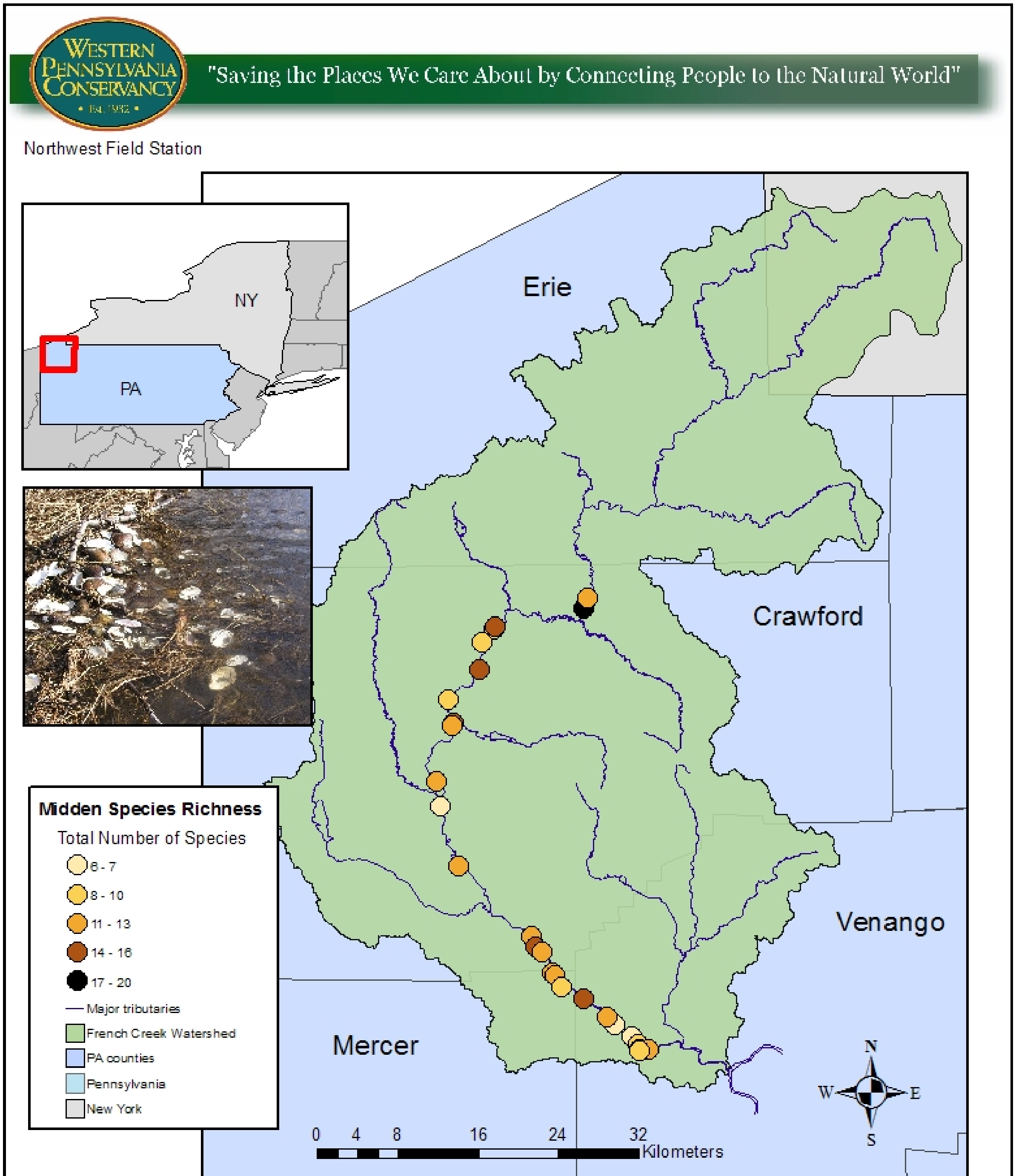

Figure 31: Freshwater Musssel Species Richness
(Total number species) in Muskrat Middens

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 Number	**Relative Abundance (%)**	**Total Number**	**Relative 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 Number	**Relative Abundance (%)**	**Mean Length (mm)**	**95% CI Length**	**Total Number**	**Relative Abundance (%)**	**Mean Length (mm)**	**95% CI 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 Number	Relative Abundance (%)	Total Number	Relative 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**	

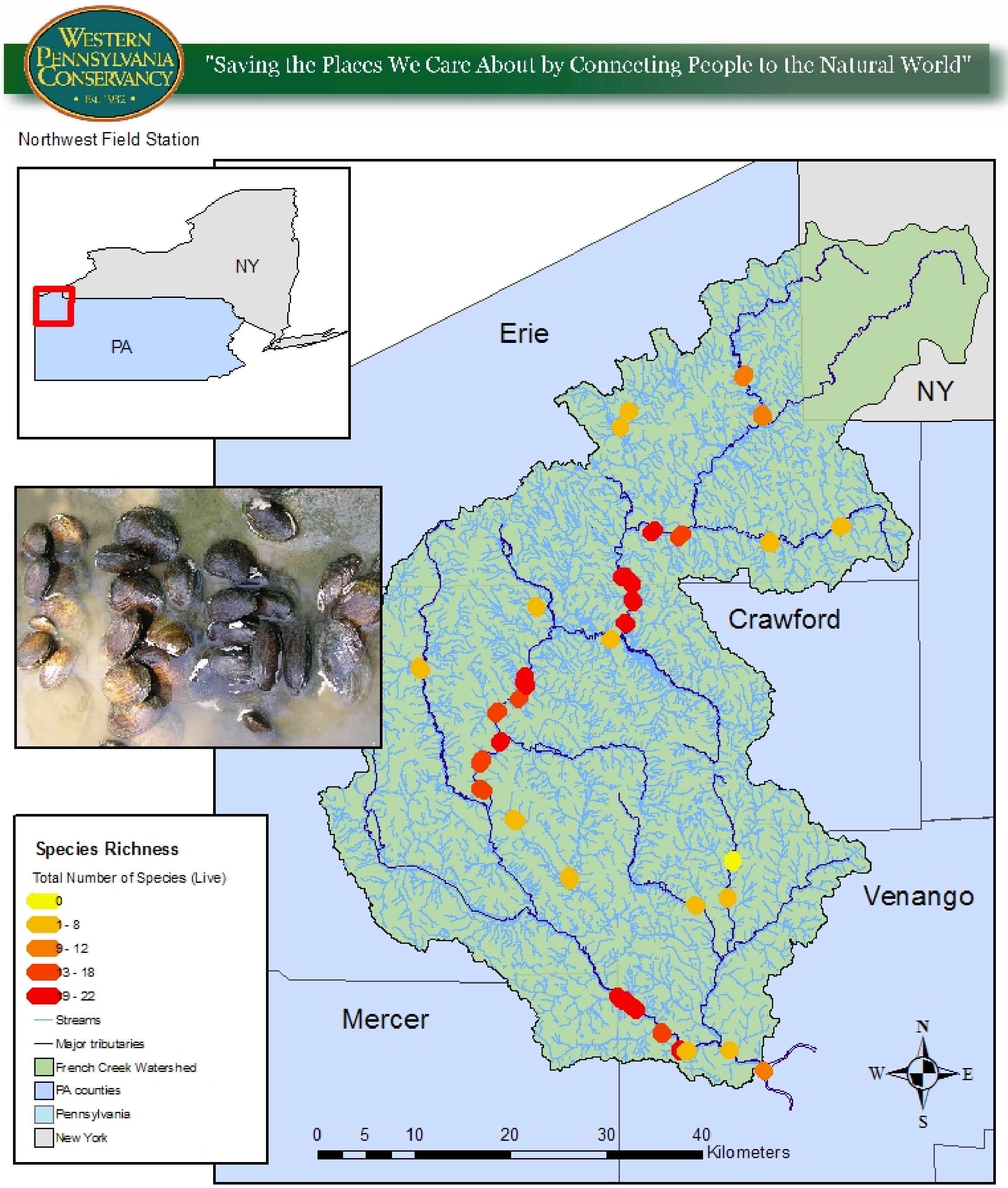

Figure 32: Freshwater Musssel Species Richness from 1993/1994 Survey (Total No. Live Species)

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;

$$\text{Mean} = (\Phi16+\Phi50+84\Phi)/3;$$

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.

$$\text{Sorting} = ((\Phi 84-\Phi 16)/4 + (\Phi 95-\Phi 5)/6.6)$$

≤ 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

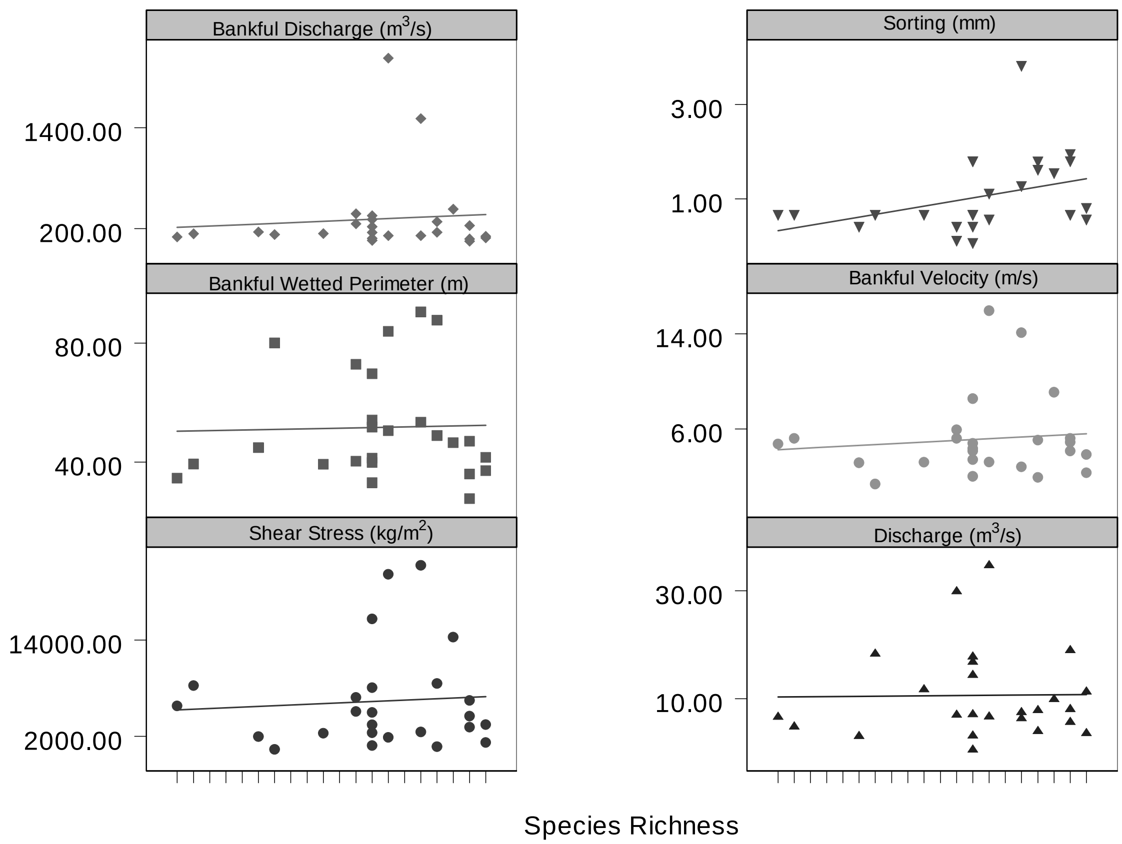

Figure C.1: Bankful discharge (m^3/s), sorting (mm), bankful velocity (m/s), wetted perimeter (m), discharge (m^3/s), and sheer stress (kg/m^2) plotted against species richness.

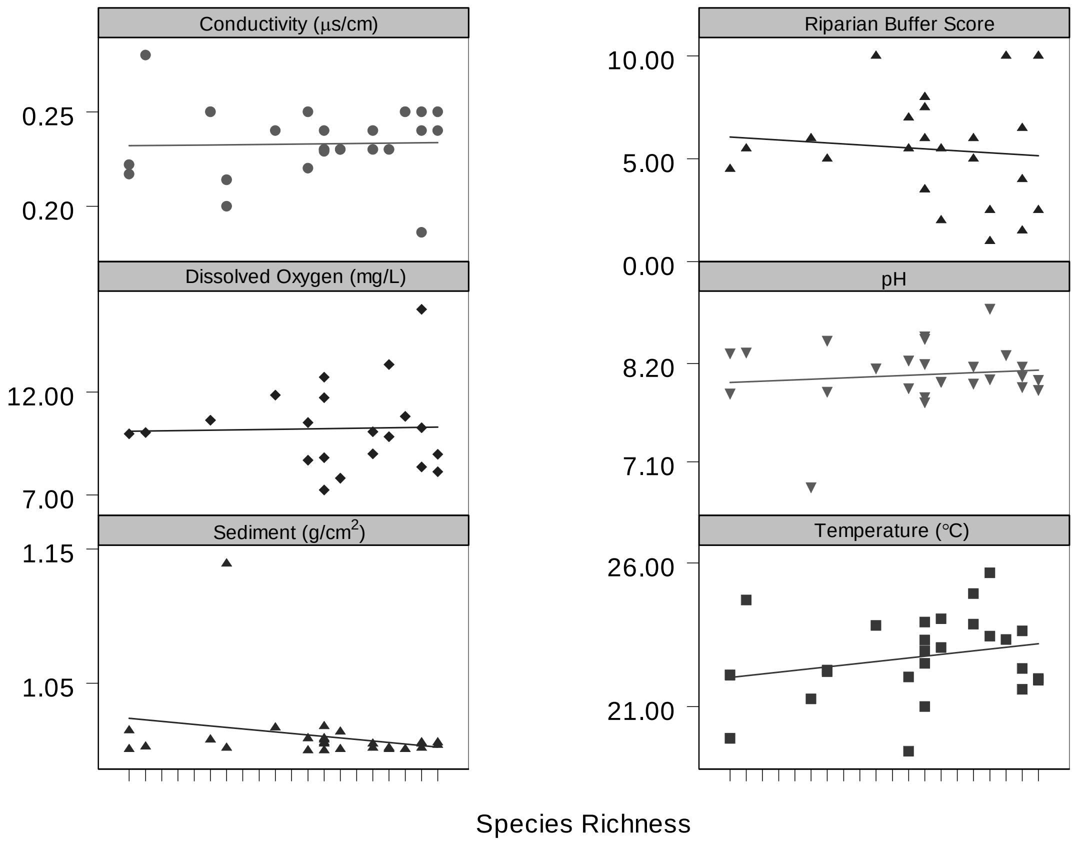

Figure C.2: Conductivity (µs/cm), pH, dissolved oxygen (mg/L), temperature (°C), sediment loading (g/cm^2), and riparian buffer score plotted against species richness.

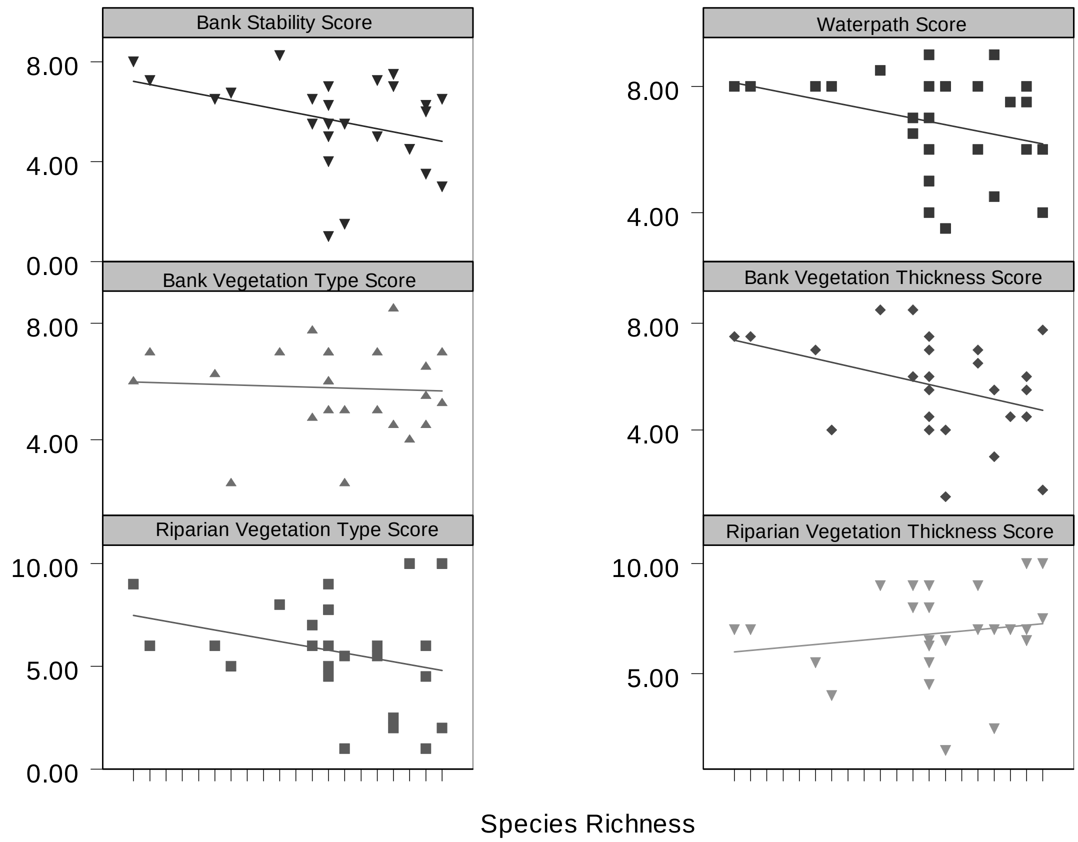

Figure C.3: Bank stability, waterpath, bank vegetation type, bank vegetation thickness, riparian vegetation thickness, and riparian vegetation type plotted against species richness.

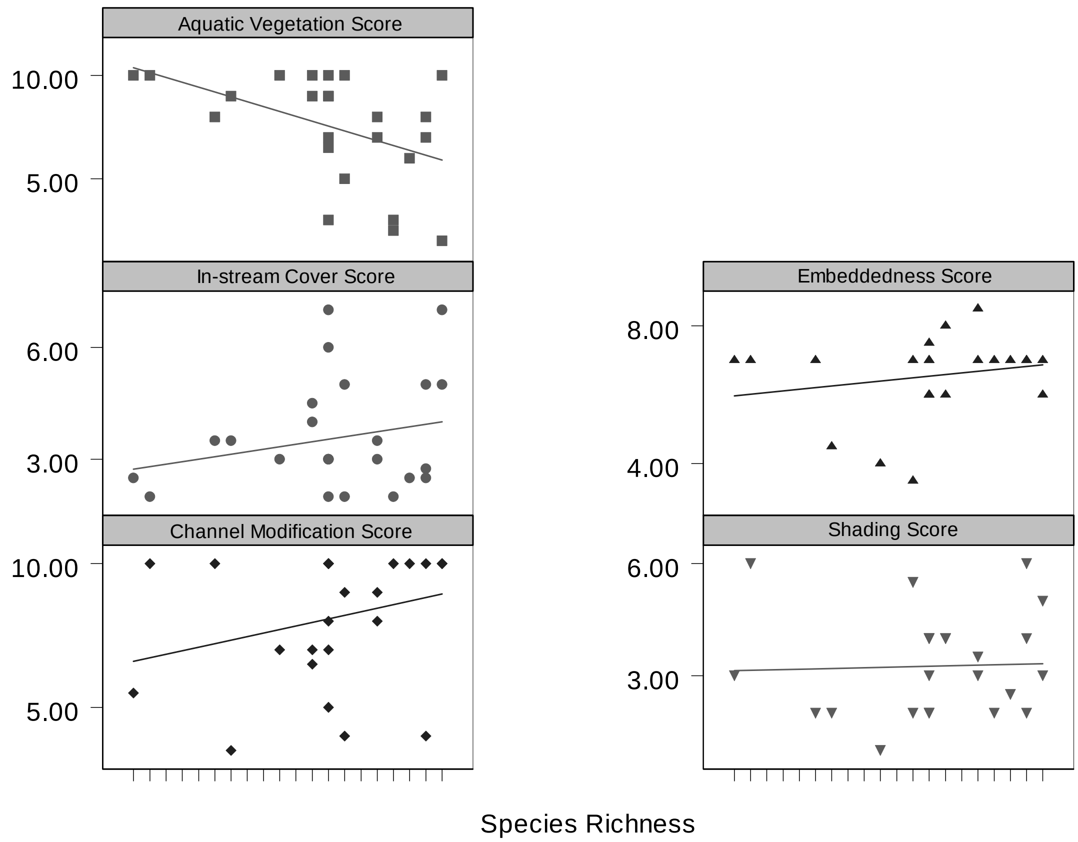

Figure C.4: Aquatic vegetation, in-stream cover, embeddedness, channel modification and shading scores plotted against species richness