fish populations, as well as chemical and physical properties, to conditions in the French Creek watershed. By using French Creek as a reference, we hope to evaluate protection and restoration opportunities for freshwater mussel and associated fish populations in these watersheds where many mussel species have been lost or are declining. Freshwater mussels face a host of stresses including damming and impoundments, increased siltation from improper land uses, pollution, and loss of host fish species (Bogan, 1993). Because of their long life spans (up to 100 years) freshwater mussel populations may consist of primarily older individuals with little or no recruitment of young occurring. These effects could be the result of loss of host fish species, unstable substrate, or a combination of these and other factors. Whatever the cause, the resulting loss of mussel populations may be avoided or reversed if we can better understand the stresses faced by these animals.

Information collected about unionid populations in the French Creek watershed will allow WPC to compare chemical and physical parameters in other areas of the Allegheny River and Shenango River watersheds to determine reasons for freshwater mussel decline in those watersheds. Ultimately, this information will lead to protection efforts for remaining viable freshwater mussel populations as well as restoration efforts for species lost from portions of their historic ranges.

The Western Pennsylvania Conservancy is currently seeking funding to initiate a comprehensive study of spatial distributions and factors affecting the freshwater mussel species of the Allegheny River and Shenango River watersheds in western Pennsylvania.

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APPENDIX A. RIPARIAN ASSESSMENT (Schnier, 2003)

Riparian Buffer Width

Poor	Marginal	Moderate	Good	Excellent
0-3 meters	3-10 meters	10-25 meters	25-50 meters	50+ meters
1 2	3 4	5 6	7 8	9 10

Riparian Vegetation Type

Poor	Marginal	Good	Excellent
Grasses/herbaceous plants (grazed or mowed short)	Grasses/herbaceous plants (full height)	Shrub or shrub and grasses mix	Forested or forest mixed with shrubs and/or grasses
1 2	3 4 5	6 7 8	9 10

Riparian Vegetation Thickness

Poor	Marginal	Good	Excellent
Vegetation very sparse, covers less than 25% of the ground. Large bare spots are visible.	Vegetation somewhat sparse, several bare spots are visible. Covers 25-50% of ground.	Vegetation fairly thick, a few gaps or bare spots. Covers 50-80% of ground.	Vegetation very thick and well-developed. No gaps or bare spots. Coverage nearly 100%.
1 2	3 4 5	6 7 8	9 10

Bank Vegetation Type

Poor	Marginal	Good	Excellent
Grasses/herbaceous plants (grazed or mowed short)	Grasses and other herbaceous material (full height)	Shrub or shrub and grasses mix	Trees or tree mix
1 2	3 4 5	6 7 8	9 10

Bank Vegetation Thickness

Poor	Marginal	Good	Excellent
Vegetation very sparse, covers less than 25% of the banks.	Vegetation somewhat sparse, several bare spots are visible. Covers 25-50% of banks.	Vegetation fairly thick, a few gaps or bare spots. Covers 50-80% of banks.	Vegetation very thick and well-developed. No gaps or bare spots. Coverage nearly 100%.
1 2	3 4 5	6 7 8	9 10

Bank Stability

Poor	Marginal	Good	Excellent
Unstable; eroded or "raw" areas frequent, bare roots visible, slopes nearly vertical.	Largely unstable; almost half of the bank has areas of erosion, bare roots visible.	Moderately stable; some small area of erosion, mostly healed over.	Stable; no evidence of erosion or bank failure, bank slopes are moderate.
1 2	3 4 5	6 7 8	9 10

Water Pathways

Poor	Marginal	Good	Excellent
Many rills and gullies visible-banks are deeply scarred with gullies all along the stream.	Breaks in the vegetation frequent with some rills or scars every 50 meters.	Very few rills or gullies visible, breaks in the vegetation occur less then every 50 meters.	No rills or gullies visible. Riparian area intact, with no breaks in the vegetation.
1 2	3 4 5	6 7 8	9 10

Channel Modification

Poor	Marginal	Good	Excellent
Channel is highly modified. Stream is confined to a concrete channel or both sides are modified.	Channel has been slightly modified. One side of channel has been rip rapped or stabilized.	Channel has slight alteration, occasional modifications are present, but overall free-flowing.	Channel is not modified. Stream is completely free-flowing on both sides.
1 2	3 4 5	6 7 8	9 10

Shading (Canopy Cover)

Poor	Good	Excellent
Little to no canopy cover (<25% of the stream is shaded).	Partial canopy cover (25-75% of the stream is shaded).	Nearly complete canopy cover (>75% of the stream is shaded).
1 2 3	4 5 6 7	8 9 10

In-stream Cover

Poor	Marginal	Good	Excellent
Not much fish habitat-lack of habitat is obvious.	Some stable habitat, but examples are infrequent, further than 25 meters apart.	There are several examples of habitat or cover within 10 meters of each other.	Habitat examples are frequent, and are continuous throughout the stream.
1 2	3 4 5	6 7 8	9 10

Embeddedness

Poor	Marginal	Good	Excellent
Rocks are deeply stuck into sand, silt or mud. Rocks barely visible.	Rocks are more than half surrounded by fine sediments. Kicking does not dislodge rocks.	Rocks are partially surrounded by fine sediment. Rocks are easily flipped over.	Rocks free from fine sediments-little sand, silt or mud on stream bottom.
1 2	3 4 5	6 7 8	9 10

Aquatic Vegetation

Poor	Good	Excellent
Aquatic vegetation is abundant on or below the surface of the water.	Some aquatic vegetation is present, mainly under the water surface.	No aquatic vegetation is present.
1 2 3	4 5 6 7	8 9 10

Land Use Outside the Buffer

Urban (pavement, roads, parking lots)	Row-crow agriculture	Residential lawn, golf course, sports fields or parks	Pasture or fallow agriculture	Forest

APPENDIX B. FORMULAS USED TO CALCULATE HYDROLOGIC DATA AND SORTING

Wetter perimeter (WP) equals the length of the wetted sides and bottom of a waterway:

$$WP = \sqrt{(\text{total width})^2 + (\text{depth of water at bankful})^2}$$

Hydraulic radius (R) equals the cross sectional area of a stream divided by the wetted perimeter:

$$R = \text{area at bankful} / \text{wetted perimeter at bankful}$$

Discharge (Q) is the rate at which a volume of water flows past a point pr unit of time and equals the product of cross-sectional area of flowing water and its velocity (Dunne and Leopold 1978):

$$Q = Au,$$

where A = area (m^2), and
u = velocity (m/sec).

Shear stress refers to the ability of water to mobilize materials from the bed and banks in streams and is given by (Armantrout 1998):

$$Y = \rho RS,$$

where ρ = density of water;
R = hydraulic radius;
S =channel slope.

We used Manning's equation (Armantrout 1998) to determine the average velocity (V). In English units:

$$V = (1.486(R)^{2/3}(S)^{1/2})/n$$

Where R = hydraulic radius;
S = energy gradient parallel to water slope;
n = Manning's coefficient of roughness.

We used $n = 0.025$, which is Manning's coefficient of roughness for rivers in fair condition with some algal growth (Dunne and Leopold 1978).

A mean of the small rocks was determined using the equation;

$$\text{Mean} = (\Phi 16 + \Phi 50 + 84\Phi)/3;$$

Grain diameter in phi (Φ) units = $-\log_2$ of grain diameter in mm.

Sorting is the measure of the distribution or variability of particle sizes in substrate that is frequently expressed as the square root of d_{75}/d_{25}, where d_{75} and d_{25} are diameters where 75% and 25% of the cumulative size-frequency distributions are larger than a given size. Substrate with large sorting coefficients is termed well sorted (Armantrout 1998).

Sorting of variation in grain size conveys the number of significant size classes in a population (Prothero and Schwab 2004). Sorting may reflect variation in velocity and the ability of a particular process to transport and deposit certain grain sizes.

$$\text{Sorting} = ((\Phi84-\Phi16)/4 + (\Phi95-\Phi5)/6.6)$$

≤ 0.35Φ	Very well sorted
0.35-0.50Φ	Well sorted
0.50-0.71Φ	Moderately well sorted
0.71-1.00Φ	Moderately sorted
1.00-2.00Φ	Poorly sorted
≥ 2.00Φ	Very poorly sorted

APPENDIX C –PHYSICAL HABITAT VS. MUSSEL SPECIES RICHNESS

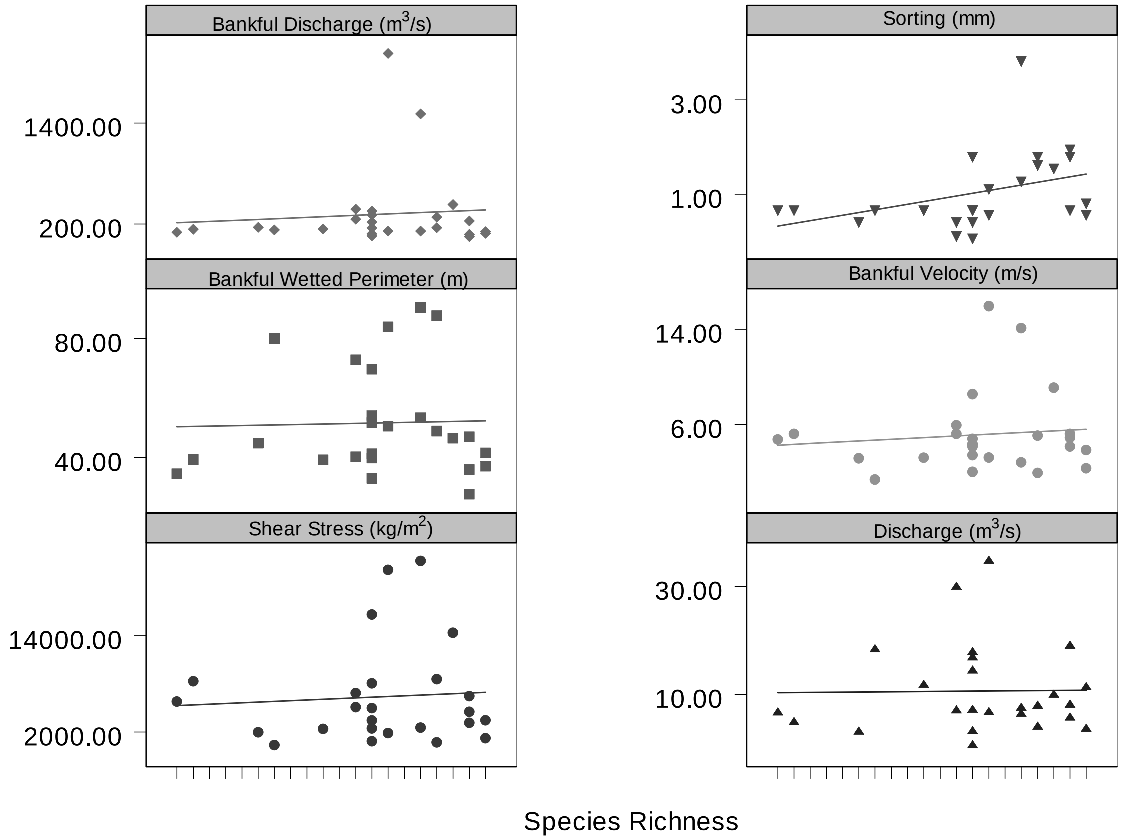

Figure C.1: Bankful discharge (m^3/s), sorting (mm), bankful velocity (m/s), wetted perimeter (m), discharge (m^3/s), and sheer stress (kg/m^2) plotted against species richness.

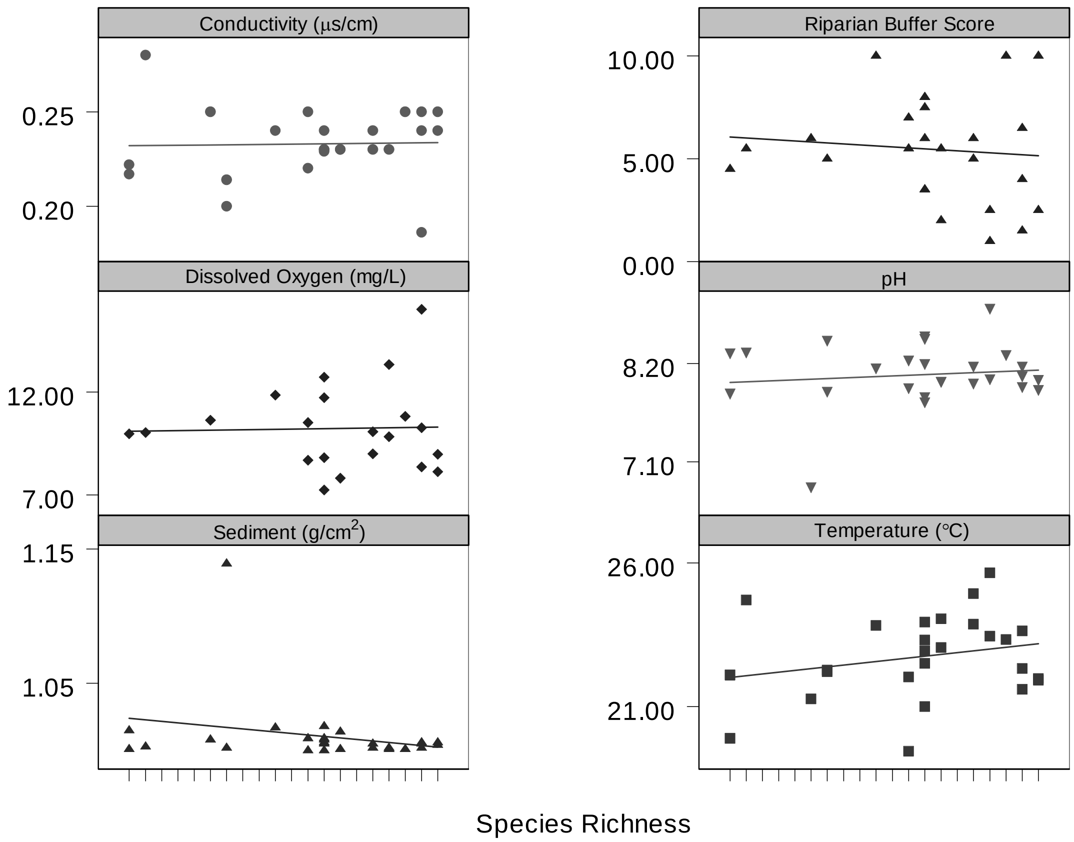

Figure C.2: Conductivity (µs/cm), pH, dissolved oxygen (mg/L), temperature (°C), sediment loading (g/cm^2), and riparian buffer score plotted against species richness.

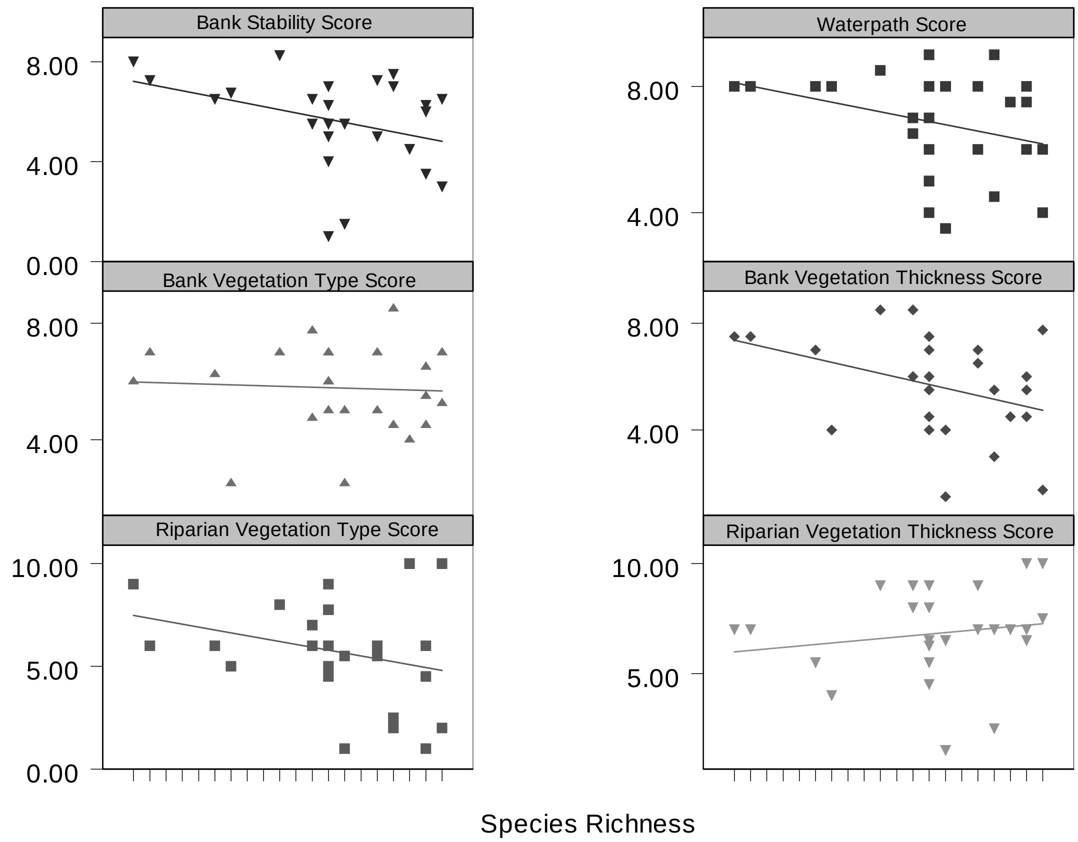

Figure C.3: Bank stability, waterpath, bank vegetation type, bank vegetation thickness, riparian vegetation thickness, and riparian vegetation type plotted against species richness.

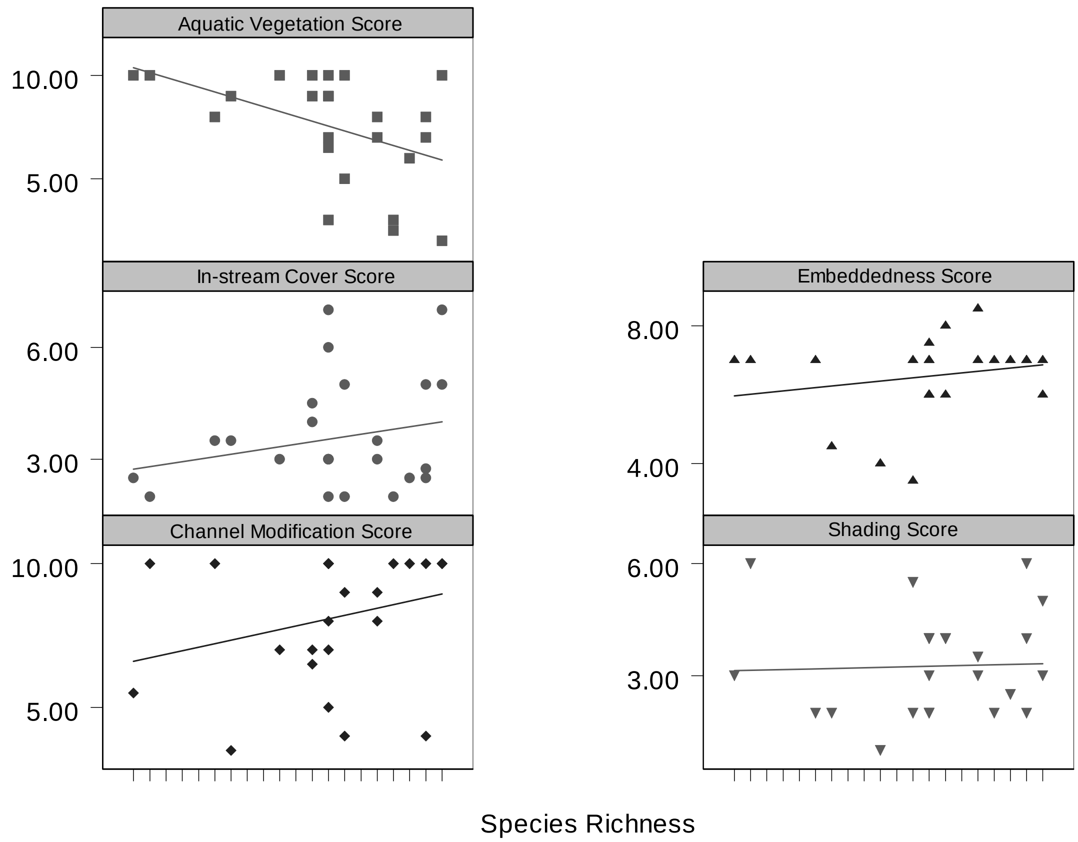

Figure C.4: Aquatic vegetation, in-stream cover, embeddedness, channel modification and shading scores plotted against species richness